CARBON CAPTURE, UTILIZATION, AND STORAGE TECHNOLOGY: REDUCING EMISSONS TO RESOLVE THE GLOBAL ENERGY CRISIS

SOCIETY AND CLIMATE CHANGE: HOW CULTURAL FACTORS INFLUENCE THE POTENTIAL TO SHIFT TOWARD A SUSTAINABLE FUTURE

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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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Approved:______________________________________ Date:_______________
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Approved:______________________________________ Date:_______________
Eric Anderson, Department of Chemical Engineering

Since the 1980s, the atmospheric levels of greenhouse gases, particularly carbon dioxide, have sharply and steadily increased, contributing to the gradual destruction of the Earth as an inhabitable planet. The current concentration of carbon dioxide significantly exceeds previous records, “peaking at 415 parts per million this year, far above the level during most of human history, around 300ppm” (Milman, 2019). This presents the urgent need of developing innovative solutions to either reduce the production of emissions, or capture them before they are released into the environment. Carbon Capture, Utilization and Storage (CCUS) is a form of technology that enables the removal of nearly 90% of carbon dioxide from gaseous emissions (“What is CCS?”, 2019). By attacking the source of the problem, particularly the various industrial energy production sites that greatly contribute to the release of greenhouse gases, CCUS has the potential to reverse the trends of global warming and preserve the planet for future generations. CCUS can be carried out through multiple methods, the specifics of which will be the focus of the technical portion of the following analysis. The STS analysis will be tightly coupled with the technical topic, exploring the ways in which sociocultural factors either promote or limit efforts to mitigate climate change. Technical research and initial analyses, including modeling processes within the Aspen Plus simulation software, will be performed during the fall semester in preparation for the completion of a design project in the spring semester, in which the aim is to create a successful model of CCUS. This includes a Design Basis Memorandum (DBM), a written document that provides a detailed description of the relevant chemical processes as well as an evaluation of economic feasibility. The DBM will be presented to Eric Anderson, the technical advisor and Lecturer of Process Synthesis, Modeling, and Control, the design course in the Chemical Engineering department. This analysis will be completed by the end of the fall semester, serving as an initial analysis for the project that will be further developed in the spring.

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As the world's population continues to grow exponentially, energy demands increase proportionally. Although renewable energy sources are gradually becoming more prevalent, "fossil fuels [will] still account for more than three-quarters of world energy consumption through 2040" (Doman, 2017). Thus, while furthering the development of renewable fuels positively contributes to lessening society's reliance on fossil fuel-driven energy sources, action must be taken to reduce carbon dioxide emissions in order to provide an immediate, viable solution to the world's energy crisis. The technical portion of this analysis pertains to the design of an effective application of CCUS technology, a method that has the potential to reverse the alarming emissions trends. CCUS involves removing carbon dioxide from gaseous byproduct streams produced in industrial processes, and either storing it or using it to create other valuable products, including fuels. While CCUS has been applied to pilot-scale operations, industries have yet to put forth the financial resources required to create large-scale systems. The primary challenge that is preventing this commitment is the drastic energy demands of separating carbon dioxide from other gases, resulting in a high cost. Based on the initial CCUS designs, this single step alone "could consume 25 to 40% of the fuel energy of a power plant" (Haszeldine, 2009, p. 1648). In order for CCUS technology to thrive, the design of the separation process must be optimized to decrease its associated cost, which is the most pressing challenge and one of the primary objectives associated with the technical project. The design is not only required to be economically viable, but additionally must operate as efficiently as possible while taking safety and environmental concerns into account. Based on preliminary research, the removal of carbon dioxide from emissions streams at coal-fired power plants using monoethanolamine (MEA), a chemical solvent, is a viable approach for the design of CCUS technology.

Power plants that rely on fossil fuels as a source of energy burn the substance at high temperatures, producing flue-gas as a result of combustion, a vapor stream that includes carbon dioxide as well as water vapor, nitrogen, oxygen, and traces of other gases. In order to begin the CCUS process, the carbon dioxide must be separated from the other species, producing carbon dioxide with the highest possible purity. The overall separation process is represented by the "Separation System" block within Figure 1, which outlines the process of CCUS. The first step of the separation process involves cooling the flue-gas and feeding it to an absorption column, where it comes into contact with the MEA solvent, which absorbs the carbon dioxide, separating it from the other gaseous compounds. The resulting solvent stream, which is rich in carbon dioxide, is heated and fed to a stripping column, where additional heating causes chemical bonds to break, allowing carbon dioxide to be released and collected

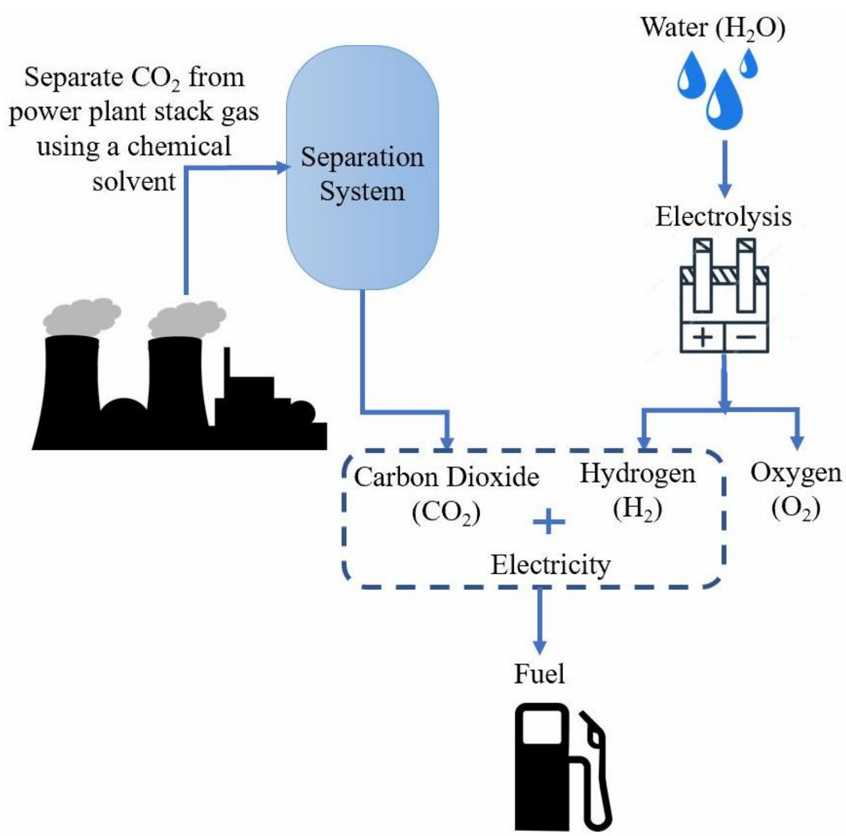

Figure 1: The Pathway of Carbon Capture & Storage: CCUS begins with the separation of CO_2 from an emissions stream such as flue-gas from a power plant, after which it can be combined with hydrogen and electricity to produce renewable fuel (Magner, 2019).

(Liao et al., 2018, p. 528). As shown in Figure 1, the CCUS process additionally includes the electrolysis of water, which involves running an electric current through the water molecules to break them into their individual elements, hydrogen and oxygen. The separated carbon dioxide and hydrogen can be combined with energy in the form of electricity in order to produce fuel, which provides “a potentially cost-competitive way to make gasoline, diesel, or jet fuel that doesn’t add any additional CO_2 to the atmosphere” (Leahy, 2018). The use of carbon dioxide to produce an alternative fuel source significantly increases the economic feasibility of the CCUS process. Although using MEA to separate carbon dioxide from flue-gas is criticized due to the significant energy demands associated with regenerating the solvent, combining this separation technique with the production of fuel is a novel approach that can maximize efficiency and economic yield (Luis, 2016, p. 94). By developing a model of this process for a specific industrial power plant, the intended outcome is to determine the optimal conditions for applying CCUS technology. This will include the detailed simulation of process equipment and layout, the calculation of heat and material balances to determine the properties of inputs and outputs, and an analysis of the economic feasibility of the design.

The ultimate goal of this project is to contribute to the creation of a more sustainable future in the energy sector, meeting the objective of the Paris Agreement, which, according to Zheng et al. (2018), “…is that the global average temperature must be controlled within 2 °C in this century” (p. 1). Through the technical analysis, which will be presented in the form of a scholarly article, the chosen approach to CCUS technology will be evaluated based on its viability in both reducing carbon dioxide emissions at their source, and transforming this compound from a potential pollutant into an economically feasible source of renewable fuel. Creating a successful design for CCUS encourages the widespread application of this technology, which has the potential to alter the trajectory of the energy industry, preserving the future of the Earth's climate.

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Despite the widespread presentation of evidence that illustrates the damaging effects that the continuous increase in carbon dioxide emissions has on the environment, society continues to primarily consume energy sources that heighten the severity of this issue. As proven through demonstrations of activism surrounding climate change, many individuals acknowledge the current energy crisis, and are aware that change is necessary. For example, millions joined the Global Climate Strike, "marching to demand that government and businesses commit to a goal of net-zero carbon emissions by 2030" (Chappell & Neuman, 2019). However, the research question that the STS portion of the prospectus seeks to explore is how sociocultural factors influence the potential to address climate change in an effective and feasible manner. Despite the increased presence of environmental activists, the views they represent are still not considered mainstream. There are current cultural viewpoints, social structures, and regulatory policies which, as Adger (2009) expresses, "act as limits to public engagement in adaptation to climate change (and indeed mitigation of emissions)" (p. 336). In addition, reducing emissions would "require cooperation by major carbon emitters to have a significant effect," bringing the ethical responsibilities of energy industries into consideration ("Climate intervention", 2015). The STS portion of the undergraduate thesis will evaluate the effects of the obstacles impeding change, and the actions that are necessary to overcome them in order to preserve the Earth as an inhabitable environment, as well as exploring the distribution of responsibility for addressing climate change among various stakeholders.

Although engineers are continuously developing innovative solutions to the current climate crisis, even the most thoroughly researched and seemingly effective technologies may fail to diffuse through society as rapidly as is necessary to produce change. This is particularly relevant to innovations that address global warming, which is significantly influenced by consumer behavior and economic concerns. For example, engineers who are developing CCUS technology to reduce carbon dioxide emissions face the challenge of lessening associated costs to fall within a range that is considered acceptable by a large number of stakeholders in various categories. Figure 2 compares the current and predicted future costs of CCUS technology to the cost of operating a typical power plant, as indicated in the gray box. Costs are given in megawatt hours ($MW/hr), a unit that measures power use. A single $MW/hr is equivalent to using one million watts of power for one hour. As Figure 2 illustrates, the cost of applying this technology currently greatly exceeds the maximum desired cost, decreasing the likelihood that it will be accepted and implemented by industrial corporations. In addition, as Figure 2 displays, the current models for CCUS operations are far

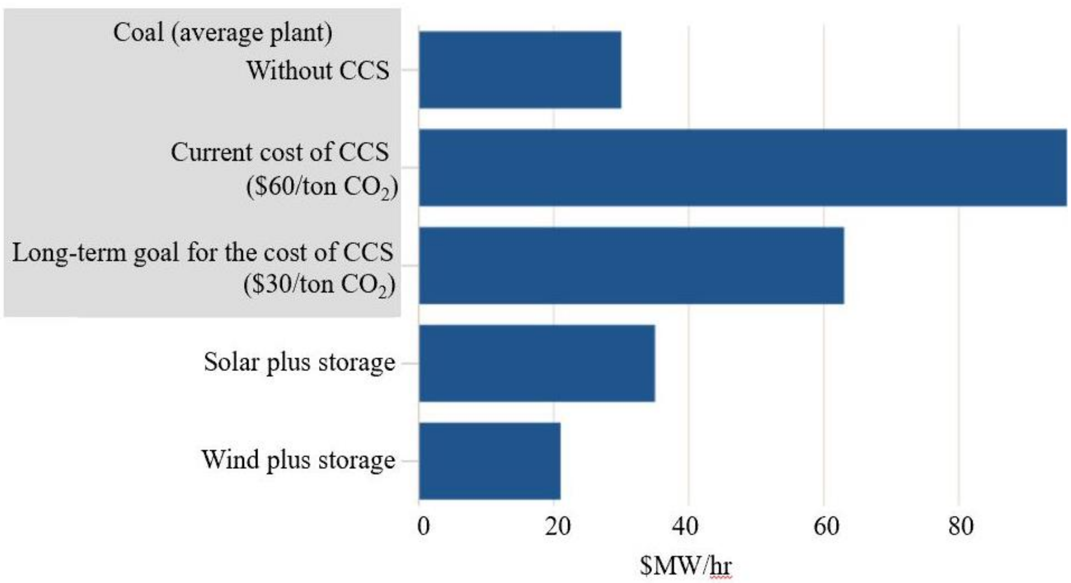

Figure 2: Cost Comparison of Sustainable Energy Sources: The current applications of Carbon Capture & Storage are not economically feasible in comparison to widely researched sources of renewable energy (Adapted by Abby Magner from Sanderson, 2019).

more expensive than alternative energy sources such as solar and wind power, promoting research and development in the renewable energy field rather than CCUS. Thus, methods of addressing climate change must be economically favorable and must satisfy groups of stakeholders with a wide variety of beliefs. Differing opinions regarding whether humans are the source of global warming limits impactful change, as Adger et al. discuss, highlighting the relevance of "the way in which the agents of adaptation—individuals, institutions, governments—view knowledge about weather and climate from the deep past through the present to the long future" (Adger et al., 2009, p. 342). The difficulties presented due to divergent sociocultural factors exemplifies the Social Construction of Technology (SCOT) theory, which is applied to technologies that address climate change in Figure 3. The graphic illustrates the relevant social groups, each of which have varying priorities and values. As mentioned in the discussion of the SCOT theory, "to understand the developmental process of a technological artefact, we have to consider more than its technical functioning. The primary point of focus should be the perception of

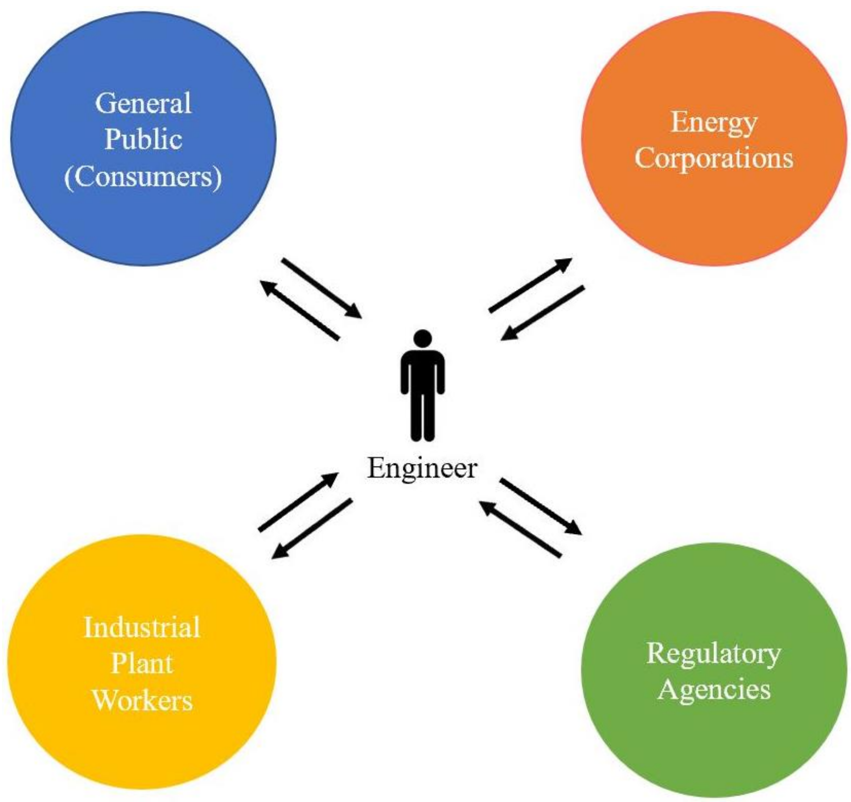

Figure 3: Relevant Social Groups Involved in Addressing Climate Change: The various categories of stakeholders with varying perspectives surrounding global warming must be carefully considered to promote the success of new innovations (Adapted by Abby Magner, 2019 from W. Bernard Carlson, adapted by C. Baritaud, 2009).

problems and solutions by members of those social groups" (Bijker, Bönig, & van Oost, 1984, p. 41). This notion is directly applicable to the relationship between the engineer who designs technologies that aim to promote a green future, as represented by the black silhouette in Figure 3, and the energy consumers, corporations, plant workers, and regulatory agencies who affect the success of these innovations. For example, Shove (2003) analyzes the ways in which inherent human values inhibit impactful change, stating, "…the environmental challenge is at heart one of understanding how meanings and practices of comfort, cleanliness, and convenience…fall into the realm of the taken for granted, and how they change" (p. 396). Shove's argument directly relates to societal patterns of behavior, such as the persistent reliance on fossil fuels to power gasoline-burning cars due to the convenience factor of abundant gas stations, in comparison to environmentally friendly alternatives. Furthermore, engineers must consider the guidelines that their designs must meet due to governmental regulations, as well as ensuring that technologies are technically effective, economically feasible, and safe in order to meet the needs of energy corporations and industrial plant workers.

The STS analysis aims to determine how to most effectively merge the various values and goals of each distinct social group in order to maximize the likelihood that technologies that promote environmental sustainability will be widely adopted. By providing an analysis of the SCOT theory in relation to innovating to combat climate change, this paper will evaluate the obstacles that currently stand in the way of progress toward a greener future, as well as considering techniques to overcome these obstacles, exploring the actions that are necessary to preserve the state of the Earth as an inhabitable planet.

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