Production of Carbon Dioxide and Methanol via Carbon Capture and Conversion

(Technical Paper)

Is Easing the Labels on Products Ethical if it Helps Sell Waste Originated Products for the Purpose of Preserving the Planets Resources

(STS Paper)

A Thesis Prospectus

In STS 4500

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Bachelor of Science in Chemical Engineering

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.

Introduction

The objective of this capstone project is to design a chemical system to produce methanol with a carbon-neutral process. With climate change being a major issue in today's world, reducing carbon emissions is vital to stabilizing the planet. The temperature of the planet has been increasing every year, and the burning of methanol releases a significant amount of CO_2 into the atmosphere. Building off of the capstone project of the carbon capture and conversion team from 2022, this project will dive into the synthesis of methanol from CO_2. The fundamental feature of the process this project is looking to achieve is to be able to take an amount of CO_2 from the atmosphere to synthesis methanol that is equivalent to, if not greater than, the amount that burning methanol produces. For this, direct air capture (DAC) technology will be used, along with a reverse water gas shift reaction and the hydrogenation of methanol. The final technical paper for this project will cover the process more in depth, and go into the unit operations for the model, the equipment used, an economic analysis, and the impact that the project could have on social and environmental levels. For the STS research project, the paper will seek to evaluate the ethical impact that labeling has on products that originate from waste sources. While the technical portion will be to synthesize methanol, another carbon capture use is to purify CO_2 from pollution to food grade CO_2. Similarly, drinking water can be made the purification of wastewater, but in both of these examples of waste to consumption, the products must be labeled that they originated from waste sources. This label leads to a decrease in their use due to a stigma around consumption of anything that originated from waste, even though these products have been purified to levels that are safe. The STS research will utilize the social construction of technology(SCOT) framework to analyze the ethical implications of removing the origin label from these products so that they would be more widely used.

Technical Prospectus: Carbon capture and conversion

The average temperature on Earth has risen 0.08° Celsius per decade since 1880, but this rate has more than doubled since 1981, rising 0.18° C per decade in recent years. The effects of global warming are driving regional and seasonal temperature extremes. These extremes have played a role in melting glaciers, intensifying hurricanes, extreme heat waves, and drastically altering the habitats that many life forms depend on for survival.[1] Following the Industrial Revolution, carbon dioxide (CO_2) emissions from man-made sources have been increasing. Now, 87 percent of all anthropogenic carbon dioxide emissions come from burning fossil fuels.[2] Greenhouse gases, such as carbon dioxide, are the leading cause of climate change, and while diverging from fossil fuels towards renewable energy is the ultimate goal, carbon capture technologies represent an important tool in emission reduction.

Direct air capture (DAC) is a new type of technology that serves to decrease ambient carbon dioxide concentrations as opposed to traditional carbon capture technologies which target point source emissions. In this project, a direct air carbon capture system and methanol production plant are designed based on "Carbon-Neutral Production of Methanol Via Direct Air Carbon Capture," a technical report submitted in 2022 by Brown, Huynh, Lee, Park, and Smith.[3] DAC is achieved by the chemical reaction cycles shown below, while methanol production is achieved by catalytic hydrogenation of CO and H_2 syngas produced from reverse water-gas shift reactions.

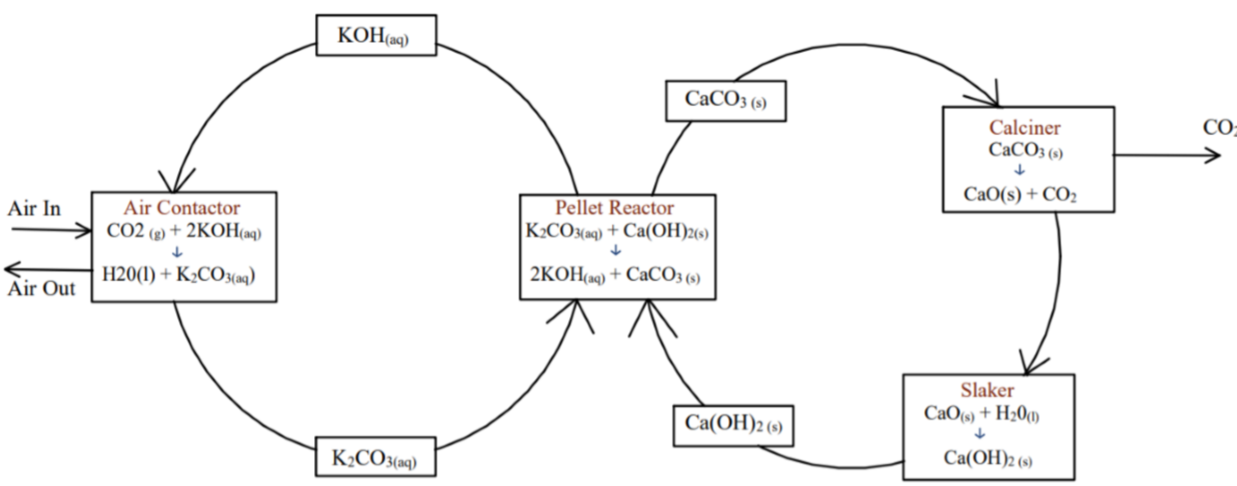

Figure 1. CO2 Production Via Potassium Hydroxide Sorbent and Calcium Caustic Recovery Loop System (Keith et al., 2018)

This project is still of interest for several reasons. First, the methanol market is expected to grow from \$36,803 million in 2022 to \$54.630 million in 2030[4]. Second, most DAC systems are in early stage or experimental in nature, thus the government provides a \$180 tax credit (Q45) for each ton of CO_2

captured directly from air[5]. These two factors combined creates a strong economic driving force for reconsidering this project. Moreover, some parts of the process were blackboxed and not optimized; the true potential of DAC methanol production could not be comprehensively evaluated under such conditions.

Our group aims to complete one of the blackboxed designs, the power island, and optimize the methanol production process. The power island consists of a natural gas turbine and a heat recovery steam generator (HRSG), according to Carbon Engineering's plant report. Heat recovery systems are designed to create additional steam to contribute to the turbine. To ensure no additional CO_2 is emitted from the turbine, all combusted fuel from the turbine will be sent to the CO_2 absorbers, which are also blackboxed in the 2022 design report. All amounts of fuel and products of the turbine process will be evaluated, and electricity supplied to the turbine will be calculated and costed, as well. The steam resulting from the generator is combined with steam from the slaker unit, passed through the superheater to extract heat from the calciner off-gases, and then used to drive a steam turbine that generates the remainder of the power required for the plant. As done in Carbon Engineering's Aspen simulation, we will also reduce the complexity by using independent steam cycles for the gas turbine and the slaker/superheater.[6] Material and energy balances for this process will be found and cost evaluated in this report.

The previous design had a water knockout system for the CO_2 product stream out of the calciner and precedes the methanol synthesis process. However, this system is costly in terms of both capital and utilities. The excess water comes from the combustion of natural gas in the calciner. To address this issue, the calciner will be redesigned as a heat exchanger-reactor, in which combustion takes place at the outer shell of the calciner, providing heat for the reaction at the inner shell. Water from the distillation bottom and condenser #1 will be recycled back to the slaker to increase $Ca(OH)_2$ production. New material and energy balances and economic analysis will be derived based on the improved model.

Similar to the 2022 design report, the scale up of this project will be designed with a capacity to capture 0.98 Mt of CO_2 per year based off of an internal pilot plant designed by Carbon Engineering with a capacity of approximately one tonne of CO_2 per year. The goal of the methanol synthesis is to yield 412 million kilograms of methanol per year at a production schedule of 6000 hours per year.

This project will be done as part of a two-semester team project fulfilling the requirements of CHE4474 Process Synthesis, Modeling, and Control. Modeling of process flow diagrams will be performed using ASPEN software. Two members of the team will likely focus on the power island and two members will focus on the methanol synthesis process. However, in order to create a seamless design and report, all team members will aid in work for the process as a whole and likely will shift focus as the semester progresses to work more on areas which require more complex modeling and design effort.

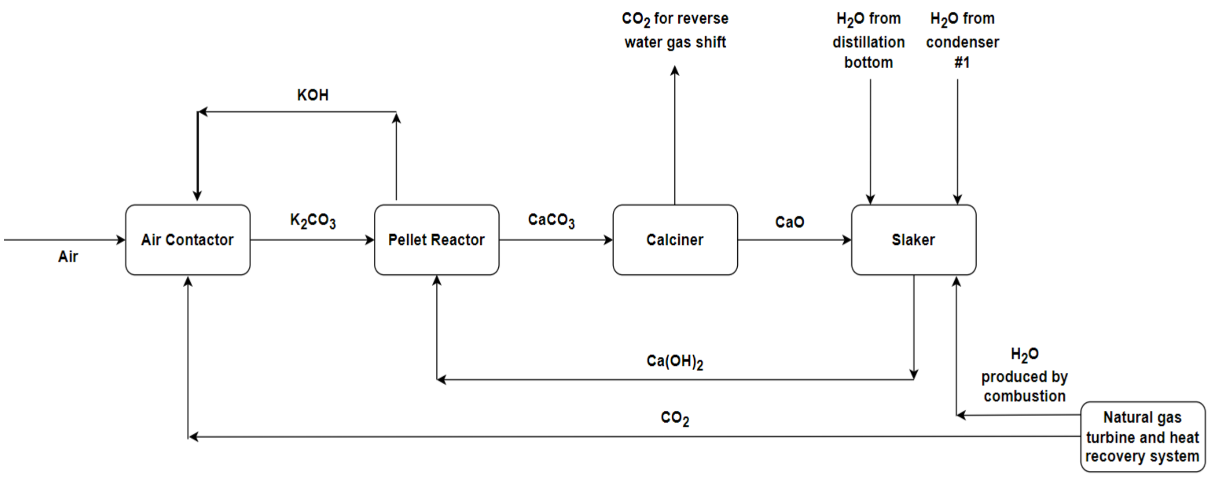

Figure 2: Flow Diagram for the Direct Air Capture Process

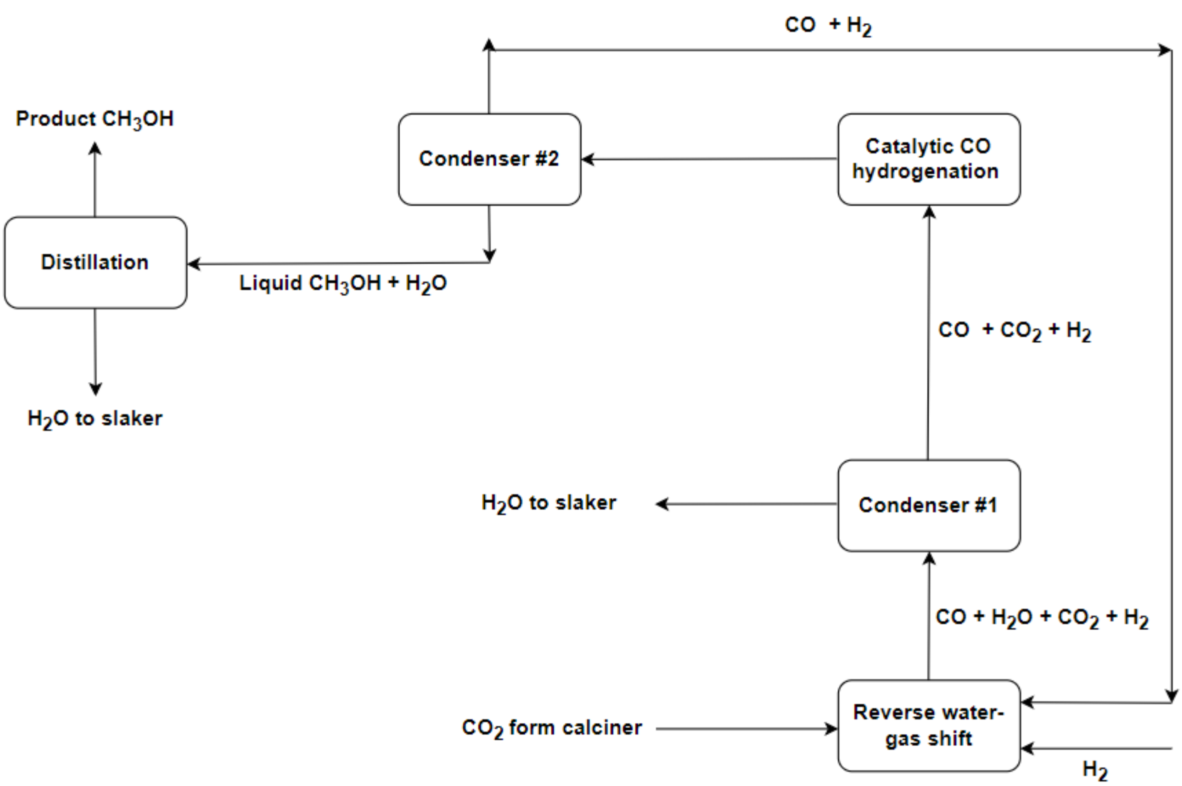

Figure 3: Flow Diagram for the Methanol Synthesis Process

STS Topic: The Ethics behind withholding information on product labels

Engineers have many sources when it comes to CO_2 capture. Sources such as landfills and burning fossil fuels can be strong target sources for carbon capture and conversion, but what if the intended final product was food grade CO_2? Food grade CO_2 is classified as CO_2 with 99.9% purity, compared to 99.5% purity for industrial CO_2 and 99.999% for research grade CO_2[7]. This level of purity and safety in a product can be reached from pollution sources and be safe for consumption, but would then most likely require a label that makes consumers aware of the origin of the product. This label, signifying that a source for something to be consumed was a waste product, can hold a stigma around it that discourages people from purchasing the product. This leads to the question of would the product sell differently without the label, and if so, what would be the ethical implications of withholding said label.

Along with carbon emissions, another source of waste-to-consumption is water. In direct potable reuse, or DPR, highly treated sewage water is converted almost directly to a drinking water system for distribution to communities[8]. However, this water legally requires distribution through a specific location due to its origin as a waste source. Laws for DPR are on the state level, but as of September 13th, 2022, only Arizona, California, Colorado, Florida, New Mexico, and Washington have directly addressed DPR as a legitimate way to produce drinking water[9]. Therefore, it should be an easy choice to drink this water, as it has been shown to be clean and healthy.

However, just the label originating from waste can lead to a stigma around a product. A 2015 survey of 2,000 people across the U.S. found that 13% definitely refuse to try recycled sewage, 38% are uncertain and 49% are willing to try it[8]. Ethically, lying and deception are obviously not accepted, but this line becomes blurred when the possible positive impacts of the reuse of waste are analyzed. The current CO_2 shortage, diminishing supplies of drinkable water, and other resource shortages of similar vein could be helped if an origin label was withheld, and a product was sold as 'normal' compared to the same resource from a publicly accepted source. This product would be just as pure as one of the current market standards, if not purer due to a focus on the purity of said product due to its origin. While this could be considered unethical, it could also help to address issues in today's world.

Ethics behind labeling are more complex than just withholding information to sell a product. An increase in consumption of products from these sources could address legitimate concern in supplies, and avoid the stigma that prevents the usage of these sources on a major scale. The deliverable of the STS research paper will be a paper examining the history of why specific labels are mandated on products, and the ethical implications of withholding these labels in respect to the idea of lying or deceiving versus the possible benefits on a large scale of holding back a label to help with resources. For this, the research into this topic must first go into the laws that currently exist. The focus will be on the United States, so looking at both federal and state specific laws on labels will be vital for the research. From there, the next step would be to do research into how laws could be changed, and if they are, how it would be determined where the line would be drawn on reducing the labels so that there would not be too much removed. This research will then lead into the main analysis of the thesis, and the debate on the ethicality of removing some labels and the pros and cons that removing some labels could cause.

The focal STS framework will be social construction of technology (SCOT). This paper will be diving into labels and how we can use them and ways they should be rejected. As a technology, labeling has major social aspects to it, making SCOT the most important framework. Furthermore, both the frameworks of case studies and public policy, as case studies into any legal cases over similar labeling ethics and the policies that currently exist will provide fundamental information towards analyzing the ethics of labels. For the ethics themselves, looking at the big picture of would taking action to reduce labels better for people or harm more people, and making sure to take a look at every demographic. Furthermore, for the ethical guidelines themselves, analyzation needs to be done to account for how significantly different groups could be affected. Maybe a large organization could lose thousands of dollars, but this would be less significant than if the same change made a significant portion of low-income families lose thousands of dollars as well.

Overall Conclusion:

Our technical deliverable will be a design for a process to produce CO_2 and methanol on a large scale via carbon capture and conversion. This will include the materials, equipment, energy balances, process conditions, process safety, and the economics of the project. The STS deliverable will be a paper analyzing and debating the ethics of labeling products and how withholding label could be considered ethical at any point for the purpose of helping the planet's consumption. Based on the technical project, if say, a landfill was used as the emission source of carbon into the atmosphere, there could be an ethical justification of taking the produced CO_2 from the carbon capture and purifying it to food grade CO_2, while withholding the label of landfill CO_2 to avoid a stigma on consumption.

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