Methanol Production Via Direct-Air Capture

The Effect of Climate Change on the Coffee Production Industry And American Life

A Thesis Prospectus
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Bachelor of Science in Chemical Engineering

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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

While the hole in the ozone layer is in every elementary school science textbook, climate change itself remains a highly politically contested topic. 99% of scientists agree that climate change is real and poses a significant threat to humankind. From the increasing severity of weather patterns to mass extinctions, climate change is projected to affect everyone on the planet in one way or another. 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 (Lindsey, 2022). 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 ("Main Sources of Carbon Dioxide Emissions," 2017). 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. The goal of this Capstone project is to design a carbon capture process that uses the captured carbon dioxide to create methanol that can be used industry to provide economic incentives for the use of this technology while studying the effects of climate change on the production of goods to provide a social incentive for industry to move away from the use of fossil fuels. The technical section of this Capstone will focus on the redesign of the methanol synthesis process and implementation of a power island for a previously designed carbon capture facility. The STS section of this Capstone will focus on the effect that climate change will have on the lives of people who live in the United States through its effects on the coffee production industry.

<u>Technical Topic:</u>

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 (Huynh 2021). 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.

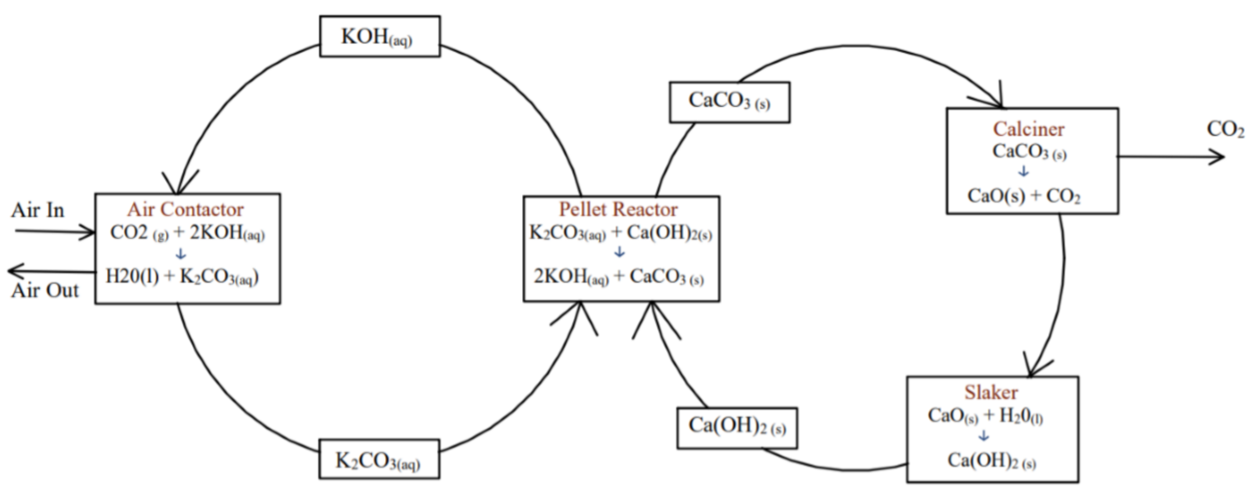

Figure 1: Process chemistry and thermodynamics for Carbon Engineering's aqueous direct air capture system

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 ("Methanol Market Report" 2022). 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 (Cooper 2022). 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.

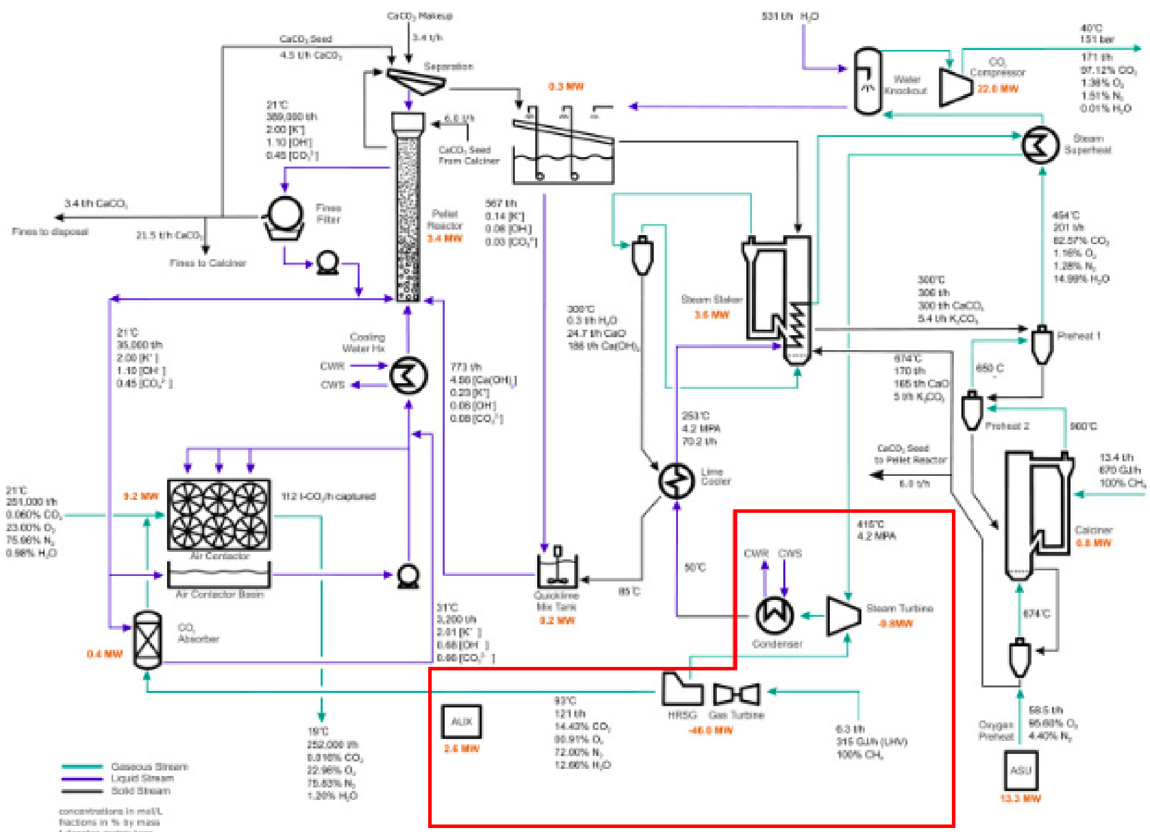

Figure 2: Overview of carbon capture and methanol synthesis system from Carbon Engineering's design. Highlighted is the power island: The methanol synthesis shows the process before the water knockout system is removed

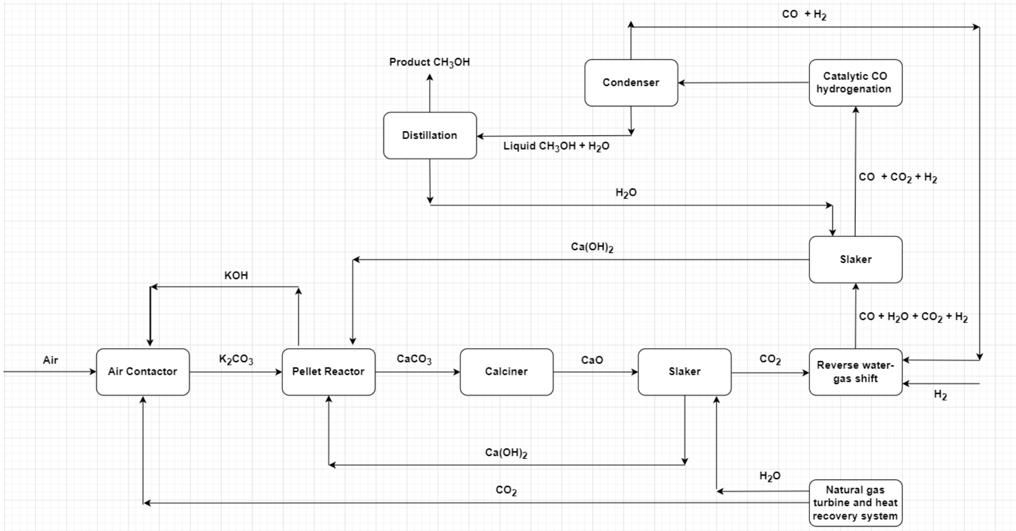

Figure 3: Overview of carbon capture and methanol synthesis based on Carbon Engineering's design. The methanol synthesis block is redesigned without the water knockout system

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 slacker 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 produce 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.

STS Topic:

Coffee consumption became extremely popular in the U.S. during the Civil War, leading to the invention of instant coffee in the late 1860s. Instant coffee remained supreme until the first Starbucks opened in Seattle in 1971 (Wulff 2016). But recently, the practice of drinking coffee has become less about socializing and more about energizing. The capitalist nature of American life has created a need to live at an extreme pace that is dependent on the use of caffeine. Coffee is currently a more popular drink in the U.S. than tap water ("The Economic Impact of Coffee" 2016). Starbucks allowed coffee to be transformed from a leisure activity to a form of human gasoline that the majority of people in the United States have come to rely on.

Changes in temperature and weather patterns will result in strains on the coffee industry that will be felt throughout the world, but especially in a society that depends on a significant amount of caffeine to function ("Most Unexpected Effects of Climate Change" 2019). Different types of coffee will be affected in various ways with temperature, elevation, and rainfall affecting Arabica coffee and Robusta coffee differently (Chemura 2021 and Kath 2021).

One of the main issues with a decline in coffee production is that many Americans are not aware of the people or processes involved in the production of coffee. Susan Star defines infrastructure as having certain properties that demonstrate its relationship with humans and the surrounding environment. In my research to find the effects of coffee production decline in the US, I will be using this framework to view the impact coffee has in society in the United States. One of these properties is how normally invisible aspects of working infrastructure become visible when broken. The average US coffee consumer does not think about the roughly 25 million small-scale farmers that produce their coffee thousands of miles away and rely on coffee production for their livelihoods ("How Climate Change is Killing Coffee" 2019). However, the consumer will notice when coffee prices begin to increase due to those farms not being able to produce as much coffee as they have in previous years. The scope of coffee production, or its reach throughout the globe is another aspect of coffee production at which I will be looking. I want to discover how badly the coffee industry will have to decline for the people of the United States to notice and to decide it is important to change. Fitting perfectly with the scope of coffee is its aspect of links with conventions of practice. I will use this aspect to analyze how the coffee industry has impacted social interactions and patterns.

Research Questions and Methods:

To research the effects of a decline in coffee production I will be viewing case studies and interviewing with three different types of people. The goal of the interviews is to meet with three different types of people in the US: a standard everyday coffee drinker, the owner of a coffee chain such as Dunkin or Starbucks, and the owner of a local coffee shop. The purpose of meeting with these three people is to see how they are affected by the current decline in coffee production and increase in prices and see their plans for future price increases and production decline. Some of the questions I will ask the coffee consumers is how price affects where and when they buy coffee, as well as if they have noticed a decline in the quality of coffee in past years and what they have done about it. For shop owners I want to ask them about their import process and how they plan to deal with future supply chain issues. If I cannot get interviews with the large coffee chains I will focus on smaller, local coffee shops instead.

Conclusion:

The completion of the technical project will provide a more economically viable option for carbon capture systems that can provide a source of income for the companies that implement it.

This will hopefully encourage companies to use the technology and reduce the amount of carbon emissions released into the atmosphere. The completion of the STS investigation on the coffee industry will provide more information on an industry where the effects of climate change are uncertain. Since so many people in the United States rely on coffee, the desired effect of this investigation is for this information to convince more people that climate change is real and technologies like direct air capture are an important part in the maintenance of this planet.

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