Production of Biodiesel from Algae

The Impacts of Crop-based Biofuels on Food Insecurity in the United States

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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

The ten warmest years on record have all occurred since 2005, with seven of these record years occurring since 2014 (U.S. Global Change Research Program et al., 2017). This is a direct result of global warming and climate change, which are partially attributed to the combustion of petrochemical based fuels. As a result, a desire and a need for a fuel that is both environmentally-friendly and able to meet the specifications set up by the government is created. Biofuels are a way to potentially address the concerns associated with global warming. The various feedstocks used for biofuels absorb carbon dioxide from the atmosphere. These potential feedstocks vary between conventional biofuels, which are produced from food crops, and advanced biofuels, which are produced from crops that do not compete with food crops (Biofuel Feedstocks, n.d.). The STS portion of this paper will focus on bioethanol produced from corn in an attempt to determine its impact on food security and whether it is financially feasible to reallocate corn usage in the United States. The aim of this portion is to analyze and determine the socioeconomic impacts associated with the use of food crops for biofuel production in the United States. The technical portion of this paper will focus on advanced biofuels; specifically, it will focus on the production of biodiesel from algae. The aim of this portion is to determine the conditions needed to successfully produce an affordable biodiesel from algae using a hybrid photobioreactor and raceway system.

Production of Biodiesel from Algae

Introduction & Background

Climate change has become a predominant problem recently; biofuels are a potential solution due to their absorption of carbon dioxide from the atmosphere. Biodiesel produced from algae will be the focus of this project; this project will address the need for an environmentally friendly fuel source that is able to meet the necessary specifications. Biodiesel has the potential to be used within existing infrastructure, which is partially due to its ability to be used in existing diesel motors. Unlike traditional methods for growing algae for fuels, this process will involve the simultaneous use of a closed photobioreactor and open raceway pond. Research supports that hybrid systems outperform isolated systems in algal growth and productivity (Narala, 2016), so the goal of this project is to design a system which delivers biodiesel at a comparable wholesale price to that of petroleum diesel, which is around $2.50/gallon (U.S. Energy, n.d.). This makes algae biofuels a favorable alternative.

In this process, there are three main steps after selecting the algae strain and nutrient source: 1) cultivation, where algae are allowed to grow and increase in lipid content, 2) extraction, where lipids are extracted from the harvested algae, and 3) refining, where lipids are purified to biodiesel.

Project Design: Sourcing

The algae that will be used is *Chlorella Vulgaris*, which is well-researched. The advantages of using *C. Vulgaris* include its high oil content, short growth cycle, and wide growth space (Mao et al., 2020). The nutrient source will be chicken litter from the Shenandoah Valley region, with approximately 200,000 tons of chicken litter being produced per year (Fears, n.d.). This is a cheaper option than traditional sources of nutrients (*Maximizing Value: 2021 Spring Application*, n.d.).

Project Design: Cultivation

The two methods for cultivating algae for biodiesel production are closed photobioreactors and open raceway ponds, the latter being the cheaper option (Yun, 2018). However, one concern with raceway ponds is the potential introduction of bio-contaminants, which compete with algae growth (Yun, 2018). A hybrid system which simultaneously uses a photobioreactor and a raceway pond is a possible solution for this concern.

This system works by inoculating a culture of cells within a photobioreactor, and transferring a portion of the growing cells for continued growth in an raceway pond, which stimulates lipid biosynthesis through nutrient depletion (Narala, 2016). By using a hybrid system, the bio-growth phase and lipid-accumulation phase are separated into different parts of the process (Narala, 2016).

Project Design: Extraction

Once the algae have been grown, the lipids in the algal cells need to be extracted. The industry standard for this extraction is a dry extraction process, where an organic solvent is used to extract oils from dry algae cells, which are typically at a water content of around 10% (Ranjith, 2015). The harvested algae will first need to be dewatered to its maximum cell concentration, then dried into a solid powder. Traditional methods of dewatering involve the use of dissolved air flotation, followed by centrifuging the resulting algal sludge. The sludge is then dried and any lipids are extracted using organic solvents such as chloroform or hexane (Ozer, 2014). The primary design questions for this step are how much the wet algae should be dewatered, the drying method to be used, and the solvent to be used.

Project Design: Refining

Biodiesel in the form of fatty acid methyl esters (FAME) are commonly derived through transesterification of algal lipids, with the goal of using triglycerides extracted from the algae cells. While transesterification is recognized as the simplest method, it requires high temperatures and catalysis to run efficiently (Kröger, 2012). The successful refinement of algae biofuels from the lipid extraction will be the consequence of many experimental factors. The main variables of concern that can influence transesterification are the algal species, reaction time, temperature, moisture, as well as the order and mixture of chemicals into the reactor (Kröger, 2012). One major approach under investigation will be in the heating process of the reaction. Previous research has shown high yields and short reaction times with microwave heating mechanisms in contrast to traditional heating methods (Marwan, 2015).

Design Data Acquisition/Computational Tools

Physical data pertaining to chemical feedstocks used can be obtained from chemical data sources, such as Perry's Chemical Engineering Handbook. Data pertaining to algal and nutrient feedstocks will be obtained from peer reviewed journals. If necessary, algal data can be obtained using in-house equipment. After obtaining the design data, a simulation software, such as Aspen, will be used to model and assess the process.

Work Division

This is a two-semester, 4-person team project done for CHE 4474/4476 (Technical Advisor: Eric Anderson, Chemical Engineering). The work will be done in a collaborative style with small tasks divided up, with subtasks focusing on individual parts of the overall process. We will discuss the objectives of our project bi-weekly to ensure group members are contributing. Disputes will be handled cordially and major decisions will be put to a vote. If any group members are unable to honor their commitment to the team, we will discuss and consider the situation at hand and bring it to the attention of our instructor if needed. The contents of the final design report will include material and energy balances, equipment design for the process, and the economics of the process. The report will also contain considerations of the safety, environmental, and societal impacts associated with the process.

The Impacts of Crop-based Biofuels on Food Insecurity in the United States

Biofuels are a new, innovative attempt at addressing climate change, but what if there are negative aspects associated with biofuels? What if the materials used to produce biofuels were better suited to feed those who are in need? There are a number of biological feedstocks for biofuels; however, for the STS portion of this project, the focus will be on corn as a biofuel feedstock. Corn was chosen due to it being one of the most produced crops in the United States; therefore, data surrounding corn will be ample. There are over 90 million acres in the United States that are dedicated to growing corn for various purposes (Top 10 Produce Crops Grown in the U.S., 2019). In the United States alone during 2020, there were 14.99 billion bushels of corn produced. 5.05 billion bushels of this corn was used as a feedstock for ethanol (Alternative Fuels Data Center: Maps and Data, n.d.). A major challenge that a large number of people face in the United States is food security. In 2019, there were a total of 35.2 million people facing food insecurity, with 10.7 million being children (Hunger & Poverty in the United States, n.d.). Some of the crops that are used towards biofuels could be used to help stave the impact of food insecurity in the U.S.

For this project, the stakeholders involved include the farmers growing the corn, the scientists developing biofuels, the consumers who use biofuels, and people who are facing food insecurity. The purpose of this STS-based research is to analyze and develop the social and financial impacts of using products that could be used as food, such as corn or soybean oil, for the production of renewable biofuels. For this pursuit, various factors surrounding the production of biofuels in the United States will be examined. Corn will be the focus due to its prominence in the U.S.; Sources will be identified surrounding the production of corn, cost to process corn, the nutritional value of corn, financial value of corn as both a food and a biofuel, food insecurity rates, other uses of corn besides food and biofuels, and people's opinion surrounding the usage of corn as biofuel (Thompson, 2012).

Using this data, a narrative surrounding the food versus fuel conflict associated with biofuels will be brought to light through the exposure of additional related factors. These factors include the use of corn as a solution to food insecurity in the U.S. and what the socioeconomic implications of this solution would be. As a result of this research, there is hope that a better allocation of resources to suit social needs rather than technological needs will be found. The first STS theory that will be used is co-production due to it providing insight into how society and biofuels live in tandem, constantly evolving one another. Co-production is the simultaneous process through which modern societies form their epistemic and normative understandings of the world (*Sheila Jasanoff*, n.d.). Co-production was a result of researchers seeking an integrated framework to explain the simultaneous production of scientific knowledge and the countless, complex social relations that formed with it (Miller & Wyborn, 2020). This framework shows how scientific ideas and beliefs, and associated technological artifacts, evolve alongside the representations, identities, discourses, and institutions that give practical effect and meaning to ideas and objects (*Sheila Jasanoff*, n.d.). It implies that society and technology have a relationship in which society produces technology and that technology influences the society continuously. Some critiques of co-production include the following: concerns surrounding its ability to meet the promises of ameliorating complex problems, the lack of evidence supporting claims of outcomes and impact, fear that the process is very resource intensive without the ability to produce usable findings, and its failure to adequately account for power within science-society relationships (Co-Producing Sustainability, n.d.). This analysis is important because it will address how technology, through biofuels, and society, through food needs, financial factors, and public opinions, interact with one another; it will also provide the opportunity to recommend a reallocation of resources to help better provide for social needs over technological needs.

The second STS theory that will be implemented is the Social Construction of Technology (SCOT) framework, which will work to analyze the ways that different groups perceive biofuels as a technology. Using SCOT, the development of a technological artifact is described as an alteration of variation and selection (Pinch & Bijker, 1984). This results in a multi-directional model that highlights the fact that the "successful" stages in development are not the only stages possible (Pinch & Bijker, 1984). A key part of a SCOT analysis is looking into the relationship between the artifact and the relevant social groups that interact with the artifact. In the case of this thesis, the relevant social groups will include the producers of corn ethanol, those who experience food insecurity, the producers of the corn, and those who would consume the energy produced from the corn ethanol. Interpretive flexibility is another defining feature of a SCOT analysis, and it claims that artifacts are open to radically different interpretations by various social groups (*Social Construction of Technology | Encyclopedia.Com*, n.d.). Some of the major criticism surrounding SCOT involves excessive emphasis on agency and neglect of structure (Klein & Kleinman, 2002). One of the main critiques of SCOT is its view that society is composed of equal groups, for it leads to a failure to adequately acknowledge that there is usually a power asymmetry between groups (Klein & Kleinman, 2002). SCOT will be an important framework to see how different groups view biofuels, and it will help to build upon whether society believes that the corn supply in the U.S. would be better suited for food or fuel.

Conclusion

The technical deliverable from this project is to design a hybrid photobioreactor and raceway system which delivers biodiesel at a comparable wholesale price to that of petroleum diesel. If the technical project is successful, it could help to affirm the use of hybrid systems when attempting to produce biodiesel from algae. The outcome will show that the process is attainable and the cost of the produced biodiesel will be lower than that of a bioreactor or raceways; however, the cost will likely still be higher than that of petrochemical based diesel. The goal for the STS portion is to determine the social, financial, and logistical interactions between the production of biofuels and society. The results from this research will be able to explain these interactions in regards to the food versus fuel debate and lead to an opportunity to achieve a balance between the two. It is expected that it will be found that various factors will prove the usage of the excess corn as food to be infeasible, which leads the excess to be better used as a fuel.

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