Sourcing Biodiesel from Algae

Can Biodiesel be a Reliable Tool for the Future of Energy?

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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

As our world moves away from fossil fuels, we have introduced many interim solutions like biofuels to mitigate the impact of climate change and increasing energy demand. The benefits of biofuels, such as their infrastructural "fit" and renewability, have ecosystemic consequences through its optimal use of resources, energy, and monoculture. As a society we must quantify and qualify the risks associated with biofuel implementation before we can scale it as a fossil fuel replacement.

Background:

Climate change has been on the rise since the first industrial revolution as a result of burning carbon-based fuels and releasing greenhouse gases into the atmosphere. The trapping of heat within our atmosphere has resulted in a temperature increase with implications for major catastrophic events taking place. Bio-based fuels have emerged graciously as a carbon-neutral solution for energy and heat production.

Use Case

Biofuels carbon-neutrality is achieved through the feedstocks absorbing carbon dioxide from the atmosphere when growing. Biodiesel produced from algae will be the main focus of this project, and through it, the need for a fuel source that is both suitable to supply the demand and does not contribute to climate change will be addressed. Biodiesel is a product that has the potential to be implemented without much change to existing infrastructure, which is in part due to its ability to be used in existing diesel motors and internal combustion engines.

Algal's natural use case gives it a particular edge when it comes to scaling potential. While sourcing, it undergoes photosynthesis 30 times faster than food crops without the need for freshwater resources(natgeo). This means the chemical reaction that absorbs carbon dioxide and other pollutants from the air to be harnessed for energy has a biological edge with algal plants. If current operational costs can be reduced and scaled, algal biofuels will provide more resources than it needs to grow(natgeo).

Biodiesel

This project will be of novel interest, since unlike traditional designs which convert algae into biodiesel, it will incorporate a hybrid reactor system which utilizes both a closed photobioreactor and an open raceway pond. There have been studies which support that hybrid systems outperform photobioreactors and raceway ponds in algal growth and productivity(Narala, 2016), so the goal of this project is to design a system which delivers biodiesel at a comparable price to that of petroleum diesel ($3.18/gallon), ultimately making algae biofuels an economically and environmentally favorable alternative(U.S. Energy, n.d.).

Biodiesel can be used to power our world through its fueling of engines and generators. The mechanical energy or electrical energy is sourced from the combustion of diesel fuel within the drivetrain. Most drivetrains will harness the chemical energy by igniting the combustion reaction of oxygen and fuel, to push the exhausted energy into a mechanical turbine in a series of short, continuous explosions (Brain & Geisler).

This project will investigate the efficient sourcing of biodiesel from algae and unpack the socio-technical implications of the biofuel use and implementation.

Technical Topic and Methods

Sourcing biodiesel from algal feedstock has many potential benefits but is currently limited by the manufacturing costs and operations. The technical goal that will be addressed is designing a biodiesel manufacturing process that will achieve a highly efficient yield of fuel from the growth to refinement of the supply chain. An efficient system will reduce costs and increase the competitiveness of biodiesel; these results have positive implications for climate change, our energy grid and bioprocessing facilities across the globe.

The Process design outlined below is the experimental draft for the technical portion of this thesis. The experimental design is outlined in chronological order and not a definite strategy. It serves as a tool to design the resources needed and outline the tested unit operations while investigating the most efficient manufacturing of biodiesel from algae.

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 rector (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).

STS Topic

The use of biofuels is a multi-faceted issue that poses many systemic consequences; in this section these consequences will be framed throughout the implications biofuels have within society, organizations, and technology. Figure 1, shown below, is meant to capture the societal, technical and organizational connection of biofuels. The socio-technical triangle has value in representing the different perspectives that influence behavior in the biofuels industry. Each point of the triangle is connected to the two other perspectives and its entities have similar relationships with each other as well. The goal here is to emphasize what key motivations will move the biofuels industry forward and show this in a connected way.

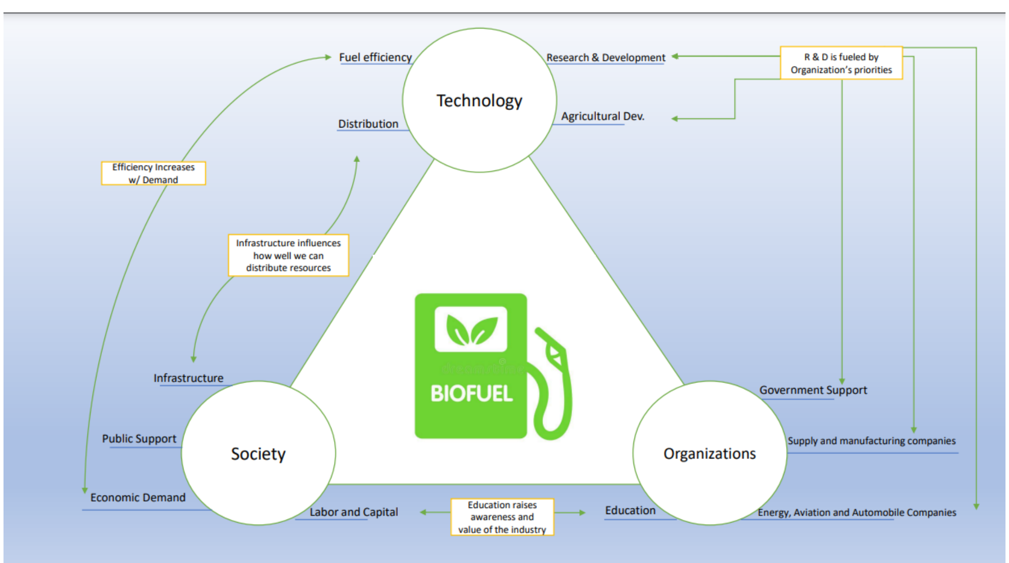

Figure 1: Sociotechnical Triangle of Biofuels

Technology

The most influential property of the biodiesel industry is technology. I've highlighted the major tech as biofuel fuel efficiency, research and development, distribution, and agricultural development. It's these nodes of biodiesel technology that will determine how the economy, public perception, and organization's begin to adopt the industry.

Firstly, fuel economy is important in motivating consumers to purchase fuel. In the western capitalist economies, demand and supply typically goes to the most profitable or practical product. According to ConsumerReports, B20 or 20 percent biodiesel blend and B100 or pure biodiesel sell for 20 cents and 85 cents more per gallon respectively(ConsumerReports). While B5 has a greater fuel conversion and a competitive price, before widespread adoption there needs to be more progress to widen the gap in price and competitiveness for higher purity biofuels(ConsumerReports).

Secondly, r&d represents how fuel efficiency will be accomplished. Making sure that biofuels are continually being improved and investigated will ensure its most optimal use in our world. This is touched on heavily with the technical portion of this paper.

Additionally, distribution is relevant in providing biofuels and their availability. There is no value in a fuel that cannot be accessed, the value of petroleum/diesel stems from its accessibility within our infrastructure.

Lastly, agricultural development is one of the major shortcomings or pain points for biofuels. Before they can be represented widespread, the ecosystemic issues such as monoculture, deforestation, and energy use must be prioritized. "Economic models show that biofuel use can result in higher crop prices, though the range of estimates in the literature is wide. For example, a 2013 study found projections for the effect of biofuels on corn prices in 2015 ranging from a 5 to a 53 percent increase" (Zhang et al. 2013). This problem has real-time economic and environmental implications directly related to the use of biodiesel, this also adds to the impetus to focus on algal biodiesel as the industry moves forward.

Society

Society will determine the sturdiness of the bioplastics industry in tandem with technology and organizations. The communities of people involved: farmers, workers, and users will be influenced by education, distribution and unit economics to begin and continue supporting the biofuel industry.

Firstly, our infrastructure must be able to support biofuel use. We need distribution centers and fuel stations just as much as we need cars that can efficiently process the fuel provided. This infrastructure is determined by how our society chooses to structure it and where we decide to invest our money. This goes hand-in-hand with public support and capital. Human resources in the form of labor and capital resources from businesses and consumers as demand, all influence the long-term success of biofuels.

In general public opinion has shown support for biofuels through polling, however they were less informed about the politics and environmental beliefs. Notably, most consumers of biofuels, typically truckers, have had positive experiences with biodiesel but those who didn't were not willing to continue consumption in any capacity and denied educational materials(Fung).

Organizations

The organizational perspective of biofuels isn't overly important but will become seminal as biofuels find their place in our infrastructure. The government support portion will lead the organizational development for biofuel. The government has the opportunity to promote development or contention right off the bat with legislation in the form of credits or subsidies; in turn this motivated businesses or research facilities to look into biofuel. The Energy Independence and Security Act of 2007 has already begun to motivate biodiesel production to 36 billion gallons by 2022 and 21 billion of those gallons must come from cellulosic or advanced biofuels that are not cornstarch(EPA).

Secondly, I'm going to group supply, manufacturing, and energy companies all together. These entities represent the economic structure of biofuels. This industry can only be successful if someone is sourcing the feedstock, refining the fuel, and using it for travel or power. All together the economic "push and pull: of these companies motivate the connection between organizations like the government as well as how the technological and societal views develop over time. Lastly, the education of biofuels interacts with how the public perceives the fuel source. Are car companies educated on the benefits of biofuels? Do schools teach kids that biofuels are harmful to the environment? Are repair shops taught how to work with biofuel tanks? These are all examples of how education can influence adoption and development.

Research question

The question to be answered here is can biofuels, specifically algal biodiesel, be scaled for widespread use in competition with cheaper and efficient traditional methods of fuel? This question is multi-faceted and will be answered by understanding the infrastructure and the efficiency of algal sourcing, growth, extraction, and fuel refinement.

Conclusion

In synthesis, this project will investigate the feasibility of biodiesel from both the production and infrastructural lenses in an attempt to understand the scalability within the highly competitive fuel industry. While algal biodiesel has natural potential to provide high margins of energy, it faces many challenges within its agricultural and production costs. If these setback are proven to be overcome, algal biodiesel could provide a mainstream source of fuel to power our world carbon-neutral.

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