BIODIESEL PRODUCTION FROM MICROALGAE: A NOVEL PROCESS

THE EVOLUTION OF ECONOMIC VALUES SURROUNDING RENEWABLE ENERGY

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By
Cynthia Bing-Wo

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Technical Team Members:
Soren Andrews
Alex Hawkins
Aydan Moskowitz
Pablo Newton

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.

ADVISORS

Rider Foley, Department of Engineering and Society

Eric Anderson, Department of Chemical Engineering

INTRODUCTION

We will run out of oil and gas by 2050. Or at least, that's what Shahriar Shafiee and Erkan Topal found in their 2009 projection of fossil fuel use. If we assume that statement is true, we only have about thirty years to fully develop alternatives. Thankfully, we have already begun the transition with 20% of all electricity in the United States being sourced from renewables (Renewable Energy, n.d.). However, there are many industrial machines that are still configured for or require a liquid fuel like diesel or gasoline. Specifically, when it comes to vehicle capabilities like towing, electric vehicles and trucks may have large towing capacities, but they are still not yet recommended as this activity greatly decreases the range on the battery (Valdes, 2023). For example, Rivian produces a truck with an 11,000-pound towing capacity, but during a towing situation with that weight, the range on the vehicle is reduced by half to 164 miles from 328 miles (Valdes, 2023). This means renewable alternatives to gasoline and diesel are necessary to ensure a retention of current vehicle capabilities.

Biofuels have long been touted as viable alternatives to fossil fuels, but fuels sourced from plants require a large landmass for relatively little fuel production. Corn, part of the first generation of biofuels, can be a feedstock for ethanol, but it requires copious amounts of land and water to sustain. Because of the upfront costs, the price of the final fuels also ends up being quite high (Ogg, 2007). Simply put, fuels have to be cheap enough to burn. Some people are willing to spend a little more money to stay "green," but that opinion does not apply to everyone (Degirmenci, 2017). But exactly how much more are supporters of the energy transition willing to pay? And what about those who are unwilling to spend more money?

To help mitigate this issue, algae biofuels can be employed. Algae is a fast-growing organism that can reduce years-long time investment in crop based fuels to a matter of months (Hannon, 2010). Algae can also be cultivated on land that is not suitable for farming, ensuring no conflict with other areas of the agricultural industry. Unfortunately, algae biofuel remains relatively expensive to produce due to the intensive harvesting and separation processes and their lack of efficiency (Milledge, 2013). In short, while algae is cheaper than other biofuels, it is still not as cheap as traditional oil and gas. All of this culminates in the technical goal of creating an economically competitive algae biodiesel. The mass production of an affordable biodiesel can take the strain off of fossil fuel resources and further the transition to renewable energy. This transition will also have strong financial implications for energy consumers who will be the focus of my thesis.

BIODIESEL AND LUTEIN CO-PRODUCTION

In response to climate change and other environmental imperatives, our society has begun to actively seek sustainable alternatives to many contemporary, petrochemical-fueled technologies. Thus far, long-distance travel has resisted shifts to electrification, making the adoption of greener fuels a necessity (Gross, 2020). Algae-based biodiesel has emerged as a promising tool to help fight the global climate crisis. Algae-based methods can be more advantageous than first and second generation biofuel sources due to high energy content, rapid growth times, and reduced land and water requirements. However, industrial-scale algal biodiesel production remains constrained by its limited commercial feasibility (Prommuak et al., 2013). This capstone project aims to address these economic deficits.

The objective of our technical capstone project is to design a novel method of producing microalgal biodiesel by optimizing previous process strategies while simultaneously subsidizing costs through the co-production of lutein as a high value byproduct in order to improve economic viability. Lutein, a carotenoid with anti-inflammatory properties, is widely recognized for its benefits in promoting eye health, particularly in preventing age-related macular degeneration. Additionally, research suggests potential positive effects in various clinical areas, including cognitive function, cancer risk reduction, and cardiovascular health improvement (Buscemi et al., 2018). The overall pathway is outlined in Figure 1.

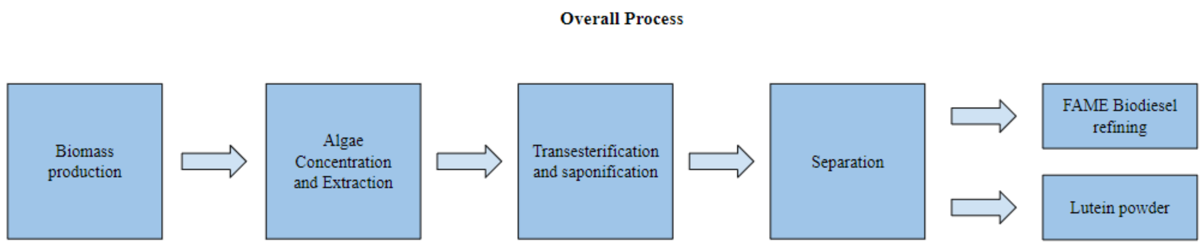

Figure 1. Overall process for FAME biodiesel and lutein.

We are drawing upon the insights presented by Tabernero et al. (2012) as inspiration for the development of our overall process. The first stage begins with the cultivation of *Chlorella vulgaris* in raceway ponds. Raceways offer an affordable and low maintenance method for growing algae (Griffiths et al., 2021). Agricultural waste will provide an inexpensive source of carbon and nitrogen. Paddles and spargers will be utilized to ensure complete mixing of nutrients and adequate aeration, therefore promoting a high rate of algae growth. Algae harvested at the end of the raceway will undergo a dewatering process to increase its concentration for further processing. This will involve a combination of mechanical centrifugation and a flocculation process assisted by nano magnetites described by Patel et al. (2022) to increase efficiency.

The downstream steps are modeled after the methodology outlined by Prommuak et al. (2013) but will be augmented to accommodate industrial scale production. Triglycerides and lutein fatty acid ester, crude forms of the desired products, will be removed from harvested algae via cell disruption. A scaled-up version of a Soxhlet extraction employs methanol and chloroform as solvents (Wang et al., 2023) to extract the lipids and dissolved lutein from the algal biomass. The remaining algae residue will be recycled back into the raceway as an additional carbon source. The chloroform and methanol will subsequently be removed to isolate the crude lipids, where they will then be converted to biodiesel and lutein through a coupled transesterification and saponification process. This process as well as the following separation processes to derive the final biodiesel and lutein powder products are demonstrated in Figure 2.

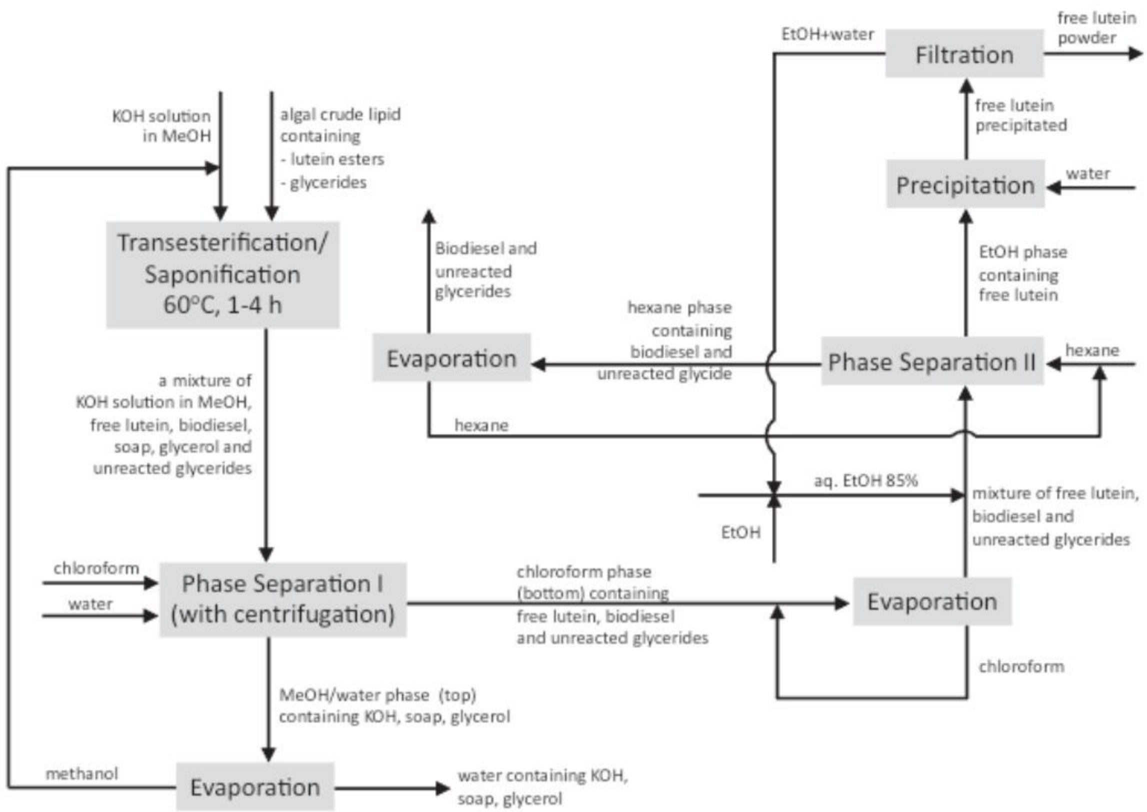

Figure 2: Reaction and separation to produce lutein and FAME biodiesel (Prommuak et al., 2013).

Further refining of the biodiesel with a fractional distillation column may be able to achieve higher purity and thus increase the value of this product. The ultimate goal following the process design is to perform an economic analysis to determine the viability of microalgae biodiesel production alongside lutein co-production.

This project will be completed over the course of two semesters by our 5 person group. Certain aspects, including biodiesel refining and phase separation, will be modeled using the chemical process simulation software Aspen Plus. Since lutein and lipid production are well-established processes, we have access to an abundance of papers to reference and will utilize more specialized sources for each unit operation. To ensure an even distribution of work and timely completion of the project, we will assign team leaders to each process defined in Figure 1. Team leaders will oversee and delegate tasks like selection and calculations on specific operation units, ensuring a balanced workload and schedule flexibility. This approach ensures team members gain familiarity with all process aspects.

The final product of this design project will be a technical report containing material and energy balances, equipment designs, and an evaluation of the proposed process on economic, environmental, and safety grounds. This report will be produced in CHE 4476 in the spring of 2024. This project will align technology, innovation, and environmental responsibility in the pursuit of developing sustainable energy solutions.

ECONOMIC VALUES VS RENEWABLE ENERGY COSTS

Although the goal is to transition from fossil fuels to renewables, the implications and constituents of algae biofuel are vast. Consumers, oil and gas employees, policymakers, and energy leaders are all stakeholders. Consumers are used to paying the price of fossil fuels, and an increase in dependence on biofuels may see higher energy costs. They have also slowly been introduced to renewable energy through solar and wind electricity sources, often finding them to be cheaper than burning fossil fuels (Marcacci, 2020). How will the introduction of more expensive biofuels influence their renewable energy ideals? How will the evolution of biofuel and biodiesel costs affect consumers’ decisions? It is predicted that oil and gas will still dominate the fuel industry in 2040 (Magill, 2022). If use remains the same while supplies run low, diesel costs could surpass that of biodiesel whose costs are expected to fall in the coming years (OECD & Food and Agriculture Organization of the United Nations, 2020). It is not a simple inverse relationship, though. In the past, biodiesel and diesel prices have been closely linked trending up and down together with demand (Gervani et al., 2022). A high demand for diesel drives both of the prices, making a transition even more complicated. As the fuel landscape is continuously changing, consumers may find themselves grappling with sustainability and costs more often than they would think. A choice between biodiesel and fossil fuels will not be made only once in a consumer's lifetime.

Additionally as we move to biofuels, oil and gas employees that have dedicated long periods of time to their specialized work would be out of jobs. Oil and gas lobbyists also have a profound effect on policymakers who may be divided in their support for renewable energy. At the top, the leaders of energy giants stand to lose or gain a significant amount of money and power depending on if they intend to pursue biofuels and if so, the scale at which the biofuels will be produced. Furthermore, there are longstanding ideals about the reliability of fossil fuels. This is all to say that while a transition to biofuel is necessary, it will not happen quickly.

In connecting biofuel technology with these stakeholders, the theory of *technological momentum* can be applied. This is the idea that technological systems exhibit patterns of growth and evolution that adapt to and merge with social and environmental systems (Hughes, 1987). One aspect of technological momentum is the idea of *transfer* where a system or artifact is adapted to fit into a different structure. Oil refineries can be modified and repurposed to refine biofuels where biocrudes can serve as a feedstock for these "new" systems (Su, 2022). Transfer is portrayed through this updated use of old technology; while the end goal remains the same (energy), the overall impact on the environment is vastly changed. Another aspect of technological momentum is *competition* where multiple systems are trying to solve the same problem and become the standard. Algae is not the only source of biofuel; ethanol can be derived from starch found in crops like corn, biodiesel can be sourced from animal fats, and oil-rich plants like soybeans can be converted to bioethanol (Rodionova 2017). Competition can be seen in these numerous systems to produce biofuel. Technological momentum's facet of *growth*, where there is a period of expansion in the scope or scale of a technological system is also exemplified by biofuels. First and second generation biofuels were extremely limited due to cost and land availability while third and fourth generation biofuels have circumvented the land issue, greatly increasing potential production and with that, applications of biofuels Cavelius et. al., 2023). Growth is modeled through the increased scale and application potential of these newer biofuels. As biofuels have developed, so has their ability to compete in the fuel market. Finally, technological momentum's *consolidation* where subsets are merged into one standardized system will ideally be seen in solving the impending energy crisis. Biofuels are very diverse which helps currently in solving specific energy needs, but with so many companies, methods, and forms, it is difficult to synthesize a fully renewable energy system that has the perceived reliability that the current fossil fuel network does. To actually complete a transition to renewables, consolidating the fuel solutions will be necessary.

RESEARCH QUESTION AND METHODS

This culminates in my question: How have economic values surrounding energy changed in the US with the increased prevalence and accessibility of renewable energy, and can those values predict the reception of biofuels? A complete transition to renewable energy is necessary for the continuation of our electricity-based lives and that transition is not feasible without substitutes for fossil fuels like biofuel and majority buy-in from constituents. To complete this research, I will use case studies from countries that have had an extensive transition to renewables. I will analyze these case studies using Yin's method (2009). To use that data within the context of the United States' political and economic landscape, I intend to review financial opinion articles surrounding renewable energy in the U.S. Using multiple news sources with different biases, I will consolidate opinions and their frequency to establish an economic viewpoint on renewable energy. Using this data, I will then create general profiles of American citizens and analyze their economic tendencies to try to predict biofuel reception.

CONCLUSION

A complete transition to renewable energy is necessary to prevent system collapse after we run out of fuel. Biofuels are essential to aid this transition and cover systems that traditional renewables like wind and solar cannot. The impact of an economically viable biodiesel pathway could be a massive step in this transition and the start of industrial-scale biofuel production. This would greatly reduce the stress placed on dwindling oil and gas reserves. As we continue to see the greater effects of climate change, I believe that generally people in the US will be more receptive to paying more for renewable energy, although more conservative sects will likely reject all increases in price. I think that the new economic values will be able to predict biofuel acceptance in specific communities, but more innovation will be required to achieve a majority buy-in.

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