Undergraduate Thesis Prospectus

Microalgal Production of Biodiesel and Lutein

(technical research project in Chemical Engineering)

Transformative Adaptation and Policy Reform: Climate Change Action in the United States

(sociotechnical research project)

by

Alex Hawkins

October 27, 2023

Technical project collaborators:

Soren Andrews
Cynthia Bing-Wo
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.

Alex Hawkins

Technical advisor: Eric W. Anderson, Department of Chemical Engineering

STS advisor: Peter Norton, Department of Engineering and Society

General Research Problem

How can The United States foster a clean energy economy?

Around the world, countries are battling the global climate crisis through changing the way we create and use energy. Nations searching for the solution to climate change are acting by tackling the technological and sociological problems of modern-day energy usage. For instance, federal grants are funding novel research enabling energy sources previously deemed ineffective as potential tools for fighting climate change. Governments are also reforming energy budgets and public policy to influence social factors associated with harmful energy usage.

The Climate Change Performance Index (CCPI) assesses a nation's performance in meeting climate action demands. Among some of the lowest countries in the CCPI 2023 rankings is The United States at 52^{nd} out of 63 (CCPI, 2023). For the U.S. to become a world leader in climate change action, clean energy policies will have to be implemented at a faster pace while maintaining a healthy economy. Adaptation of novel technologies in combination with reformative climate policies may help the U.S. build a clean energy economy while simultaneously establishing itself as a climate change leader.

Microalgal Production of Biodiesel and Lutein

How can fatty acid methyl esters (FAME) be economically and sustainably harvested from Chlorella vulgaris?

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 subsidizing costs through the co-production of lutein as a high value byproduct 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.

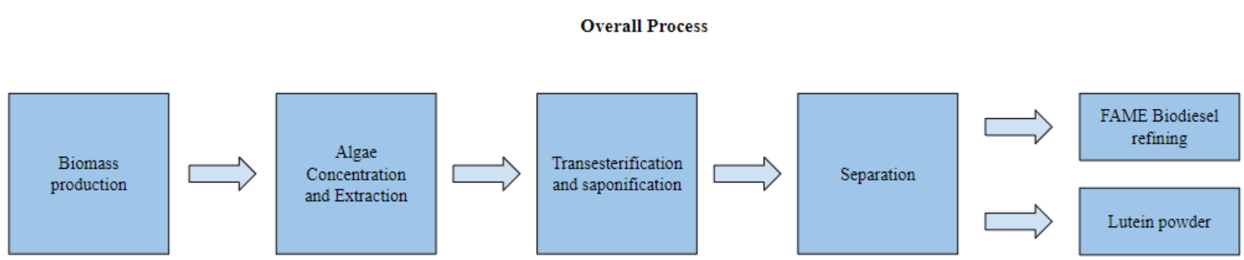

Figure 1. Overall process for FAME biodiesel and lutein.

We are drawing upon the insights presented by Tabernero, Martín Del Valle, and Galán, (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 subsequent separations needed to derive the final biodiesel and lutein powder products will be inspired by the flow diagram in Figure 2. 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 goal following the process design is to perform an economic analysis to determine the viability of microalgae biodiesel production alongside lutein co-production.

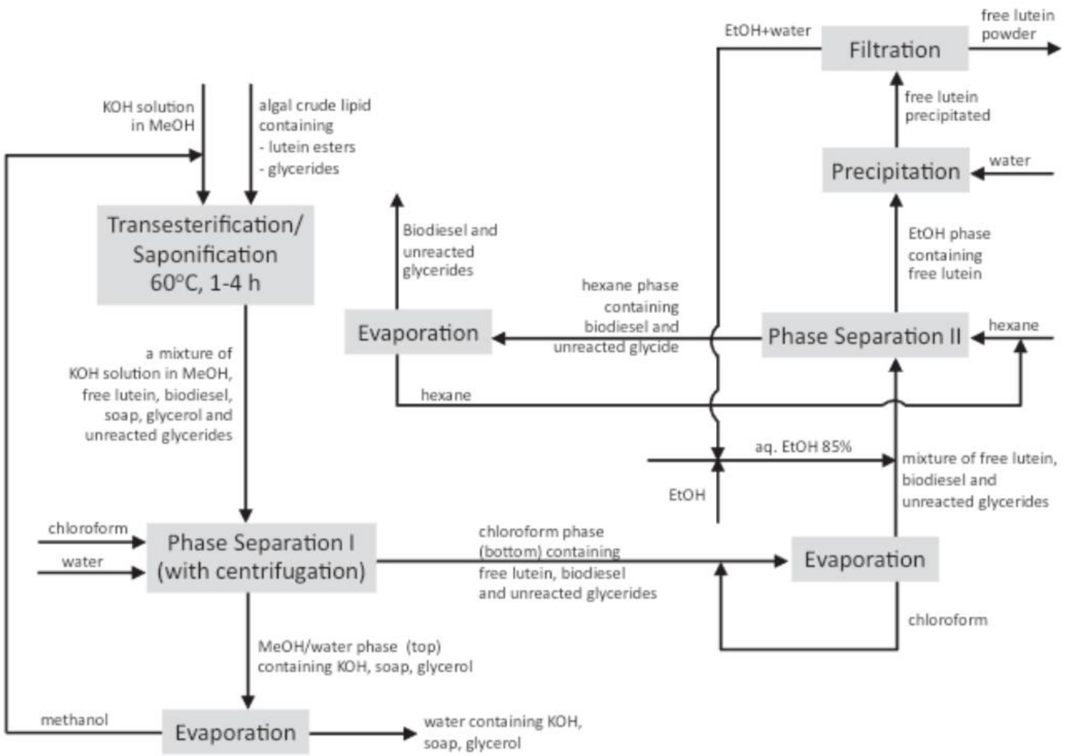

Figure 2: Reaction and separation to produce lutein and FAME biodiesel as presented by Prommuak et al. (2013) The final design will incorporate further separations for solvents used in reactions to improve overall functionality.

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 in 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 of 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.

Transformative Adaptation and Policy Reform: Climate Change Action in the United States

In the United States, how are interest groups competing to influence the federal energy policy response to the climate emergency?

In response to the global climate emergency, national governments have been called upon to urgently adopt new policies to reduce global emissions. In the United States, initial actions to address climate change grew from state and local efforts due to a lack of federal leadership (Byrne et al., 2007). Momentum caused by these regional efforts has led to the development of interest groups aimed at influencing federal climate action. With the economic costs of delayed climate action expected to increase, interest groups need to operate efficiently to ensure success of their agendas (Goulder, 2020). To do this, interest groups must drive transformative adaptation at the federal level to foster climate action (Shi & Moser, 2021).

Advocacies and trade associations are among some of the participants. Citizens' Climate Lobby (CCL) is an advocacy that utilizes a network of volunteers across the U.S. to lobby congressional representatives. The CCL favors the adoption of a carbon tax on corporations. This tax becomes distributed to Americans as a dividend to improve the affordability of clean energy transitions (Winchester, 2023). While groups like the CCL are advocating for federal regulation, other groups are influencing the federal energy budget. For instance, in August 2023 the American Clean Power Association (ACP) petitioned the Federal Energy Regulatory Commission in attempt to change its capacity accreditation methods to integrate more renewables into the energy grid (Banks, 2023). The methods used by the ACP and others demonstrate how interest groups can implement their values and interests through federal policy.

Opposition groups, such as American Petroleum Institute (API), purport ideas associated with clean energy movements to serve material interest. In an October 2023 press release, API opposed oil restrictions in the Gulf of Mexico by arguing such restrictions would hinder emissions goals and compromise U.S. energy security (API, 2023). The API also argued that such restrictions on oil vessels in the Gulf of Mexico would negatively impact conservation efforts and fail to comply with the Endangered Species Act. The National Association of Manufacturers (NAM) is another trade association known to limit federal climate action. NAM repeatedly opposes carbon tax initiatives claiming a carbon tax on manufacturers would "dampen manufacturing productivity… as energy costs would rise and send a ripple effect through supply chains" (Volcovici & Gregorio, 2013). The API and NAM illustrate how opposition groups relate climate activism with economic decline and reduced energy freedom to conserve current energy practices that benefit their interests.

References

API (2023, Aug. 23). American Petroleum Institute. New Analysis Finds Gulf of Mexico Restrictions Diminish Energy Security, Hinder Economic Growth. https://www.api.org/news-policy-and-issues/news/2023/10/05/new-analysis-finds-gom-restrictions-diminish-energy-security-hinder-economic-growth

Banks, T. (2023, Aug. 22). ACP files petition with FERC seeking capacity conference. *ACP*. https://cleanpower.org/news/acp-files-petition-with-ferc-seeking-technical-conference-on-capacity-accreditation/

Buscemi, S.; Corleo, D.; Di Pace, F.; Petroni, M. L.; Satriano, A.; and Marchesini, G. (2018). The Effect of Lutein on Eye and Extra-Eye Health. *Nutrients 10(9)*, 1321. https://doi.org/10.3390/nu10091321

Byrne, J.; Hughes, K.; Rickerson, W.; and Kurdgelashvili, L. (2007). American policy conflict in the greenhouse: Divergent trends in federal, regional, state, and local green energy and climate change policy. *Energy Policy 35*, 4555-4573. https://doi.org/10.1016/j.enpol.2007.02.028

CCPI (2023). Climate Change Performance Index. CCPI 2023: Ranking and Results. https://ccpi.org/ranking/

Goulder, L.H. (2020). Timing Is Everything: How Economist Can Better Address the Urgency of Stronger Climate Policy. *Review of Environmental Economics and Policy 14,* 143-156. https://doi.org/10.1093/reep/rez014

Griffiths, G.; Hossain, A.K.; Sharma, V.; and Duraisamy, G. (2021). Key Targets for Improving Algal Biofuel Production. *Clean Technol*., *3*, 711-742. https://doi.org/10.3390/cleantechnol3040043

Gross, S. (2020, Oct.). The Challenge of Decarbonizing Heavy Transport. *Brookings*. https://www.brookings.edu/wp-content/uploads/2020/09/FP_20201001_challenge_of_decarbonizing_heavy_transport.pdf

Patel, A.K.; Kumar, P.; Chen, C.-W.; Tambat, V.S.; Nguyen, T.-B.; Hou, C.-Y.; Chang, J.-S.; Dong, C.-D.; and Singhania, R.R. (2022). Nano magnetite assisted flocculation for efficient harvesting of lutein and lipid producing microalgae biomass. *Bioresource Technology*, *363*. https://doi.org/10.1016/j.biortech.2022.128009

Prommuak, C.; Pavasant, P.; Quitain, A.T.; Goto, M.; and Shotipruk, A. (2013). Simultaneous Production of Biodiesel and Free Lutein from Chlorella vulgaris. *Chemical Engineering & Technology*, *36(5)*, 733–739. https://doi.org/10.1002/ceat.201200668

Shi, L.; Moser, S. (2021). Transformative climate adaptation in the United States: Trends and prospects. *Science 372*. https://doi.org/10.1126/science.abc8054

Tabernero, A.; Martín Del Valle, E.M.; and Galán, M.A. (2012). Evaluating the industrial potential of biodiesel from a microalgae heterotrophic culture: Scale-up and economics. *Biochemical Engineering Journal, 63*, 104–115. https://doi.org/10.1016/j.bej.2011.11.006

Volcovici, V., Gregorio, D. (2013) U.S. manufacturers say carbon tax could cut factory output. *Reuters*. https://www.reuters.com/article/us-carbon-tax-us/u-s-manufacturers-say-carbon-tax-could-cut-factory-output-idUSBRE91P14220130226

Wang, X., Zhang, Y., Xia, C., Alqahtani, A., Sharma, A., & Pugazhendhi, A. (2023). A review on optimistic biorefinery products: Biofuel and bioproducts from algae biomass. *Fuel*, *338*. https://doi.org/10.1016/j.fuel.2022.127378

Winchester, F. (2023, Aug. 7). *Carbon pricing bill would supercharge effect of IRA subsidies, cut carbon pollution.* Citizens' Climate Lobby. https://citizensclimatelobby.org/blog/news/carbon-pricing-bill-would-supercharge-effect-of-ira-subsidies-cut-carbon-pollution/