Supercritical Production of Biodiesel from Waste Cooking Oil

(Technical Paper)

Identifying the Social and Economic Implications of Alternative Fuel Solutions

(STS Paper)

A Thesis Prospectus Submitted to the

Faculty of the School of Engineering and Applied Science

University of Virginia -- Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

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STS 4500, Fall 2024

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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 society shifts into a more developed and technologically advanced setting day by day, there grows concerns of the increasing demand for energy and the environmental impacts of these trends. Because of these trends, there are global concerns about emissions and the release of greenhouse gases, which heat our atmosphere (United Nations). This happens as these gasses act like a blanket in our atmosphere, insulating heat by absorbing the Earth's infrared radiation and preventing it from going out into Space. Governments across the globe have acted against the acceleration of climate change, implementing policies like net zero emissions by a certain year. The United States, specifically the Environmental Protection Agency or EPA, have outlined a plan to have net zero emissions of greenhouse gasses across our economy by 2050 (US EPA, 2023). In the United States specifically, 28% of the greenhouse gasses emitted into the atmosphere are through transportation, a sector that is more easily transitioned into renewable energies than others like our power grid (US EPA, 2015). Vehicles can run on a variety of fuels from gasoline to diesel, so by replacing these fuels with a green solution, specifically biodiesel in the case of this prospectus, we can cut down on one of the larger contributors of greenhouse gas emissions. Biodiesel in recent years have seen a substantial amount of research and development, more specifically within producing biodiesel in a supercritical pathway to cut on costs. The technical project outlined in this prospectus aims to design and understand the economics behind a supercritical biodiesel manufacturing process in an attempt to create a profitable product that moves our country towards net zero emissions.

Technical Project Discussion

The primary goal of this project is to design and evaluate the economic feasibility of a supercritical biodiesel processing plant. The current methods for producing biodiesel involve alkali, acid, or enzyme catalysts in order to trans esterify the triglycerides within the waste cooking oil (Bharathiraja et al., 2023). These current methods also require the use of an alcohol molecule, typically methanol, to convert the triglycerides to free fatty acid methyl esters, or FAMEs, which is what makes up biodiesel (Figure 1) (Zeng et al., 2014). In producing biodiesel via this catalyzed transesterification reaction there are significant limitations. For one, they can have slow reaction rates depending on what is being used to catalyze the reaction, and they are also sensitive to water (Van Kasteren & Nisworo, 2007).

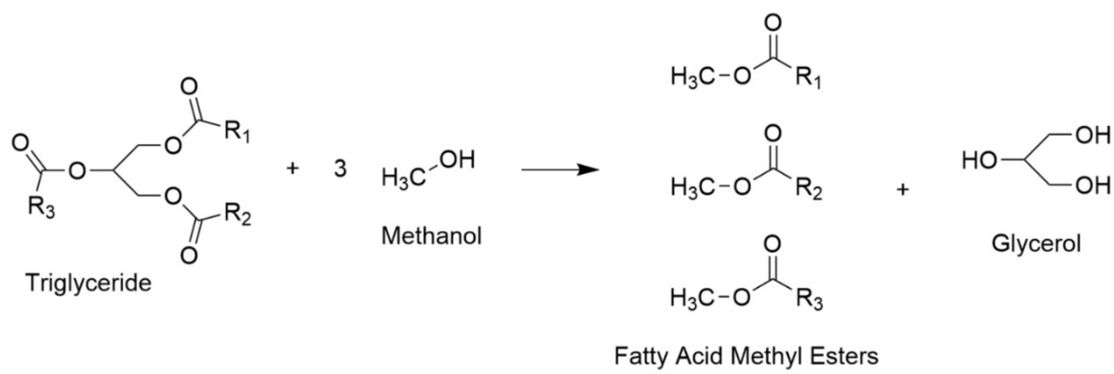

Figure 1. Production of fatty acid methyl esters (biodiesel) and glycerol from the reaction of triglycerides and methanol. Adapted from Van Kasteren and Nisworo (2007)

Additionally, the free fatty acids found in waste oils, due to degradation of the oil from cooking, can react with alkali catalysts to produce soaps that are unsalable and waste raw materials as well as any produced methyl esters (Raza et al., 2022) (Dobarganes). In order to prevent this adverse reaction from happening, an expensive treatment process of the waste cooking oil has to happen. So, with this and all the costs for catalysts, enzymes, or acids, it can prove challenging to have an economically feasible manufacturing process for biodiesels made from waste cooking oils. This is where the primary goal of this project comes into play and where manufacturing biodiesel through supercritical methods can save costs.

Recent developments in supercritical transesterification methods have shown a trend in lowering costs (Rhaman et al., 2024). This pathway for producing biodiesel involves the same reactants and products shown in Figure 1, however no acid or catalyst is required to run the transesterification reaction as the conditions of this reaction are at extremely high pressure and temperature. The changes in pressure change the solubility of the compounds present, allowing methanol, which exists at normal conditions as a fluid, to behave both as a liquid and vapor at this critical point (Zeng et al., 2014). Since there is no need for catalysts, the need for purifying waste cooking oil prior to reacting it is not needed, as there is no alkali catalyst to react with free fatty acids to produce waste. In Figure 2, the production costs of various biodiesel manufacturing pathways are modeled, and for a production level of 128,000 tons of biodiesel a year, supercritical transesterification was shown to have the lowest costs.

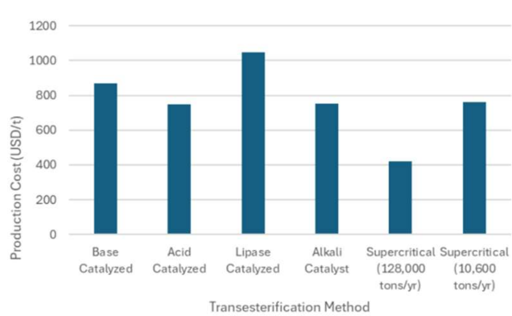

Figure 2. Production cost of biodiesel from WCO. Modeling of supercritical processes shows lowest production cost per ton. Adapted from Brahma et al. (2022) and Nagapurkar & Smith (2023)

However, this model is still rudimentary, and once consideration of site, costs of construction, and cost of feedstock and operation are plotted out, a more rigorous comparison of the various transesterification methods can be made. A valuable side product, glycerol, is made from this supercritical pathway as well (Singh et al., 2022). Glycerol is produced as a side product in any transesterification pathway as shown in Figure 1, however, when made through acid catalysis or the other methods, the glycerol produced is not pharmaceutical grade. Since our plant will be operating at extreme pressures and temperatures, a pharmaceutical grade glycerol is produced as the plant would meet the stringent requirements for sterility through the extreme conditions of operation (D02 Committee, 2024). Having this glycerol be pharmaceutical grade will increase its price and allow us to better turn a profit on this plant as biodiesel is a relatively low cost product. Through cutting costs in a new transesterification pathway and obtaining an additional valuable product to sell, this project should exemplify the design and the economic viability of a supercritical processing biodiesel plant.

STS Project Discussion

Biodiesel production from waste cooking oil is a crucial process in preventing environmental damage while addressing the issue of energy sustainability. The produced biodiesel offers significant benefits, while not showing any immediate major downsides. This project will explore the potential benefits and challenges of biodiesel produced from waste cooking oil, focusing on how we can reduce carbon emissions and minimize our reliance on fossil fuels.

Our world continues to face major challenges with the environment year by year, as record-breaking temperatures and natural disasters pose massive problems for every aspect of society. The reliance and perpetuation of fossil fuels, especially in America, is one of the main problems of transitioning to a carbon neutral society. In creating a sustainable solution like biodiesel from waste cooking oil, there are challenges in making it economically feasible, which is what the technical project is addressing, and in selling it as well. As seen in Figure 3, biodiesel still remains to be more expensive than petroleum diesel on average, so this poses problems with

trying to sell a product that has a cheaper alternative.

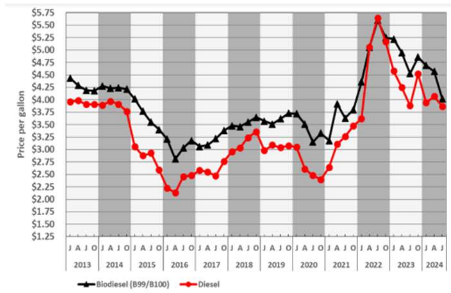

Figure 3. Cost of B100 fuel versus petroleum diesel since 2011. Copied from U.S. Department of Energy Clean Cities and Communities Alternative Fuel Price Report from July 2024

Without government subsidies or other legislation, the price of biodiesel will remain higher than diesel, so there needs to be consideration behind selling the biodiesel. People in America have many varying opinions on the current state of climate change and their personal contributions towards it, so there is not a current clear-cut reason for choosing biodiesel over petroleum diesel if the prices are the way they are. To better understand why people are skeptical of climate science and do not see the benefits of transitioning to sustainable energies, a survey will be conducted to understand people's thought process behind choosing fuel and their own personal contributions to climate change. This study should provide insight into how we can better sell this fuel in a competitive market that is still dominated by fossil fuels.

Typically, waste cooking oil is either discarded into landfills or improperly disposed of, which contributes to environmental pollution. By repurposing this waste as biodiesel, we can reduce landfill waste and create a more sustainable fuel source, gaining an additional talking point for choosing biodiesel over conventional petroleum diesel despite its price (U.S. EPA, 2017). By designing and modeling the supercritical biodiesel manufacturing process and running surveys for public opinion on renewable energies, a big picture will be produced for creating a sustainable process that can be implemented on a large scale.

Research Question and Methods

This project's main research question is whether supercritical biodiesel from waste cooking oil manufacturing process is economically viable. The research team will use Aspen Plus Simulation software in order model the plant and supercritical transesterification process. Aspen Plus is able to employ complex thermodynamic models to simulate chemical processes. As for designing the plant, the team will consult Professor Ronald Unnerstall in the Chemical Engineering Department for his safety insights as he holds decades of experience in this field. This is essential as designing a supercritical process poses many safety considerations with extreme pressures and temperatures of operation. Additionally, the team will use past studies on waste cooking oil biodiesel for kinetic data such as reaction rates or overall efficiency/yield in order to best model the reaction process. The project will take place over two semesters through CHE 4474 and 4476, with guidance from technical advisor Professor Eric Anderson along the way. Through all this, the team will aim to robustly model the supercritical process with accurate startup and production costs to determine the full economic viability of this design.

Conclusion

While the biodiesel market is projected to reach a value of $50-$70 billion in 2030, the costs for producing biodiesel through conventional methods is still considerable, making for a difficult case of economic viability without subsidies or things of the sort (Grand View Research). Our research team aims to mitigate the costs of conventional pathways through recent developments in supercritical transesterification, a process that not only prevents losses from adverse reactions, but also provides an additional product for sale to turn a profit on the plant. Once site location, building specifications, and sourcing feed stock are modeled, the team can move into Aspen Plus simulation to obtain overall yield, efficiency, and product flow. We are striving to design this project in order to model and create more economically viable solutions for clean energy as our world continues to grow and has a need for sustainable solutions. Without research into these topics, companies and people are less incentivized to create these solutions, so through this project, we will hope to provide valuable data and insight for any person or company looking to create their own biodiesel manufacturing process.

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