Sustainable Utilization of Whey By-Product Through the Production of Biobutanol

Analysis of Barrio Logan's Biodiesel Plant Failure

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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

How can biobutanol be better implemented in today's society?

In the early 1700s, Benjamin Franklin discovered electricity, sparking the beginning of humanity's harnessing of electrical power. As time progressed humanity learned to use electricity in a multitude of ways which has evolved to our current uses where electricity is integrated into our everyday lives. We utilize electricity as a form of energy to power our homes, computers, phones, and cars, resulting in a large global demand for energy. As the global population continues to grow, so does our energy demand.

A pressing problem surrounding our current energy sector is the use of fossil fuels like oil and gas as our primary energy source. These fossil fuels are responsible for large amounts of greenhouse gas emissions resulting in global warming. Reducing greenhouse gas emissions becomes increasingly important as the global temperature rises. A solution can be found in biofuels. Biofuels are liquid fuels derived from biowaste streams such as paper, sawdust, food scraps, or feedstocks like corn. A particular feedstock of interest is liquid whey, an abundant waste stream from the production of greek yogurt. This project will focus upon a sustainable process for creating Biobutanol from this liquid whey, addressing both whey disposal challenges and the need for low carbon emission fuels. Additionally, this project will analyze the factors leading to the eventual failure of Barrio Logan's biodiesel plant, to further understand the complexities of a sociotechnical system created by the implementation of a biofuel plant and how the system evolves overtime.

Production of Biobutanol from yogurt waste - liquid whey

Converting a waste stream and creating whey protein and biobutanol via chemical processes

During the formation of Greek yogurt, a problematic and abundant waste product is liquid whey. When discarded into wastewater treatment systems, whey contributes a high organic load, destroying aquatic life, causing algae blooms, and polluting waterways (Buchanan et al., 2023). Dairy farms currently utilize whey as fertilizer or animal feed, but at a rate that is insufficient to match production levels (Valta et al., 2017). Furthermore, treatment facilities face substantial energy demands and costs, as the waste product requires intensive aeration processes to break down. To address these waste management issues and environmental concerns, the conversion of whey into biofuel provides a promising solution.

Converting whey waste from yogurt production into butanol is particularly relevant due to a convergence of environmental, economic, and technological factors. Utilizing a waste stream aligns with the principles of a circular economy, which seeks to maximize resource use and minimize waste. Converting whey, an environmental pollutant, into a biofuel represents a shift from a negative environmental impact to a positive contribution to energy production. By foregoing the whey disposal process and instead utilizing the proteins as an energy source, a yogurt plant could become more energy-neutral.

This technical project aims to design a viable process for producing biobutanol from liquid whey for implementation in dairy manufacturing plants. In yogurt plants, the milk is heated to remove pathogens and for homogenization, inoculated with a starter culture, and then incubated at an optimized growth temperature and time to create yogurt, or quark, our feedstock of choice (Chandan & Kilara, 2013). To produce Greek yogurt, the quark is strained to remove liquid whey, a waste product that is rich in organic acids, lactose, and proteins, and as such has high utility for use as a medium in fermentation. Fermentation is an extremely useful tool to convert sugars into biofuels which through proper isolation, can yield an incredible source of sustainable and profitable energy. After separation from the solid curd, whey protein can be harvested from the mixture using ultra-filtration. After running the whey protein through a dryer, it is possible to sell this dry protein as a side product to other companies who can process it. The remaining whey (with protein extracted) can be run through a reverse osmosis (RO) system, which separates water from the particulates and concentrates the mixture for later steps in the process. The substrate from this point can be fed into an ABE reactor to complete fermentation.

The technical team will use Aspen Plus Software to model process flow diagrams and the individual equipment involved, such as the distillation column and the fermentation reactor. Also, we will use MATLAB to analyze cell growth kinetics in the reactor and draw on insights from previous capstone projects. Each team member will focus on a specific aspect of the design, performing the necessary calculations and determining dimensions as needed. The processes are divided as follows: quark separation via centrifugation, ultrafiltration and filtration, RO, fermentation in the bioreactor, and distillation/extraction. All work will be reviewed by at least two other team members, and we anticipate tasks to be redelegated as the semester continues, given the varying complexity of each process step. We will source experimental data from literature, as similar operations have already been implemented in several dairy plants.

Recent advancements in RO technology make this approach even more promising; new technologies such as nanomaterials-enhanced membranes have been developed to improve water permeability and resistance to fouling, leading to higher productivity and reduced energy use (Ahmed et al., 2024). This increased efficiency reduces the energy needed for upstream processes, making the conversion of whey to butanol more viable than in the past. Additionally, many dairy plants already have separation and filtration equipment in place, such as those used for producing quark, allowing for minimal additional investment to adapt existing infrastructure for this process, thereby reducing startup costs and enhancing the economic appeal of this project.

Despite these advancements, challenges such as high production costs, low yield and efficiency, low concentrations of butanol in the fermentation broth, and the degeneration of butanol-producing strains hinder large-scale adoption of the process. Additionally, the complexity of such a biotechnology process might require a processing plant that exceeds the size of small-to-medium dairy farms, limiting its accessibility (Asunis et al., 2020). While the technology has improved, it is still cheaper for many facilities to send whey to wastewater treatment plants rather than investing in butanol production due to startup costs, employee training, and extra workers needed to ensure that the process is running smoothly. Despite the relatively large market for fuels, whey-derived butanol may be less competitive with other energy sources due to its lower market price (Asunis et al., 2020). Addressing these issues, however, presents an opportunity for innovation. By optimizing fermentation processes, improving strain resilience, and reducing waste in the production stages, this project could pave the way for a more economically viable method of generating renewable energy from dairy waste. With further improvements, this approach could become an important part of the broader effort to create more sustainable energy systems.

Analysis of Barrio Logan New Leaf Biodiesel Plant

How does analyzing the Barrio Logan Biodiesel Plant shut-down help to understand how a socio-technical system surrounding biodiesel plants succeeds or fails?

Diesel has become integral to the US economy, fueling diesel trucks, construction equipment, military vehicles, and other diesel-based engines. However, using traditional diesel and other fossil fuels as energy sources results in large amounts of carbon emissions, harming the global environment. An alternative to traditional diesel is Biofuels, which can be used as a supplement or a direct substitute to reduce carbon emissions.

Biofuel production is a growing part of the energy sector, as the US's biofuel capacity continues to rise annually (Shakelly, 2021). Many operational biofuel plants are long-standing and seen as positive by the local community. An example is Georgia Biomass, a plant that has been in operation since 2011 and accounts for approximately 5% of Georgia's energy source (*Georgia - State Energy Profile Analysis - U.S. Energy Information Administration (EIA)* (n.d.)). Despite the many positive impacts the implementation of biofuel plants may offer, the construction and operation of these plants are often contentious. Supporters of renewable fuels often clash with NIMBYs, or "not in my back yard", on the location and operation of these plants. However, local communities are often overlooked in these arguments.

These communities are the people most affected by the continual operation of biofuel plants, feeling both the positive and negative effects over a long time. Because of this, biofuel plants need to learn to work harmoniously with the local community to foster the sociotechnical system being created. If the needs of the plant and local communities begin to misalign, the entire system could fail. One example is found in Barrio Logan, California, where a biodiesel plant recently shut down due to local community pushback. For years the residents of Barrio Logan complained about the odors associated with New Leaf's biodiesel production, which the company tried to address on multiple occasions. However, the local community's activism resulted in heavier regulation and legal pressure that forced New Leaf into shutting down its plant.

Technical Framework

This research will be conducted through the lens of Actor Network Theory, ANT, created by Bruno Latour in *The Pasteurization of France*. ANT suggests that both human and non-human "actors" influence each other, creating dynamic networks of relationships that evolve over time. ANT was specifically chosen for this system as the interactions between biofuel technology and community needs are an ever-changing dynamic network. Furthermore, ANT provides an effective framework for understanding the interactions between all actors. Some of the involved actors include the local community, New Leaf (the biodiesel company), and the Californian state government. Analysis of this specific sociotechnical system would elucidate what actions lead to its success or failure, which could be further applied to other or future biodiesel-based sociotechnical systems.

Evidence and Analysis

During this research process, I plan to further the discussion on "community energy". A topic that describes the "local production of renewable energy, governed by citizens, with a view to contribute to the transition to a sustainable energy system" (van der Schoor & Scholtens, 2019). Papers such as *Communities Matter* (Wirth, 2014) already tackle this topic and have drawn attention to the importance of working alongside the local community. Other papers within the community energy discussion will be further explored to gain a holistic view of the success and failure of renewable-energy-based sociotechnical systems.

When specifically analyzing Barrio Logan, the main source of evidence will be drawn from local news articles. A multitude of sources have detailed the local community's pushback on New Leaf's expansion, one of which being The San Diego Union-Tribune which recently released an article on the local community urging New Leaf to shut down its operation. Additional evidence will be found in the Barrio Logan town meeting minutes being sourced from a government-operatred website for the city of San Diego. The website keeps track of monthly meeting minutes from the Barrio Logan planning committee. These two primary sources will be analyzed to better understand the wants and needs of each actor, and whether they were properly addressed. Furthermore, how each actor responded to each other and how that led to the eventual failure of the sociotechnical system.

Conclusion

How can understanding the scenario in Barrio Logan help to implement more biofuel plants across the US?

The technical project will develop a chemical operation for the conversion of whey waste to biobutanol, with a thorough process model and simulation. This proposal will be modeled as a compliment to a corporation-sized Greek Yogurt production plant and will address their need for waste treatment while creating a renewable alternative energy solution. The STS research paper will try to explore the alliances and interactions between the local community in Barrio Logan and New Leaf's biodiesel plant. This will be completed through the lens of ANT, to fully encapsulate the sociotechnical system and the intertangledness of the actors' actions. The combination of these research topics will aim to create a better system for developing bio-friendly alternative fuel sources and to design a better approach for the implementation of these fuel sources.

References

Ahmed, M. A., Mahmoud, S. A., Mohamed, A. A. (2024). Nanomaterials-modified reverse osmosis membranes: a comprehensive review. *Royal Society of Chemistry*, 14, pp. 18879-18906. https://doi.org/10.1039/D4RA01796J

Gustafson, A., Goldberg, M. H., Kotcher, J. E., Rosenthal, S. A., Maibach, E. W., Ballew, M. T., & Leiserowitz, A. (2020). Republicans and Democrats differ in why they support renewable energy. *Energy Policy*, *141*, 111448. https://doi.org/10.1016/j.enpol.2020.111448

Karimi, S., Dufresne, A., Md. Tahir, P., Karimi, A., & Abdulkhani, A. (2014). Biodegradable starch-based composites: effect of micro and nanoreinforcements on composite properties. Journal of Materials Science, 49(13), pp. 4513–4521. https://doi.org/10.1007/s10853-014-8151-1

Kraemer, K., Harwardt, A., Bronneberg, R., Marquardt, W. (2011). Separation of butanol from acetone–butanol–ethanol fermentation by a hybrid extraction–distillation process. *Computers & Chemical Engineering*, 35(5), pp. 949-963. https://doi.org/10.1016/j.compchemeng.2011.01.028

Latour, B. (1984). *The Pasteurization of France.* Harvard University Press.

Shakelly, N. (2021). *Biofuels production and development in the United States – Bioenergy*. Ieabioenergy.com. https://www.ieabioenergy.com/blog/publications/biofuels-production-and-development-in-the-united-states/

U.S. Energy Information Administration. (2024). *Monthly Energy Review* [Data set]. U.S. Department of Energy. Retrieved November, 2024. https://afdc.energy.gov/data

Wirth, S. (2014). Communities matter: Institutional preconditions for community renewable energy. *Energy Policy, 70, 236–246. https://doi.org/10.1016/j.enpol.2014.03.021*

van der Schoor, T., & Scholtens, B. (2019). The power of friends and neighbors: a review of community energy research. *Current Opinion in Environmental Sustainability, 39, 71–80. https://doi.org/10.1016/j.cosust.2019.08.004*

Zhen, X., Wang, Y., Liu, D. (2020). Bio-butanol as a new generation of clean alternative fuel for SI (spark ignition) and CI (compression ignition) engines. *Renewable Energy*, 147(1), pp. 2494-2521. https://doi.org/10.1016/j.renene.2019.10.119