Producing a Bioplastic from Biodiesel Waste: Polyhydroxybutyrate using Crude Glycerol

(Technical Project)

Examining Inequality in the Vaccine System in the COVID-19 Pandemic Era

(STS Project)

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By

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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

Currently, plastic waste production from a variety of industries is growing globally. Single use plastics are abundant from the pharmaceutical industry, in terms of packaging, and from the food industry, with packaging and heavy reliance on plastic bags. Ritchie & Roser (2018) emphasize that plastic waste production has grown exponentially from 1950 to 2019, and in 2019 alone, 9.54 billion tons of plastic waste was produced globally. Biopharma waste on its own is hard to recycle and separate due to components such as silicon, polyethylene and polypropylene in bioreactor bags or chemical waste containers, so the waste is generally burned or landfilled (Kohn, 2019). Furthermore, large amounts of plastic pollution accumulate due to plastic bags and bottles, which reportedly take around 20 or 450 years, respectively, to fully degrade, posing harm on the environmental habitats for years ("The Lifecycle of Plastics," n.d.). The unsustainable nature of plastics is what motivated the premise of the technical project. The technical project explores an approach to produce Polyhydroxybutyrate (PHB) from Crude Glycerol. By nature, PHB is a biodegradable polymer that is produced by microorganisms and efficiently degrades in the presence of microorganisms (Akhlaq et al., 2022). PHB can be used to produce biodegradable plastics for food packaging, biomedical applications in terms of surgical implants or sutures, and pharmacological applications in medical encapsulation (Yeo et al., 2022). Currently, Polylactic acid (PLA) is a widely used polymer for bioplastics, but it can only biodegrade in industrial composting facilities ("KleanIndustries," n.d.). The production of PHB provides an alternative to PLA usage as PHB is formed from a biological process (microorganisms), rather than petrochemical, and it can also biodegrade anywhere in the presence of microorganisms. Essentially, this makes PHB attractive as it is both a bio-based and biodegradable polymer (Waldrop, 2021). The current lack of sustainability in plastics design or reliance on fossil fuels for biodegradable plastic production, poses harm on the environment and life. This connects to Winner's (1980) idea that artifacts, in their structure or design, have politics. But, with the production of PHB, a sustainable approach can be taken to integrate biodegradability into plastics design to address environmental concerns.

Winner's framework serves as the bridge between the aim of the technical project and the aim of the STS research. At a glance, the STS research explores the political ramifications of the healthcare system and the venues in which its embedded bias posed disproportionate effects on minority populations during and after the COVID-19 pandemic. The bias built into the healthcare system influences factors such as healthcare access, vaccine access, and insurance affordability, making it harder for some racial and ethnic groups to interact with these services than others. In areas with majority Black populations, Golestaneh et al. (2020) have noted that with COVID-19, there was "three times the rate of infection and almost six times the rate of death" compared to areas with large White populations. COVID-19 hospitalization rates were also noted as higher for American Indian or Alaska Native (AIAN), Black, and Hispanic populations compared to White people (Hill & Artiga, 2022). Essentially, during periods of COVID-19 peaks, people of color, generally of the lower socioeconomic class, suffered more from healthcare disparities and COVID-19 effects.

Technical Project

We intend to produce polyhydroxybutyrate (PHB) using the crude glycerol co-product from a biodiesel plant. PHB is a biodegradable polymer that is produced by microorganisms (Akhlaq et al., 2022). Posada et al. describes a process for the production of PHB in Colombia that we will adapt to fit the specifications of glycerol waste stream from a biodiesel plant in Iowa. The general block flow diagram begins with purification of the crude glycerol using a distillation column to prepare it for the fermentation process (Figure 1).

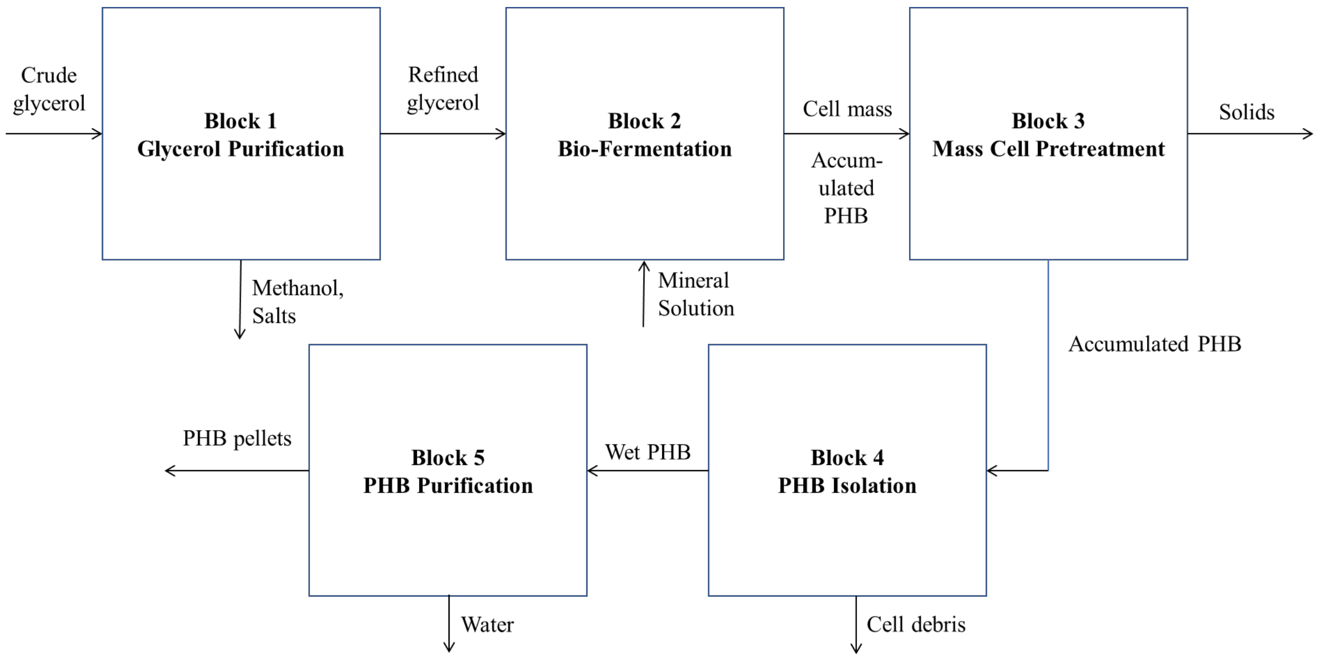

Figure 1. Block Flow Diagram of Overall Process for PHB Production

In the fermentation process, a growth fermenter and an accumulation fermenter will be used to cultivate mass cell growth and promote PHB synthesis, respectively. In the growth fermenter, glycerol will serve as the carbon source for the cultivation of the microorganism *Cupriavidus necator*. The fermentation is a fed batch process, and the first fermenter will be at optimum nutritional conditions to achieve high cell density. Restricting nitrogen in the accumulation fermenter will then promote PHB synthesis. During the second fermentation stage, cell density remains constant while PHB concentration increases. After the fermentation process, the PHB is extracted from the microorganisms and purified. Cells are pretreated in a high-pressure homogenizer and centrifuged to extract excess water. Following pretreatment, the product stream undergoes solvent extraction. Once isolated, the PHB stream is treated to reach 99.9% product purity. For commercial sale, the PHB stream is extruded to form pellets.

Biodiesel is a growing commodity as the transportation sector transitions to low carbon fuel sources (Hejna et al., 2016). Glycerol is the main byproduct (10 wt%) of biodiesel production, and there is currently an untapped market for turning this waste into a profitable end-product (Posada et al., 2011). Glycerol is mostly produced synthetically and is used in many consumer products. It can also be used as a carbon source to produce PHB, a biodegradable plastic. Transitioning to the use of biodegradable plastics will decrease the amount of waste in landfills and will avoid the release of harmful substances into the environment from the breakdown of plastic (Mostafa et al., 2020). Currently, the total capacity for PHB production is 30 kilotons per annum (ktpa) and is produced by Monsanto through the genetic modification of plants (Koller & Mukherjee, 2022). Our proposed method is more sustainable and uses a lower price material as a feedstock, making it price competitive with Monsanto's process (Koller & Mukherjee, 2022). The PHB plant would be located in Iowa, where US biodiesel production is concentrated, to maximize access to waste glycerol and limit transport costs. To produce 0.130 ktpa of PHB, we would need 12 ktpa of crude glycerol feedstock. REG is one of the major biodiesel producers in Iowa with a total glycerol production capacity of about 30 ktpa. REG operates 3 plants within 150 miles of each other and we would buy waste glycerol from one or more of their biorefineries (Table 1).

Table 1. Feedstock Sources for PHB Plant in Iowa (US Biodiesel Plants, n.d.)

	Location in Iowa	**Biodiesel Annual Capacity (ktpa)**	**Glycerol Annual Capacity (ktpa)**
REG Ralston LLC	Ralston	99.55	9.95
REG Newton LLC	Newton	99.55	9.95
REG Mason City LLC	Mason City	99.55	9.95
		Total Supply	29.86
	Maximum PHB Production Capacity		1.856

We will execute the technical project as a team over the course of two semesters. Aspen, a unit operations modeling software, will be utilized to model the different unit operations such as the fermenter and distillation column for purification. Along with modeling, material stream analysis will be done in Aspen. Excel will be used to perform further analysis on the process data (purity, stream flow rates, compositions) and for economic analysis of the entire process. A Design Basis Memorandum, including a description of the starting materials, products, scale and process as well as a brief economic appraisal, will be completed in the fall semester. The remainder of the research and complete design of all equipment, plant specifications, and full economic analysis will be developed in the Spring semester. The design data will be derived from multiple journal articles that detail process steps and parameters.

STS Research

In recent years, during and following the COVID-19 pandemic, there has been increased discussion on how the healthcare system is not equally accessible to all people. During COVID-19, the nation struggled, but only some were able to afford medicine and hospital bills when chronically ill, while others had to suffer without medical aid. When the vaccine was developed, it offered a glimpse of hope, but issues with access and affordability snatched that sentiment and posed as a health threat to minority groups (Njoku et al., 2021). Essentially, the healthcare system poses disproportionate effects on populations based on sociodemographic background and this was magnified during the pandemic (Maina et al., 2018). As Winner (1980) emphasizes, “a long lineage of boosters have insisted that the ‘biggest and best’ that science and industry made available were the best guarantees of democracy, freedom, and social justice” (p. 121). But, these guarantees that are to be provided by such a large and influential infrastructure, like the healthcare system, are provided selectively. The human implications of this project lie with the issue of whether people will adhere to getting vaccinated or even access institutions to educate themselves, enquire about virus symptoms, or even receive the vaccine due to factors such as hesitancy and literacy, which vary with sociodemographic background. The social implications lie with the issue of discrimination and selectivity that the healthcare system practices on specific social groups.

There are both internal and external factors that contributed to the health disparities during the pandemic era. Internal factors are ones that fall within the healthcare infrastructure, while external factors are ones that fall outside the healthcare infrastructure, but affect individuals' ability to interact with the infrastructure and therefore, their health. The internal factors that I will study are vaccine access, distribution, literacy, uptake and vaccine hesitancy. External factors that I will study include residential segregation, living conditions and areas, and lack of access to transportation. As Parolin & Lee (2022) point out, people living in poverty are more susceptible to COVID-19, but also struggle to access any or any substantial medical help, which worsens the virus' effects. Neighborhoods of lower economic status, where there is a large minority population, are located in areas with less access to transportation, whether it is public transportation or personal vehicles, making it harder to access medical institutions. Traces of redlining and residential segregation perpetuate COVID-19 effects as people do not live nearby to any healthcare infrastructure and these areas emulate poor and unhygienic living conditions, which make these populations more vulnerable to the virus (Li & Yuan, 2021). Another factor, vaccine hesitancy, has been shown to be correlated with factors such as race, age, and socioeconomic status. This hesitancy culminated due to the absence of thorough vaccine education for minority groups and the general mistrust in the healthcare system due to years of racial exploitation by healthcare professionals (Quinn & Andrasik, 2021). High vaccine hesitancy is observed among low income households and people of color, which worsens COVID-19 effects on these groups (Willis et al., 2021).

In regards to the STS framework, I will be consulting the works of Langdon Winner and Carolyn Marvin (1988) to interpret the social implications of COVID-19 healthcare disparities. Winner's framework, from *Do Artifacts Have Politics?*, will be applied to evaluate the entirety of the healthcare system and the inequality it exercises on the population. Essentially, the framework will be used as a lens to view the healthcare infrastructure as a system which innately discriminates against minority groups. Its roots and the elements of its design will be addressed to evaluate the interwoven bias. Marvin's perspective, adopted from *Inventing the Expert*, examines the relationship between electrical engineers and the user community. The nature of the relationship between experts in a field and the non-experts that engage with that field will be translated and applied to the vaccine system. Specifically, the framework will be used to study vaccine literacy, and the role that experts play in exacerbating disparities amongst *aliens* on this topic. Marvin expresses how "experts appealed to the purity of professional integrity to justify their claim to public trust, [but] they did not feel bound to exercise that integrity in their relations with stigmatized groups" (p. 32). This idea of selectively exercising knowledge as power during the pandemic will be explored in depth to examine how the relationship between minorities and experts was exploited and consequently, furthered COVID-19 disparities. Together, the technical project and STS research will provide a developed understanding of how artifacts or systems can be implemented to fulfill a political agenda.

Research Question & Methods

My thesis aims to answer the following research question: *In light of the recent pandemic, how has inequality risen through the vaccine system?* I believe this question is important because it prompts the exploration of the venues through which disparities in the vaccine system have grown. Healthcare disparities have been acknowledged, but their roots need to be furthered studied and altered. Essentially, I proposed this question with the purpose of study the topic of vaccines and emphasize how disparities in vaccine related factors peaked with the pandemic and highlight the depth of discrimination engraved into the system. To investigate the research question, I will consult peer-reviewed literature to detail the ways in which inequality has grown through the vaccine system during the pandemic. From this, I can analyze the data on factors such as vaccine access, hesitancy, uptake, literacy, and distribution (in relation to COVID-19 deaths and infections) among different socio-demographic groups. I will use this data to perform a comparative analysis to highlight the degree of prejudice that persists against groups of specific sociodemographic background. Furthermore, I will note other aspects that influenced this inequality as well– such as residential segregation, transportation access, language barriers, and social class. Essentially, to conduct my research, I will focus my search on studies conducted or data collected from 2019 to present day. In terms of content, I will consult literature that provide a qualitative detailed analysis with facts and general statistics. Beyond that, I will also rely on articles that conduct quantitative analyses to evaluate the significance of relationships between vaccine factors and COVID-19 disparities on the premise of socio-demographic backgrounds. By discussing significance in my thesis, I can make more sound conclusions on the topic of vaccine disparities and sociodemographic factors and emphasize the need to dismantle the healthcare system's bias.

Conclusion

At the completion of the technical project, we expect to have a complete design for a sustainable process that produces PHB from crude glycerol. Reaction times, process variables, and economic variables such as energy and operation costs will be known so that the process can be replicated or altered as needed for future research. The design could contribute to improving the state of plastic pollution by manufacturing biodegradable plastics that can degrade easily and do not rely on industrial methods for composting. Furthermore, using crude glycerol as the starting material for the process will allow us to repurpose waste from another industry. With the STS research, I expect to have a deep understanding of the structural barriers and venues through which the healthcare system enforced bias and practiced discrimination during the pandemic. I expect to understand how bias is embedded in the vaccine system and how this magnified COVID-19 effects on marginalized groups. The research can be used to explore solutions to alter and hopefully, eradicate structural barriers and establish equality within the healthcare system.

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