Producing a Bioplastic from Biodiesel Waste: Polyhydroxybutyrate using Crude Glycerol

Analysis of the Plastic Pollution Crisis in the Rio Motagua, Guatemala

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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

Plastic pollution is one of the world's most urgent environmental issues. Although the issue is most particularly visible in developing nations in Africa and Asia, about 8 million tons of plastic waste drift from coastal communities to global oceans every year (Parker, 2019). Production of plastics surged during World War II due to their superior material properties and the demand for synthetic alternatives to natural materials. Eventually, in the 1960s, awareness for plastic pollution in the ocean and its potential threat to human health began and as a result, the plastics industry offered recycling as a solution in the 1980s (History and…, 2016). Despite the introduction of recycling efforts decades ago, according to the U.S. Department of Energy, an analysis of data from 2019 shows that only 5% of plastic waste is recycled in the United States due to water-intensive processes. Furthermore, 85% of plastic waste is directed to landfills and the remaining 10% is incinerated, which, in turn, contributes to global carbon emissions (Gammon, 2022).

Many countries, including the U.S. and those in the EU, export plastic waste to developing countries that lack resources to financially support a proper waste management infrastructure. However, in 2017, China, a primary importer of plastic waste since 1992, announced a permanent import ban of nonindustrial plastic waste, after implementing increasingly restrictive policies for nearly a decade. As a result, researchers estimate that by 2030, 111 million metric tons of plastic will be displaced (Brooks et al., 2018). Meanwhile, the issue is exacerbated by the estimate that the annual plastic production rate around the world of 380 million tons, is estimated to double by 2035 and quadruple by 2050 (The plastic…, n.d.).

To effectively analyze the sociotechnical crisis of plastic pollution, the technical and social factors associated with the issue must both be considered. To address this issue technically, I will improve on a process design for the production of polyhydroxybutyrate (PHB), a biodegradable alternative to plastic by using crude glycerol, a cheaper feedstock material and a byproduct of biodiesel production, to be more economically attractive for corporations and to combat the issue of plastic pollution at the source. Additionally, I will employ the Science, Technology, and Society (STS) framework of the actor-network theory to analyze the social factors associated with the plastic pollution crisis in the Rio Motagua in Guatemala, such as international political corruption and the stability of the plastics industry, to assess the process that caused the failure of The Ocean Cleanup's Trashfence Interceptor engineering project and to further understand the social challenges that contribute to the resistance against the implementation of sustainable alternative materials.

Technical Project Proposal

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).

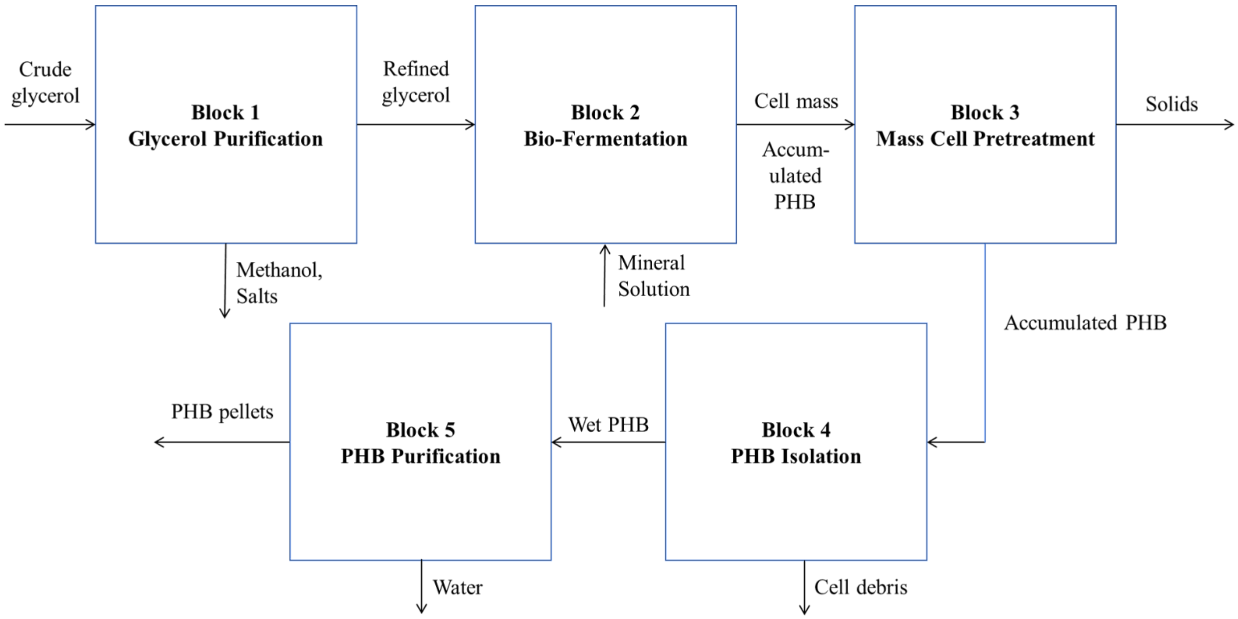

Figure 1. Block Flow Diagram of Overall Process for PHB Production

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 million tons per annum (mtpa). 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 Project Prosposal

In May 2022, The Ocean Cleanup, a non-profit organization focused on tackling plastic pollution, introduced the Interceptor Trashfence in the Rio Las Vacas, Guatemala City. The Rio Las Vacas is a tributary preceding the main branch of the Rio Motagua which is the largest river in Guatemala. An estimated 20,000 tons of plastic waste flow through the Rio Motagua and settle in the Caribbean Sea every year (Kerins, 2022). This estimated amount of plastic waste consequently contributes to 2% of the overall plastic emissions into the world's oceans. Additionally, with the organization's cumulative study of various rivers around the world with heavy plastic emission, The Ocean Cleanup believes that the Rio Motagua is the heaviest-emitting river in the world, prompting them to start their Guatemala project over three years ago (Kerins, 2022).

After the failure of previous designs, the Interceptor Trashfence, or Interceptor 006, was designed to realistically accommodate the massive volumes of plastics flowing down the river by adapting technology used in avalanche and rockfall protection. Currently, the project is still in its experimental stage, and the research and development team is still learning about the operability of the system. The system's first trial was initially successful in stopping a large plastics flow but ultimately did not hold due to the pressure of annual flash floods (Kerins, 2022). The Ocean Cleanup confirmed that it intends to optimize the system's design in order to manage the capacities forced by extreme floods. However, it also acknowledges that the solution is a temporary one that focuses on actions that can be taken now to reduce plastic pollution in oceans. To mitigate the issue higher upstream, the organization states that it remains in a close collaborative relationship with Guatemalan authorities to improve waste management in landfills (Kerins, 2022).

The Ocean Cleanup accounts for the technical weaknesses of the Trashfence Interceptor as well as the complicated socioeconomic circumstances of Guatemala City that inhibit the development of a proper waste management infrastructure and consequently, enables illegal waste disposal in landfills. However, this view limits the analysis of social factors to the network of plastic waste disposal in Guatemala and eventually its displacement to the Atlantic Ocean, and overlooks the role of other actors in the larger preceding network that is associated with the production, life cycle, and displacement of these plastics to Guatemala, to begin with.

If the lack of waste management control in Guatemala City is the only socioeconomic factor that is considered, then we will not gain a comprehensive account of the wide range of socioeconomic actors that contributed to the project's failure. Due to the ever-growing increase in the production rate of conventional plastics and the displacement of plastic waste exports soon to follow after the implementation of waste import bans by developing countries, an approach with a larger scope network, with particular emphasis at the source of plastic production, is crucial. Through the STS framework of Actor-Network Theory (ANT), I will argue that it was the lack of proper waste management infrastructure in Guatemala City in conjunction with the corruption of international political systems by corporations, the economic value of current modes of plastic production to those in positions of power, and the consumer culture that upholds the stability of the plastic industry that caused the failure of The Ocean Cleanup's Trashfence Interceptor design. ANT tasks engineers to build networks of diverse actors to identify and solve a specific problem (Cressman, 2009). Typically, actors must realign their interests to serve those of the overall network in order to function stably. This process of network formation is termed as translation (Law & Callon, 1988). By applying the concept of translation in ANT, I will analyze how various social and economic factors in the larger network encompassing plastic production and pollution, align with one another to maintain the network's stability and eventually cause the failure of engineering projects and networks designed to mitigate plastic pollution, specifically the Trashfence Interceptor. To support my analysis, I will analyze evidence from accounts that report on international corporate and political relations affecting the environment, studies that track the societal use and displacement of plastic waste from the United States to Guatemala, and economic reports on profits from plastic production and consumption as well as future projections for the plastics industry based on corporate investments.

Conclusion

The design of a process to produce a sustainable material, PHB, with the low-cost feedstock material of crude glycerol will be both economically and technically attractive as a solution to replace the conventional plastics at the root of the plastic pollution crisis. Through the Actor-Network Theory, the social and economic factors that uphold the global plastics industry and contribute to the traffic of plastic waste in the Rio Motagua, Guatemala will also be analyzed. To successfully execute this technical solution, it is critical to understand the socioeconomic factors behind the crisis being addressed, by assessing the network formation of the plastics industry that caused the failure of previous engineering solutions and that may cause resistance against the proposed technical solution. By analyzing both technical and socioeconomic factors, we will obtain a comprehensive viewpoint to aid in reducing plastic pollution from the source.

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