Producing a Bioplastic from Biodiesel Waste:
Poly(hydroxybutyrate) using Crude Glycerol
(Technical Paper)

Plastics in Fashion:
How Consumer Culture Obscures the Petrochemical Life Cycle
(STS Paper)

A Thesis Prospectus
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By
Alexa Madison Cuomo

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Technical Team Members:

Isabelle Deadman
Allison Feeney
Hamsini Muralikrishnan
Justine Yun

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.

ADVISORS

Eric Anderson, Department of Chemical Engineering

Bryn E. Seabrook, Department of Engineering and Society

Prospectus

Introduction to STS Research Topic and Capstone Design Project

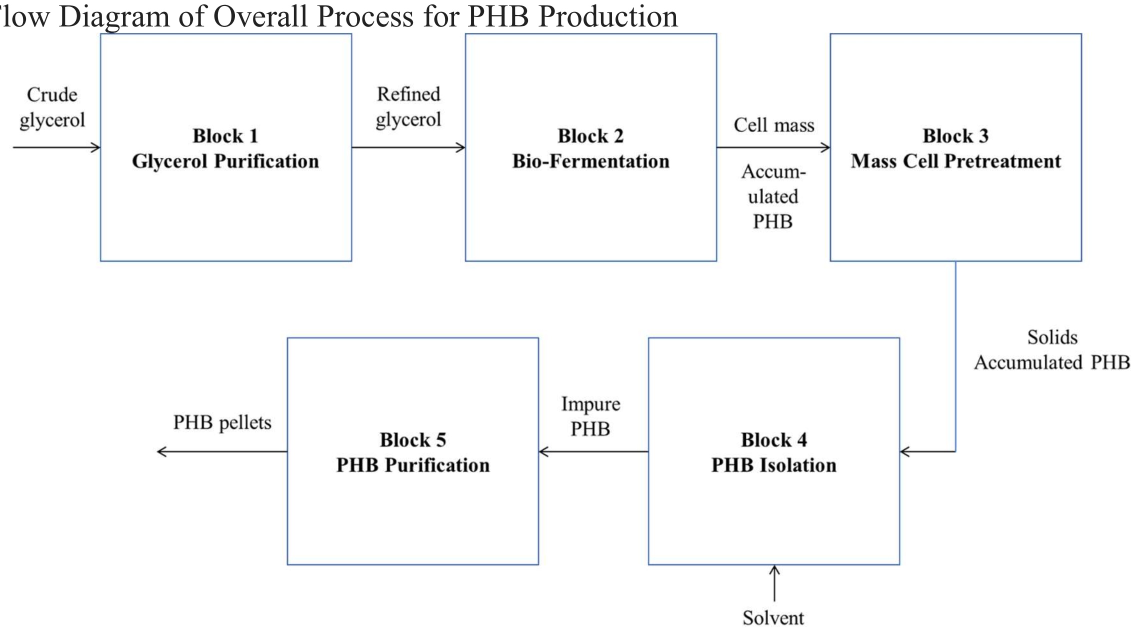
Generation Z is known as the changemaker – we are the sustainable shoppers, the social activists, and the future leaders. Last year, the fast fashion retailer giant, Shein, generated $15.7 bn in revenue from a targeted base of Gen Z and Millennial consumers (Curry, 2022). A key takeaway from this juxtaposition is that our values and actions often misalign. As climate change takes its toll on our environment through severe weather events, ocean acidification, and habitat destruction, the massive problem of human waste generation often gets overshadowed (Kolbert, 2015). However, the two global issues are intrinsically linked through how our society has developed over the past century. Consumer culture emphasizes speed and convenience – in my STS research paper, I will explore how its ubiquity in American society obscures the life cycle of petrochemicals. While the pressing need for a cultural shift in our consumption habits and lifestyle choices demands satisfaction, the question remains whether that shift will be driven by the consumers themselves, or the producers. Given the evident disconnect between public awareness and public action (or inaction), the case for private sector corporations facing the plastic pollution crisis head on becomes not only favorable, but essential (Duncan et al., 2020).

For the technical portion of this capstone, my team chose a design project dedicated to fulfilling the need to manufacture sustainable materials that are societally relevant. "Sustainability" has amassed popularity over the past decade, and its impact has been somewhat diluted through overuse and greenwashing. However, our aim is to produce a material that is "sustainable" from start to finish. Utilizing crude glycerol, a low-cost waste product from the biodiesel industry, we intend to design a plant to produce poly(hydroxybutyrate) (PHB). PHB is a degradable bioplastic synthesized using microorganisms, and its applications range from medicine and packaging, to agriculture and energy (Akhlaq et al., 2022). In doing so, we will implement a localized solution for waste reduction for energy and product consumption.

Producing a Bioplastic from Biodiesel Waste: Polyhydroxybutyrate using Crude Glycerol

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 (" The Latest News and Data About Biodiesel Production," n.d.)

	Location in Iowa	Biodiesel Annual Capacity (mtpa)	Glycerol Annual Capacity (mtpa)
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*
		TOTAL DEMAND	*0.01*

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.

From Convenience to Conscientiousness: Who Will Lead the Cultural Shift?

A three-word mantra comes to mind when plastic consumption is the topic of discussion – reduce, reuse, and recycle. While this action plan drills itself into consumers' minds from a young age, the unfortunate reality of plastic since its dawn on society almost makes the phrase a cliché. "As of 2015, approximately 6300 Mt of plastic waste had been generated, around 9% of which had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment" (Geyer et al., 2017). The generated waste is a substantial portion of the 8300 Mt total plastic produced since 1950, and the overwhelming majority of it does not fall into the meek reduce, reuse, and recycle categories (Geyer et al., 2017). The insecurity of the available methods for plastic recycling or disposal leads to hazardous pollution freshwater and marine ecosystems, and their origins can be difficult to track. For example, urban areas with high population density and inefficient waste management strategies are among the most polluting in marine environments through their annual riverine emissions (Meijer et al., 2021).

While many know about plastic pollution from either their own personal experience or depressing news clips, there appears to be a general knowledge gap regarding where plastic originates from and which industries utilize it the most. Plastic in packaging, consumer products, and textiles are the highest short-term usage sectors, meaning virgin plastic entering these sectors is typically discarded in less than five years (single-use plastic packaging leaves use the year it enters, if not recycled) (Geyer et al., 2017). Since biodegradable plastics only have a global production capacity of 4 Mt, the vast majority of plastic used in these sectors is petrochemical-derived (Geyer et al., 2017) (Chamas et al., 2020). Petrochemicals are the nonrenewable fossil fuels, such as oil, natural gas, and coal, that drive climate change through carbon emissions (Chamas et al., 2020). They are also the raw materials that are transformed into non-fiber plastics, such as water bottles and Styrofoam, and fiber plastics, such as polyester and nylon.

Consumers often look at reducing their non-fiber plastic consumption through carrying a reusable water bottle or buying food in bulk. However, reducing clothing consumption often does not come to mind when implementing sustainable choices in one's life, especially among young consumers. This "inherent dissonance" strikes its chord within the hordes of fast-fashion consumers, many who hold environmental concerns as a young person living in our modern society, but "indulge in consumer patterns antithetical to ecological best practices" (Joy et al., 2012). There are many reasons why these patterns flourish in environmentally-minded young people – the most interesting one is advertising's and marketing's adaptation to the digital world. The ability of fast fashion companies to quickly find, exploit, and drive trends through social media is a relatively new phenomenon, but its genius has lead to exponential growth for companies like Shein (Curry, 2022). For an industry built to revolve around "planned obsolescence," the newfound speed at which petrochemical-based clothing items are introduced and produced is shocking, reaching 700-1,000 pieces per day (Curry, 2022) (Gupta et al., n.d.). While younger generations are responsible for making the corporate stakeholders profitable, a complete sociotechnical analysis should include the older generations of executives and advertisers who fostered a materialistic culture and are now capitalizing on fashion's role as a paragon of identity (Gupta et al., n.d.).

The chosen framework to tackle the complicated, generation-spanning relationship between consumers, plastic, and major industries is co-production. A major co-production theme relevant to this research topic is "the emergence and stabilization of new techno-scientific objects and framings," but the framework includes other themes such as scientific and technical controversy resolution, processes that make science and technology socially accessible, and the adaptation of science to its cultural context (Jasanoff, n.d.). The theory organizes itself around how people, institutions, identities, and discourses develop, and what responsibilities and values are prioritized along the way (Jasanoff, n.d.). However, there exist multiple critiques regarding the framework, especially in sustainability and health sciences (Wyborn et al., 2019). A major shortfall is how co-production does not "adequately account for power within science-society relationships" (Wyborn et al., 2019). However, awareness of these critiques when approaching sustainability issues allows for analytical compensation through acknowledging the politics and oppositions at play (Wyborn et al., 2019). Diverse stakeholders have different knowledge bases and motives, so it is essential to examine the extent to which they can collaborate to solve a problem (Wyborn et al., 2019). While I chose this framework as a means of understanding how we ended up as a society motivated by convenience and ease, I also see the possibility for the current stakeholders to reframe consumer culture to one that revolves around conscientiousness through co-production.

Research Question and Methods

Research Questions: How has consumer culture obscured the life cycle of petrochemicals? Is it more feasible to alter consumption or production?

To answer my first research question, I will use a Life Cycle Analysis (LCA) framework of various petrochemical and biodegradable plastics (Huff et al., 2020) (Rezvani Ghomi et al., 2021). The life cycle analyses will be critical for determining all points in plastic's lifespan that are negatively impacting the surrounding environment, aside from the known issue of waste accumulation. Additionally, an in-depth look at the entire life cycle of a product would provide new insight into how profitable stakeholders (advertisers, plastic manufacturers, etc.) might obscure the most controversial practices to uphold consumption. As the LCA framework is an objective and quantitative perspective on plastic production and consumption, it would well complement the co-production sociotechnical framework with the addition of some documentary research on market trends and consumer behavior. In the end, I will be able to articulate informed conclusions on how plastic technology came to pervade society through its development alongside consumer culture.

To approach the second, broader research question, I will use a case study of the slow fashion movement arising in opposition to the fast fashion industry. The movement emphasizes sustainability in the fashion industry through valuing local resources and economies, transparent and shortened supply chains, and products with a longer usable life and unique merit (Clark, 2008). I chose to focus on the fashion industry because of its appeal to young consumers and society's need to build a sustainable future through it's young generations. Moreover, the industry meshes well with the co-production framework in the sense that fashion design and technology complement each other throughout their development. As I analyze the stakeholders on both the production and consumption ends of the fashion industry, as well as how the slow fashion movement proposes their transition towards sustainability, I hope to discern new strategies that can be applied across all industries utilizing petrochemicals.

Conclusion

The deliverables for this undergraduate thesis portfolio include a technical design project on bioplastic production using biodiesel waste and an STS research paper on the obscurity of petrochemical life cycles in the midst of consumer culture. For the technical capstone, we expect to design a PHB production plant in Iowa that takes advantage of the crude glycerol waste from local biodiesel facilities. The economical production process would set an example for creating sustainable materials in a localized context that can be used to support consumer applications society has grown accustomed to. The STS analysis will lend new insights into how knowledge about petrochemicals and their lifespans vary from producers to consumers. Additionally, the slow fashion case study will highlight a pathway towards sustainable practices for other industries reliant on petrochemicals. Ultimately, advancements in bioplastics or public awareness on waste management will only take our society so far – we must reframe our culture from one of convenience to one of conscientiousness.

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