RISE OF BIOPLASTICS: HUMAN AND ENVIRONMENTAL IMPACT OF PETROLEUM PLASTICS

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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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Take a deep breathe… and feel the cool air enter the lungs and transporting oxygen and nutrients to the rest of the body. The average person takes 20 thousand breaths per day, and plastics have never been a part of our respiration until recently (Brown, 2014). The rate of particles ingested via dust and fibers in the air is 11 particles per hour air (Prata, 2018). The first plastic, Bakelite, was produced back in the 1950's and ever since then, its adoption by modern society for disposable packaging dominates consumer products. Today, consumer dependance on plastic is threatening not only our health but the health of our planet. In 2015, 200 million tons of plastic were produced, and that number is only going to increase (Jambeck et al., 2015). Upwards of 8 million tons of plastic find their way into ocean (www.WWF.org). The average person consumes up to five grams of microplastics weekly through food water, and air we breathe. One hundred years after the beginning of plastic use, the cumulative total plastic is expected to reach 33 billion tons. The negative impacts of plastics on human health and the environment are not looking great and more research is needed to understand the severity of the problem. Harmful additives and plasticizers like BPA are in the polymer matrix and have been known to be harmful endocrine disrupters. An actor network analysis is applied to better understand the relationship of creators, users, and regulators with the plastic as a technology and with each other to find a better solution to the current flawed framework.

The use of petroleum plastics is not sustainable at the current rate and has caused many people to look into alternatives. Biodegradable alternatives are possible in alleviating some of the plastic problem because normal plastics take at least 500 years to for plastics to degrade completely (Chamas et al., 2020). An emerging material that has the potential to replace petroleum plastics are a class of biopolymers call polyhydroxyalkanoates (PHAs). PHAs are produced through metabolic reaction pathways in bacteria. PHA is energy storage mechanism for bacteria which is analogous to fat in the human body. Our technical project aims to develop large-scale production of a specific PHA as a biocompatible plastic for medical applications. The plastic is used in surgical implants, sutures, and skin scaffolding and can be processed by the body converting it into water and carbon dioxide (Utsunomia, 2020). The aim of the technical project is to design a sustainable process for the production of PHAs that will provide evidence for the widespread adoption of PHA as a better alternative to petroleum plastics for applications larger than medical devices. You need to include a sentence or two about the STS portion and be sure to include the STS framework. I have moved a paragraph up which would do it for you.

Actor Network Theory (ANT) can be applied to the interactions in the petroleum plastic industry and the users of plastic to understand the accumulation of plastic pollution has become a concern by many scientific communities and societal organizations. By looking at the social institutions and roles of key players (Law & Callon, 1988), "a method of social analysis that takes the technical aspects of the engineer's work to be profoundly social." ANT enables the mapping of things that are simultaneously physical and conceptual, as well as their interrelationships. Actors may be people or materials, whose interactions can be examined as a continuously evolving network. Actors can be analyzed individually in fine detail and the use of ANT enables their mapping. The network analysis will focus on the systems currently in place for the production, waste management, and use of petroleum plastics as well as identify gaps of communication and knowledge between the actors.

UBIQUITY OF PETEROLEUM PLASTIC IN EVERYDAY LIFE AND ITS PERSISTANCE IN NATURE

Plastic is integrated into every aspect of our lives: from toothbrushes, soap containers, cellphones, computers, food containers, and even bigger things like appliances and nearly all our clothing. Plastics have been used virtually everywhere for their amazing ability to take any form and structure for desired purpose. The ease of adaptability and structural flexibility has caused people to only increase their use of plastics. Not only are we using it more, but we are using more at an increasing rate. The more we introduce and use these plastics into our environment, the greater the damage we inflict on our environment and ourselves. Microplastics have been found in the highest peaks of Mount Everest, far-reaching depths of the Marians trench, and even the remote archipelagos in the Indian Ocean that were once thought to be inapproachable (Gibbens, 2018; Saliu et al., 2018; Wilkinson, 2020). In order to understand how these plastics reached ever corner of the globe within a century of their appearance, looking at the key actors and their relationship in the use and adoption of polymers plastics.

Changes to the actor network of plastic use for technologies must be accepted by the four main actors that use the technology, as well as regulatory agencies that oversees all parties. Creation of plastics and plastic technology is performed by manufacturers and industrial processors. Manufacturers are one of the more influential actors in this network, as they allow for the creation of plastic technology. Plastics popularity greatly increased when manufacturers realized waste products from the oil industry could be turned into any shape or form necessary: giving the waste more value, a longer life, and generating its ubiquitous presence. Once the waste oil product has is processed, it is formed into little, tiny pellets that are easily transportable. Industrial processing of the plastic pellets allows them to be melted down molded into any form imaginable. The unparalleled durability and adaptability at every step of plastic processing was one of their biggest advantages, which lead to a plethora of industrial processors incorporated plastics into their products.

Use, consumption, and byproduct handling of plastic technology is performed by consumers and waste management organizations. Over 36% of plastic produced plastic packaging which is only intended to be used once, and widespread use of such single-use products contribute to an excess of plastic waste generation (Lear et al., 2021). In January, the annual brand audit named Coca-Cola as the world's top plastic polluter (Breaking Free From Plastics, 2021). Other brands that are in the leaderboards for top plastic polluter include, Nestle, and Proctor and Gamble. Consumers of plastics include every person on the plant. It is impossible to go a day without relying on plastic. Soon after plastics adoption for everyday consumer packaging, litter waste from both individuals and large organizations quickly began to fill the landscape. The current waste management system is not able to handle all the plastic waste that is produced so much of it is landfilled. The waste management system employs poor handling of plastic waste, as a gross majority of such waste ends up in landfills as a non-biodegradable material. Estimates that by 2040, 710 million tonnes of plastic will have accumulated in the environment (Lear et al., 2021).

In the United States, the Environmental Protection Agency (EPA) is the primary regulatory agency that has authority and large responsibility overseeing manufactures, industrial processers, and consumers in preventing the direct littering of plastic into the environment. Typically, the safety profile of product that enters your body would fall under the responsibility of the FDA, but it is not since the product is consumed by indirect means. Anti-littering programs and recycling programs put responsibility on the consumer to make sure the plastic waste is disposed of responsibly through recycling. An advertisement by Keep America

Beautiful trying to emotional appeal to consumers to prevent littering by showing a native America man shed a single tear when faced with littering on the ocean front and at his feet. Many of these programs are in part funded by plastic industry trade groups (Dunaway, 2018). For example, Keep America Beautiful, which continues to push the message to consumers alone, have the responsibility to prevent plastic from entering the environment (Pennolio & Werner, 2021). Although an effort is made by regulatory agencies to monitor waste management and safety of plastic material, inefficient handling of plastic waste cannot handle its respective large generation and consumption. Figure 1 on page 6 illustrates the large and uneven burden placed on consumers and regulatory agencies that prevents the network's ability to properly handle the propagation of plastic waste.

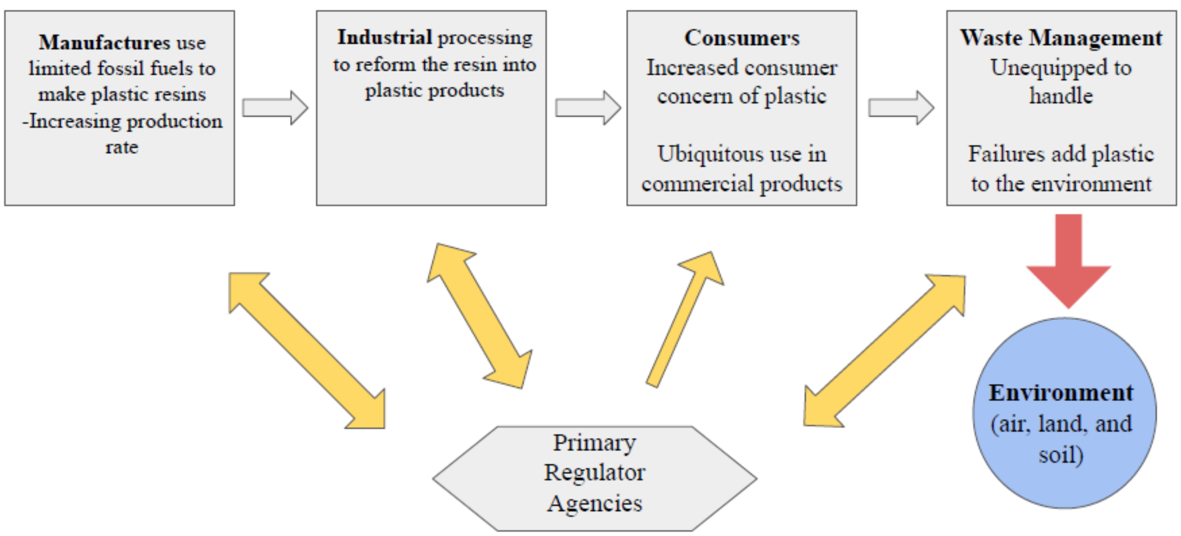

Figure 1: Key actors in the petroleum plastics life cycle: The network contains manufactures of plastic resins from refined crude oil products, industrial manipulations of the plastic for consumer products, the waste management system, and the environment. Governmental agencies communicated and impose regulations on the use of plastics with each actor. (Adapted by Hall (2021) from Law & Callon, 1988)

IMPLICATIONS OF PLASTIC USE ON HUMAN HEALTH AND THE ENVIORNMENT

Within the last year, researchers have found microplastics in the placenta of babies (Ragusa et al., 2021). The children being born today are not able to give consent in the use of microplastics in their body, and there is little effort on the part of the manufacturers and industrial processors to recognize this as a problem. They do not see any negative consequences due to the lack of research related to the everyday levels of plastic concentrations. Their current means of disposal primarily by landfill is not adequate. As we use more and more plastic, we must anticipate this distribution to be widespread. These plastics are putting unwanted and unethical burden all living beings on the planet, especially since the consequences of are not entirely understood.

New Zealand government funded program called the Aotearoa Impacts and Mitigation of Microplatics (AIM^2) strives to provide a nationwide overview of microplastic pollution; and asses the risk it poses to their environment, economy, and well-being (Woods, 2018). The slogan of AIM^2 is a proverb from the indigenous people, known as the Māori, is “He iti te mokoroa nāna i kakati te kahikatea,” and was translated by Himenoa and Gill (2020) meaning, “while the mokoroa grub is small it cuts, through the white pine. There is power in small things” (p. 38-39) Kevin Lear of the Biological Sciences departments understands the importance of small things and his research at the University of Aukland in New Zealand attempts to conceptualize and understand the power of small things like microplastics by studying their broad impact the microbial communities that inhabit humans, soil, and aquatic environment.

Lack of communication and education between manufacturers, industrial processors, consumers, and regulators about the known and unknown risks of these plastic is a key factor in excess waste and environmental harm. Major actors do not carry the responsibility of the ensuring the proper disposal of the pollutant they create. Industrial processors have known of the respiratory hazards associated with inhalation of small plastic.

Since 1999, there has been many occupation exposures to plastic flock and had an associated negative health impacts (Washko et al., 2000). Plastic flock, small fragments of plastic or microfibers, can have negative respiratory effects called flock inhaled and cause occupational interstitial lung disease (ILD), which has been termed "flock worker's lung". (Atis, 2005). Synthetic materials that produce flock include: nylon, rayon, polyester, polyolefins, as well as the more common types of plastic PP, and PE. An immune response carried out as cytokines secreted from macrophages play a key role in the inflammatory response development of the disorder (Washko et al., 2000). Microplastics have additional health risks in that they also can carry due to additives or undesirable microbes leaching out. Microbial communities like pathogens can use microplastics as a transportation mechanism by attaching to their surfaces.

Harmful additives are added to common plastics for tuning polymer structure for desired physical properties. Bisphenol A (BPA) is added to plastics to make it clear, is commonly used in plastic water bottles, and is known to be a disruptor of the endocrine system (Rudel et al., 2011). It is commonly used in the manufacturing of polycarbonate for water bottles, food packaging, and in the resin used for lining canned food. Phthalates are a class of plastic additives in the group of endocrine disrupting chemicals (EDCs) that are mass produced and commonly used and consumer food packaging. Higher molecular weight phthalates have been studies to inhibit the testosterone production process in rodents (Gray, 2000). Other epidemiological studies link the excretion of phthalate metabolites through urine with changes in thyroid hormone levels, semen quality in adults, and neurological behavior in neonatal babies (Engel et al., 2009; Gray, 2000). CDC researchers found that the population had higher concentrations of phthalate metabolites provides evidence of exposure and consumption to phthalates across the US (Center for Disease Control and Prevention, 2021). Bis(2-ethylhexyl) phthalate (DEHP) used to be produced as a plasticizer, but further research has found it to be carcinogenic (Risotto, 2011).

Plastics affect the environmental microbiome physically by altering the water-soil interactions and to increase shading in aquatic environments inhibiting photosynthesis. Toxic leaches can enter the environment though physicochemical plastic weathering (Lear et al., 2021).

WHAT DOES A BETTER PLASTIC LOOK LIKE?

Plastics as whole lot of utility in that they can be durable, flexible, thermo molded or set but their persistence for extremely long times. This is especially true for single-use or disposable plastics. Another negative of the currently produced petroleum plastics is that there is little research into the nature of plastic degrading organisms, despite the ubiquitous contamination of micro plastics and nano plastics in environmental microbial communities. Further research looks in to relevant enzymes and genes of bacteria and fungi is needed since there is little evidence on the topic.

Kevin Lear is leading research in this regard by monitoring plastic eating microbes using mass DNA sequencing and metagenome of field samples rather than laboratory environments. Figure 2 shows the phylum names and number of plastic degrading organisms found in literature.

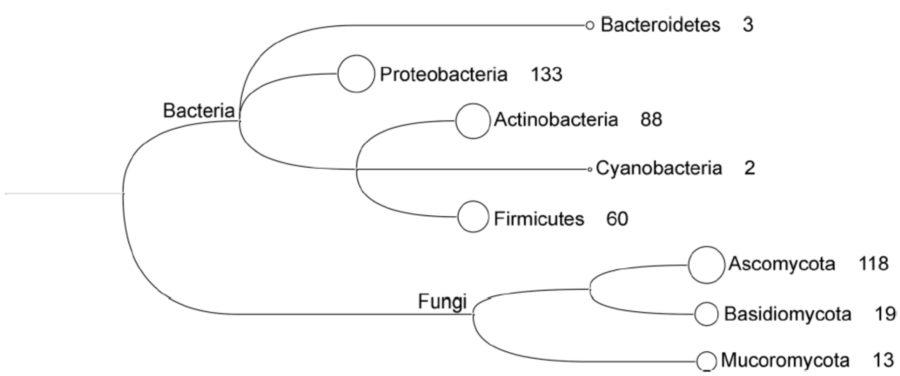

Figure 2: Number of potential plastic-degrading organisms per phylum as reported by Gambarin, et al. (Adapted by Hall (2021) from Lear et al. 2021)

Identifying correct taxa and enzymes for plastic degradation is the first step in improving the environmental, biotic, and genetic manipulation to mitigate an negative impact of microplastics on humans. However, best practices for reporting microbial plastic degradation to guide research in future studies are to maximize reproducibility and build strong evidence for the research. Key parameters that should be investigated with multiple analytical techniques include changes in the polymer structure, detection of plastic degradation, and generation of plastic metabolites. These novel degradation pathways may aid in the mitigation of microplastics and also help with the disposal of synthetic plastics so they do not persist in the environment.

A shorter life span for plastics means that there is likely a microbial metabolic pathway for an organism to use the plastic as a carbon and energy source. Polyhydoxyalkanoates (PHAs) and polylactic acid (PLA) are two biodegradable plastics that have lifespans on the order a year in marine and soil environments. The technical portion deals with the microbial manufacturing of a specific PHA that is used in scaffolding and sutures for reconstruction surgeries. The specific PHA which is referred to as poly-4-hydroxybutyrate (P4HB) is a natural metabolite in humans and therefore currently, the only approved bioplastic for surgical use in humans by the FDA (Utsunomia et al., 2020). The bioplastic's existence is a result of energy storage in bacteria similar to starch in potatoes and white fat in humans. This makes bioplastics an interesting alternative to single-use plastics because of their ease of disposal and even value as a reliable energy source for bacterial communities.

In the 1970's, more research began exploration into alternative sources of plastic other than petroleum because the oil crisis in the United States made citizens view oil as nonrenewable resource for the first time (Williams et al., 2016). Similar to how plastic started using a waste product of the oil industry, plastics today are looking to be made from natural resources and waste products. Drops in plastics or plastics made from renewable material have been made, but the same durability and life span as their synthetical created identical counterpart. An example of a drop in plastic is Polyethylene terephthalate (PET), but the plastic still has the same disposal issues regardless of the material used to make the plastic. Using waste product from other industries like the food or dairy industry helps companies seeking to close industrial waste loops and creating more circular economy.

The waste management system of plastics has multiple avenues to deal with municipal plastic waste which include landfills, recycling, incineration, and composting as shown in Figure 3. Landfilling accounts for 58% of plastic waste disposal where it will spend the rest of its life their slowly breaking down into smaller fragments which makes it easier for them to escape into the environment (Ritchie & Roser, 2018). Much of the plastic landfilled does not even reside in the US. As of 2018, the US and other developed nations stopped sending plastic scrap to China. This is referred to as China's sword policy is an act of them refusing to be the "garbage-dump" of the world (Katz, 2019). The Basel convention in 2019 sought to limit exports of plastic waste from richer countries to poorer ones however, the US is not part of the agreement. Other countries like Malaysia, Indonesia, and Kenya that are poorer and more willing to accept the waste trade as a source of income, but the citizens of these poorer countries are not consenting to letting their countries open to waste which can negatively ruin their health and home. In January, the Basel agreement set new ban that restricts the shipping low quality plastic scrap on most countries, but since not rules specifically restricting the US from sending plastic scrap waste(Tabuchi & Corkery, 2021). New data from a nonprofit called Material Research shows that since the new ban was set in place there has been an increase in the shipment of plastic waste. American recycling companies claim that all the plastic being shipped is being used by the extensive recycling system in countries like Kenya and Mayalasia, but to others like Jim Picket, the executive director of the Basel Action Network claims that the trade done by US countries violating international law (Katz, 2019).

Surprisingly, recycling only accounts for 8% of current plastic waste disposal methods. This might seem low communities across the US continue to collect plastic and recycle for lots of it to be sent overseas and lots of time living the rest of its life in a landfill until it breaks down and enters the poorer countries soil, rivers, or oceans (Tabuchi & Corkery, 2021). This number is so low because not only does the recycling of old plastic require the virgin plastic which is preferred by plastic manufactures, it also requires additional energy input and resources. Another reason this number is lower than expected is that plastics cannot be infinitely recycled because of contaminations that is introduced during the creation and use of the plastic and only certain plastics.

Incineration of the plastics seeks recover the value in the form of energy by burning the plastic, but only accounts for 14% of plastic waste disposal. This strategy is commonly used in the medical industry given their need for sterility and biohazards waste. Compositing currently accounts for zero of the plastic waste disposals, but further research is need to correctly identify and optimize the environment for plastic degrading bacteria. This sector of waste disposal is only going to increase as bioplastics are further adopted by society.

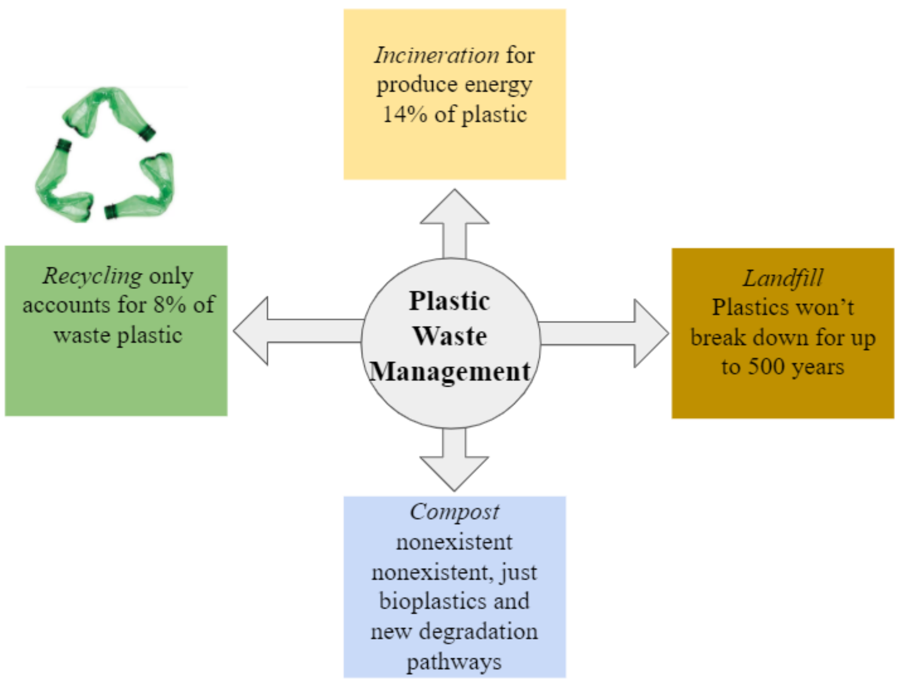

Figure 3: Benefits and drawbacks of the current waste management system for petroleum plastics: Landfills, recycling centers, incinerators for energy recovery, but most of the plastic produced ends up in a landfill. (Hall, 2021)

MOVING FORWARD USING PLASTICS

In combination with the goal of eventual elimination of non-biodegradable plastics, manufacturer accountability of consumer and waste management handling needs to implemented. Unrestricted communication between primary regulatory agencies and key actors of plastic use will create transparent expectations, results, and reviews. Since it may be harder for the uneducated consumer to observe the full effects of improper plastic waste management, accountability and communication of waste management organizations to their respective consumers. The US is one of the only developed countries without EPR bills addressing packaging (Semuels, 2020). Requiring the eventual transition of waste management organizations transforming plastic waste into energy for useful microbial systems must also be set up. Figure 4 on page 13 illustrates ideal communication between key actors, accountability of manufacturers to consumers and waste companies, and the accountability of waste management companies for proper consumer education and transformation of microbial waste into useful energy.

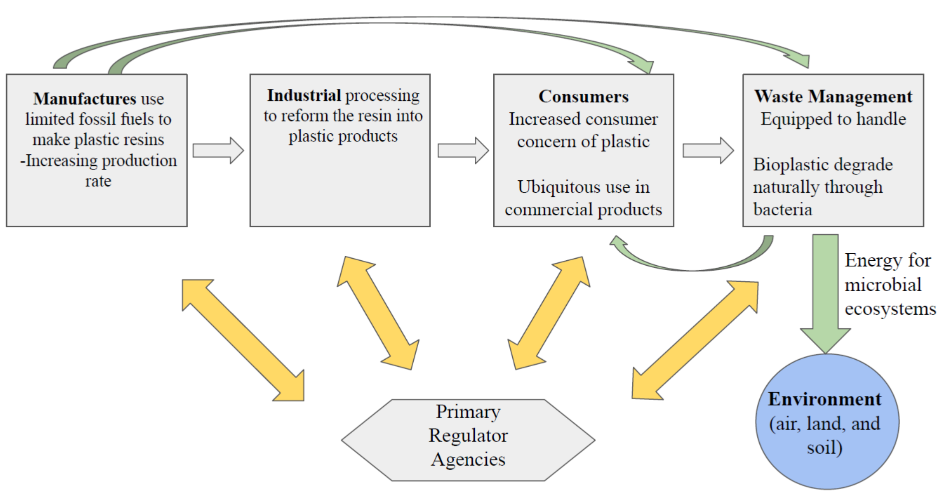

Figure 4: Key actors in the adoption of alternatives plastics: The additional communication between consumers (Adapted by Hall (2021) from Law & Callon, 1988)

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