An Opportunity for the Needed Transformation in Plastic Pollution

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Abstract

This paper traces plastic waste management's historical evolution and its global impact. It highlights soaring plastic production and its environmental and economic consequences. Traditional methods like landfills and incineration are assessed. Innovative technologies like Cat-HTR show promise for a circular economy. The paper emphasizes the potential of biotechnology, focusing on microbial solutions like Ideonella Sakaiensis and BAV1 bacteria for biodegradation. These advancements signal a crucial step towards sustainability and economic growth. In conclusion, the paper stresses the urgency for innovative plastic waste management in light of escalating environmental challenges. It offers insights into evolving strategies for plastic waste.

Introduction

Throughout history, from the birth of life on earth until now, problems have been inevitable; a benefit to one came as misfortune to another, completely independent of their own gravity. The introduction of new times meant new issues, most notably the introduction of cognitively able beings, the Roman Empire, the Industrial Revolution, and the recent still-ongoing technological boom. The common ground of all of these periods is that they were powered by a singular topic or global trend fueled by the desires of humans: Julius Caesar's desire to conquer, businessmen's efforts to become economic giants, and the dream of a fully automated world. From the late 20th century, when the technological boom was a mere fledgling, the problems that had been slowly but steadily growing behind the scenes started to show themselves, ready than ever to bring about damage. Namely, the status quo of global problems include climate change, pollution, political tension, lack of education, hunger, and plenty more. Thus, the 17 sustainable development goals were constructed in 2015 to establish the ideal direction of the world. Among these, the dangers of plastic waste take up a significant part, affecting anyone's life, branching out its influence in numerous aspects. These range from the more conspicuous land and ocean pollution to the less covered economic and political effects. This paper will seek to primarily illustrate the position that plastic holds on earth and the contemporary efforts being put in to manage it.

Background

Firstly, to give a clearer picture of its detrimental effects, in 2018, plastics accounted for more than 18% of the total Municipal Solid Waste (MSW), more commonly known as an average person's everyday garbage. According to National Geographic, production of plastic has been increasing exponentially, from 2.3 million tons in 1950 to 448 million tons in 2015, a close to 220 times increase in only 65 years. Among all of this plastic, an annual number of approximately 8 million tons of plastic waste escaped into the oceans from only the coastal nations, now covering 80% of all oceanic debris. In addition, as of 2020, the annual production of plastics worldwide reached a record of 367 million metric tons, with only 9% of it being recycled. The remaining whopping 91% percent end up mostly in landfills, while some are dunked in the ocean or buried underground.

Plastics come in a variety of different forms in packaging, construction, textiles, consumer products, transportation, electronic parts, and large-scale machinery. The most prominent use for the average consumer would be the plastic bags used in basically every store or for packing products. These common plastics were found to be the most harmful to wildlife, especially oceanic organisms. Millions of animals, over 700 species, are threatened by the plastic that finds its way into natural habitats, which can be fatal to them through either entanglement or starvation. For example, turtles are strangled by abandoned fishing gear or plastic waste illegally dumped into the ocean. However, these aren't the only types of plastics that devastate our earth. Microplastics, or tiny fragments of plastic measuring less than 5 mm in length, are even more of a pain. These near-microscopic fragments have been found in almost every corner of the globe, including the deepest and highest points accessible to humans. Due to their minuscule size, they can easily enter the waterways and soil necessary for primary producers, leading to a butterfly effect of dangers that could ultimately be passed on to animal digestive systems or organs and greatly decrease their metabolism.

Additionally, the water pollution from plastic disrupts the chemical balance of the ocean, or specifically, causes ocean acidification. Ocean acidification is the increase of water acidity caused by the decrease in pH levels due to the fact that CO_2 levels have risen dramatically over the past century. Essentially, it is a major indirect cause of economic damage.

The wide variety of damage plastic holds on the world's ecosystems inevitably leads to economic loss. 70% of the earth is covered by the ocean, which means that there would also be several industries that entirely depend on the well-being of the waters. These include fishing, any ship-related industries, transportation, recreation, oil, and more. The best representation among these industries that are most affected by plastic waste is none other than fishing. Fishery, led by China, Ghana, and the Solomon Islands, is a major consumer goods industry as a very sought-after foodstuff product. As previously mentioned, 80% of all oceanic debris is composed of plastic material. They physically harm marine animals, making them suffocate or intoxicated from chemicals. These chemicals, mostly coming from very small particles like microplastics, can affect the nervous systems or cell tissues of marine organisms, becoming ingested throughout their life cycle. Another threat to fisheries is overfishing, or simply catching too many fish at once for the breeding to catch up to. This steadily but quickly decreases the fish population, decreasing the amount of available fish in the future.

As it becomes more and more evident that the extent of the effects caused by plastic pollution increases, or as the positive linear correlation between plastic usage and damage continues, global efforts have been being made. The most renowned international agreement would be the Paris Agreement, signed on April 22, 2016, by 193 parties, including the European Union. Some of the agreement's goals are to 'Limit temperature rise below 2°C, publish greenhouse gas reduction targets, and become carbon neutral by 2050.' The goals stated are all closely tied topics to plastic waste, and in fact, the Paris Agreement officially claimed that "if unchecked, plastics' production, use, and disposal will constitute approximately 15% of the total allowed greenhouse gas emission by 20250." It is possible to deduce the significance of plastic waste to the almost 200 parties under the Paris Agreement. Not only are there collective international actions, but the majority of first-world countries have their own laws and regulations on plastic. Starting in 2021, Canada has banned six types of single-use plastics: plastic grocery bags, straws, stir sticks, six-pack rings, cutlery, and food take-out containers. The United Kingdom introduced a tax on plastic bags in 2015 that banned the sale of products containing microbeads or small spherical forms of plastic. In the United States, there is not yet an official federal ban, but the states of New York, California, and Hawaii banned single-use plastic bags. The leading plastic producer, China, has announced a plan to ban non-degradable bags nationally by 2022. Finally, South Korea banned the distribution of free plastic bags unless they were being used to hold wet produce such as fish and meat.

General Methods of Plastic Management

As the first method of plastic management, landfills are not only the most common location where plastic waste ends up but also one of the most notorious methods of management. The practice of dumping all kinds of unwanted goods or trash in landfills has been in action for over 5 millennia, where archaeologists found evidence of landfills dating back to 3000 BC. Its old history can be considered to be a clear reason why landfills became the obvious option when plastic first started to be mass-produced back in 1907 after the first synthetic plastic material, Bakelite, was created. At first, plastic was considered to be a miracle material, being marketed as "the material of a thousand uses." However, the undisputed optimism about plastic did not last long, as the world became increasingly aware of the looming environmental crisis. Its reputation plunged as more and more destructive events started pointing at plastic waste to blame. For the sake of plastics value and the earth's health, the world needed answers on how to manage plastic waste. This was a turning point since recycling wasn't even a considered option until then. As environment-protection organizations and government agencies were introduced, for the first time, unfriendly methods of plastic management were widely and strongly blasted publicly, forcing reevaluations of each method in hopes of finding new, healthier methods. However, even as of 2021, of the 8.3 billion tonnes of plastic produced until now, 6.3 billion tonnes, or more than 75%, have been turned into plastic waste. Of that 6.3 billion, only nine percent has been recycled, with 79% sent to landfills and the remaining 12% mostly burned.

Moving onto a more specific analysis of these plastic management methods, the pros and cons of each of these ways are critical to acknowledge. Starting with the pros of landfills, sending plastic waste to landfills is the cheapest way to get rid of plastic. When plastic is dumped in landfills, most of the time, it is not only plastic that is dumped with it; in fact, it is highly likely that no additional manual labor was taken prior to the dumping to sort out the materials based on their chemical qualities. Thus, all kinds of garbage, including paper, metals, glass, and rubbers, are dumped together with plastic waste. Thus, this process requires the bare minimum amount of labor to accomplish. The cons of landfills can be considered to be rather straightforward. Most countries, especially the smaller first-world countries, don't have land available to be used as a landfill due to the rapid spread of development throughout the country. Speaking of land, countries that house landfills with large amounts of land available include the United States, Canada, China, and India. In fact, it is actually possible for landfills to become a source of income, especially for undeveloped countries, where other countries can pay for the rights to use another country's land as a landfill. An example of this is the United States, where in 2018, the US exported 1.07 million tons of plastic waste, and in 2021 alone, it exported more than 30 million pounds of plastic waste to Malaysia, Vietnam, and Indonesia, with about one-third of the amount being recycled. The main aspects to consider in the use of landfills are that they are cheap, easier to handle, and generally less environmentally troublesome than other popular methods.

The traditional method of dumping garbage in landfills is accompanied by another method of waste management, incineration. As mentioned above, incineration is the process of high-temperature burning of waste and is used on approximately 12% of plastic waste. Incineration actually requires a much more complicated process compared to how trash is dumped in landfills. First, materials are prepared for combustion by going through required preparations such as grinding or removing large rocks and debris, or removing excess water. It is only then that the materials can be placed in the combustion chamber of an incinerator, where they are heated to an extremely high temperature for a specified period. The time is different for each type of material due to their difference in levels of heat capacity or resistance. In addition, pure oxygen, a fire catalyst, is often added to supply the long burning periods. Typically, plastic, an MSW, should be heated for 30 to 90 minutes to remove condiments. The critical point of incineration comes when distinguishing between incineration processes that practice "waste to energy" and those that do not. Also known as combustion with energy recovery, this process is considered to be a key step towards achieving a non-hazardous waste management system, being a part of its hierarchy. It ranks below source reduction and recycling but above disposal and treatment. The reason behind this is not only its incineration process but also its energy recovery ability. Energy recovery is the process where the burning of non-recyclable waste materials converts them into usable heat, electricity, or fuel through a variety of processes, and in this case, combustion. The recovered energy cannot really be used as a means of trying to create a circular structure where the energy recovered is reused to burn more material but can be used for external means. However, not all incineration facilities actually utilize the energy recovery method, mainly because the management will obviously have to cost more to maintain. By the early 1990s, the majority of the United States's waste incinerators practiced energy recovery and had installed pollution control equipment. Moving on to its pros and cons, the strengths of incineration lie specifically with combustion with energy recovery. The energy produced from the recovery process is frequently used when manufacturing products such as cement, a key material used in construction. Additionally, plastic can be considered a substitute for the fossil fuels that have been used excessively over the years.

Incineration is not the only method of plastic management that involves high-temperature heating. Pyrolysis is another technique that can convert plastic into energy. Its difference from incineration comes from the fact that it does not involve direct contact between the plastic waste and fire; rather, the waste is heated from an external source, with the absence of oxygen. This process normally uses heating of more than 430°C together with extreme pressure in order to both physically and chemically change its state. During this process, the bonds among the hydrocarbon compounds making up long chains are broken into much smaller pieces. The pyrolysis process always produces products in the solid, condensed liquid, and gas state. These include biochar, bio-oil, methane, carbon monoxide, carbon dioxide, and synthesis gas. Sometimes, a mixture of plastic and other biomass goes through co-pyrolysis to produce bio-oil to increase oil yield while reducing the water content and increasing the caloric value. One of the most efficient and common types of pyrolysis reactors used in the industry is the Bubbling Fluidized Bed Pyrolyzer. Others include Circulating Fluid Beds & Transported Bed and Ablative Pyrolyzer. However, is pyrolysis really an optimal method for plastic waste management? The advantage of the method is that it is a simple technology to utilize a variety of feedstocks to create energy. In addition, it is relatively inexpensive compared to disposing of plastic waste in landfills.

Most importantly, it displays a high efficiency since the vast majority of plastics are processed in one main reactor, making accessory reactors unnecessary. For example, plastics such as Polyethylene, Polypropylene, and Polystyrene all contain a higher oil yield. This means that when ten tons of this plastic waste is pyrolyzed, it has a theoretical yield of 5 tons of bio-oil. In fact, the pyrolysis oil market is already in play, where it was valued to be worth $302 million USD in 2020. Its estimated CAGR growth rate is 4% from 2021 to 2031, expected to reach $459 million USD by the end of 2031. However, despite the fact that the efficiency of this method is close to verified, its environmental effects can be a problem. The specific supply of waste plastic has to be chosen in order to meet environmental emission standards. If not, the waste emissions can cause a stretch of air and soil pollution. This is also a direct obstacle to businesses; as such, environmentally harmful projects will cease to continue.

Modern Methods of Plastic Management and Economic Advancement

In addition to the general traditional methods of plastic management used, businesses worldwide are continuously making attempts to reach the next level of efficient waste management. Most of them strive to achieve a circular economy for waste, where no harmful products have to leave the cycle of managing the waste. Accordingly, novel technologies and ideas are consistently generated, together with foreign countries adopting them with their own approach. One excellent and influential example of such technology is the Catalytic Hydrothermal Reactor, or Cat-HTR in short. It was originally developed by Licella Holdings, a business based in North Sydney, Australia. "The world's most advanced hydrothermal liquefaction technology" is what Licella describes as its possibly revolutionary technology. It has been widely considered a pioneering technology for a lower carbon future, where its proper usage can make the dream of a circular economy a reality. Similar to other methods using heat sources, Cat-HTR can use various biomasses and plastics to reverse what is now 'waste' back into being a useful material. After the removal of non-plastic contaminants, the non-recyclable plastic feedstock is melted and pressurized, then mixed with water at a high temperature. The produced material will enter Cat-HTR reactors for approximately 20 minutes, which will then be depressurized and made into separable products. The byproducts of such a process are notably minuscule compared to the methods mentioned prior to this. Dr Len Humphreys, the CEO and inventor of the cat-HTR, focused on methods to use the common products produced from processing plastic, which people normally consider as 'garbage.' He claimed, "Plastic is nothing but the resources we are not harvesting. We allow them to be dispersed because we've been ignorant of their value," a belief that is tied directly to a circular economy. Several foreign companies worldwide have engaged in active partnerships with Licella starting in 2011, spreading its influence and declaring the next generation of advanced recycling.

Licella partnered with Mura Technology, with it becoming the UK-based licensee of the CAT-htr technology. Mura further reached out to foreign businesses that hold a shared vision for a lower carbon future. One of these companies was LG Chem, a leading global chemical producer. It supplies petrochemicals ranging from basic distillates to specialty polymers, mainly common plastics such as acrylonitrile butadiene styrene (ABS) and polyvinyl chloride (PVC). Mura and LG Chem plan to build a Hydro-PRT advanced recycling plant in South Korea, with the goal of achieving an annual production capacity of 25,000 tons per year by early 2024. Kug-Iae Not, the President of Petrochemicals Company of LG chem, announced, "We see this as an extremely important step towards tackling plastic waste pollution and slashing the carbon emissions which threaten our environment." Not only that, Licella has placed strategic partnerships in place with other Asian companies, such as Mitsubishi Chemical Corporation of Japan. Through this and a few other partnerships, their forecast for 2025 is the development of one million tonnes of recycling capacity globally.

Other partnerships with Mura Technology include the United States Dow Technologies, a global leader in materials science. On April 22, 2021, the two announced a partnership aimed to prevent plastic and carbon from entering the natural environment while creating the feedstocks for a sustainable, circular plastic economy. This serves a crucial role in Mura Technology's goal of 1 metric tonne of recycling capacity by 2025. Corresponding to Mura's plan to recycle 80,000 tonnes of plastic waste per year, Dow will be receiving and using these recycled materials to develop new, virgin-grade plastic for a variety of applications, such as food packaging. Dr Steve Mahon, CEO of Mura Technologies, stated, "We're changing the way the world thinks about plastics – not as something to throw away, but as a product that can be used over and over again, and sustainably, without damaging our natural environment. Our partnership with Dow will help make this a reality for global brands and deliver a circular plastics economy globally within the next decade." Mura has future sites planned in the US, Germany, and Asia to accelerate the spread of their Hydro-PRT technology.

The Next Steps of the Plastic Economy

It is indisputable that the disposal of plastic waste has developed remarkably towards renewability and environmental welfare due to the advances in technology. However, from an innovative standpoint, there are multiple fields of science and technology left as a blue ocean. Namely, this includes biotechnology. Biotechnology is the use of applied biology to produce products or processes. This study is widely used in industries like healthcare, pharmaceuticals, fuel, and environmental safety. [1] Common practices that fall under this category include genomics or the manual change of genetic code in living organisms.

Biotechnology, in relation to plastic waste, has stayed in a latent state, not going beyond the boundaries of producing bioplastics or biopolymers. Although the market for these products has been on a consistent rise, there is still room for progress to reach more direct solutions for the sustainability of plastics. [2] One key example of a potential biotechnological breakthrough involves the use of microscopic life or bacteria. For a while now, the idea of biological degradation of plastics has been observed and confirmed in members of filamentous fungi Fusarium Oxysporum and F.solani. They use chemical components found in PET by breaking it down with a special enzyme. Recently, Japanese scientists were able to isolate a novel bacteria, Ideonella Sakaiensis, which uses two unique enzymes to break down PET into much smaller molecular compounds. They are able to rely on PET as a major energy and carbon source while producing two products, terephthalic acid and ethylene glycol, both unharmful compounds to the environment in small doses. [3] Although it is difficult to make use of these bacteria at an industrial scale, such as incorporating it into utility-scale plastic waste disposal plants, it shows potential to be used within smaller margins. An example of this is the utility of these bacteria in agriculture or waterways, with the purpose of mitigating microplastics. Microplastics, a threat to human and environmental health, are abundant in soil and groundwater. This inevitably leads to toxic chemicals being absorbed by plants, without the exception of vegetation consumed by the majority of the public. Through the use of Ideonella Sakaiensis and the addition of the proper external measures to account for other possible safety factors, the amount of microplastics existing within our proximal food and waterways can be mitigated. [4] Since Ideonella Sakaiensis has specific enzymes to break down PET, which is the most common type of plastic, but also the easiest to treat. Although the research is only at the early stages, there is a microorganism that is able to carry out similar chemical processes to Ideonella, but instead of treating PET, it is able to treat vinyl chloride. This is significant because Vinyl Chloride is the environmentally most difficult type of plastic to treat. However, the bacteria BAV1 is able to "eat" vinyl chloride and its toxic derivative, dichloroethane. However, the primary problem for BAV1 to be used commercially is that the bacteria attach themselves to the soil and ingest vinyl chloride close to the surface levels of the soil. This creates a filter that also tends to trap water, which inhibits the creation of aquifers and groundwater formations, which are critical in the hydrological cycle and fundamental soil health. [5] In all, the idea of using microbes or microorganisms to approach the plastic sustainability problem is highly underrated, and deserves wider attention to its potential.

Conclusion

Ever since the material of plastic became the go-to for all sorts of conveniences, the concern for environmental problems has followed right behind it. However, due to the incredible progress in technology and environmental awareness, international efforts have been consistently put in, including ESG practices and progress towards circular economies. Even after accepting the fact that contemporary technology of plastic disposal has its crucial benefits, there is still an unexplored blue ocean of biotechnological advancements in microorganisms to be found.

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