# Saving the Planet and Humankind with Plastic Alternatives and the Circular Economy

Plastic industry and plastic waste are one of many earth pollutants extensively affecting aquatic and terrestrial systems.[1] Plastic pollution receives much attention with stories depicting animals dying by ingesting plastic waste or entangled in plastic debris. Plastic waste carried by ocean currents has created five floating islands across the planet made entirely of garbage.[2] Dangerous chemicals leach from plastic waste into the soil, ground water, and oceans, fundamentally changing their biophysical properties and killing hundreds of thousands of organisms.[3] Microplastics are increasingly found in drinking water, food, cosmetics, and toiletries. Chemicals in plastics and their by-products increase risk of fertility issues, poor fetal development, cancer, and mimic hormones responsible for reproduction, growth, and metabolism.[4] Plastic pollutants affect air quality from their mechanical breakdown and from oil and gas refineries and manufacturing plants that create and recycle them.[1]

Despite the health and ecological harm caused by plastics; they continue to be produced. Plastics are strong, durable, flexible, light weight, and are manufactured at low-cost for many industries including packaging, building, transportation, and medical devices. The versatility and utility of plastics provide containment and protection to reduce food waste and decrease the weight of products easing fuel emissions for transport. In addition, the plastic industry employs millions of people providing income to many.[3] However, the utility of plastics comes at a high cost to the planet and human wellbeing. Efforts have been made to curb plastic pollution and waste by recycling, developing plastic alternatives (e.g., mushroom based products), and discovering new ways to re-use plastic products as part of the switch to a circular economy, an economic model where products are used until their material value is no longer viable or they are recycled or upcycled through processes like composting. Some of these solutions come at an equally high price or have not been made scalable. The international community must act swiftly and collectively to transition from oil-based, non-biodegradable plastic sources to alternative, bio-degradable sources while implementing a circular economy to increase human and environmental wellness.

The amount of plastic developed and expended is tremendous. In the last thirty years, plastic utilization has increased fourfold and roughly 507 million tons of plastic are created each year. It is believed that without immediate action, plastic production will triple by 2060 and some sources even expect that number to grow to 36 billion tons by only 2050.[1,5,6] Most plastic waste is transported to landfill (50%), incinerated (19%), or leaked into the environment (22%) through unregulated dumpsites, burned in uncontained pits, or by itinerant passage through water and land sources. Plastic waste continues to rise due to increases in population and a more

disposable, convenience driven society. Nearly two-thirds of plastic waste occurs from plastics disposed of within 5 years, of which 40% is packaging, 20% construction supplies, 6% electronics, 3% agriculture products, 11% from clothing and textiles, and the rest from other consumer goods like appliances and sporting merchandise.[1,5] In just 2019, 6.7 million tons of plastic waste made its way into freshwater environments while 1.9 million tons entered marine environments. It is now estimated that there are 33 million tons of plastic waste in seas and oceans and 120 million in rivers that will continue to seep into oceans for decades more.[5]

The methods of plastic waste disposal are problematic and so are the chemicals which comprise oil-based plastics. Almost 50% of plastic is generated by 18% of countries and sovereign states with a per person annual average of 487 lb in the United States, 251 lb in European countries, and 152 lb in both Japan and Korea.[1] Landfill, incineration, and recycling are the most common methods to manage plastic waste, and all create harmful effects because plastic is composed of over 3,200 hazardous chemicals. Thus, it is not surprising that plastic waste management methods create health and environmental issues especially in waste management workers and in areas and communities near processing plants.[7] However, the majority of plastic pollution comes from ineffective and insufficient collection and disposal of macroplastics, and leakage of microplastics.[5] Microplastics (< 5 mm in diameter) are by-products caused by the degradation of everyday materials e.g., packaging, industrial plastic pellets, automobile tires, road markings, synthetic clothing, cosmetics, and cleaners.[4,5] There are common chemicals associated with some plastics that have been highlighted as hazardous (Bisphenol A (BPA), phthalates, and Perfluoroalkyl and polyfluoroalkyl (PFAs)). Even still, these plastics continue to be used in items like non-stick cookware, dental floss, plastic packaging, and food grade containers. However, there are still many chemicals in plastics of which we are not aware because chemicals in plastics and other materials do not undergo comprehensive safety tests due to a lack of requirement and oversight by the government. Plastic makers have little financial incentive to regulate themselves and have sought alternative solutions to gain continued support of their products.[4]

As alternatives to fossil fuels increase and the negative effects of plastic pollution become more apparent, the reliance on gasoline and diesel fuels decreases, impacting oil and gas producers' profitability, requiring them to seek alternative solutions. The petrochemical sector, which includes plastics, has found ways to continue to increase oil and gas demand by increasing humanity's reliance on plastics.[8] New plastic made primarily from crude oil or gas is cheap and higher quality than recycled plastic.[5,8] America's Plastic Makers have stated their

solution to plastic packaging in the US is to be “reused, recycled, recovered, by 2040.” The plastics industry has promoted recycling even though they have long understood it would never be effective on a large scale. Their goal was a public relations tactic rather than a solution for preventing environmental damage.[8] What is less known is that only 9% of plastic waste is recycled although years have been spent on recycling campaigns.[5,8] While 15% of plastics are collected for recycling, 40% of that is disposed.[5] Recycling becomes limited or not an option for non-biodegradable containers that would usually be recyclable but that are contaminated by food.[3] What’s more, the recycling of plastics moves the many toxic chemicals used to make plastics around, harming our environment, and threatening our health.[7] Recycling plastic costs as much as or more than its material worth and while investing in improved technologies could help make recycling more competitive and profitable, it comes with its own environmental and health challenges.[5,8] In order to get plastic pollution under control, reducing the amount of new plastic made is essential.[8]

Reducing use of plastic by switching to common alternatives like glass, metal, paper, wood, cotton, and wool is a helpful way to curb plastic reliance. However, these substitutes cannot solve the plastic pollution problem alone. Some are heavier to ship, requiring more fuel to be expended. Some are cost prohibitive as viable alternatives. Others deplete natural resources faster than they can be renewed (deforestation), require significantly more energy to produce, or are destructive in other ways (pesticides).[9,10] Many cannot replace the application of  plastic. Finding an alternative source to plastic that can match its versatility and utility yet be able to breakdown to beneficial compounds while protecting valuable resources is vital.

Biodegradation is the ability for something to be broken down into harmless products by living things, e.g., microorganisms.[11] Oil-based or traditional plastics may have some biodegradable properties, but they are limited, require a significant amount of activity from multiple micro-organisms, and none have proven to be able to fully mineralize and converted into biomass, the mass of microorganisms from biodegradation.[3] Bioplastics are in some, or all, parts developed from biomass, but not all bioplastics are biodegradable, some result in such slow degradation they differ little from their non-biodegradable counterparts, and some bioplastic chemical formations look and act just like oil-based plastics. The biodegradability of a plastic depends on its structural make-up including the use of additives as well as the environment in which it is placed during the biodegrading process. Therefore, it is imperative to ensure individual bioplastics be studied for their biodegradability in various environments before they be adopted and widely used.[1,3]

Implementing alternatives to oil-based and slow degrading plastics with biodegradable and compostable substitutes is necessary. The International Standards Organization (ISO) and the American Standard Testing Method (ASTM) suggest for a product to meet biodegradable standards in natural environments, it must mineralize by 56 days in water and 2 years in soil while the product should break down within 180 days through industrial composting and 1 year in home composts.[3,12] There have been some promising inventions using biodegradable sources used in place of plastic that meet ISO and ASTM standards. For example, Green Ocean Group has developed a water-soluble packaging that uses a bio-based synthetic polymer without dangerous heavy metals and that dissolves in boiling water.[13] Researchers at Northeastern University have discovered a way to make a naturally compostable tableware (cups, bowls, take-out containers) using bamboo fibers and sugarcane pulp, which are fast growing, renewable resources, that can fully biodegrade within 60 days.[14] Others have been able to find innovative ways to make biodegradable plastic alternatives or additives using casein from milk, grape waste, lignin (by-product of paper mills), corn, starch, and wheat.[15] Many options seem to be promising plastic alternatives, depending on the plastic item being replaced, but one source stands out as most encouraging and may be a viable source for use in breaking down petroleum-based plastics.

Fungal-based materials or those made from mycelium, the “roots” of the mushroom, otherwise called mycelium composite materials (MCM), have become of significant interest in recent years.[16] The diverse properties and versatility of mushrooms and other fungi across thousands of species have proven to be effective in a myriad of applications and industries including biofuels, fabric, leather, footwear, transportation, packaging, automotive, computing, furniture, coffins, infrastructure, construction materials, insulation, foams, dyes, soil, pharmaceuticals, and even food and drinks, like meat and coffee alternatives.[16–18] Additionally, mycelium is purported to have the potential to be added to other materials as a bonding agent or for self-healing.[16] Mushrooms can be grown using remnants from forestry and agriculture and can increase soil viability increasing their benefits.[19] What is more, MCM are biodegradable, strong, abundant, inexpensive, water-resistant, flame resistant, thermal insulators, that can be grown to mold into any shape and even in home environments. Fungal-based materials have the added benefits of mycoremediation, the process of removing contaminants like petroleum, pesticides, and heavy metals from soil and water.[18] However, while mushrooms provide planetary health benefits in addition to being a profitable alternative to plastic, MCM still face some environmental and health challenges as they are often grown in closed spaces creating health issues for growers and may reduce

the genetic diversity in wild plant and fungal populations. Some mushroom spores can be controlled by harvesting before the spores are released, but not all have this ability. MCM is often grown in single use heat-resistant plastic bags which add to plastic waste. MCM produces large amounts of spent mushroom substrate (SMS) that are the remains of what mushrooms have used to grow. The two most common ways to dispose of SMS are through composting, which should be done industrially and is expensive to build, or burning, which is not eco-friendly.[19] Thus, it is evident that there is a need for an efficient and environmentally supportive method to which eco-friendly practices can work together as one system.

In a circular economy waste and pollution cease and nature is restored and renewed. Plastic products that are unnecessary are not manufactured and, for those that are essential, alternative, eco-friendly sources are revolutionized so that they are either recyclable or up-cyclable, ensuring everything produced is circulated and waste is eliminated.[6] Reusing, recycling, and upcycling a biodegradable plastic product, including by composting or redistributing a product's natural biomass, would be central to a circular economy.[3] For the circular economy to be feasible, the current economic model of short-term gains at the expense of diminishing resources, environmental destruction, and human health must change. With international government support, industries can be penalized for polluting and incentives in support of a circular economy and resource efficiency can be provisioned, making it the most attractive option.[6]

Elimination of plastic pollution requires action and international cooperation, to reduce reliance on oil-based plastics, to realize innovative, environmentally friendly, biodegradable alternatives to plastic, and to improve waste management.[5] There is a need to evaluate the recycling process and reform how products are constructed, supplied, distributed, and collected. Nature provides many sources for biodegradable alternatives to plastic. However, not all are created equally. It is evident that like the many hundreds of materials that make up different types of oil-based plastics, multiple plant-based, biodegradable sources should be sought as a solution to the ever-growing problem of plastics. Mushrooms are a tenable option for both breaking down plastics and being utilized as plastic alternatives, but they are not the sole answer to the plastic waste problem. However, with the combined support of the international community and government accountability, the chemicals that make their way into water, food, and soil can be regulated and a circular economy can be the strength of society and the path to healing the planet and humankind.

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