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Recycling and Management of Microplastic Waste

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ABSTRACT
PL pollution is caused by contemporary society's unsustainable consumption and dumping of PL items, placing economies, landscapes, and people's health in risk So far, remediation operations have attempted to mitigate the negative effects of PL pollution, but efforts are still unable to cope with the increased volumes of PL released to the environment. As a consequence, emphasizing a standardized measurement strategy to recycle PL emissions into the environment is essential. Badly run garbage is a significant ground cause of PL pollution that could be reduced by changing life of PLs, especially in terms of production, usage, and destruction, with an Effective Waste Management System. In this review article, we describe existing techniques for improving the life span and waste disposal of PLs that may be applied to decrease PL waste and environmental and health implications. (1) Regulatory oversight of manufacturing and utilization; (2) eco-design; (3) rising the demand for recycled PLs; (4) lowering the use of PL products; (5) use of renewable power for reprocessing; (6) extended producer responsibility over waste; (7) advancements in collection systems; (8) good planning of composting; (9) utilisation organic and degradable PL products; and (10) advancement in recyclability are among the ten suggestions for decision makers to reduce its environmental footprint.
Key words: *Microplastic, microplastic conversion, source, types and health impacts,*

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INTRODUCTION

"Pliable and readily made" was the original definition of plastic (PL). It wasn't until recently that the name "polymer" was used for a group of materials. Polymers (PLYs) are long chains of molecules with the word "polymer" meaning "many parts." In nature, PLYs abound. A common natural polymer is cellulose (CL), which is found in cellular membranes. During the preceding century and a half, humans figured out how to make synthetic PLYs, sometimes using natural materials like CL, but more often with the copious carbon atoms provided by petroleum-based goods. Synthetic PLYs are made up of lengthy chains of atoms arranged in repeating units, which are often much longer than natural PLYs. Because of the length of the chains and the patterns in which they are arranged, PLYs are strong, lightweight, and elastic. To put it another way, that's what gives them their flexibility. Such characteristics that make synthetic PLYs incredibly beneficial, and we've been using them since we learned how to produce and control them. Especially in last 50 years, PL have penetrated our culture and influenced how we live [1].

First Synthetic PL

In answer to a $10,000 reward offered by a New York corporation for anybody who could make an ivory substitute, John Wesley Hyatt created the first synthetic PLYs in 1869. Billiards' popularization had put a huge strain on natural ivory resources, that were acquired by killing wild elephants. By mixing cotton CL with camphor, Hyatt found a PL that can also be shaped into a range of shapes and molded to simulate natural substances such as tortoiseshell, horns, linen, and ivory. This discovery was revolutionary. Human output was not bound by natural restrictions for the very first period in history. Mother Earth could only provide far more timber, metal, rock, bones, ivory, and horn. Humanity, on the other hand, are concerned with producing substances [1]. Not only did this technology assist people, but it also helped the ecosystem. In commercials, celluloid was hailed as the saviour of the elephant and tortoise. PLs have the ability to preserve the ecological landscape from the detrimental effects of human demand. The invention of new substances also liberated humans from the economic and social constraints imposed by a shortage of mineral wealth. Due to the obvious inexpensive cost of celluloid, material luxury has become more fashionable and attainable. As well as the PL revolutionary was only getting underway [2].

Development of New PLs
Leo Baekeland invented Bakelite, a first completely synthetic polymer, in 1907. It didn't include any molecules found in nature. Baekeland had been seeking for a synthetic substitute to shellac, a natural electrical insulator, to satisfy the demands of the quickly electrifying United States. Bakelite was not only a good insulator, but it was also lengthy, high - temperature, and, like celluloid, well with the mass production. "The material with a thousand uses" is how the chemical is promoted. Bakelite could be moulded or moulded into whatever, opening world of possibilities. Major chemical businesses were inspired by Hyatt and Baekeland's success to invest in the research and innovation of additional PLYs, as well as other PLs swiftly joined celluloid and Bakelite. Whereas Hyatt and Baekeland are seeking for substances with certain characteristics, the latest research initiatives are seeking for novel PLs in the hopes of finding future applications for them [1,2].
Age of PL
World War II (WWII) necessitated a substantial expansion of the PLs sector in the US, as economic growth was as as important as military victory. The need to conserve precious natural resources spurred the development of synthetic fibers to the top of the priority list. Options were provided by PLs. Nylon was invented by Wallace Carothers in 1935 as a synthetic silk, and it was widely used in the war for parachutes, ropes, body armour, helmet liners, and other products. Areophane windows were replaced with Plexiglas. As a consequence of the fight, "PLs have indeed been turned to specific uses, and the adaptability of PLs has been proved all over again," as shown in a Time magazine report. During WWII, PL output in the United States rose by 300 percent [1]. After the war, the increase in PL production continued. Americans were ready to spend again after the Great Depression and WWII, and the majority of what they bought was made of PL. As per author Susan Freinkel, "PLs challenged traditional substances and won in product after product, market after industry, filling the role of steel in automobiles, paper and glass in containers, and timber in furniture." The promise of PLs gave some onlookers a near-utopian vision of a future filled with great material riches thanks to an inexpensive, safe, and sanitary material that individuals could shape with their every want [2].
Growing concerns about PLs
The perfect hope of PL was short-lived. In the postwar years, PLs were no longer seen as unquestionably good, leading to a shift in American attitudes. The discovery of PL garbage in the seas occurred in the 1960s, during which time Americans were increasingly aware of environmental concerns. Rachel Carson's book Silent Spring, published in 1962, highlighted the dangers of pesticides. In 1969, there was a large oil spill off the coast of California, and the polluted Cuyahoga River in Ohio caught fire, raising environmental concerns. Observers were concerned about the permanency of PL rubbish as public awareness of environmental problems expanded. PL started to be used to denote anything inexpensive, flimsy, or deceptive over time. An elder acquaintance pushed Dustin Hoffman's character in The Graduate, one of the finest films of 1968, to seek a career in plastics. Audiences grumbled at what they saw as misguided enthusiasm for a business that, rather than being full of potential, was a symbol of cheap uniformity and artificiality, as Hoffman did [2].
Effect of PL on human health
As public concern about waste developed in the late 1970s and early 1980s, PL's reputation suffered dramatically. Because, whereas many PL things are disposable, PL persists in the environment permanently, it became a special emphasis. The PLs industry offered recycling as a solution. The plastics sector led a successful push in the 1980s to persuade municipalities to collect and process recyclable materials as part of their waste-management systems. Recycling, on the other hand, is far from perfect, and the great majority of PLs still end up in landfills or the environment. PL supermarket bags have been a target for environmentalists aiming to limit single-use, throwaway PLs, and bag bans have already been passed in a number of places across the United States. The Great Pacific Debris Patch, a swirl of PL debris the size of Texas drifting in the Pacific Ocean, is the epitome of the PL waste dilemma. As a result of growing concern about the potential harm they pose to human health, PL's image has deteriorated further. The chemicals, such as phthalates, that are introduced into plastics throughout the manufacturing process to make them more flexible, durable, and transparent are at the focus of these issues. Some researchers and members of the public are concerned that these chemicals are leaking from PLs and making their way into our food, water, and bodies. The endocrine system can be influenced by these drugs in exceedingly high concentrations. Researchers are especially worried about the effects of these chemicals on children, as well as the long-term consequences of their accumulation for future generations [1,2].
PLs future
Despite growing scepticism, PLs are critical in today's world. Computers, mobile phones, and the vast majority of life-saving advances in modern medicine were all made possible by PLs. PLs are light and

insulating, reducing the usage of fossil fuels for heating and transportation. Low-cost plastics, maybe most crucially, raised people's living standards and increased access to material goods. If PLs were not accessible, many of the items we take for granted would be unavailable to everyone except the wealthiest Americans. Many of our products have been made cheaper, lighter, safer, and stronger by substituting PL for natural materials. Since PLs are clearly crucial in our life, several scientists are striving to make them safer and more long-lasting. Certain businesses are developing bioplastics, which are made from plant crops rather of fossil fuels, to make chemicals that are more environmentally friendly than standard PLs. Others are working to create PLYs that are completely biodegradable. One of the ambitions of some innovators striving to enhance recycling efficiency is to develop a technology that converts PLs back into the fossil fuels from which they originated. According to all of these creators, PLs aren't perfect, but they're an important and critical part of our future [1,2].

PL to microplastic (MP) conversion

MPs are microscopic PL particles with a diameter of less than 5 millimetres. In water, MPs are invisible and float or sink depending on their composition. Because MPs like polypropylene are lighter than seawater, they float and disperse widely over rivers. Acrylic and other MPs have a higher density than seawater and will collect in the ocean's deepest depths. About 99 percent of the PL in the ocean is thought to be made by MPs. Floating MPs will eventually assemble in massive gyres. MPs that sink seeking food are perplexed by sea life. The hadal zone (the deepest part of the ocean) may be one of the most important MPs sinks on the planet. Microfibers (MFs) are included in MPs. They include microscopic threads that enter the water when synthetic clothing like polyester and nylon is washed [3-5].

Sources of MP **pollution**

Automobile industry: Tyre wear and tyre dust (Adachi and Tainosho, 2004), emissions from non-exhaust vehicles [6, 7], road dust resuspension [8], leachate from weathering PLs [9], brake friction materials [10], brake pad materials [11], pavement-tire interface ultrafine particles [12], tire tread wear particles [13] and lithium-ion battery packs [14].

Textile industry: Polyester clothing [15], MFs produced by washing dryers [16], 3-D printing [17] and synthetic fibers from textiles [18].

Food industry: PLY film packaging for food [19], PL-coated paper products [20], PL bags [21], PL straws [22] and disposable PLs and wooden chopsticks [23].

Cosmetic industry: Facial cleansers [24], microbeads (MBs) in facial scrubs [25, 26] and hair conditioner and eye shadow [27].

Health industry: Nylon flock [28-30], COVID-19 pandemic face mask [31], medical waste disposal [32] and PVC medical product waste [33].

Fisheries and aquaculture: Marine paints (antifouling agent) [34], resin pellets [35], bisphenol A [36], derelict traps [37], polystyrene spheres [38], PET bottles [39], phthalate esters [40], polyethylene wear debris [41], 4-nonylphenol [42], HDPE cages [43], Bisphenol S [44], Polybrominated diphenyl ethers [45], polyfilament nylon fragments [46], pelagic plastic and tar [47], neuston plastic [48], polychlorinated biphenyls [49], fibrinogen-coated polystyrene [50], LDPE [51], 60 nm polystyrene particles [52], polystyrene microspheres [53], Styrofoam debris [54], styrene oligomers [55], plastic garbage that floats [56], polyethylene microbeads [57], spirocyclic polyacetal ethers [58], nylon threads [59], Hexabromocyclododecane [60], dioxin-like PCBs [61], polypropylene [62], polyamide 6 multifilament fishing net [63], Polystyrene nanoplastic [64], nonylphenol [65] and micro-sized PVC particles [66].

Types of MPs

MPs are divided into two types: primary and secondary. Primary MPs include MBs in personal care products, PL pellets or nurdles used in industrial manufacturing, and PL fibres used in synthetic textiles (e.g., nylon). Primary MPs enter the environment through product consumption (e.g., personal care goods rinsed into wastewater systems from homes), unintentional loss from spills during manufacturing or transportation, or abrasion during washing (e.g., laundering of clothing made with synthetic textiles). When larger polymers deteriorate due to weathering, such as exposure to wave action, wind abrasion, and UV radiation from the sun, secondary MPs emerge (Fig. 1) [67].

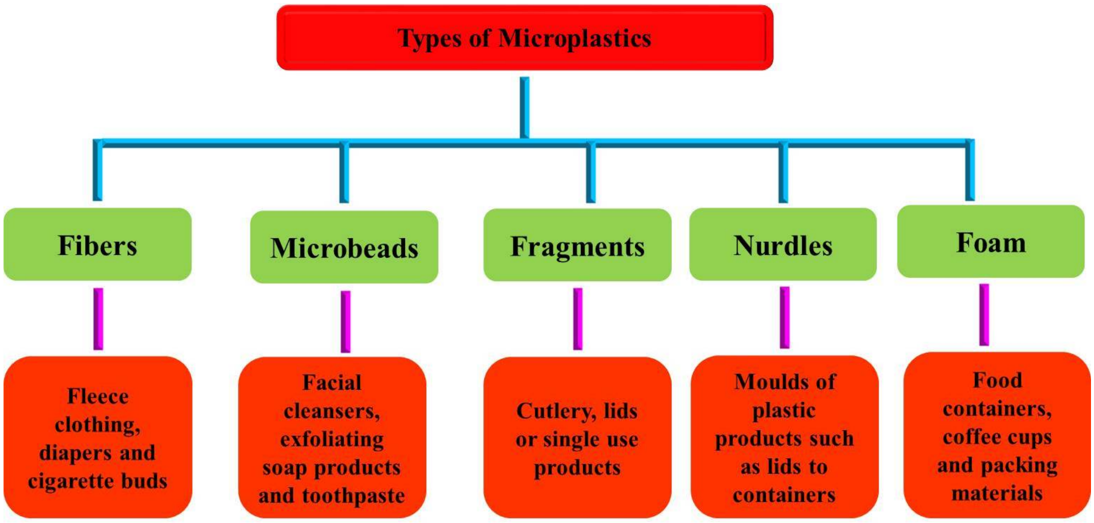

Fig. 1: Five types of MPs

Diseases caused by MPs

Human beings: Crohn's disease [68], Endoplasmic reticulum stress [69], endocrine-disrupting substances' potential for causing harm to humans [70], Oral squamous cells carcinoma [71], MPs absorption in human stool [72], clathrin-mediated endocytosis [73], gastric adenocarcinoma [74], mitochondrial injury pathways [75], metabolic disorders in the offspring [76], immunotoxicity [77], disruption of thyroid hormone [78], Coronary Artery Disease (CAD) [79,80] and oxidative stress [81].

Aquatic animals: Inflammation of the intestine, oxidative stress, vascularization, and metabolome and microbiome abnormalities in zebra fish [82, 83], *Pomatoschistus microps* predatory performance and efficiency are reduced [84], hemocytopenia in crab [85], hepatic stress in the fishes [86], toxicity in Antarctic Krill [87] and endocrine disruption in adult fish [88].

Birds: Chemicals generated from PL accumulate in marine birds [89], endocrine disturbance and reproductive toxicity [90], MP ingestion and dispersion by vultures [91], cerebellar toxicity in Quails [92] and kidney injury in Quails [93].

Ruminants: Sheep and goats' digestive tracts accumulate PL detritus [94].

Techniques used to detect, identify and quantify MPs

ICP-MS [95], micro-ATR-FTIR [96], TEM and GC-MS [97], TGA-FTIR-GC-MS [98], Pyroloysis-GC-MS and FTIR [99], FTIR imaging [100], TGA/DSC-FTIR [101], DSC [102], TGA-DSC [103] and AFM-IR [104].

Methods used to degrade MPs

A modern strategy to developing novel synthetic PLYs is based on their life span and takes into account environmental effect from conversion to disposal [105]. Polymeric materials endanger natural habitats and the quality of life on the earth when improperly disposed or under unmanaged situations [106]. Few products are designed with the end user in mind (management of waste or reprocessing) in mind, incredibly simple PLYs have been extensively denounced for their visual pollution, difficulties in eliminating them from the ecosystem, and great resilience to deterioration.

Degradation is a synthetic process that causes the splitting of PLY chains and can irreversibly change the characteristics of PLY composites. A number of physical and chemical variables can cause it to occur [107]. One of the decade's greatest issues is determining how long a material can withstand prior to actually deteriorating or anaerobic decomposition, so that it could be disposed of in an environmentally friendly manner. According to research, thermoplastic materials degrade after being dumped in a number of ways, which might happen slowly or quickly depending on the environment and molecular makeup. Unlike biodegradable PLYs, which can include heteroatoms in the molecular chain and so disintegrate quickly when exposed to the right conditions, saturated polymeric chains do not allow for microbial degradation [108].

Gradually degradable or non-biodegradable PLYs have been studied as a greener alternative to biodegradable PLYs like chitosan or CL. However, it is widely acknowledged that today's biodegradable PLYs have unsatisfactory mechanical or surface properties for some applications, and that some of them are costly, restricting their use in select applications [109]. The density of PLs in compared to the density of saltwater influences whether they float or sink when they reach the marine environment. The type of a PLY and the conditions to which it is exposed, which might range from abiotic to microbial absorption, impact its degradation process [110]. As a result, either abiotic or biotic degradation of PLYs may be classified. The damage caused by environmental variables such as temperature, UV irradiation, wind, and waves is referred to as abiotic deterioration. Biotic degradation, on the other hand, is characterized as biodegradation caused by microorganisms (MOs) that alter and consume the PLY, altering its properties (Table 1). Both forms of deterioration are often active at the same time in nature [111].

Table 1: List of MOs used for biodegradation of PL and MPs

Name of the MOs	PL/MPs	References
Bacillus subtilis	PET	[112]
E. coli	PET	[113]
Ideonella sakaiensis	PET	[114]
Ideonella sakaiensis	PET	[64]
Ideonella sakaiensis	PET	[115]
Spirulina species	PET	[116]
Listeria monocytogenes	PET	[117]
Penicillus simplicissimus	PET	[118]
Brevibacillus borstelensis	PET	[119]
Streptomyces species	PET	[120]
Streptomyces species	Poly (3-hydroxybutyrate) and poly (30hydroxybutyrate-co-3-hydroxyvalerate)	[121]
Alcaligenes faecalis	Poly (3-hydroxybutyrate)	[122]
Alcaligenes faecalis	Polycaprolactone	[123]
Comamonas acidovorans	Polyester polyurethane	[124]
Phanerochaete chrysosporium	Polyvinyl chloride	[125]
Thermomonospora fusa and *Fusarium solani*	PET	[126]
Comamonas acidovorans	Polyurethane	[127]
Pseudomonas putida	Phenylacetic acid	[128]
Pseudomonas and *Bacillus* species	PET	[129]
Pseudomonas putida	PET	[130]
Pseudomonas aeruginosa and *Achromobacter species*	Polyvinyl chloride	[131]
Acinetobacter species	PET	[132]

Biodegradation of MP using algae

In sewage water, algae have been discovered to grow on artificial substrata such as polythene surfaces, and these colonizing algae have been proven to be less harmful and non-toxic [133]. The biodegradation of PLY begins with algae adhering to the surface, and their production of ligninolytic and exopolysaccharide enzymes is essential [134]. Algal enzymes in the liquid media interact with macromolecules on the PL surface, causing biodegradation to occur [135]. Algae use PLY as a carbon source because species that grow on the polyethylene surface have larger cellular contents and a faster specific growth rate [134]. Furthermore, the transverse section of the algal-colonized polyethylene sheets has clearly shown surface deterioration or disintegration [136]. Fouling, corrosion, hydrolysis and penetration, breakdown of leaching components, and pigment colouring via diffusion into the PLY are all examples of biodegradation techniques that have been documented in previous studies. Anabaena spiroides, a blue-green alga, degraded the lowest density polyethylene, followed by the diatom and the green alga [136]. Sarmah and Rout (2018) [134] found that readily available, fast-growing, and easily isolable freshwater nontoxic cyanobacteria are capable of colonizing the polyethylene surface and biodegrading low-density polyethylene efficiently without any pretreatment or pro-oxidant additives (Table 2) [137].

Table 2: List of algae used for biodegradation of PL and MPs

Name of the algae	PL/MPs	References
Uronema africanum	LDPE	[138]
Chlorella and *Cyanobacteria species*	LDPE	[139]
Sargassum linifolium	PET	[140]
Chlamydomonas reinhardtii	PET	[141]
Galleria mellonella	PET	[142]
Eucheuma cottonii	PET	[143]
Chlorella vulgaris	PET	[144]
Dunaliella salina	PET	[145]
Chlorella vulgaris	PHB	[146]
Skeletonema costatum	PET	[147]
Spirullina species	PET	[148]
Arthrospirs species	PET	[149]

Biodegradation of MP using worms

PL wastes that have accumulated in the environment are creating an ever-increasing hazard to the ecosystem. Biodegradable plastics are environmentally friendly; they have an expanding range of possible applications, which is fueled by the increased usage of PLs in packaging. For many years, polyethylene was thought to be non-biodegradable. The wax worms that consume plastic were found by chance. Federica Bertocchini of the Institute of Biomedicine and Biotechnology of Cantabria in Spain, a scientist and hobby beekeeper, was irritated when she discovered wax worms in one of her beehives at home. She decided to clean the beehive while going about her business, keeping the wax worms in an ordinary plastic shopping bag. She'd hidden the worms in a plastic bag in another room. When she returned to the room, she was astounded to see worms crawling all over the place. The plastic bag was punctured. This indicated that the wax worms (*Achroia grisella*, *Galleria mellonella* and Plodia *interpunctella*) had bitten their way out of the plastic bags at a fast rate [150]. Other than wax worm's super worms such as *Zophobas atratus* which are used to degrade polystyrene [151] and meal worms of *Enebrio molitor* used for biodegradation of PET and PLs mixtures [152].

CONCLUSION

MP pollution is becoming a growing environmental problem, notably in the world's seas. PET, a polymer utilized in a variety of applications such as textiles and food packaging, is one of the most common components of PL trash. PET is very resistant to environmental biodegradation, resulting in a slew of environmental issues, such organic pollution absorption and concentration, harmful impacts on marine animals, and the spread of potentially invasive species to new habitats. Landfill, incineration, and recycling are the only three large-scale PL disposal technologies now in use. Each method has its own set of downsides and drawbacks. Both landfilling and incineration discharge hazardous secondary pollutants into the environment, and landfilling has the added disadvantage of requiring a considerable amount of land space. Recycling alleviates landfill and incineration-related environmental issues; nonetheless, the process is inefficient, and the deteriorating quality of the PLY generated is a determining factor. Since the process is less cost-effective, there is less incentive for recycling facilities to be built. Biodegradation is a popular alternative for disposing of PL trash in an ecologically acceptable and effective manner. To date, no commercially viable biodegradation protocol for PET has been developed; however, significant research is still being conducted in the field of PLY biodegradation, and given the vast metabolic potential of MO's, it is expected that viable biodegradation processes will be developed in a matter of time.

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