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A REVIEW OF PLASTICS AND THE ENVIRONMENT: CHALLENGES IN MANAGEMENT, IMPACTS, AND THE ROLE OF BIOPLASTICS IN SUSTAINABLE SOLUTIONS

HEMABARATHI R

KUMARAGURU COLLEGE OF TECHNOLOGY

ABSTRACT :

Plastics have become indispensable in modern society due to their durability and lower production costs. However, the persistent accumulation of plastic waste poses severe environmental challenges, affecting the biodiversity. This review provides an overview of the issues related to conventional plastics and waste management practices, challenges in recycling, and socioeconomic impacts due to plastic pollution. Bioplastics emerge as a promising alternative to resolve the issues relates to conventional polymer. This paper helps in understanding different types of bioplastics, their properties, and degradation mechanism, by considering the current limitations in its production and waste management.

INTRODUCTION :

While plastics comprise a significant portion of municipal solid waste the recycling component remains very less. High-density polyethylene (HDPE) and Polyethylene Terephthalate (PET) are the mostly recycled plastics, but their recycling rates are not significant to its production. The packaging industry is the leading contributor to plastic waste due to its short product lifespans.[1] The Middle East, mainly the Gulf Cooperation Council (GCC), has emerged as a significant player in the global polypropylene (PP) market. The growing petrochemical industry and their increasing demand, is the major driving force in the expansion of PP production and consumption. The GCC's mainly focus on diversifying its economy and creating new job opportunities which has further helped in the growth of this industry.[2]

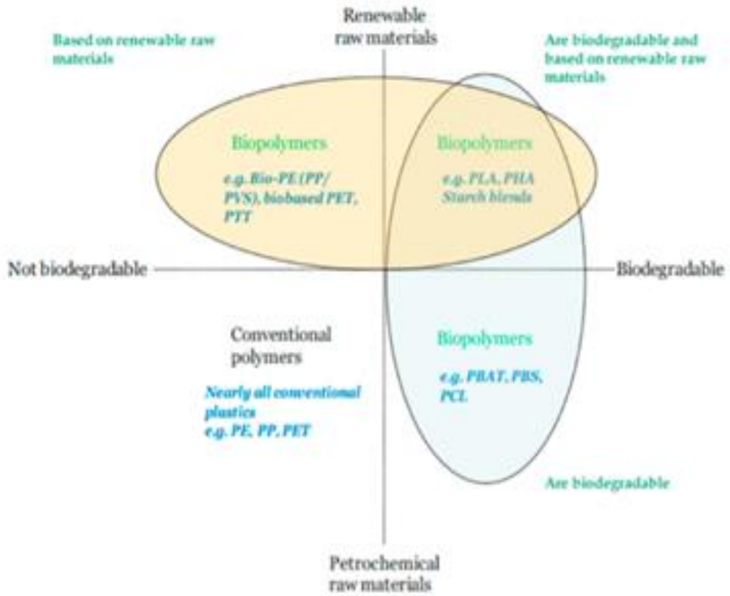

Fig 1: Types of polymer [3]

ILLEFECTS OF PLASTICS TO ENVIRONMENT

Plastic production has skyrocketed since the mid-20th century, with mostly ending up in Oceans and landfills. The mismanaged plastics, mainly single-use items, often ends up in oceans, posing a significant threat to marine life. These plastics degrade into microplastics and nano plastics, which enters the food web and also atmosphere. While very few plastics are recycled, remaining leds up in contributing to environmental degradation and climate change.[4]

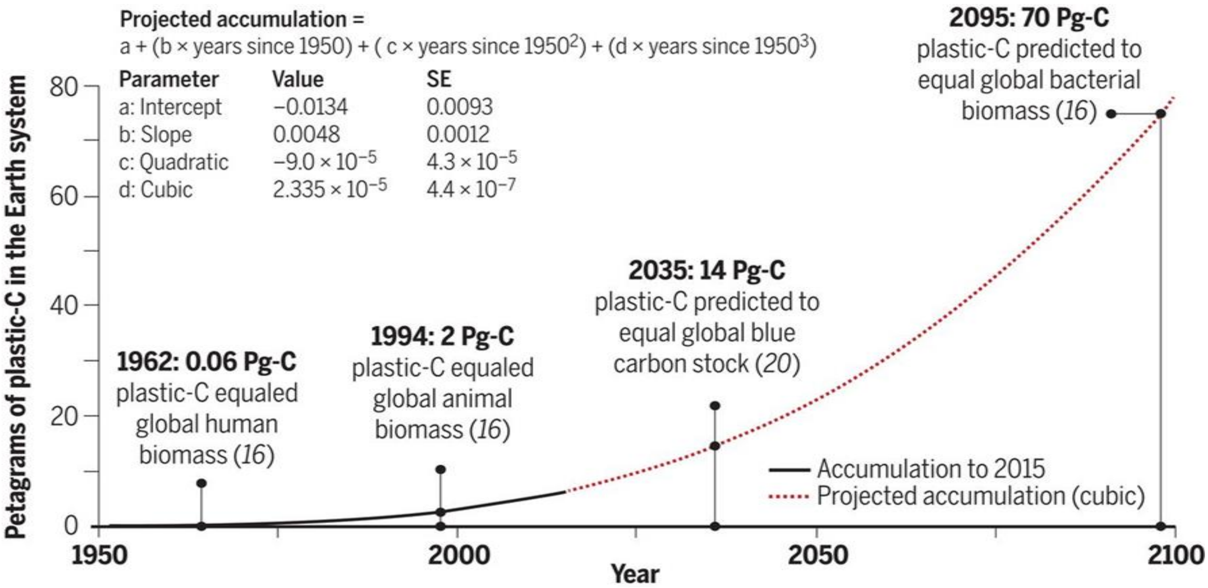

Fig 2: Projected growth of plastic accumulation [5]

The Plastics that end up in environment significantly impact microbial communities. They also alter soil environments, produce leach toxic additives, and impact the microbial dispersal. Microbial communities at its initial stage colonize plastic surfaces, forming the layer known as "plastisphere." These communities can degrade some plastics, but to what extend and there is need to study specific microbial roles in degradation. Additionally, some insects like wax, moth larvae, can consume and degrade plastics, which often aided by the microbes in the gut.[7]

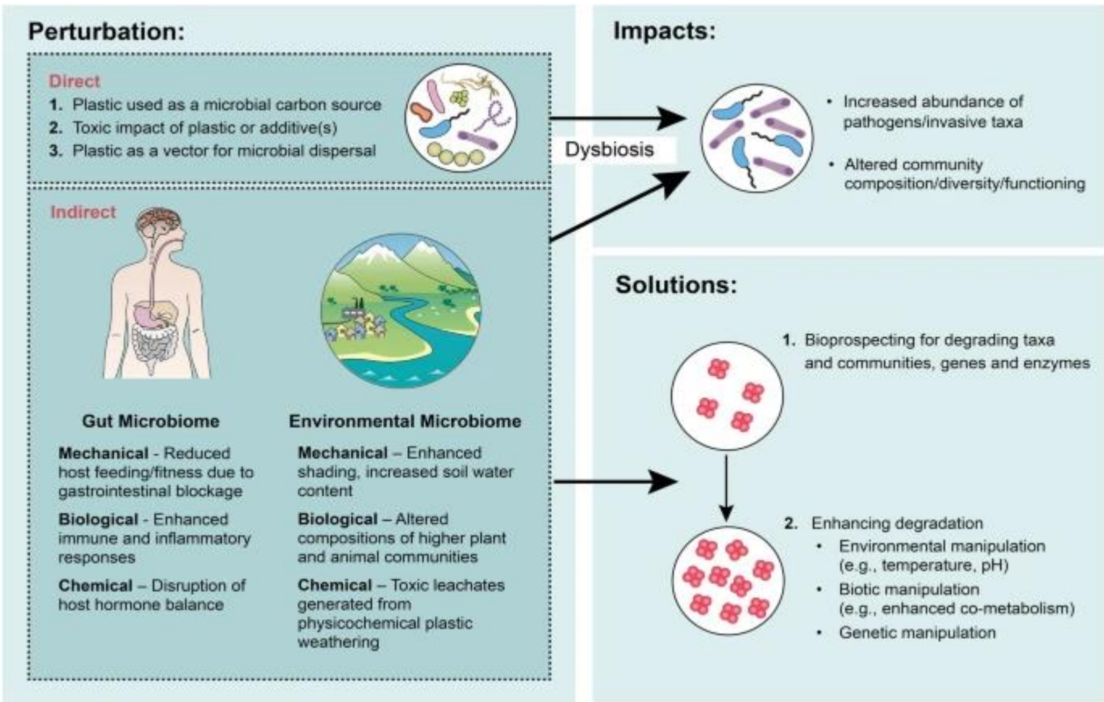

Fig 3: Impact of plastic [7]

PLASTIC MANAGEMENT:

Recycling plastic is mainly hindered by economic factors and some technical challenges. Low-cost mechanical recycling often led to comprising the material quality, while chemical recycling can be promising but its costly. The complex nature of plastic formulations and various additives used in it further complicates the recycling processes. Additionally, the variability in the properties of recycled plastics reduces its viability. To improve the plastic recycling, efforts should be taken on developing a cost-effective solution, addressing the impact of additives in the polymer and ensuring consistent product quality.[1]

The life cycle of plastics as three main phases: production, use, and disposal. Despite the advancement in recycling and waste management, still a large portion of plastic waste ends up in landfills or been burned which emits pollutants like CO and CO_2. In Europe, even with advanced waste management systems and technologies nearly 50% of plastic waste goes to landfills, as a wasted resources or else it could be used in energy recovery.

Plastic recycling includes three stages: Primary recycling - reusing plastics in their original form example PET bottles but it's limited due to contamination and polymer variability, making secondary recycling more common. Secondary recycling - using plastics in less demanding applications.

Tertiary recycling methods such as pyrolysis can convert plastics into useful as energy resources like hydrocarbons or chemical feedstocks, reducing non-renewable resources dependency and waste being dumped in landfills. The energy recovery from combustion can release hazardous emissions, mainly when plastics containing halogens are been incinerated, which can lead to the release of dioxin and equipment corrosion. Even through controlled combustion in advanced facilities can be used to limit these risks, the process still relies on fossil fuels which contributes to greenhouse gas emissions. [8]

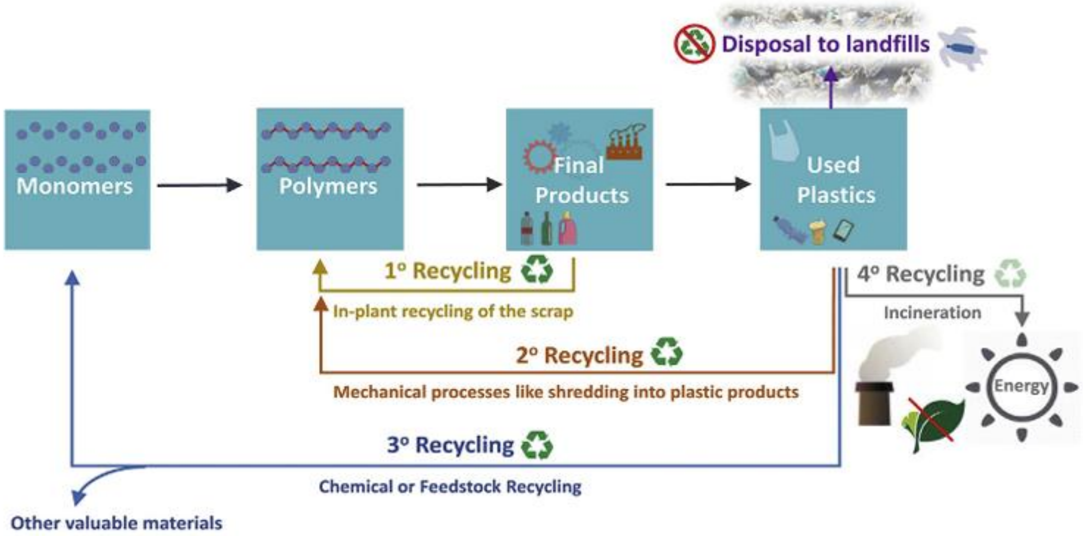

Fig 4: Plastic recycling methods [9]

PLASTIC DEGRADATION ASSSESSING METHODS :

Mass Loss: Measures the reduction in the mass of polymer. It can be influenced by factors such as surface area, biofilm formation, and fragmentation. It's less reliable due to the potential mass gain from debris or oxygen incorporation.

CO2 Evolution: Measures the release of CO2 by microbes as byproduct of polymer degradation. Provides the understanding into the rate of mineralization. It requires careful interpretation as not all released carbon is immediately oxidized to CO2.

Gel Permeation Chromatography (GPC): Analyses changes in molecular weight distribution. It requires a suitable solvents and conducive environment to avoid further degradation during analysis.

Chemical Analysis: NMR, IR Spectroscopy and Contact Angle Measurement

Material Property Analysis: Dynamic Mechanical Analysis (DMA), Thermal Analysis (DSC and TGA), Surface Analysis (SEM and AFM)[10].

BIOPLASTIC :

Plastics have become essential commodity yet it's problematic, due to its environmental concerns seeking for alternatives like biodegradable and bio-based plastics. This shift aims to reduce plastic pollution and CO2 emissions by using eco-friendly materials for various industries. Despite their benefits, challenges in defining and improving biodegradability standards. Biodegradable plastics can be decomposed through microbial action, without leaving non-toxic compost. However, there's consumer confusion that exists around biodegradable vs bio-based polymer, which is derived from biomass, aren't always biodegradable. Future advancements has to be done on refining these terms for enhancing the eco-friendly properties and establishing a clear cut policies to support bio based plastics [11]. Bioplastics offers many environmental benefits over traditional plastics, like reduced reliance on fossil fuels, energy recovery, lower greenhouse gas emissions, and biodegradability which has been contributing to a more sustainable future.[12]

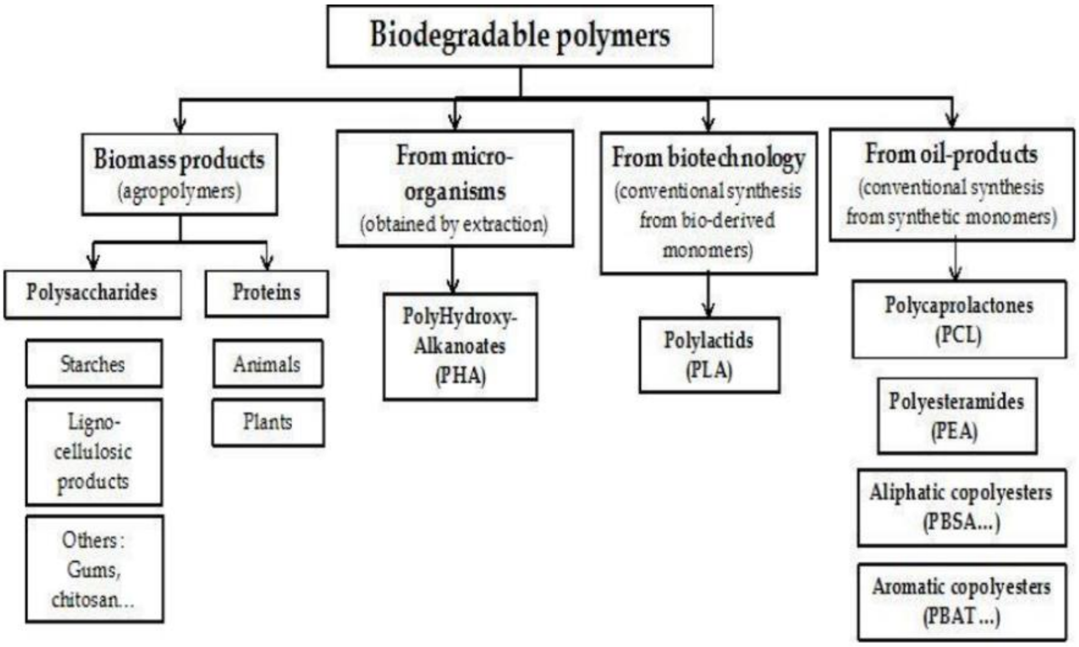

Fig 5: types of bioplastic[13]

BIOPLASTICS DEGRADATION :

Bioplastics mostly end up in landfills along with other municipal solid waste due to a lack of proper infrastructure. Which can lead to the release of greenhouse gases such as CO2 and CH.[14]

Amycolatopsis and Streptomyces species of microbes, bacterial species such as Paenibacillus, Pseudomonas, Bacillus, Bulkholderia species and fungal species such as Aspergillus, Fusarium and Penicillium species as fungal ate the most commonly isolated microorganisms from various environment used for degrading bioplastic. The biodegradability of bioplastics can be increased by increasing the soluble sugar content and protein in the compost. Sisal fibre dispersed PLA matrix has resulted 50% higher weight loss in soil burial for 14 weeks [15].

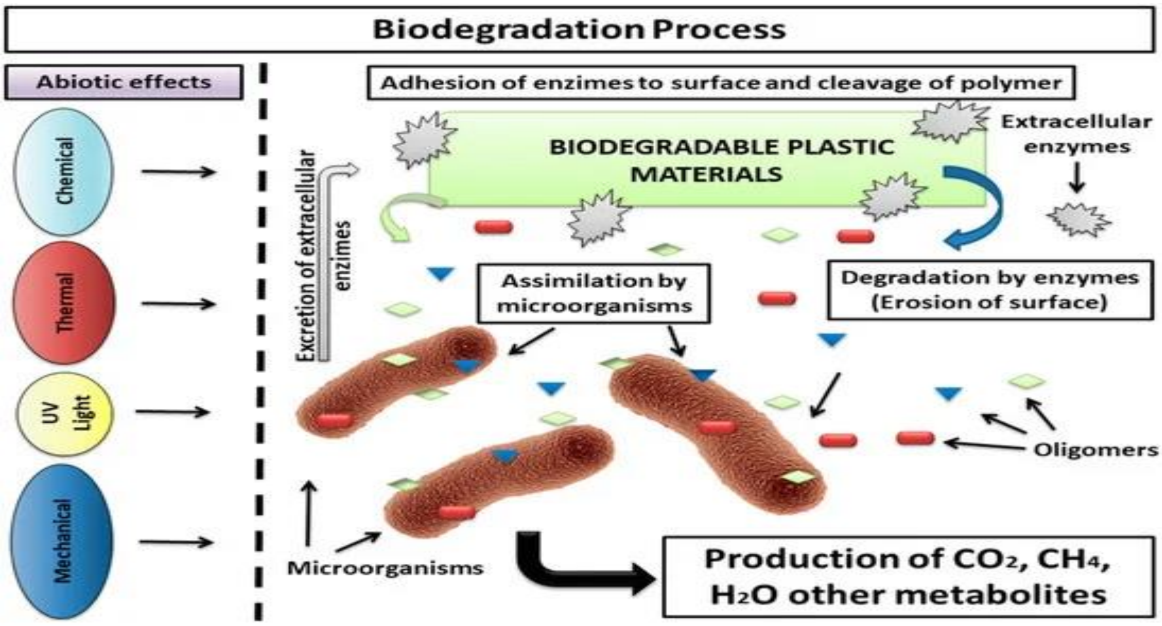

Fig 7: Polymer degradation mechanism[16]

DETERMINATING THE DEGRADATION OF BIOPLOYMERS

Testing and certifying biodegradability for plastics has a range of international standards and costly assessments. These tests are established by organizations like ISO-International Organization for Standardization, CEN-European Committee for Standardization, and ASTM-American Society for Testing and Materials measures the biodegradation rates in specific environments like soil, seawater, sludge, etc... Tests for aerobic degradation which determines the biodegradability each with specific duration and biodegradation percentage. For example, a material is teamed to be biodegradable if it degrades 70% of its mass in 14 days, while for termed as readily biodegradable it must reach 60% in 10-days. The certifications require accreditation, and each test includes multiple controls and specific measurements. [17]

- Soils - ASTM D5988 and ISO 17556
- Marine - ISO 18830 and ISO 19679 (water sediment interface)
- ASTM D 7991
- ISO 22404 (intertidal interface)
- ISO 16221
- OCED 306 (static aqueous system)

The biodegradable plastics has shown to have a 10 times greater degradation rate in the sediment than in the water column in which 70% of plastic debris that reach the oceans and end up as sediment [15].

While PBS-polybutylene succinate is environmentally friendly and cost-effective, whereas PP is economically viable but has higher environmental impacts. Overall, PLA- Polylactic Acid offers a balance between environmental and economic sustainability[18]. Increasing use of bio polymers mainly in food packaging (48%), consumer goods (11%), fibres (10%), agriculture (9%), automotive (5%), coating and adhesives (4%), construction (3%), electronics (3%) and other sectors (7%) [19].

WAY FORWARD

- The biodegradability of plastics can vary depending on environmental conditions and the specific polymer composition.
- Proper waste management practices, including sorting and composting, are crucial for effective biodegradation of these materials.
- Further research is needed to optimize biodegradation processes and develop new, more sustainable plastic materials.[20]
- Mechanical and chemical recycling can extend the life cycle of bioplastics, but they have limitations and energy costs. To fully realize the sustainability potential of bioplastics, a comprehensive approach is needed, combining recycling and efficient biodegradation strategies.[12]
- There is need for policies to support bioplastics, investments in production, and education on bioplastics' benefits, aligning with sustainable development goals[21]

CONCLUSION :

Biopolymers don't have a clear-cut advantage over petroleum-based polymers in all the impact categories. While they often perform good in some areas, they can also a have higher impacts in the other areas[22]. The higher costs, limited production, and lack of consumer awareness hinders the growth[21]. Bioplastics, though seem to be a promising sustainable alternative but it's not a complete alternative solution to the plastics. While they may help in reducing some environmental impacts, biodegradation rates, and the scalability still remains as challenge that require a technological innovation. Furthermore, bioplastics must be produced in such a way that it minimizes their own environmental footprint, ensuring that they offer a net benefit over conventional plastics. There is a need for stronger regulatory frameworks and collaboration between governments, Institutions, industries, and the public, is essential to promote a circular economy, to reduce plastic waste, and which helps in protecting the planet's health for our future generations.

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