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Bioplastics: Its Timeline Based Scenario & Challenges

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Abstract There has been substantial interest in the advancement and production of biodegradable polymer to solve the current problem of pollution triggered by the continuous use of synthetic polymer of petroleum origin. The likelihood of producing these bio- polymers commercially and at comparable cost has been the key focus in this area. The most promising way of making plastics from other abundant renewable sources like corn, soy beans, sugarcane etc. is the avenue of Bio plastics. This paper is a comparative study that confers the likelihood of the conventional petro-plastics being substituted by the new-age degradable and renewable bio-derived polymers. It presents the keynote issues that support findings of the benefits these materials have in relation to conventional, petrochemical based counterparts. It is the view of the authors that biodegradable plastic materials are most apt for single-use disposable applications where the post-consumption waste can be locally composted.

Keywords: *biodegradable, bio-plastic, bio-polymers, disposable, renewable*

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1. Introduction

It is tough to exaggerate the significance of the environment to sustainable development. It is the foundation on which our existence lies. Any global scheme of development created without taking the environment into account will actually be a house built on sand [1].

The Plastic industry in its initial stages promised to be a boon to mankind. But with its use over the years turning into an overuse has subjected its adverse impact on the society. Climate change and resource restraints, particularly for fossils, have set refurbished impetus to the development of plants for the sustainable production of a sizeable spectrum of chemicals and materials required by mankind. While the recent focus is on using plants for biofuels, such as bioethanol and biodiesel, plants are a prospective source of a much diverse range of useful chemicals and biomaterials. Biopolymers presently occupy a very small but emergent share of the polymer market. Some of these materials have distinctive properties that make them superior to synthetic polymers, particularly in medicine, where biocompatibility and biodegradability are strong assets. However, biomaterials often lack desired virtues such as the durability, strength and low price required for their use in large-scale low-value consumer products. Thus, with the prominent exception of natural rubber, cellulose and suberin (as found in cork), only a small section of the potential material market is currently covered by biomaterials. To improve the effectiveness of biomaterials, new biopolymers and production technologies are required [2].

Humans produce about 34 million tons of plastic waste per year, recycling a mere seven per cent. The remaining 93 per cent ends up in landfills and oceans. Plastic materials that have been universally used in our daily lives are now causing serious environmental problems. Millions of tons of these non-degradable plastics accumulate in the environment per year. The environmental impact of unrelenting plastic wastes is escalating widespread global concern and disposal systems are inadequate. Incineration may engender toxic waste pollution, suitable land-fills are limited, and reutilizing techniques for waste are usually expensive and involve high-energy consumption. Adding to it, the petroleum resources are finite and rationed. It is crucial to find enduring plastic alternates, especially in short-term packaging and disposable applications. The unceasingly growing public concern has incited research interest in biodegradable polymers as substitutes to the conventional non-degradable polymers like polyethene etc. [3] For efficient management of used-plastic materials, recycling is one solution. Another solution to decrease plastic residue is the employment of biodegradable plastics and among them polyhydroxyalkanoic acids (PHAs) are drawing much attention [4,5].

Synthetic polymers (known as plastics) have become noteworthy since the 1940s, and since then they are substituting glass, wood and other constructional materials, and even metals in many industrial, domestic and environmental applications. [6] These prevalent applications are not only due to their good mechanical and thermal properties but mainly due to the stability and durability On the other hand, plastics also play a significant role for many "short-term" applications such as packaging and these epitomise the major part of plastic waste. Because of their perseverance in our environment, several communities are now more perceptive to the impact of discarded plastic on the environment, including detrimental effects on wildlife, marine life and on the aesthetic qualities of cities and forest. The increased cost of solid waste disposal as well as the prospective menaces from waste incineration such as dioxin emanation from PVC makes synthetic plastic, a waste management problem. Subsequently, for the past two decades, there have been mounting public and scientific interests concerning the use and development of biopolymer (biodegradable polymers) materials as an ecologically valuable alternative to plastics, which must still maintain the desired physical and chemical properties of conventional synthetic plastics; thus proposing a solution for the existing grave problem of plastic waste [7].

2. Plastics: Its Classification, Structure and Uses

Plastics are essentially a by-product of petroleum refining. . Webster's Dictionary defines plastics as: any of various complex organic compounds produced by polymerization, capable of being modeled, extruded, cast into various shapes and films, or drawn into filaments and then used as textile fibres. In plastics production, the components of oil or natural gas are heated in a cracking process, yielding hydrocarbon monomers that are then chemically bonded into polymers. Different combinations of monomers produce polymers with different characteristics.

The carbon atoms act as a basic backbone of hydrocarbon polymer, with hydrogen atoms branching off the carbon spine. Some plastics contain other elements as well such as Teflon containing fluorine, PVC containing chlorine, and nylon containing nitrogen [8].

Plastics have vast applications in every prospect of life. They are used in the production of packaging items, furniture, and fabrics to medical equipment and construction articles etc.

There are several reasons for the popularity of plastics. Some of them are as follows:

- Low cost.
- Resistance to chemical solar and microbial degradation.
- Thermal and chemically insulating properties.
- Low weight.

Plastics can also be customised for numerous uses like prosthetic limbs, bullet proof vest etc. The use of plastic materials in cars and airplanes lessens their weight and hence upsurges their fuel efficiency.

Plastics are roughly classified into two main classes. These are explained in the table below which gives a general overview of both the types.

Table 1. Classification of plastics

THERMOSETS	THERMOPLASTICS
1. Solidifies or sets irrevocably when heated.	1. Softens when exposed to heat and yields to original state at room temperature.
2. The molecules of these plastics are cross linked in three dimensions and this is why they cannot be redesigned or recycled.	2. Do not undergo significant chemical change.
3. They are useful for their durability and strength.	3. Weak bond, which becomes even weaker on reheating.
4. Used predominantly in automobiles and construction applications. Other uses include adhesives, inks, and coatings.	4. Thermoplastics can easily be shaped and modelled into products such as floor coverings, credit cards, carpet fibres, etc.

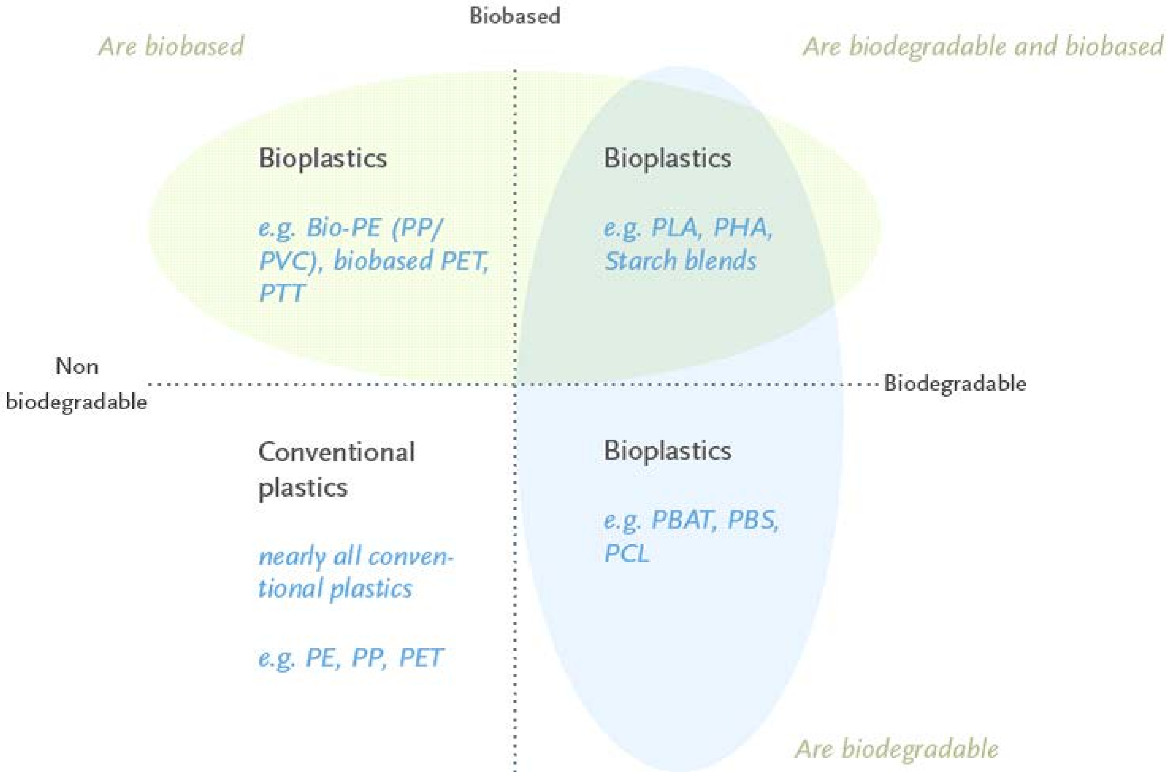

Figure 1. Broad categories of bio plastics [9]

Plastics are so crucial to our lives and so resourceful in their usage, that their usage cannot be completely discontinued. Hence, complementary solutions to this challenge are being looked at. The most promising way out seems to be coming in the form of bio plastics [9].

Plastics that are composed from renewable resources (plants like corn, tapioca, potatoes, sugar and algae) and which are entirely or partially bio-derived, and/or biodegradable or compostable are called **bio plastics**.

European Bio plastics have cited 2 extensive categories of bio plastics:

Bio based Plastics: The term bio based suggests that the material or product has (partly) resulted from biomass (plants). Biomass utilised for bio plastics stems from plants like corn, sugarcane, or cellulose.

Biodegradable Plastics: These are plastics which break down/disintegrate into organic matter and gases like CO2, etc. in a particular time and compost which are stated in standard references (ISO 17088, EN 13432 / 14995 or ASTM 6400 or 6868) [10].

Conversely, it should be observed that the property of biodegradation does not depend on the resource origin of a material, but is rather related to its chemical structure. In other words, 100 per cent bio-based plastics may be non-biodegradable, and 100 per cent fossil-based plastics could be biodegrade.

Thus all the highlighted regions in the graph correspond to bio plastics. They can thus be bio based-biodegradable, non-bio based-biodegradable and bio based-non biodegradable.

3. History

A plastic is a kind of synthetic or man-made polymer; comparable in many ways to natural resins found in trees and other plants. The expansion of artificial plastics or polymers began around 1860, when John Wesley Hyatt developed a cellulose derivative. His creation was later patented under the name “Celluloid” and was rather successful commercially, being used in the production of products ranging from dental plates to men’s collars. [11]

Over the next few decades, many more plastics were introduced, comprising some modified natural polymers like rayon, made from cellulose products. Soon after the turn of the century, Leo Hendrik Baekeland, a Belgian-American chemist, developed the first fully synthetic plastic which he sold under the brand name “Bakelite”. In 1920, a foremost breakthrough occurred in the development of plastic materials. A German chemist, Hermann Staudinger, theorised that plastics were made up of very large molecules held together by strong chemical bonds. This prompted an increase in research in the field of plastics. Many new plastic products were conceived during the 1920s and 1930s, including nylon, methyl methacrylate, also known as Lucite or Plexiglas, and polytetrafluoroethylene, which was marketed as “Teflon” in 1950. Nylon was first formulated by Wallace H. Carothers of DuPont, but was set aside as having no useful characteristics, because in its original form, nylon was a sticky material with slight structural integrity. [12] Later on, Julian Hill, a chemist at DuPont, spotted that, when drawn out, nylon threads were fairly strong and had a silky appearance and then comprehended that they could be useful as a fibre. The World Wars also provided a big boost to plastic development and commercialization. Many countries were hit by a scarcity of natural raw materials during World War II. Germany was cut off quite early on from sources of natural latex and altered to the plastics industry for a replacement. A feasible synthetic rubber was developed as an appropriate substitute. With Japan’s entry into the war, the United States was no longer able to import natural rubber, silk and various metals from most Far Eastern countries. Instead, the Americans depended on the plastics industry. Nylon was used in many fabrics, polyesters were used in the engineering of armours and other war materials and an escalation in the production of synthetic rubbers transpired. [13]

4. Timeline of Plastics

4.1. The First Man-Made Plastic - Parkesine

The first man-made plastic was produced by Alexander Parkes who visibly exhibited it at the 1862 Great International Exhibition in London. The material called **Parkesine** was a biological material derived from cellulose that once cooked could be moulded, and maintained its shape when cooled again.

4.2. Celluloid

Celluloid is a resultant from cellulose and alcoholised camphor. John Wesley Hyatt invented celluloid as an alternative for the ivory in billiard balls in 1868. He first attempted using colloid on a natural substance, after dripping a bottle of it and learning that the substance desiccated into a hard and flexible film. Yet, the significant was not sufficiently strong enough to be used as a billiard ball, until the supplement of camphor, a by-product of the laurel tree. The new celluloid could be modeled with heat and pressure into a resilient shape. Furthermore billiard balls, celluloid became famous as the first flexible photographic film used for still photography and motion pictures. John Wesley Hyatt produced celluloid in a strip format for movie film applications. Not later than 1900, movie film was an exploding market for celluloid [14].

4.3. Formaldehyde Resins - Bakelite

After cellulose nitrate, formaldehyde was the next creation to evolve the technology of plastics. Around 1897, struggles to produce white chalkboards directed to casein plastics (milk protein mixed with formaldehyde) Galalith and Erinoid are two initial examples in the trade.

In 1899, Arthur Smith established British Patent 16,275, for "phenol-formaldehyde resins for using an ebonite substitute in electrical insulation", the first patent received for processing a formaldehyde resin.

However, in 1907, Leo Hendrik Baekeland upgraded phenol-formaldehyde reaction performances and invented the first entirelysynthetic resin to become commercially successful, trade named Bakelite.

Advances in the plastics industry suffered after the end of the war. Plastics were being used up in place of metal in goods such as machinery and safety helmets, and even in a variety of high-temperature devices. Karl Ziegler, a

German chemist established polyethylene in 1953, and the following year Giulio Natta, an Italian chemist, developed polypropylene. These are two of present day's most universally used plastics. During the next decade, the two scientists received the 1963 Nobel Prize in Chemistry for their research of polymers. [15]

5. Present Scenario in the Field of Bio-Plastics

A considerable amount of research and study has been carried out in the field of bio plastics already where Polyhydroxyalkanoate, PLA and PHBs have been extracted from various plant-based sources [16] such as sugarcane [17], corn and rice [18], switch grass, cellulose [19], vegetable oil [20] or even some genetically modified sources [21] etc. or the advances in the plastic production from agricultural and industrial waste [22] like waste water activated sludge [23], milk whey, lignin (waste product in the pulp and paper industry) [2] or the bacterial sources [24] like the gene from bacterium R. eutropha, that codes for an enzyme that allows bacteria to produce polyhydroxyalkanoate (PHA)-a naturally occurring form of polyester—starting with only sunlight, water, and a carbon source patented by MIT scientists at Metabolix. The most recent of the developments being the possible production of plastic chitosan extracted from shrimp shells, a resilient form of chitin, which researchers at Harvard's Wyss Institute for Biologically Inspired Engineering say is the "the second-most abundant organic material on Earth." Capturing atmospheric Carbon and Methane presents an exciting climate mitigation strategy for the bio plastics industry. New light technologies is creating PHA from the air carbon. These are the highlights that helped us to come up with the idea and shaped the study with practicality and social-applicability.

To try and make starch more functional, researchers have tried blending it with other plastics like polythene. They anticipated that this would make the overall product more biodegradable than polythene on its own. Unfortunately, this was not the case. The plastic had a tendency to fall to bits but the pieces were less biodegradable than routine starch.[25] More recently, a scientist called Catia Bastioli from Italy has taken starch treated with acid and propan-1,2,3-triol and assorted it with the polymer PVA (used in white glue). The resulting polymer was found to be biodegradable as well as water soluble. This indicates that its use is restrained to things like packing dry goods, or replacing polystyrene foam, which is not biodegradable and is made from oil.[26]

India generates about 70 million tons of wheat per year or about 12 per cent of world production .This amount of wheat can thus be utilized in production of bio plastics by starch extraction since the major components in wheat are starch and protein. Research in the field of bio plastics intends to prove that there is a copiousness of eco-friendly, renewable sources for plastic production, that are even biodegradable in most cases thus eradicating the costs of storage and disposal significantly [27].

A wide range of oil-based polymers is presently used in packaging applications. These are essentially all non-biodegradable, and some are even difficult to recycle or reuse since the complex composites have capricious levels of contamination. Recently, considerable progress has been made in the enhancement of biodegradable plastics, largely from renewable natural resources, to engender biodegradable materials with similar functionality to that of oil-based polymers. The growth in these bio-based materials has several potential advantages for greenhouse gas balances and other environmental impacts over entire life cycles and in the use of renewable, rather than finite resources. It is anticipated that use of biodegradable materials will subsidise to sustainability and reduction in the environmental impact allied with disposal of oil-based polymers.[28]

6. Life Cycle

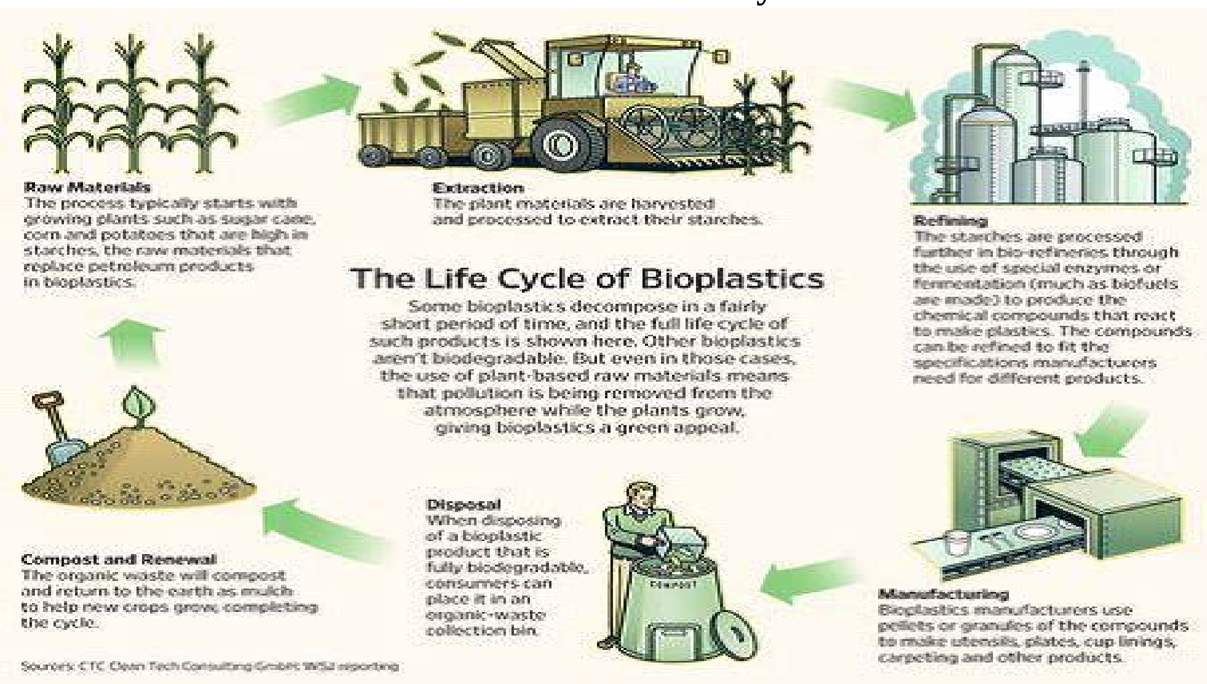

Figure 2. Lifecycle of a generic bio plastic [29]

7. Cost

With the exemption of cellulose, most bio plastic technology is fairly new and presently not cost competitive with conventional petro plastics. Bio plastics do not reach the fossil fuel parity on fossil fuel stemmed energy for their manufacturing, cutting cost advantage over petroleum-based plastic.

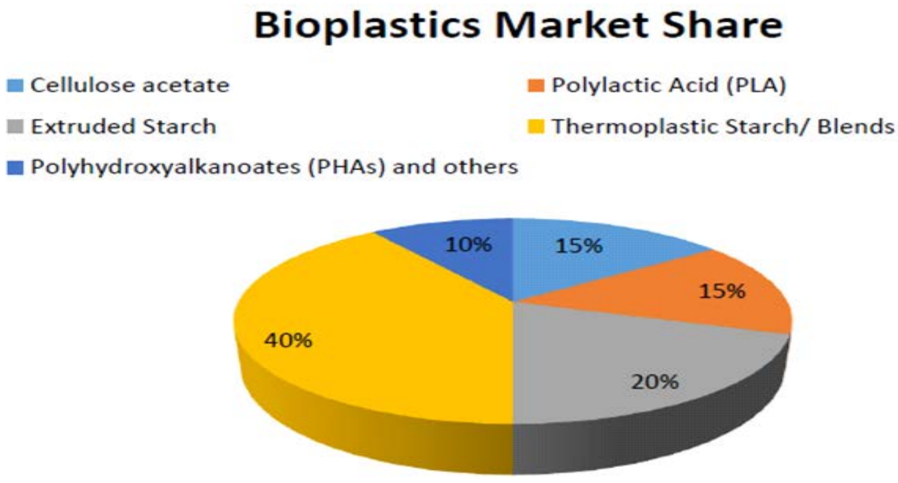

Figure 3. Market share of bio plastics[30]

Forecast market growth is anticipated to be the highest in non-biodegradable bio plastics. Bio plastics could also be used in more sophisticated applications such as medicine delivery systems and chemical microencapsulation. They may also replace petrochemical-based adhesives and polymer coatings. However, the plastics market is complex, highly refined and manufacturers are very selective with regard to the specific functionality and cost of plastic resins. For bio plastics to make market grounds they will need to be more cost competitive and provide functional properties that manufacturers require.

8. Advantages of Bioplastcs

8.1. Eco Friendly

Long-established plastics are the petroleum based plastics which depend on fossil fuels which is an untenable source. Also, procuring fossil fuels does a lot of damage to the natural environment. Bio-plastics on the other hand, are crafted from biomass like trees, vegetables, even waste which is completely bio-degradable. So bio-plastics are prepared from completely renewable sources. Even during the engineering of plastics, a lot of pollution follows, for example, during fabrication, PVC plants can release dioxins, known carcinogens that bio-accumulate in humans and wildlife and are linked with reproductive and immune system maladies [31].

8.2. Require less Time to Degrade

Conventional plastics take thousands of years to break down and degrade, these plastics stay in the environment, most markedly on the ocean beds where they do the maximum damage for years. These plastics obstruct the growth and destroy the natural habitats.

Bio plastics on the other hand, involve considerably less time to biodegrade. This degradation can be carried out at home for some bio plastics and even for the bio plastics which need definite conditions, time needed to degrade completely is significantly less. This reduces the vast pressure on our prevailing landfills.[32,33]

8.3. Toxicity

Some of the plastics degrade rapidly in the oceans liberating very harmful chemicals into the water bodies, thus impairing the animals, plants and also harming the humans by inflowing the food chain. Biodegradable plastics are entirely safe and do not have any chemicals or pollutants. This plastic innocuously breaks down and gets absorbed into the earth. Such advantages of bio plastics are of great importance, as the toxic plastic load on the earth is maturing and at this rate will trigger a complete span of problems for the future generations.[34]

8.4. Lower Energy Consumption

Companies still use fossil fuels for the production of bio plastics; however, many bio plastics use considerably less fuel for their construction. For example, Polylactic acid production involves much lesser energy consumption than the other plastics.

8.5. Environmental Protection

Incinerating fossil resources heightens the share of CO_2 in atmosphere, which results in an increase of the average temperature (greenhouse effect). Scientists see a distinct association between CO_2 increase in atmosphere and the increase of number of thunderstorms, floods and aridity. Climate protection is currently is an essential part of environmental policy, due to the fact that climate change can generate extensive negative aftermaths. Governments and organisations work against this menace with focussed measures [35].

9. Challenges for Bioplastics

9.1. Misconceptions

Even though bio degradable plastics are anticipated to be good for the environment, they can damage the nature in certain ways. Emanation of Greenhouse gases like methane and carbon-dioxide, while they are degrading, is huge at landfill sites. This can be controlled by designing plastics so that they can disintegrate and break down slowly or by accumulating the methane released and use it elsewhere as fuel. Some bio plastics require specific conditions to degrade, these requirements may not be available at all the landfills or consumers may not have access to landfills, in such cases it is essential to design bio plastics that are bio degradable in ordinary soil composting conditions. [36]

9.2. Environmental Impact

Starch based bio plastics are manufactured generally from plants like corn, potatoes and so on. This sets huge pressure on the agricultural crops as they have to gratify the needs of the ever growing populace. To craft out bio-plastics, crops have to be grown and this could lead to deforestation.

Bio plastics are commonly produced from crops like corn, potatoes, and soybeans. These crops are often genetically modified to advance their resistance to diseases, pests, insects etc. and increase their yield. This exercise however holds a high risk to the environment as such crops can be toxic for humans as well as for animals.[37]

9.3. Cost

Bioplastics are a novel technology and entail still more research and development to get ascertained. Bio plastics are not thus, equivalent to conventional plastics, with respect to cost issues.

10. Future Prospects in the Field of Bioplastics

The prompt development of plastic manufacture was a 20th century phenomenon on a historical scale. The low cost of plastics and its resourcefulness have flagged a way for an extensive range of applications. As the plastics are non-biodegradable and found to have toxic properties on human, animals and environment, the bio plastics came into being. Bio plastics are biodegradable and can be stemmed from renewable biological sources. Bioplastics have identical applications as plastics. Though, there are various sources of bio plastics like plants, animals and microbial sources, they have some boundaries such as non-availability of high biomass and complications involved in refinement. In such cases, seaweeds can aid as one of the substitutes for the manufacture of bio plastics because of its high biomass, its proficiency to grow in a varied range of environments and its fostering in natural environment when linked to other microbial sources which necessitate a definite environment for their cultivation. In addition to the above advantages, seaweeds are cost effective, minimalize the effect on the food chain and do not depend on chemicals. Bio plastics from seaweeds are stated to be more resilient to microwave radiation, less brittle and resilient. The technology expansion for the seaweeds-based bio plastics are still under the research stage and it is anticipated that suggestive developments would be made in the bio plastics industries and can make seaweed bio plastics a reality in future. Fermentation and genetic engineering can take the lead in employing novel systems to make bio plastics from seaweeds which would make them as a sustainable alternative. [38]Cassava, corn, sago and the other food yields have been frequently used as raw materials to manufacture green plastics. Yet, plastics fabricated from such crops cannot be personalized to be apt for a particular requirement owing to their weak water resistance and mechanical properties. At the moment, researchers are thus considering alternative raw materials from other sustainable resources to design plastics. Their current published studies have communicated that marine red algae that has been previously extensively used as a raw material for engendering biofuels, is one of the prospective algae crops that can be set into plastics [39].

A recent study also states that it is theoretically possible to harvest all major bio plastics from biomass. In most cases, more than even one process can be envisioned. In this case, the conceivable ways to manufacture the most frequently used polymers from biomass are studied. This includes vinyl polymers, polyesters, polyamides, polyurethanes, and synthetic rubbers. Moreover, the most assuring recently developed polymers that can be manufactured from biomass have been investigated. [40] Although production costs are still a setback for an extensive usage of biopolymers, their application as low volume high cost entries is befitting the actuality. The future trend is to direct on the expansion of more effectual and economical practices for PHA production, isolation, purification and enhancement of PHA material properties [41].

11. Conclusion

The idea for carrying out this study was to conduct a comparative study bringing up the pros and cons of the conventional petro-plastics as opposed to the new-age degradable bio-derived plastics. Round about 80% by weight of all chemicals manufactured by the petrochemical industry are employed in polymer materials. Manufacturing these resources from biomass instead of fossil resources hence significantly subsidises to the expansion of the bio-based economy. Improper plastic waste management has even led to the dwindling nature of petroleum resources, increased emission of greenhouse gases into the atmosphere and disruption of aquatic life. Bio-plastics have recently come up as an integrated sustainable alternative to plastic management in order to reduce the petroleum dependency as well as better plastic disposal means. The fundamental idea of bio-derived plastics is to alter the very source of producing plastics i.e. the classic petroleum sources were replaced with a more abundant, accessible, renewable, economic and degradable source. Through this study, the authors stress upon the need of making a much-needed switch to Bio-plastics for transforming to a sustainable future as it is the view of the authors that bio-plastics are a much more feasible, renewable and sustainable option when compared to the high-energy consuming conventional petro-plastics. Thus, research and development in the field of bio-plastics is much needed and hence, should be encouraged.

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