Bioplastics: A Green Approach Toward Sustainable Environment

3

Pratibha Singh and Roli Verma

Abstract

Petroleum-based plastics are synthetic compounds which are derived from oil and other fossil materials. Plastics are widely used because of their various superior properties like durability, but this also makes it stubborn. Most of the known plastics are not biodegradable and they persist in the environment for hundreds of years. Plastics are not bad but because they are non-biodegradable and they create harmful effects to animals, human beings, wild animals, and marine life. We are not able to manage them and also unable to find a substitute for same. Some suitable green alternatives are required to reduce plastic pollution. Plastics are referred green if they are from renewable resource, biodegradable or compostable after the end of life, and their processing is environmentally friendly. In recent years, naturally occurring biofibers have attracted increasing interest due to their wide applications in food packaging and in the biomedical sciences. Biodegradable plastics are made from starch, cellulose, chitosan, and protein extracted from renewable biomass. These eco-friendly polymers reduce greenhouse gases which require no petrochemicals. They reduce the use of fossil fuels and reliance on non-renewable resources. Manufacturing process can use up to 65 per cent less energy and generates fewer greenhouse gases than conventional plastic. Some are biodegradable and/or compostable. Therefore, biodegradable plastics should be produced and utilized at a large scale to fulfill demand of increasing population. The present paper summarizes all these content regarding the applications, production, types, challenges, sustainability, and use of eco-friendly and cheap substrates for the production of bioplastics.

P. Singh (✉) · R. Verma
Department of Chemistry, JSS Academy of Technical Education, Noida, Uttar Pradesh, India
e-mail: pratibhasingh@jssaten.ac.in

A. Singh et al. (eds.), *Environmental Microbiology and Biotechnology*,
https://doi.org/10.1007/978-981-15-6021-7_3

3.1 Introduction

Plastics consist of a main chain organic link, pendant molecular groups. They are blends of organic and inorganic additives, plasticizers, fillers etc., to enhance material properties for the final application. Polymers are large molecules made up of many smaller units of molecules, called monomers. Figure 3.1 shows a simplified version of the transition from monomer to polymeric structure.

Plastics have very distinct characteristics, but most plastics have the following general attributes: They are resistant to chemicals and corrosion. They are thermal and electrical insulators. They have very high strength to weight ratio, highly durable, resistant to water, and have low toxicity. Plastics are materials with seemingly limitless range of characteristics and colors and are easy to manufacture.

The production of plastic has been significantly intensified to meet the demand of world's rapidly growing population. Most polymers exhibit unique property combinations (Fig. 3.2).

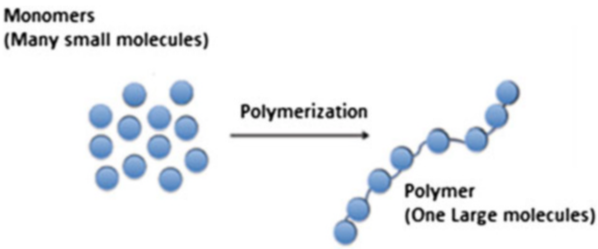

Fig. 3.1 Simplified figure of the transition from many small molecules, monomers to one large molecule, polymer (Saldivar and Vivaldo 2013)

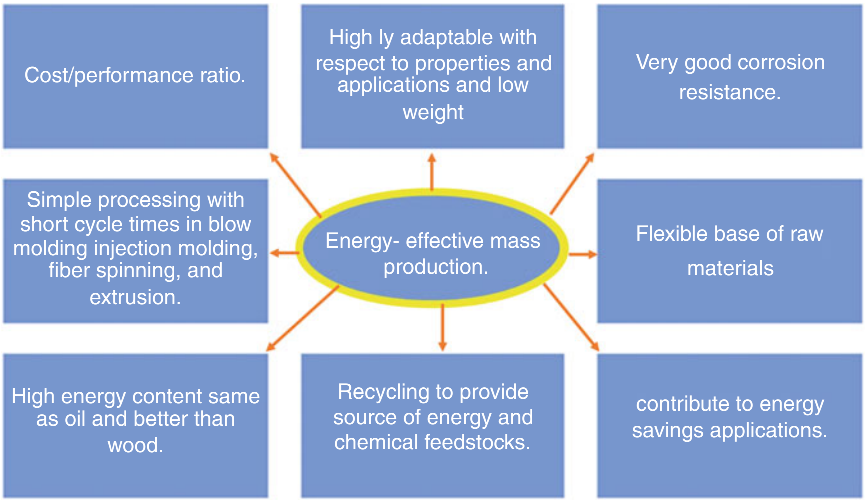

Fig. 3.2 Properties of polymer (Saldivar and Vivaldo 2013)

Chemically synthesized polymers are different in structure from the natural polymers (Saldivar and Vivaldo 2013). Natural polymers were not identified till 1861, when Thomas Graham dissolved organic compounds, such as cellulose, and reported that they could not penetrate through fine filters without leaving residuals on it. They called these materials as colloids. In 1870 John Wesley Hyatt chemically converted cellulose to produce a new material called celluloid. It was not until 1907 that the first completely synthetic polymer, bakelite, was synthesized by Leo Hendrik Baekeland. During and after the Second World War mass production of polymers as plastic materials began and has been growing ever since (Halden 2010). Synthetic fossil-based polymeric materials have been found as the largest application field of petroleum; the annual production in 2013 reached 299 million tons. The low production cost makes them versatile and are used in wide applications (Mekonnen et al. 2013).

Most of the plastics produced in the last century contain toxic additives which are hazardous for the environment and human health (Lithner et al. 2011); due to these additives precautions are required to be taken both during their production and disposal. The greatest disadvantage of plastic is the time they take to decompose—the average plastics take 500 years. The presence of additives shows adverse effects on human health as they are used in manufacturing of plastics. The three most commonly cited plastic additives are:

Bisphenol A Bisphenols are a group of chemicals used to manufacture plastics, epoxy resins, and other products since the 1960s. Bisphenol A (BPA), the most infamous of a group of around 40 chemicals, was initially investigated for pharmaceutical use as synthetic estrogen in the 1930s. It acts as endocrine disruptor in humans, causes thyroid cancer, osteoporosis, hypo and hypertension.

Phthalate or Plasticizer Phthalates are a group of chemicals most commonly used to make plastic more flexible and harder to break. They also act as a binding agent or a solvent. It has effect on reproductive organs, malformation, developmental disorders, causes pulmonary system effects including asthma allergies.

Flame Retardants Several chemicals have been used to stop the spread of fire in a wide range of plastic products. Common flame retardants include: brominated flame, OFRs, TBBPA, HBCD, and OPFRs. Brominated flame retardants belong to the same class of chemicals as PCBs, which were banned by the EPA in 1979. It has impact on immune system, fatal and child development, cancer, neurologic dysfunction.

Plastics can be micro-molecular or macro-molecular compounds depending on their structure. The burning of plastics is also a difficult chemical process. During plastic combustion, different phases take place, such as warming, degradation, flashover, and combustion. Low molecular compounds can be vaporized directly in the air and are able to form a combustible mixture. Macro-molecular plastics have

Table 3.1 Impact of uncontrolled plastic on health and economy (Ying et al. 2014)

Effect on health	Effect on economy
• Increases risk of heart disease • Aggravates respiratory ailments such as asthma and emphysema • Causes skin rashes, nausea, or headaches • Damages the nervous system • Damages the kidneys and liver • Disrupts the reproductive, endocrinal, and development systems • Disrupts the central nervous system	• Loss of income for hotels, restaurants, bathing resorts, other amenities, etc. • Loss of income for clothing manufacture, food industry, general commerce, etc. • Damage to fisheries activities • Damage to the image of the coasts as a recreational resort at both national and international levels • Damage to the local tourist infrastructure • Damage to tourist-dependent activities

to degrade into small molecule compounds to initiate the combustion process. Impacts of uncontrolled plastic burning are listed in Table 3.1. (Ying et al. 2014).

Recent studies by Jenna et al. (2015) show that plastic waste is entering the ocean and affecting the marine life; according to recent studies, 279 tons of plastic waste was generated in 190 countries and furthermore that 32 tons were mismanaged in the coastal regions of these countries (Jenna et al. 2015). Fossil-based plastics do not degrade completely in nature. The plastic due to the current of water fragmented into small pieces. This process is known as fragmentation and the small pieces are known as micro-plastics. These micro-plastics are consumed by animals and humans on daily basis through breathing and eating. With this awakening, "green" polymers are desirable, the manufacturers start investing into research of degradable polymeric materials made from renewable resource (Lithner et al. 2011). The demand for bioplastics is expected to increase and further advance and innovative research within the field is required (Bastioli and Magistrali 2014). More environmentally friendly plastics are not only obtained by using a biodegradable material from a renewable resource as a raw material, but the final product properties should also be taken into consideration with the help of Life Cycle Assessment (LCA).

3.2 Green Polymer from Solid Waste

Global production of bioplastics will increase significantly in the next years, reaching approximately four million tons in 2020 with respect to the environmental factors caused by synthetic fossil-based plastics (Mekonnen et al. 2013). Plastics can be categorized into four different groups, depending on the raw material they are extracted from (fossil- or bio-based) and if they are biodegradable or not, (Fig. 3.3).

In present scenario biopolymers have received a significant attention due to their environment-friendly nature and sustainability (Mekonnen et al. 2013). Properties such as nontoxicity, hydrophilicity, biodegradability, and biocompatibility contribute in vast range of applications i.e. biomedical field, cosmetic, food, and textile industries. (Petrova and Garner 2014)

Bioplastic is derived from natural raw materials such as biomass and corn starch. They degrade when exposed to environmental conditions such as moisture, naturally

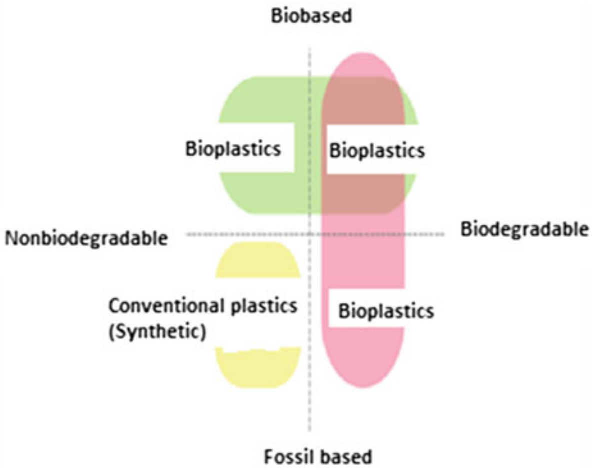

Fig. 3.3 Explanation of different plastics; based on their source and degradability (Jenna et al. 2015)

Table 3.2 Impact of uncontrolled plastic on health and economy (Ying et al. 2014)

Category	Examples
• Polymers directly extracted/removed from natural materials (mainly plants)	• Polysaccharides such as starch and cellulose and proteins such as casein and wheat gluten.
• Polymers produced by "classical" chemical synthesis from renewable bio-derived monomers	• Polyglycolic acid(PGA), Polylactate
• Polymers produced by microorganisms or genetically transformed bacteria	• Polyhydroxyalkanoates (PHAs)

occurring microorganisms such as bacteria, fungi, and algae or in a composting condition.

Bioplastics are plastics in which all carbon is derived from renewable feedstocks. They may or may not be biodegradable. The range of biodegradable plastics available includes:

- Starch-based products including thermoplastic starch, starch and synthetic aliphatic polyester blends, and starch and PVOH blends.
- Water-soluble polymer such as polyvinyl alcohol and ethylene vinyl alcohol.
- Naturally produced polyesters including PVB, PHB, and PHBH.
- Renewable resource polyesters such as PLA.
- Synthetic aliphatic polyesters including PCL and PBS.
- Aliphatic-aromatic (AAC) co-polyesters.
- Hydro-biodegradable polyester such as modified PET.
- Photo-biodegradable plastics.
- Controlled degradation additive master batches.

Bio-based plastics contain both renewable and fossil fuel-based carbon. The percentage of bio-based ingredients and the conditions, under which the bio-based

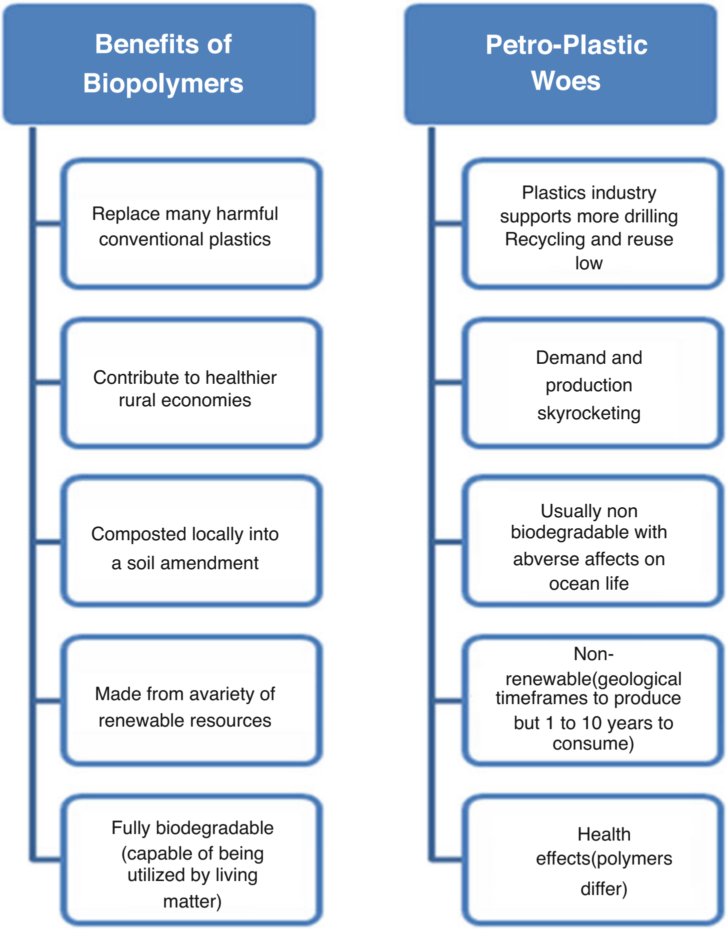

Fig. 3.4 Comparison of bioplastic and petro-plastic waste (Davis and Song 2006)

product may biodegrade, if at all, vary widely. Biodegradable polymers are divided into following category as shown in Table 3.2 (Kong et al. 2010).

These biodegradable polymers have become the recent attraction due to its unique properties. A comparative study of potential benefits of bioplastics, problems with petro-plastics are summarized in Fig. 3.4. These biodegradable polymers have become the recent attraction due to its unique properties. A comparative study of potential benefits of bioplastics, problems with petro-plastics are summarized in Fig. 3.4.

An organic material from which carbon is derived is a renewable resource. Bio-based materials include all plant and animal mass derived from CO2 recently fixed via photosynthesis, per definition of a renewable resource. Life cycle of bioplastic is shown in Fig. 3.5.

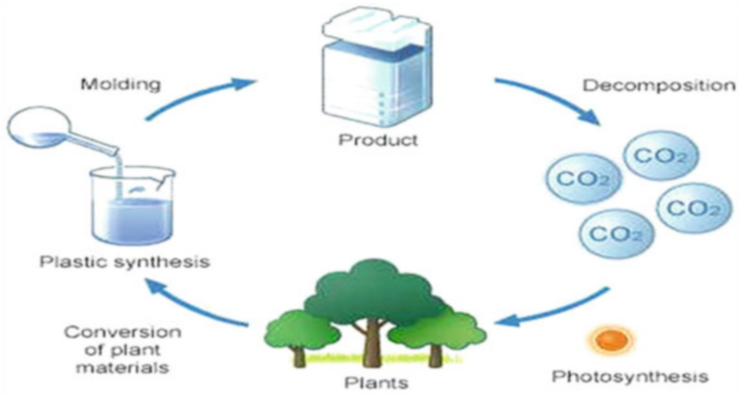

Fig. 3.5 Life cycle of a biodegradable plastic (Mekonnen et al. 2013)

Table 3.3 Starch-based polymers (Source: https://www.greendotbioplastics.com/starch-based Plastics)

S. No.	Type of plastic	Applications
1	Thermoplastic starch products	Food packaging, disposable eating utensils; loose fill, antistatic, and formed protective packaging; compostable films and bags for trash, retail, and agriculture
2	Starch synthetic aliphatic polyester	Blends high-quality sheets and packaging films
3	Starch and PBS/PBSA polyester blends	Thermoformed biscuit trays or film products
4	Starch-PVOH blends	Water-soluble laundry bags, drug control release carrier and bio-membrane, expanded foams as loose fill package

3.2.1 Suitable Solid Waste

Generally used types of bioplastics are based on starch, cellulose, glucose, and bio-oil. The feedstocks are converted into thermoplastic starch, polylactic acid, poly-3-hydroxybutyrate, polyamide 11, and bio-polyethylene by specific techniques.

Starch Thermoplastic starch accounts about 50% of the global bioplastics market according to today's trend and is the most significant and widely used bioplastic. Plasticizer and flexibilizer like sorbitol and glycerine are included to process the starch. Thermoplastic starch usually highlight just one component of starch based bioplastics. Some starch-based polymers and their applications are listed in Table 3.3.

PLA (polylactic acid or polylactide) is a very versatile polymer. Polylactide has been able to replace the conventional petroleum-based thermoplastics because of excellent combination of properties it possesses (Cosimo 2013). It is one of the most promising biopolymers used today and has a large number of applications such as healthcare and medical industry, packaging, automotive applications, also the use of

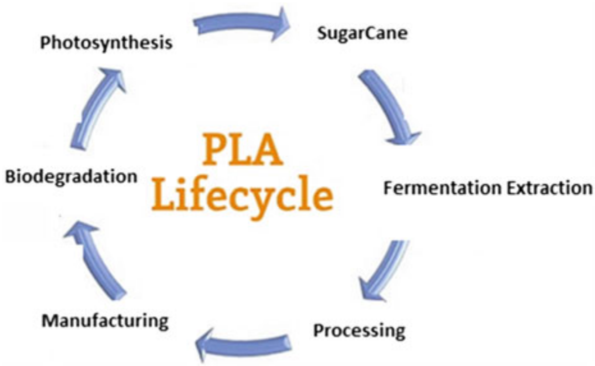

Fig. 3.6 Breakdown of polylactides into nontoxic products during degradation

PLA nanoparticles as drug carrier or MRI contrast agent is currently investigated. Its blends have a wide range of applications including computer and mobile phone casings, biodegradable medical implants, foil, molds, tins, cups, bottles and packaging devices, etc. (Chen and Patel 2012) As compared to other biopolymers, PLA exhibits several benefits such as:

1. Eco-friendly—It is renewably sourced, biodegradable, recyclable, and compostable.
2. Biocompatible—It is nontoxic.
3. Processability—It has better thermal processability compared to poly(hydroxyl alkanoate) (PHA), poly(ethylene glycol) (PEG), and poly(γ-caprolactone) (PCL).
4. High transparency—it has extraordinary stability, as well as high transparency.

Polylactides break down into nontoxic products during degradation and being biodegradable and biocompatible also reduce the amount of plastic waste (Fig. 3.6). PLA is mostly extracted by the fermentation of starch from crops, generally corn, wheat, or sugarcane into lactic acid followed by successive polymerization (Viviana et al. 2014). PLA has some disadvantages:

1. Its glass transition temperature is low (Tg ~ 55 °C.) It is thermally unstable and has poor gas barrier performance.
2. It has low crystallization rate and processing results mainly in amorphous products.
3. Its poor ductility, low impact strength, and brittleness limit its use as compared to other thermoplastics such as ABS.
4. As compared to PET (aromatic polyester), PLA is much more susceptible to chemical and biological hydrolysis.
5. It has low flexibility and requires long mold cycles.
6. It is relatively hydrophobic.
7. It has slow degradation rate.

Table 3.4 Applications of PHB

Area	Application
Biomedical	Part of bones, sutures, engineering of heart valves
Packaging	Food packaging
Environmental	Bags, bottles, disposable items
Agricultural	Encapsulation of fertilizers
Pharmacological	Encapsulation of medicines
Industrial	Synthesis of polymers

Wide application is still restricted due to the high cost of production that is significantly higher. But the cost of crude oil is constantly increasing and better PLA manufacturing methods are developed, the difference in prices may continuously decrease (Goodship 2007).

PHB (Polyhydroxybutyrates) are members from family of polyesters. They accumulate in intercellular granules by gram-positive and gram-negative microorganisms. They are produced in excess carbon source with a shortage of one essential nutrient (Tabone et al. 2010; Nishino et al. 2011). They are known as biopolymers as they are produced from microorganisms. They are thermoplastic polymers and are biodegradable. Physical characteristics of PHB are as follows:

1. Insolubility in water and its resistance to hydrolytic degradation.
2. It produces transparent film at a melting point of 175 °C.
3. It is biodegradable without residue.
4. Good oxygen permeability.
5. Good ultraviolet resistance.
6. Poor resistance to acid and bases.

Applications of PHB are summarized in Table 3.4:

PA 11 is a biopolymer extracted from polyamide natural oil. Rilsan is the trade name of polyamide bioplastic. PA 11 derived from castor beans is not biodegradable (Davis and Song 2006). Application of PA 11 is as follows:

- Automotive fuel lines,
- Pneumatic airbrake tubing,
- Electrical anti-termite cable sheathing,
- Oil and gas flexible pipes,
- Control fluid umbilical,
- Sports shoes,
- Electronic device components and catheters.

Polyethylene (PE) also known as fossil-based polymer is obtained from bioethanol (by dehydration). It is produced in large scale by fermentation of agricultural feedstock such as sugarcane or corn. Bio-polyethylene is identical to traditional polyethylene and it is not biodegradable but can be recycled (Alexander 1993).

3.2.2 Production Techniques and Constraints

Market products are produced from a variety of natural feedstocks including corn, potatoes, rice, tapioca, palm fiber, wood cellulose, wheat fiber, and bagasse. These products can be used for a broad range of applications such as bottles, cups, cutlery, plates, bags, bedding, carpets, film, textiles packaging materials, and furnishings (Fischer et al. 2008; Jinghua et al. 2009).

In addition, the use of renewable resources for green polymer production should not compete with food production, promote intensified farming or deforestation, use transgenic plants or genetically modified bacteria (Tanaka et al. 2008).

Biomass can be directly converted into renewable coal and oil by using energy-efficient processes. Agricultural and forestry wastes already have utilized to manufacture renewable monomers. Processes have been designed to transform carbon dioxide into carbon monoxide, methanol, formic acid, and formaldehyde (Xiaoyun and Shuwen 2013). Vegetable oils are utilized to make biodiesel and glycerol as a byproduct, which can be further used to produce different monomers such as propane diol, acrylic acid, and even epichlorohydrin for the manufacture of epoxy resins. Similar cycle process to produce biodegradable polymers is shown in Fig. 3.7.

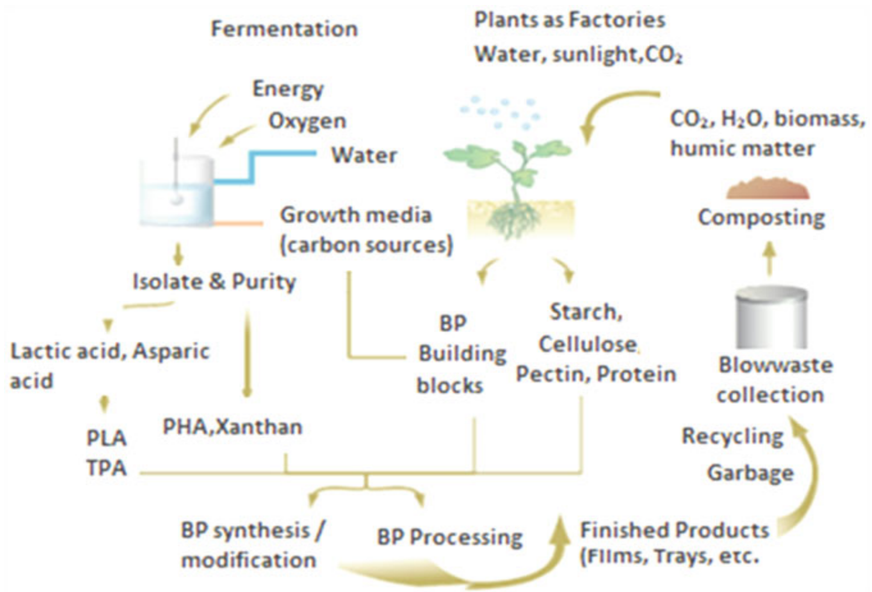

Fig. 3.7 Cyclic process of yielding of biodegradable polymers (Tanaka et al. 2008)

Fig. 3.8 Constraints with bioplastic (Axel 2009)

The inspiring factor for the innovative bioplastics technology was to handle our habit to dispose everything. The addiction of disposing everything eased out our lives, but on the other side it created huge problem on our environment which encouraged to the development of biodegradable disposables to reduce the problems produced by us to the environment. In 2010, disposable bioplastics contributed to more than 65% of the total bioplastic production capacity. However, 6 years down the lane, the durable bioplastics contribute to huge 77% of the overall bioplastic production capacity which is likely to grow above 80% by 2020. Bioplastics can be generally broken down into two types: durable and biodegradable. Biodegradable bioplastics break down naturally into the environment. This is unique, as the vast majority of plastics today will never break down. On the contrary, the Plant Bottle is a more durable bioplastic substitute to traditional PET bottles made by Coca-Cola. Produced with up to 30 percent ethanol sourced from plant material, the Plant Bottle will not degrade, but it can be recycled with traditional PET containers and bottles. Constraints with development and widespread acceptance of bioplastics are exhibited in Fig. 3.8 (Axel 2009).

3.2.3 Factors Affecting Degradation Behavior

The polymeric materials may break down by microbial action, chemical degradation, and photodegradation. Most of the biopolymers are considered to be discarded in landfills, composts, or soil. The materials will be broken down, if the required microorganisms are present. Microbially reduced plastics need soil bacteria and water (Goodship 2007). Naturally grown materials based polymers (such as starch or flax fiber) are prone to degradation by microorganisms. The microorganism degrades the starch, leaving behind a porous, sponge like structure with a high interfacial area, and low structural strength.

Biopolymers can be microbially degraded by another way which involves growing microorganisms on the surface of digesting polymer materials. This is a more rigorous process which costs more, and avoids the use of renewable resources as biopolymer feedstock. The microbes under consideration are developed to target and break down petroleum-based plastics (Cheng 2010). Although this technique decreases the volume of waste, it does not help in the preservation of non-renewable resources.

Photodegradable polymers are thermoplastic synthetic polymers which are incorporated with light-sensitive chemical additives or copolymers for purpose of weakening the bonds of the polymer in the presence of ultraviolet radiation. Photo sensitizers include diketones, ferrocene derivatives (aminoalkyferrocene), and carbonyl-containing species. The effectiveness is dependent on exposure intensity and will vary with factors such as the season, geography, dirt or water cover, and shading. Photodegradable plastics may be useful in applications where littering is an issue and in those that pose a threat to animal and marine life.

Some biodegradable polymer materials experience a rapid dissolution when exposed to particular (chemically based) aqueous solutions due to the following properties:

- Chemical structure and chemical composition and molecular weight.
- Presence of low molecular weight compounds (monomers, oligomers, solvents, plasticizers, etc.) and distribution of repeating unit in multimers.
- Presence of ionic groups, chain defects, and unexpected units.
- Configurational structure and morphology (crystallinity, presence of microstructure, orientation, and residual structure.)
- Processing methods and condition.
- Method of sterilization, annealing, and storage history.
- Absorbed compounds, physicochemical compounds.
- Mechanism of hydrolysis (enzymes vs. water).

Three basic strategies to produce eco-friendly plastics are with biomass and/or carbon dioxide to produce "bio oil" and green monomers for highly resourceful and energy-effective polymer manufacturing processes, through living cells, which are transformed into solar-powered chemical reactors, using genetic engineering and biotechnology way to produce biopolymers and bio-based polymers and by activation and polymerization of carbon dioxide. In the production of biodegradable polymers, following green principles must be included (Fig. 3.9).

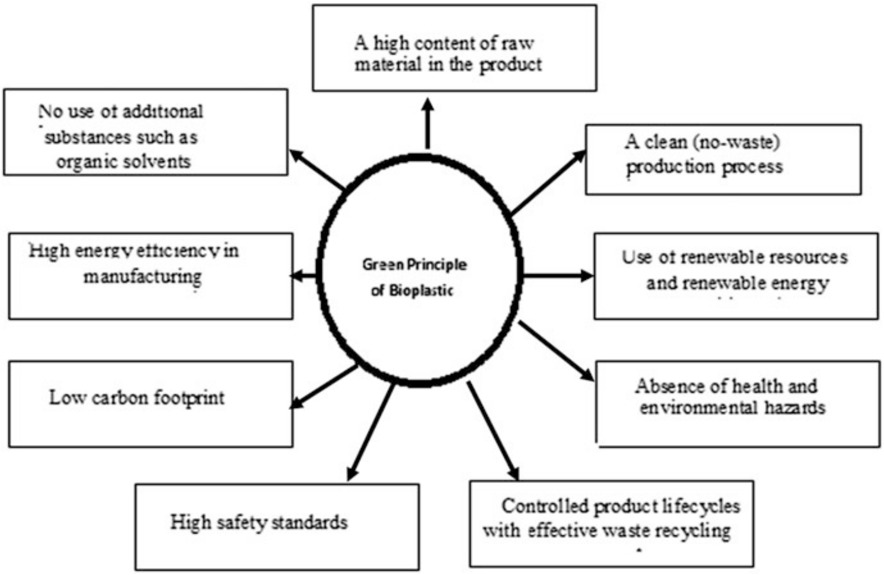

Fig. 3.9 Green principles for bioplastics

3.3 Application of Green Polymer

While 100% bio-based and biodegradable plastics are mainly used to substitute the plastics that might end up as litter (usually shopping bags, food packaging, disposables), partially bio-based plastics such as polythene manufactured from sugarcane, can provide a near-perfect substitute for oil-based equivalents in products where durability and robustness are vital. To have a quick look at the various types, feedstock, raw material, and applications of major durable bioplastics available in the current market, the following points are to consider:

- Bio-polyamide uses castor oil as feedstock and sebacic acid as raw material with processing of the dicarboxylic acid (sebacic acid), part of polyamide is produced from renewable resource (castor oil) that are used electronics, automotive, sports.
- Bio-based polyurethane (PUR) uses corn, sugarcane, tapioca as feedstock and bio-succinic acid as raw material with processing of the adipic acid used to produce conventional PUR which is replaced with succinic acid from renewable resources that are used as specialty foams, coatings, adhesives, TPU.
- Bio-based Polyethylene Terephthalate (PET)) uses sugarcane as feedstock and sugar as raw materials with processing of fermented and distilled to ethanol monoethylene glycol (MEG) from bio-ethanol, MEG is combined with Purified Terephthalic Acids (PTA) which are used in bottles, containers.

- Bio-based polyethylene (PE) uses sugarcane as feedstock and sugar with processing fermented and distilled to ethanol dehydrated to ethylene polymerization that are used in carry bags, films, and bottles.
- Bio-polycarbonate (PC) uses corn as feedstock and isosorbide (a monomer that replaces bisphenol A in conventional polycarbonate) as raw materials with processing of hydrogenation of glucose to produce sorbitol. Isosorbide is obtained from double dehydration of sorbitol that are used in a close substitute for high-performance glass components, electronic equipment, automotive housings, interior and exterior décor.

3.4 Application of Bioplastics

- Film including overwrap, shopping bags, waste and bin liner bags, composting bags, mulch film, silage wrap, body bags/coffin liners, landfill covers, packaging—O2 and H2O barriers, bait bags, nappy backing sheet, and cling wrap.
- Flushable sanitary products.
- Sheet and non-woven packaging.
- Bottles.
- Liquid paper board.
- Planter boxes and fishing nets.
- Food service cups, cutlery, trays, and straws.
- Loose fill foam.

Durable bioplastics are the main contributors of the growth of bioplastics industry, with polyurethane (PUR) producing around 43% and PET over 22% of the global bioplastics market. More than 75% of the bioplastics production capacity worldwide in 2015 was bio-based, durable plastics. In 2010, the share of durable bioplastic was only around 45% of the total share of 0.8 m metric tons of bioplastics in the global production capacity as shown in Table 3.5.

With mycelium (mushroom roots, funnily enough, the same stuff that Quorn is made from), packaging has literally grown. The Growth Trays are made out of PET plastic, which is reusable and recyclable. They are created by thermoforming over a solid form (precisely milled by a CNC router) to create the molded shape. The Growth Trays are then filled with a mix of substrate (hemp), nutrition (flour), and

Table 3.5 Markets growth trends in durable plastic (Cheng 2010)

Year	Total capacity (million tons)	Durable (%)
2010	0.7	42.3
2013	1.58	62.4
2014	1.697	60.9
2015	3.952	75
2016	4.16	76.8
2020 (Estimated)	5.95	79

mycelium which are sealed to grow for 6 days total. After 4 days, the mold pop out and further they are allowed to grow for another 2 days to get a velvety layer of overgrowth. The final stage is to dry the parts to prevent future growth.

Etiketten-Becker's stone paper consists of 80% limestone and 20% recycled polyethylene. This combination results in a 100% ecological product that can be used for several purposes, from posters, flyers to bags and is mostly used as (hang) labels and pot covers by growers. "It is a substitute for polypropylene because it is water-UV-, and tear-(more than paper) resistant. On top of that, it is also writable, even when it is wet." The paper can be printed with a thickness between 100 and 400 micron. PHA patents cover a broad range of PHAs products such as coating and packaging, cosmetic containers, bottles, golf tees, and pens. PHAs have also been converted into fibers, for a non-woven fabrics material. Emerging application areas for bioplastics include bait bags, fishing line and net, silage wrap, body bags and coffin liners, nappy backing sheet, coated paper, agricultural mulch film, shopping bags, food waste films and bags, landfill cover films, and various sanitary products.

3.5 Sustainability of Green Polymer

Engineers are trying to incorporate environmental considerations directly into material selection techniques, in order to protect the environment. The use of renewable and eco-friendly resources in the manufacturing of polymer materials is obtained in two ways. First of all, the feedstock being used can be replaced, either through intentional intervention by humans or natural cycles. The second environmental benefit of employing renewable feedstocks for biopolymer production is the biodegradable characteristics of the end products, thereby reducing potential pollution from the disposal of the equivalent volume of traditional plastics. At the end of their beneficial period, biopolymer materials are usually sent to landfills or composted. Recycling of plastic materials is encouraged, well promised, and advertised, but efforts of enhancing this attempt have been less than helpful. In the USA, recently less than 15% of plastic products must be known as a disposal technique, not a final aim for material development. A satisfied approach regarding recycling processes overlook the fact that advanced infrastructure is essential to systematic house recycling (Cao et al. 2007). This appears to be positive at the beginning, but the open systems by which the plastics are recycled allow the release of toxic gases at crucial levels.

Bioplastics are primarily important because petroleum oil price is rising enormously and its stock will finish in the near future. It is important for the global community to have a substitute for the product resulting from petroleum oil like plastics. PHAs will supposed to be an effective solution for most of the industries and societies, which mostly depend on resources made from plastic. No new inventions can prevent from the limitations and drawbacks and bioplastics too have some drawbacks. The most important drawback for PHA yield is its production cost, but the good news is that the price of PHA production is reducing, whereas, petroleum oil price is rising constantly. As a result, the gap between the petroleum oil and PHA are becoming very less. Following are the advantages of bioplastics:

- **Reduce carbon footprint**: It should be mentioned that the carbon footprint of a bioplastic is significantly dependent on whether the plastic permanently stores the carbon produced from the air by the growing plant. A plastic produced from a biological source sequesters the CO2 captured by the plant during the process of photosynthesis. If the resulting bioplastic decomposes back into CO2 and water, this sequestration process is reversed. But a permanent bioplastic similar to polyethylene or other traditional plastics stores the CO2 forever. Even if the plastic is recycled many times, the CO2 primarily taken from the atmosphere remains sequestered.
- **Less costs of energy during manufacturing process**: On the contrary, plastics are produced from approximately 4% of the oil that the world uses every year. With oil scarcity, the production of plastics becomes exposed to fluctuating prices.
- **Do not dependent on crude oil**: On the other hand, each kilogram of plastic usually requires 20 kilowatt hours of energy to produce more than the amount required to create the same weight of steel. Almost all of this originated from fossil sources.
- **Decrease in litter and improvement in compostability**: Biodegradable bioplastics help in the reduction of permanent litter. Single use plastics are the most obvious example of how plastics can pollute the environment with huge and unsightly persistence. A large fraction of the litter in our oceans is of disposable plastic bags. Cities and countries around the world are taking actions against the litter, sometimes by banning non-degradable plastic bags completely.

The past of bioplastics is not a very old. Bioplastics have emerged as a potential alternative to ubiquitous material (fossil fuel-based polymers) which is earth-friendly. Various reasons associated with the emergence of bioplastics are that they reduce dependency on limited fossil fuel resources, reduction in GHG. They are considered because of their contribution to increased resource efficiency through closed resource cycle. The increased use of bioplastics is an important step towards the minimizing the plastic pollution and saving the earth.

The key rule to measure the impact on environment is supported by the Life Cycle Assessment. Biodegradable polymers widen the range of waste management treatment option over traditional plastics.

The most preferred disposal options for plastic materials are composting instead of landfill as shown in the Fig. 3.10, which is the least preferred disposal option. Therefore recovery of material, from biodegradable polymers can make important contributions in reducing the landfill and consumption of renewable resources (Davis and Song 2006). Recycling is the process in which the discarded waste is recovered or reclaimed, reprocessed or refined, to yield a complete new product. Recycling of plastic mainly depends on the resin code of plastic waste. A top priority of waste management has always been recycling; it not only helps us in protecting

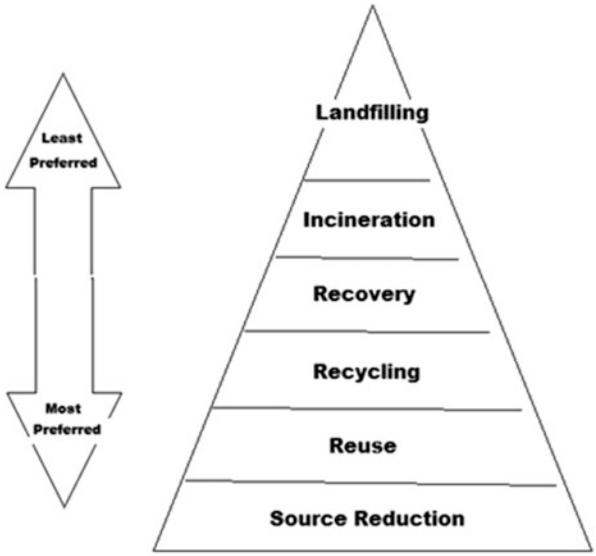

Fig. 3.10 Plastic waste management

the health of the environment, but it also contributes to reuse the waste productively thereby plummeting the space of landfill.

Incineration is the practice of burning waste products in the presence of oxygen in excess amount for thermal degradation of the waste. It is a chemical reaction in which hydrogen, carbon, and other elements mixed with waste generate lots of heat. CO2, CO, oxides of nitrogen, and water vapor are some of the gases produced in the process.

3.6 Conclusion

Crude oil prices will rise considerably in the next century, imposing the world to consider substitutes for petrochemical plastics. The renewable, eco-friendly nature and biodegradability of bioplastic consider them suitable resource to substitute synthetic plastics in various applications. In current scenario, their production is costly, but these plastics are only in their first stage of marketable development. Further research on genetically modified microbial strains, mixed cultures, proficient fermentations, recovery /purification, and the use of economical substrates can significantly reduce the production cost. Therefore, the future of bioplastics depends on the efforts towards satisfying price as well as performance necessity. Microbial synthesis of bioplastic seems to be an unlimited game; we can either make homopolymers with different monomers, or copolymers or block copolymers of different combinations. Because of their particular characteristics and wide biotechnological applications, bioplastics have a tremendously promising future. With respect to the bioplastics, future modification for improving biodegradability for certain environments can be accomplished by metallization and better barrier properties obtained by addition of SiO_2. Thermal conductivity is increased by addition of carbon fiber, or other metals.

References

Alexander A (1993) Biodegradable plastics based on cellulose acetate. Battelle- Institute E.V., Frankfurt, Germany. J Macromol Sci Pure Appl Chem 3(10):733–740

Axel S (2009) Cotton linters: an alternative cellulosic raw material. Macromol Symp 280:45–53

Bastioli C, Magistrali P (2014) Starch. In: Kabasci S (ed) Bio-based plastics: materials and applications. Wiley, West Sussex, pp 9–33

Cao Y, Wu J et al (2007) Acetone-soluble cellulose acetates prepared by one-step homogeneous acetylation of cornhusk cellulose in an ionic liquid 1-allyl-3- methylimidazolium chloride (AmimCl). Carbohyd Polym 69:665–672

Chen G, Patel M (2012) Plastics derived from biodegradable sources: present and future: a technical and environmental review. Chem Rev 11:2082–2099

Cheng H, Dowd MK et al (2010) Synthesis of cellulose acetate from cotton by-products. Carbohyd Polym 80(2):449–452

Cosimo C (2013) (Inventor), La-Es Laminate Estruses Thermoplastics S.p.a. (Applicant), Biodegradable plastic material based on cellulose acetate and relative end-products. EP 2599827 A1. Also published as CN103131052A, US20130133549

Davis G, Song JH (2006) Biodegradable packaging based on raw materials from crops and their impact on waste management. Ind Crop Prod 23(2):147–161

Fischer S, Thummler K et al (2008) Properties and applications of cellulose acetate. Macromol Symp 262(1):89–96

Goodship V (2007) Introduction to plastics recycling, 2nd edn

Halden RU (2010) Plastics and health risks. Annu Rev Public Health 31:179–194

Jenna RJ, Roland G, Chris W, Siegler T et al (2015) Plastic waste inputs from land into the ocean. Law Sci 347:68–771

Jinghua Y, Doug D, Nancy M, Ray J (2009) Characterization of cellulose acetate films: formulation effects on the thermochemical properties and permeability of free films and coating films. Pharma Technol 33(3):88–100

Kong M, Chen XG, Xing K, Park HJ (2010) Antimicrobial properties of chitosan and mode of action: a state of the art review. Int J Food Microbiol 15144(1):51–63

Lithner D, Larsson A, Dave G (2011) Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Sci Total Environ 15(18):3309–3324

Mekonnen TH et al (2013) Biocomposites: design and mechanical performance, 3rd edn. Elsevier, New York

Nishino T, Kotera M et al (2011) Acetylation of plant cellulose fibre in supercritical carbon dioxide. Polymer 52:830–836

Petrova M, Garner J (2014) Scientists use ACS Sci-Mind: case study to examine biopolymers industry posted by a_viverito in career development. American Chemical Society

Saldivar GE, Vivaldo L (2013) Handbook of polymer synthesis, characterization, and processing 1st edition

Tabone MD, Cregg JJ et al (2010) Sustainability metrics: life cycle assessment and green design in polymers. Environ Sci Technol 44:8264–8269

Tanaka R, Hirose S, Hatakeyama H (2008) Preparation and characterization of polyurethane foams using a palm oil-based polyols. Bioresour Technol 99:3810–3816

Viviana U, Pamela V, Myriam G, Michael S (2014) Bacterial production of the biodegradable plastics polyhydroxyalkanoates. Int J Biol Macromol 70:208–213

Xiaoyun Q, Shuwen H (2013) "Smart" materials based on cellulose: a review of the preparations, properties, and applications. Materials 6:738–781

Ying W, Jin Y, Guo-Qiang C (2014) Polyhydroxyalkanoates, challenges and opportunities. Curr Opinion Biotechnol 30:59–65