International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

Study of Bio-plastics As Green & Sustainable Alternative to Plastics

R. Laxmana Reddy[1], V. Sanjeevani Reddy[2], G. Anusha Gupta[3]
[1]*Asst. Prof., CED, C.B.I.T., Andhra Pradesh, India*
[2, 3] *Department of Chemical Engineering, CBIT, Andhra Pradesh, India*

***Abstract*— Bio-plastics are a form of plastics derived from plant sources such as sweet potatoes, soya bean oil, sugarcane, hemp oil, and corn starch. These polymers are naturally degraded by the action of microorganisms such as bacteria, fungi and algae. Bio-plastics can help alleviate the energy crisis as well as reduce the dependence on fossil fuels of our society. They have some remarkable properties which make it suitable for different applications. This paper tries to give an insight about Bio-plastics, their composition, preparation, properties, special cases, advantages, disadvantages, commercial viability, its life cycle, marketing and pricing of these products.**

***Keywords*— Polylactic acid, Bio-plastics, Bio-degradable polymers and Water hyacinth.**

I. Introduction

Bioplastics are not new, in the 1850s, a British chemist created plastics from cellulose, a derivative of wood pulp. Later in the early 20th century, Henry ford experimented with soy-based plastics as an alternative to fossil fuels for powering various automobiles. Since then biodegradable plastics began sparking interest, especially during the oil-crisis of the nineteen seventies.

1.1 Why Bioplastics

Plastics have become an integral part of our lives. The problems of conventional plastics are, taking decades to degrade in nature and are produced by non-renewable sources like petroleum, coal and natural gas. Environmental, economic, and safety challenges have provoked many scientists to partially substitute petrochemical-based polymers with biodegradable one's i.e. Bio-plastics. The amount of bio plastics produced worldwide is less than 200,000 tons a year which dwarfs the more than 30 million tons of oil-based plastics. Also, studies reveal that Bio-plastics are environmentally friendly as compared to traditional plastics for their production results in the emission of less green house gases such as carbon dioxide, which is one of the prime sources of air pollution and leads to environmental issues such as global warming, climate change, etc.

1.2 Composition

Bioplastics can be made from many different sources and materials. They Include - Plant Oil, Cellulose, Corn Starch, Potato Starch, Sugarcane, Weeds, Hemp etc

1.3 Classification

The Flow diagram shows an attempt to classify the biodegradable polymers into two groups and four different families. The main groups are (i) the agro-polymers (polysaccharides, proteins, etc.) and (ii) the bio polyesters (biodegradable polyesters) such as poly lactic acid (PLA), poly hydroxyl kanoate (PHA), aromatic and aliphatic co polyesters.

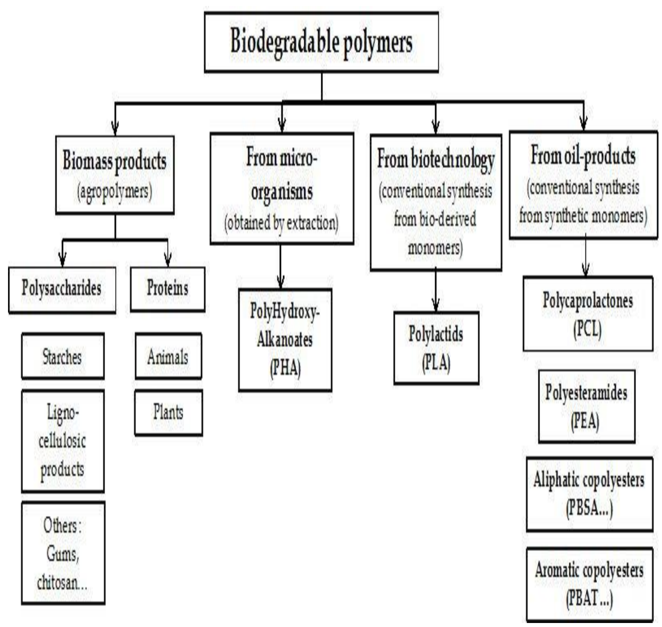


Figure – 1 Figure – 1 below shows the classification of Biodegradable polymers.

The common types of bio-plastics are based on cellulose, starch, poly lactic acid (PLA), poly-3-hydroxybutyrate (PHB).

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

Cellulose-based plastics are usually produced from wood pulp and used to make film-based products such as wrappers. Thermoplastic starch is the most important and widely used bioplastic, accounting for about 50 pc of the bio-plastics market. Pure starch's ability to absorb humidity has led to it being widely used for the production of drug capsules in the pharmaceutical industry. Plasticizers, such as sorbitol and glycerin are added to make it more flexible and produce a range of different characteristics. It is commonly derived from crops such as potatoes or maize.

PLA is a transparent plastic whose characteristics resemble common petrochemical-based plastics such as polyethylene and polypropylene. It can be processed on equipment that already exists for the production of conventional plastics. PLA is produced from the fermentation of starch from crops, most commonly corn starch or sugarcane, into lactic acid that is then polymerized. Its blends are used in a wide range of applications including computer and mobile phone casings, foil, biodegradable medical implants, moulds, tins, cups, bottles and other packaging material.

PHB is very similar to polypropylene, which is used in a wide variety of fields including packaging, ropes, bank notes and car parts. It is a transparent film, which is also biodegradable. Interest in PHB is currently very high with companies worldwide aiming to expand their current production capacity. The South American sugar industry has committed to producing PHB on an industrial scale.

At the cutting edge of bioplastic technology lie polyhydroxyalkanoate (PHA) materials. These are derived from the conversion of natural sugars and oils using microbes. They can be processed into a number of materials including molded goods, fiber and film and are biodegradable and have even been used as water resistant coatings.

II. Poly-Lactic Acid

Biodegradable polymers show a large range of properties and can compete with non-biodegradable thermoplastics in different fields (packaging, textile, biomedical, etc.). Among these bio polyesters, PLA is at present one of the most promising biopolymer. PLA belongs to the family of aliphatic polyesters commonly made from hydroxyl acids, which also includes - polyglycolic acid (PGA). It is one of the few polymers in which the stereo chemical structure can easily be modified by polymerizing a controlled mixture of l and d isomers to yield high molecular weight and amorphous or semi-crystalline polymers. Properties can be modified through the variation of isomers (l / d ratio).

2.1 Synthesis of PLA

Lactic acid is a compound that plays a key role in several biochemical processes. For instance, lactate is constantly produced and eliminated during normal metabolism and physical exercise. Lactic acid has been produced on an industrial scale since the end of the nineteenth century and is mainly used in the food industry to act as an acidity regulator, in cosmetics, pharmaceuticals and animal feed. In addition to this it is considered the monomer precursor of PLA. It can be obtained either by carbohydrate fermentation or by common chemical synthesis.

Lactic acid is mainly prepared in large quantities (around 200 kT per year) by the bacterial fermentation of carbohydrates. These fermentation processes can be classified according to the type of bacteria used as:

(i) The heterofermentative method, which produces less than 1.8 mol of lactic acid per mole of hexose, with other metabolites in significant quantities, such as acetic acid, ethanol, glycerol, mannitol and carbon dioxide and

(ii) The homo-fermentative method, which leads to greater yields of lactic acid and lower levels of by-products, and is mainly used in industrial processes. The conversion yield from glucose to lactic acid is more than 90 per cent. The majority of the fermentation processes use species of *Lactobacilli*, which give high yields of lactic acid.

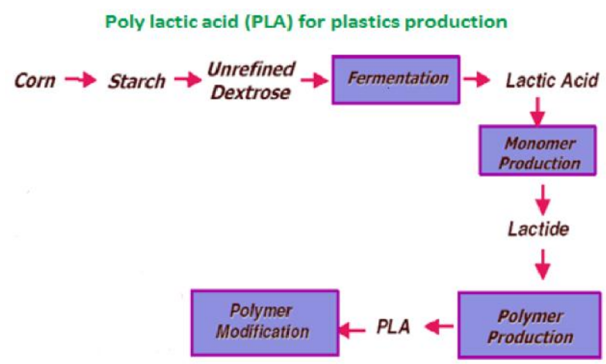


Figure – 2 shows the flow chart of PLA

The synthesis of PLA is a multistep process which starts from the production of lactic acid and ends with its polymerization. Lactic acid can be obtained from renewable sources like corn, potato, whey, sugar cane through fermentation. An intermediate step is often the formation of the lactide.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

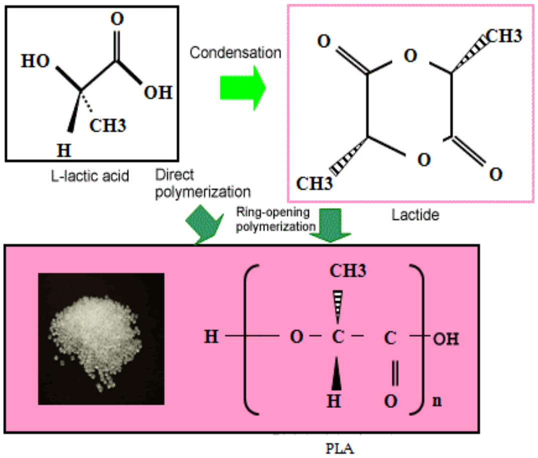


Figure – 3 shows the synthesis of PLA.

Lactic acid is condensation polymerized to yield a low molecular weight, brittle polymer, which, for the most part, is unusable, unless external coupling agents are employed to increase its chains length. Second route is the azeotropic dehydrative condensation of lactic acid. It can yield high molecular weight PLA without the use of chain extenders or special adjuvant. The third and main process is ring-opening polymerization (ROP) of lactide to obtain high molecular weight PLA.

PLA is considered both as biodegradable e.g. adapted for short-term packaging and as biocompatible in contact with living tissues e.g. for biomedical applications such as implants, sutures, drug encapsulation, etc. PLA can be degraded by a biotic degradation i.e. simple hydrolysis of the ester bond without requiring the presence of enzymes to catalyze it. During the biodegradation process, and only in a second step, the enzymes degrade the residual oligomers till final mineralization (biotic degradation). As long as the basic monomers (lactic acid) are produced from renewable resources (carbohydrates) by fermentation, PLA complies with the rising worldwide concept of sustainable development and is classified as an environmentally friendly material.

2.2 Physical and Chemical Properties.

Figure – 4 shows some of the properties of PLA

Due to the chiral nature of lactic acid, several distinct forms of polylactide exist. Poly-L-lactide (PLLA) is the product resulting from polymerization of L, L-lactide (also known as L-lactide). PLLA is crystalline to around 37%, a glass transition temperature between 60-65 °C, a melting temperature between 173-178 °C and a tensile modulus between 2.7 16 GPa. However, heat resistant PLA can withstand temperatures of 110 °C. PLA is soluble in chlorinated solvents, hot benzene, tetrahydrofuran, and dioxane. PLA has similar mechanical properties to PETE polymer, but has a significantly lower maximum continuous use temperature. Polylactic acid can be processed like most thermoplastics into fiber (for example using conventional melt spinning processes) and film. The melting temperature of PLLA can be increased by about 40-50 °C and its heat deflection temperature can be increased approximately 60°C to up to 190 °C by physically blending the polymer with PDLA (poly-D-lactide). PDLA and PLLA form a highly regular stereo complex with increased crystalline. The temperature stability is maximized when a 50:50 blend is used, but even at lower concentrations of 3-10% of PDLA, there is still a substantial improvement. In the latter case, PDLA acts as a nucleating agent, thereby increasing the crystallization rate. Biodegradation of PDLA is slower than for PLA due to the higher crystalline PDLA.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

2.3 Unique Characteristics

PLA (Poly Lactic Acid) is one of the most environment friendly Bio-plastic available today. It is made from 100% bio based resources and has multiple end-of-life options (i.e., 100% recyclable and biodegradable). PLA is a highly efficient plastic. To make a kg of PLA it requires a meager 1.6 kg of sugar. Other types of bio-plastics can require significantly more natural resources to produce the same amount of end-product. Emission of carbon dioxide is less when compared with other polymers

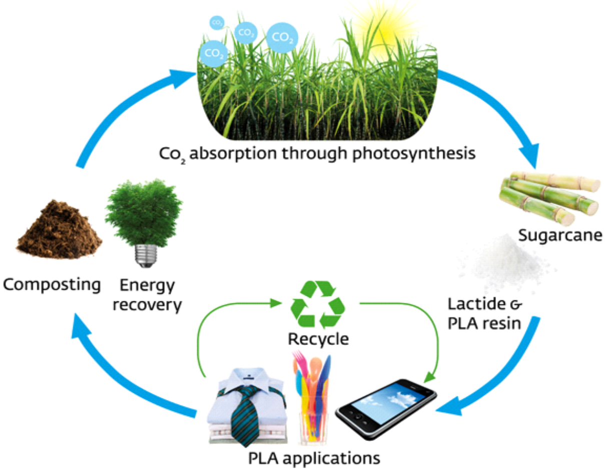
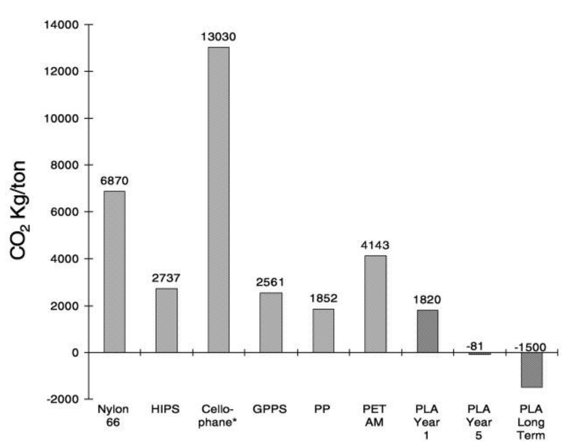


Figure – 5 shows some of the unique characteristics of PLA



III. Special Case Of Bio-Plastics

3.1 Water Hyacinth

Water hyacinth is considered one of the most notorious aquatic weeds. It proliferates rapidly in lakes, dams and irrigation channels and chokes them.

But scientists have now shown that the infamous weed is a rich source of carbohydrate and can be used to make biodegradable plastic. Water hyacinth derived sugar molecules like lignin, cellulose and hemicelluloses can be converted into polyhydroxybutyrate (PHB), a polymer that is a raw material for making biodegradable plastic.

Figure – 6 shows Water hyacinth.

3.2 Production of PHB

PHB is very similar to poly propylene, which is used in a wide variety of fields including packaging, ropes, bank notes and car parts. It is a transparent film, which is also biodegradable. Interest in PHB is currently very high with companies worldwide aiming to expand their current production capacity. To produce PHB, researchers dried and crushed water hyacinth into a fine powder and subjected it to acid and enzyme treatment in the presence of water. The end product was used to grow Cupriavidus nectar, a bacterium known to produce PHB, in the presence of organic and inorganic nitrogen sources. As the bacteria grew, PHB was found to accumulate inside them. Researchers ruptured the bacterial cells using an alkaline solution and extracted the PHB. A Maximum PHB of 4.3 grams per litre was obtained from the bacteria cultured using the products of enzymatic breakdown of water hyacinth powder. “PHB can have potential applications in a wide variety of fields such as industrial, biomedical, agricultural, domestic, and automobile.

3.3 Advantages

The quality of PHB derived from hyacinth is similar to PHB from other sources. The advantage with using water hyacinth as raw material is that it is available free of cost throughout the year. PHB derived bio plastics are heat tolerant with a melting point at 175 °C. Applications of PHB include manufacturing heat tolerant and clear packaging film.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

IV. Applications/Uses Of Bio-Plastics

Applications of Bio-plastics include single-use items such as plates, utensils, cups, and film wrap plastic bottling and as paper coatings by fast-food companies, clothing fibers compost bags, in the biomedical field, etc.

4.1 Advantages of Bio-plastics

(i) Reduced CO2 emissions: One metric ton of bio-plastics generates between 0.8 and 3.2 fewer metric tons of carbon dioxide than one metric ton of petroleum-based plastics.

(ii) Cheaper alternative: Bio-plastics are becoming more viable with volatility in oil prices

(iii) Waste: Bio-plastics reduce the amount of toxic run-off generated by the oil-based alternatives.

(iv) Benefit to rural economy: Prices of crops, such as maize, have risen sharply in the wake of global interest in the production of bio-fuels and bio-plastics, as countries across the world look for alternatives to oil to safeguard the environment and for attaining energy security.

(v) Reduced carbon footprint: Oil based plastics require fossil fuel as a key raw material. In addition, oil based plastics like PP and PS require more energy during the plastic development process when compared with bio-plastics. A Life Cycle Analysis for a typical PP or PS plastics shows a carbon footprint of approx 2.0 kg CO_2 equivalents per kg of plastic (from cradle to factory gate). These CO_2 emissions are 4 times higher than the CO_2emissions for Poly Lactic Acid (PLA) resin.

(vi) Multiple end-of-life options: valuable raw materials can be reclaimed and recycled into new products, reducing the need for new virgin material and negative environmental impact of 'used' plastic products can be greatly reduced, if not, eliminated.

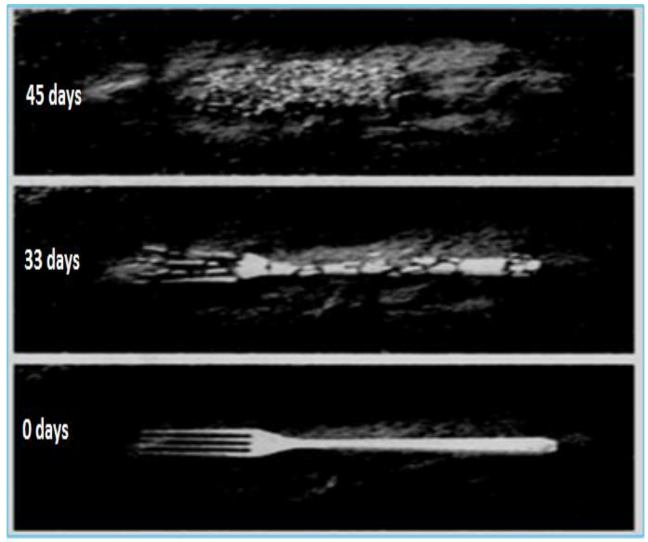


Figure – 7 shows Bio-Degradation of Bio-Plastic.

In the future, bio-plastic products might be recycled into bio-diesel. Researchers at Polytechnic University in New York have developed a fuel-latent plastic that is tougher and more durable than standard polyethylene. After use, the product can be placed in a simple converter where enzymes break it down into biodiesel suitable for home heating fuel**.**

Figure – 8 shows a Petro plastic Bottle (70% petro / 30% plant-based (sugarcane) PET bottle.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

Figure – 9 shows a "Bio plastic" Bottle - 100% plant-based (food waste)

4.2 Disadvantages of Bio-plastics

As nothing is complete in this world, biodegradable plastics, which are preferred over the conventional ones, they have few drawbacks, such as:

(i) Biodegradable plastic is not meant to be recycled with other types of plastics.

(ii) If biodegradable plastic are not properly disposed of, it leads to an inefficient breakdown of the plastic, which can release toxins (carbondioxide, methane etc) into the environment.

V. Viability Of Bio-Plastics

5.1 Land required for renewable resources

The current annual global production capacity of bio-plastics is estimated to be about one million tones, including renewable sourced plastics and petro-based bio-degradable ones. Depending on the polymer type and the used crop, respectively the agricultural feedstock, the average yield ranges between 3.5 and 5.5 tones of bio-plastics per hectare. The agricultural cultivation area needed to fully generate the current global production capacity would amount to 286,000 hectares today, which equals approximately 0.02 percent of the total arable land available in the world. Research conducted by the University of Applied Science and Arts in Hannover (Germany) indicates that even a complete shift of the plastics production of approximately 250 million tones p.a. to bio based plastics would require a share of only 5 percent of the arable land.

5.2 Renewable resources for food, feed and bio-plastics

Hunger – the most wide-spread argument against using food crops for industrial purposes – is in general not caused by a shortage of land to grow food or animal feed. In addition to production of bio-plastics, there is ample space to produce both food and feed for all. There is no lack of food as much of it is being wasted. The daily per capita production of food equates to 4,600 calories, of which 1,400 are wasted or never reach the consumer. In lesser-developed countries, food losses could be avoided through better post-harvest technologies, better storage, transport and marketing. In addition to these logistical aspects, political instability as well as the distribution of financial resources or their lack is the main reason for hunger. The decision as to which crop is to be cultivated for fuel or industrial use in free agricultural areas should be determined by efficiency, economy, ecology and sustainability. The land mass necessary for feedstock production is minimal as figures reveal that for producing 500,000 tons of PLA requires less than 0.5% of the annual United States corn crop.

VI. Carbon Cycle Of Bio-Plastics

6.1 Bio-plastic cycle

When fossil fuels are extracted from the earth, the natural cycle is disrupted and the release of carbon dioxide into the atmosphere is accelerated. This accelerated release of green house gases is far higher than the replenishing rates of the various natural processes. Bio-plastics can replace nearly 100% of the fossil fuel content found in conventional plastics, and require considerably less energy for production. Carbon cycle is the biogeochemical cycle by which carbon is exchanged among the spheres of the earth. When a plant grows, it takes in carbon dioxide, and when it biodegrades, it releases the carbon dioxide back into the earth – a perfect closed loop cycle. These natural resources undergo different processes to form polymers. Polymers are further processed to bio-plastics. These plastics are used in various ways and are further degraded. During biodegradation carbon dioxide is released back to the atmosphere. Therefore carbon dioxide which is taken from the environment is cycled back to the atmosphere by passing through different stages and forming a closed cycle.

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

6.2 End-of-Life

Many bio-plastics are 100% compostable and typically biodegrade in 180 or less days when disposed of in a municipal composting facility, whereas traditional plastics can take decades to break down. Initially, when conventional plastics begin to break down, they fragment into smaller and smaller particles that often end up in our water stream and in our food chain when animals eat the plastic particles. Conversely, compostable plastics are absorbed back into the earth and become nutrients for the soil – thus closing the deadly loop.

6.3 Cycle Time

Bioplastics have the same cycle time as traditional plastics but because the process requires significantly lower processing temperatures, bioplastic products can save up to 35% energy. In addition, bio-plastics have two thirds less harmful greenhouse gas emissions as compared to conventional plastics, during the production process.

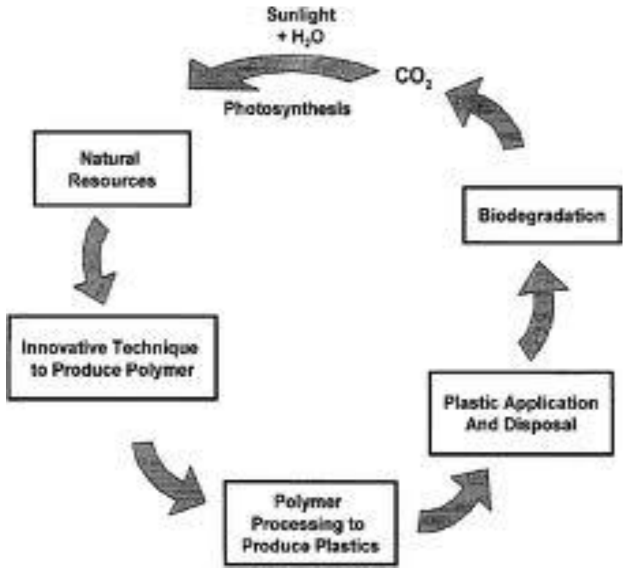


Figure – 10 shows a typical Bio-plastic cycle

Among the different polymers poly lactic acid is the polymer which emits least amount of green house gases - carbon dioxide, methane etc.

TABLE – I
Bio-plastics vs oil based Plastics

Property	Bio-plastic	Oil based Plastic
Renewable	Yes	Partially No
Break down in the environment	Biodegradable and/or compostable	Some degradable by polymer oxidation
GHG emissions	Usually low	Relatively high
Fossil fuel usage	Usually low	Relatively high

VII. Market And Price Of Bio-Plastics

According to European Bio-plastics Association, the global production capacity for bioplastics is projected to grow four times by 2020. The prices of any biopolymer are likely to be high when it is only produced on a small scale. The scale of production is likely to have a greater influence on the price than the costs of the raw material source and of the chemistry involved. According to EBA, Bio-plastics consumption is likely to reach two million tons by 2018.

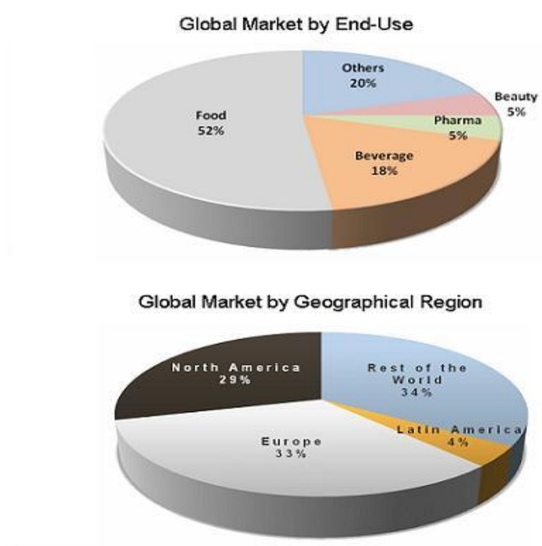


Figure – 11 shows global market for bio-plastic.

IJETAE
EXPLORING RESEARCH AND INNOVATIONS

International Journal of Emerging Technology and Advanced Engineering
Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 5, May 2013)

As shown, Europe is the biggest market in terms of consumption of bio-plastics whereas Latin America the least. Also, Bio-plastics find more place in the food industry as compared to the other markets. According to global market watchers, global Poly Lactic Acid market is expected to reach US$2.6 billion by 2016 at a Compounded Annual Growth Rate (CAGR) of 28%. Region-wise analysis shows that Asia-Pacific is forecasted to record the highest growth rate of 29.3% during the analysis period 2011-2016. Europe follows Asia-Pacific with a CAGR of 28.9%. The Americas forecasts to drive the global market with a 27.3% increase. Volume based studies reveal that the maximum share of growth rate is expected from Asia-Pacific region. Comparing the end-user industries, textiles and electronics are going to be the major supporters of this market.

VIII. Conclusions And Discussions

With increased environmental awareness and more and more communities/societies becoming environmentally conscious, those who invest in production of bio degradable plastic materials stand to gain as they have a head start. The many advantages of bio-plastics such as - 100% biodegradable, produced from natural renewable resources, able to be recycled, reused, composted or burned without producing toxic byproducts, etc. make it an excellent alternative to traditional plastic products. Biopolymers limit carbon dioxide emissions during creation and degrade to organic matter after disposal. Bio degradable polymers may not be a one stop solution to all environmental problems created by plastics but it's a step in the right direction as time is of essence for biodegradable polymer development as society's current views on environmental responsibility make this an ideal time for further growth of biopolymers.

REFERENCES

[1] Abou-Zeid, D. M., Muller, R. J. and Deckwer, W. D., Journal of Biotechnology, **86**, 113 (2001).

[2] Dang MH. Birchler F. Wintermantel E., 'Toxicity Screening of Biodegradable Plastics .2.

[3] Evaluation of Cell Culture Test with Medium Extract', journal of Environmental Polymer, Degradation, 5, 49, 1997 Jan. 9.

[4] Degli Innocenti, F., Compostability of Biodegradable Plastics - Standard Test Methods presented at International Workshop on Environmentally Degradable Plastics; Smolenice / Slovak Republic, October 4 - 8, 1999.

[5] Goldstein, N & Block, D. 'Sorting out the Plastic', Biocycle – Journal of Composting and Organics Recycling, The JG Press, Vol. 41, No.8, August 2000.

[6] Gluten/Aliphatic Polyester Blends. Eur. Polym. J. 1999, 35, 1875–1881 Materials Safety Data Sheet, Ethylene Glycol, Mallinckodt Baker, 2001.

[7] Yoshihiro, S.; Kimio, T.; Kiyoo, I.; Tetsuya, I.; Japanese Patent JP 2000129646-A (2000).

[8] Industrial Production of High Molecular Weight Poly(Lactic Acid)". In Rafael Auras, Loong-Tak Lim, Susan E. M. Selke, Hideto Tsuji. Poly(Lactic Acid): Synthesis, Structures, Properties, Processing, and Applications.

[9] Purushothaman, M., Anderson, R. K. I., Narayana, S. and Jayaraman, V. K., Bioprocess & Biosystems Engineering, 24, 131 (2001).

[10] Ohtake, Y., Kobayashi, T., Asabe, H., Murakami, N. and Ono, K., 'Oxidative degradation and molecular weight change of LDPE buried under bioactive soil for 32-37 years', Journal of Applied Polymer Science, 70, 1643 (1998).

[11] Ratto, J.A.; Stenhouse, P.J.; Auerbach, M.; Mitchell, J.; Farrell, R.(1999). Processing, Performance and Biodegradability of a Thermoplastic Aliphatic Polyester/Starch System, Polymer 1999, 40, 6777–6788.