Chapter 2

Biodegradability : Myths and Realities

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BIODEGRADABILITY : MYTHS & REALITIES

Introduction

Plastics have almost replaced materials such as metal, glass, wood, paper, fiber, ceramics and etc. in packaging, automobiles, building construction, biomedical fields, electronics, electrical equipments, appliances, furniture, pipes and heavy industrial equipments. In a nutshell, from agriculture to transport and from aerospace to food packaging, the use of plastics has become an integral part of our modern day living.

Polymers can be classified as either natural or man-made 'macromolecules' which are composed of small repeating units. Polymers, which are bio-synthesized in plants, animals, and micro and macro organisms, are called Natural polymers. Examples are polysaccharides, proteins, fats, nucleic acid and natural rubbers. The most easily recognized natural polymer is Cellulose, the most abundant organic polymer on earth.

Polymers/Plastics,which are man-made, are called synthetic polymers. Polyolefins are the most important group of synthetic polymers. Synthetic polymers are ubiquitous in our world finding diverse applications in many fields because of their useful properties and contribute to enhancement of comfort and quality of life in our modern industrial society. The properties of synthetic plastics like durability, resistance to weathering and photodegradation as well as substance to biological attack and hydrophobicity, have contributed to their utility in different applications.

The same properties that made the synthetic polymers to be so useful have contributed to their disposal problem. They receive the brunt of media attention on this issue because of their visibility in the environment as litter and garbage. Recycling of plastic waste contributes a viable option, provided appropriate collection and separation mechanisms are operative but ineffective system reduces our cities to garbage dumps. However, for materials that come in contact with food or biomedical waste, recycling is not a viable option. Indiscriminate littering of plastics and its unhygienic recycling causes great concern and pose a serious health and environmental menace. Incineration and biodegradation (landfills or composting environment) offer a solution to the disposal of such wastes.

Biodegradable polymers are polymers in which the degradation results from the action of naturally occurring microorganism such as bacteria, fungi and algae. However, biodegradable and compostable plastics are not a panacea for all issues on wastes generated by the plastics in the environment **nor they are universal substitutes for the common resins of commerce.**

This report highlights the myths and realities associated with the plastics and traditional materials used for various applications. Different issues concerning plastics in the environment are discussed. The merits and myths of plastic's ecofriendly nature is explained in detail with a discussion of emerging technologies. Different testing standards discribed. A systematic and comparative study is made on the biodegradability of synthetic and natural polymers. Guidelines and possible solutions are discussed with the recommendations from the Indian point of view for the future.

Aspects of Biodegradability

The changes from the Stone age to the Bronze age and Bronze age to Iron age took hundreds and thousand of years. At the same time, Plastic age came in just through a single lifetime after the steel age. Over the past century, synthetic plastics have become the most efficient materials ranging in applications from replacement of human body parts to the construction of supersonic aircraft and spacecraft. This growth has occurred at the expense of traditional materials like steel, aluminium, wood, paper and glass. Examples are wood, whose consumption leads to loss of forest cover, glass and paper, which consumes enormous fossil fuel for their conversion apart from generating toxic pollutants. One of the common myths about plastic is that their production depletes oil or natural gas which are nonrenewable resources. Traditional materials such as paper, wood, jute, etc. are believed to be biodegradable. Metals are non-biodegradable and can be recycled easily without much effect on desirable properties. The popular view is epitomized in the following statement from GREEN PEACE.

'Materials made from naturally occurring or biologically produced polymers are the only truly 'biodegradable plastics' available. Since living things construct these materials, living things cart metabolize them.' However, this statement is not completely true as proved by many research investigators.

Degradability and its Mechanism

Photo Degradability

Photodegradation begins with the production of macro-radical (P') in the amorphous regions of polymer substrate. This radical rapidly reacts with oxygen to give a macroperoxy radical (P00') which abstracts a hydrogen atom from the polymer backbone to produce a hydroperoxide group (POOH). The hydroperoxide group is photolytically cleaved to produce the highly reactive radicals which continue the cycle of chain degradation in the polymer'.

Chain initiation

$$\underset{\text{(polymer)}}{PH} \xrightarrow{hv\ /\ \Delta} P^{\cdot} + H^{\cdot}$$

Chain propagation

$$P^{\cdot} + O_2 \longrightarrow POO^{\cdot}$$

$$POO^{\cdot} + PH \longrightarrow P^{\cdot} + POOH$$

$$POOH \xrightarrow{hv\ /\ \Delta} RO^{\cdot} + {}^{\cdot}OH$$

The cycle is terminated when two radical combine or recombine to form a non-radical product.

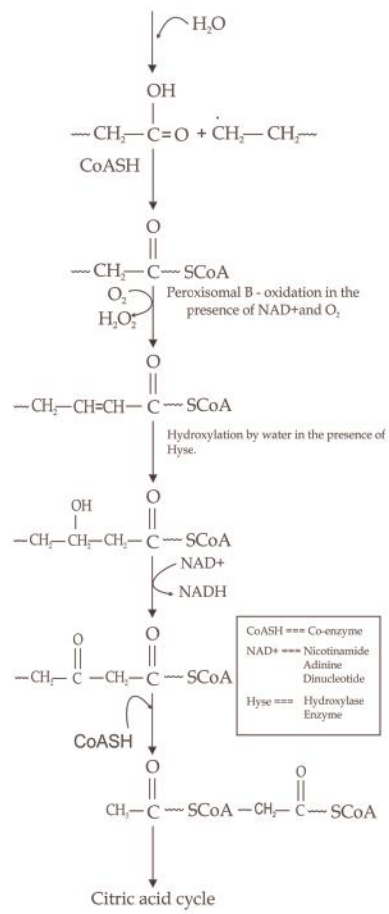
Thermal Degradability and Mechanisms

The fundamental degradation mechanisms of polymers are based on the same principles for both the thermal and photodegradation. The only exception in that photodegradation proceeds at a faster rate than thermal degradation and hydroperoxides are thermally cleaved to reactive radicals in thermal degradation.

Biodegradability

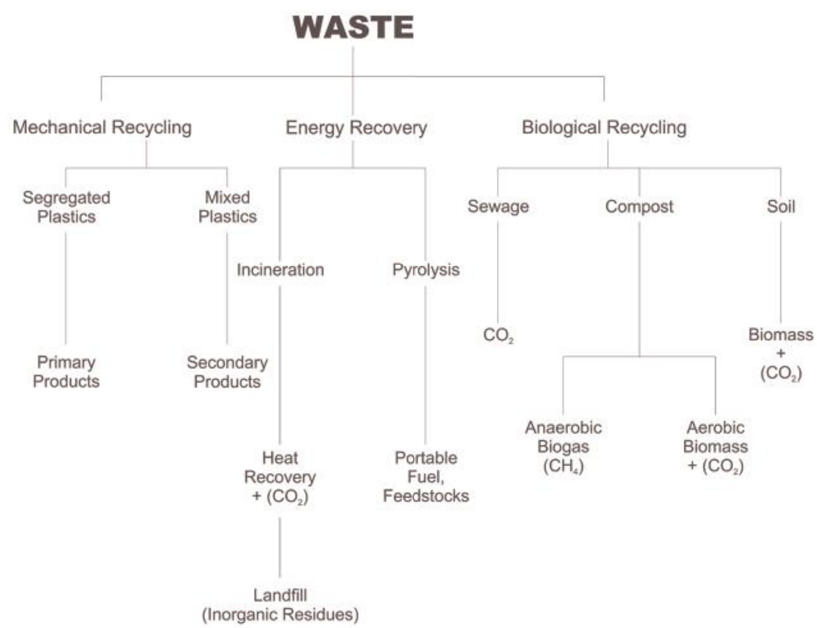
Biodegradability is the ability to be utilized as a carbon source by microorganisms and converted safely into carbon dioxide, biomass and water. Microbial attack is started where the carbonyl group is found. These functional groups are introduced in polyolefins during photodegradation and / or thermal degradation.

<u>Proposed mechanism of biodegradation:</u>
ESTER GENERATED DURING ABIOTIC DEGRADATION



Traditional Pathways of Plastic Waste Management

The purpose of solid waste management is to remove wastes from living areas in a way that protects human health and the environment. By sealing wastes in well-designed and managed landfills, one tends to preserve waste rather than degrade it. Uncontrolled biodegradation could result in production of leachate that, if leaked, would endanger near groundwater supplies, lakes and streams. Many landfills include heavy-gauge plastic liners which are required by the EPA to help protect the groundwater from contamination. While the total number of landfills is decreasing, total landfill capacity is actually increasing[7]. In 1991, 28 states in USA reported that they had less than 10 years of disposal capacity remaining. In 1996, however, only 13 reported having less than a decade. Conversely, while less than half of the states reported having more than 10 years of remaining capacity in 1991,35 states now claim to have more than a decade of disposal capacity. To manage the wastes generated by plastics in the environment, several options are available, namely mechanical recycling, energy recovery and biological recovery.



Definitions of Some Key Words, Standards and Testing Methods

a. Definitions

The definition of biodegradation is not always clear and is open to a large diversity of interpretations. Here are the definitions of some key words according to the **ASTM D20-96:**

Degradable Plastic: A plastic designed to undergo a significant change in its chemical structure under specific environmental conditions resulting in a loss of some properties that may vary as measured by standard test methods appropriate to the plastic and its applications in a period of time.

Biodegradable Plastic: A degradable plastic in which the degradation results from the action of naturally occurring microorganisms such as bacteria, fungi and algae.

Photodegradable Plastic: A degradable plastic in which the degradation results from the action of natural daylight.

Thermal Degradable Plastic: A degradable plastic in which the degradation results from the action of heat.

Composting and Plastics: A plastic that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds and biomass, compostable materials and leaves visually no disintegrable or toxic residue.

Although a number of standard committees have sought to produce definitions of biodegradable plastics, each gives its own definition of biodegradable polymer. In conclusion it can be said that the intrinsic capacity of a material to be degraded by the action of microorganism called biodegradability. More specifically there are two definitions depending on the final fate of the polymer in the environment.

i. Compost

Compost is an organic soil conditioner obtained by biodegradation of a mixture consisting principally of various vegetable residues, occasionally with other organic material and having a limited mineral content. Compost quality has to be defined by the relevant national standards.

ii. Compostable Plastics

Compostable plastic is a plastic that undergoes degradation by biological processes during composting to yield CO_2, water, inorganic compounds and biomass at a rate consistent with other compostable materials and leaves no visible, distinguishable or toxic residue. (ASTM D 6400-99)

iii Compostability

Compostability is a property of a packaging to be biodegraded in a composting process. To claim compostability it must have been demonstrated that a packaging can be degraded in a composting system as can be shown by the standard methods. The end product must meet the relevant compost quality criteria.

- **Primary Biodegradability** (Partial Biodegradability) is the alteration in the chemical structure of the material and loss of specific properties.

- **Ultimate Biodegradability** (Total Biodegradability): The material is totally degraded by the action of microorganisms with the production of carbon dioxide (under aerobic conditions) and methane (under anaerobic conditions), water, few mineral salts and biomass.

Disintegration is the falling apart into very small fragments of packaging or packaging material caused by environmental degradation mechanisms. Very often disintegration is misunderstood and is claimed as biodegradation, especially in the case of polyolefins. Many blend compositions of polyolefins (especially with starch) disintegrate and do not biodegrade.

b. Test Methods to Evaluate the Degradability

In order to fully characterize the long-term properties of polymers, a variety of techniques must be used. Several of them may give similar results but often they complement each other. The most important thing is to relate the observations obtained by the analysis with postulated degradation mechanisms, whereby it should be possible to describe the possible degradation of material.

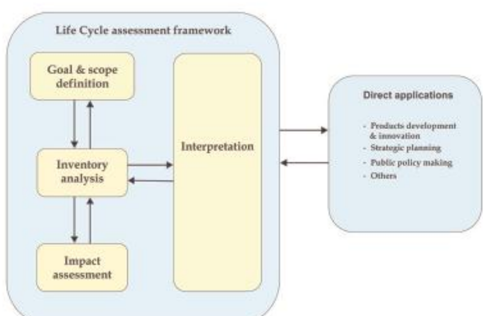
Life cycle evaluation, is therefore, a three-part process :

(i) An inventory of the raw materials, energy and wastes associated with the manufacture, use and disposal of a product.
(ii) An estimation of the impact of raw material extraction and emissions.
(iii) An improvement of analysis.

c. Life Cycle Assessment (LCA)

Life cycle assessment is now a preferred technique to describe the design of ecologically acceptable material. LCA of the materials provides a useful comparison of the ecological impact of comparable products. LCA can be used to compare the ecological acceptability of different raw materials, processes and end products. In general, there is a correlation between ecological acceptability and cost which is of primary concern to the manufacturer of polymer products. This is a 'cradle-to-grave' assessment of alternative strategies for a given application. Since the procedure generally involves a comparison of alternative manufacturing and disposal techniques, it is essentially an assessment of the overall energetic and environmental impact of a product.

Steps of an LCA



d. International Standards for Biodegradation

The American Society for Testing and Materials (ASTM) and other organizations have developed the standards for testing the biodegradability in different specified conditions. The degradation of the material must be measured by the following methods.

1.	ASTM D 5247	Determining the Aerobic Biodegradability of Degradable Plastics by Specific Microorganisms
2.	ASTM D 6002-96	Guide for Assessing the Compostability of Environmentally De gradable Plastics
3.	ASTM D 5338-98	Test Method for Determining Aerobic Biodegradation of Plastic mate rials under controlled composting conditions.
4.	ASTM D 6340-98	Test Methods for Determining Aerobic Biodegradation of Radio-labeled Plastic Materials in an Aqueous or Compost Environment.
5.	ASTM D 5209	Test Methods for Determining the Aerobic Biodegradation of Plastic Materials in the presence of Municipal Sewage Sludge
6.	ASTM D 5210	Test Methods for Determining the Anaerobic Biodegradation of Plastic Materials in the presence of Municipal Sewage Sludge
7.	ASTM D 5152	Water Extraction of Residual Solids from Degraded Plastics for Toxicity Testing.

The international Organization for Standardization (ISO) is a worldwide federation of national standards bodies (ISO member bodies). Since the working group on biodegradability of plastics was created in 1993, rapid advances have been made in this area. The following three aerobic biodegradation test methods have recently advanced to Draft of International Standard (DIS) stage.

Standard	Description
ISO/DIS 14851	Evaluation of the ultimate aerobic biodegradability in an aqueous medium-method by determining the oxygen demand in a closed respirometer
ISO/DIS 14852	Evaluation of the ultimate aerobic biodegradability in an aqueous medium-method by analysis of released carbon dioxide
ISO/DIS 14855	Evaluation of the ultimate aerobic biodegradability and disintegration of plastics under controlled composting conditions- method by analysis of re leased carbon dioxide

These three ISO/ DIS 14851, 14852 and 14855 are recognized as useful screening tests for establishing the aerobic biodegradability or compostability of plastics.

DIN (German) standards:

DIN 54900-Draft Evaluation of the compostability	
CEN (European) Standards:	
CEN TC 261/ SC4/ WG2	Evaluation of the compostability, biodegradability and disintegration

Significance of Non-biodegradability and Biodegradability of Materials

a Non-biodegradability : Merits

Non-biodegradability of the polymers enables them to be applicable to diverse applications. Perhaps the most remarkable aspect of polymers derived from natural products is that such environmentally unstable materials should be the basis of environmentally durable industrial products. Rubber tyres before fabrication are among the least environmentally stable of all polymers and yet automotive tyres survive for many years in the outdoor environment long after use. The key applications of so called non biodegradable thermoplastics are as follows:

1. In Packaging

The major use of synthetic polymers has been as replacements for more traditional materials, particularly in packaging. Polymers are light in weight and yet have very good barrier properties against water and water-borne organisms. Compared with glass they have much superior impact resistance and resilience, resulting in reduced product loss during transport. They protect not only perishable commodities from the environment and also the environment from corrosive or toxic chemicals. The production processes for plastics from crude oil are much less labor and energy intensive than traditional materials[9-11] (ref. table below).

Energy requirements for the production of materials used in packaging

Material	Energy requirement $kWhkg^{-1}$
Aluminium	74.1
Steel	13.9
Glass	7.9
Paper	7.1
Plastic	3.1

The fabrication of plastics by injection molding is also less energy intensive than the fabrication of traditional materials. The polymer is converted into useful product in a single rapid and repetitive process that does away with intermediate forming and joining procedure. When these factors are combined with lower density of polymers, the energy requirements for similar containers are found to be lower than for traditional materials.

To compete with plastics, even if no energy were involved in the transport and cleansing of returnable bottles, these returnable bottles would have to be recycled about twenty times. Further Energy requirements for similar beverage containers in comparison of plastics are shown in the subsequent table.

Energy requirements for similar beverage containers

Container	Energy usage per container (kWh)	Weight (pounds)
Aluminium can	3.00	1.41
Returnable soft drink bottle	2.40	10.60
Returnable glass beer bottle	2.00	8.83
Steel can	0.70	1.76
Paper milk carton (1 pint)	0.18	0.92
Plastic beverage container	0.11	1.23

2. In Transportation

Polymers are light in weight compared with metals and ceramics. The modern plastic milk container is only a fraction of the weight of a similar bottle made from glass and this has a significant influence in transport costs. It is a popular belief that milk delivery in returnable glass bottles is ecologically preferable to single-trip plastic containers. Non-biodegradability makes the synthetic polymers suitable to this purpose. Due to their long-term stability, plastics are also increasingly replacing traditional materials in automotive components, for example in motor vehicles, aircraft and boats. In addition, since much more energy is used in the production of metals and glass than manufacture of the common plastics, it follows that the more plastics can be used to replace metals and glass in vehicles, the less fuel will be used in transport.

3. In Agriculture

Plastics have changed the face of rural environment by their wide range of uses in agriculture, waste management and irrigation. Plastics have largely replaced glass in greenhouses and tunnels. They are much cheaper than glass in greenhouses but they have to be replaced more frequently. Biodegradable polymers would be of not much use as longevity of usage is a major criteria in these application.

4. At Home and Office

It is now taken for granted that for equipment operating at ambient temperatures, plastics are the modern materials of choice for items such as food mixers, vacuum cleaners, hair driers, television consoles, computers, word processors and other office equipments. Who would want appliances which biodegrade & disintegrate in a span of few weeks or months.

5. As Paintings and Surface Coatings

Naturally occurring 'drying oils' based on polyunsaturated fatty acid esters have been used for centuries to protect metals from corrosion and wood from biological action. By far, the most important of the 'environmentally compliant' technologies to emerge were crosslinked coatings and printing based on oligomeric acrylate monomers. These could be crosslinked rapidly by UV light in the presence of photosensitizers. Water resistance and nonbiodegradability make plastics the natural choice for such application_

6. In Building and Civil Engineering

A very visible and valuable contribution of polymers in the building industry is the replacement of wood in window frames and outdoor cladding. The advantage of plastics is their resistance to biodegradation and this characteristic, coupled with reduced decoration costs, making them the materials of choice as replacements for wood and iron.

Pigmented rigid PVC (unplasticized) is the most widely used polymeric material for outdoor use where they have to be stabilized against the effects of weather. It is achieved by the use of synergistic stabilizers. It is also used in. windows and roof-lights which need a long life of a few decades in extreme weather condition neccesiating non- biodegradability.

7. In Public Utilities

Polymers have, in recent years, assumed an increasingly important role in underground applications. These include piping, ducting and underground chambers where previously steel or concrete were used. New uses include impermeable membranes the contaminant of water in reservoirs and of effluents in sanitary landfill, in grids and nets in soil stabilization and in underground electricity cables. These sub-soil uses cc polymeric materials make use of their resistance to biodegradation. The underground transport of oil, water and gas by pipeline is an ever-increasing aspect of utility supply to industrial and domestic destinations. Iron. and steel were the main materials for construction 50 years ago and as they fail due to corrosion, they are now replaced by plastics that do not corrode. Particularly favoured are HDPE, LLDPE, PP and to a lesser extent rigid PVC.

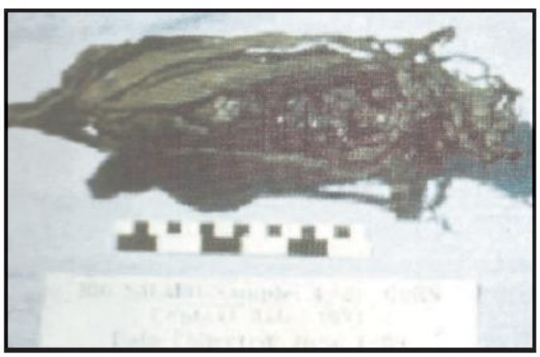
8. In Biology and Medicine

The biological inertness and lightness of polymers make them very attractive in potential biomedical applications. Typical examples of this are dental applications. Replacement plastic prostheses are now state of the art. However, in this application the durability and biocompatibility of the polymer under the aggressive conditions to which they are subjected subjected in use is a basic design parameter.

b. Biodegradability of Traditional Materials: Realities and Myths

This is a misunderstanding that there is intrinsic difference between the biodegradability of natural polymers and synthetic ones. In fact, it is not so for example, natural rubber cis-poly(isoprene], as produced by the rubber tree, is bio-assimilated into the environment initially by peroxidation followed subsequently by bio-degradation of low molar mass oxidation products (laevulinic acid, acetic acid, formic acid). Synthetic cis-poly(isoprene), manufactured from petrochemical feedstock, behaves in exactly the same way under the same conditions. However, both natural and synthetic cis-poly(isoprene) become highly resistant to biodegradation when made into industrial products (e.g. tyres). This has nothing to do with the inherent bio-degradability of *cis*poly (isoprene). It is a direct consequence of the presence of highly effective antioxidants added during manufacture. [4,12]

It is generally believed that paper and cellulosic materials are biodegradable and do not pollute the environment like plastics. However, several studies on biodegradability of cellulose material including newspapers has shown that these materials can persist in the environment even after land filling for more than 30 years.



A corn ear after 18 years of land filling

A news paper after 37 years of land filing

Wood, a natural material, which is normally considered biodegradable, may be highly resistance to biodegradation. Sequoia trees are well known to remain stable under normal climatic conditions for 500 years. Trees contains hydroxy phenols which not only protect the wood from bacterial and fungal attack but are also very powerful antioxidants with activity similar to the most effective synthetic chain breaking antioxidants[5,6]. In fact such antioxidants present in polyolefins protect them from environmental degradation. In the absence of such protective additives polyolefins will easily disintegrate in the environment.

A comparison of overall environmental burden in the process of polyethylene and paper is shown in the table below.

Comparison of air and water pollution associated with plastic and Kraft papers

Environmental burden	Polyethylene	Unbleached kraft paper	Paper combinations
Energy (GJ) for production process	29	67	69
Air pollution (kg.)			
$S0_2$9.9	19.4	28.1	
NO_x	6.8	10.2	11
CH3.8	1.2	1.5	
C0 6	3.0	2	
Dust	1	3.2	3.8
Waste water burden (kg.)			
COD	0.5	16.4	107.8
BOD_5	0.02	9.2	43.3

It is obvious that the energy cost of plastic per pound is substantially less then that of all its major competitors. The conclusion is *"The replacement of polyethylene by paper carry bags makes no sense ecologically. The production of polyethylene carry bags requires less energy, and in the process result in less burden to the environment. There is no significant difference in the disposal of polyethylene and paper bags"*

Thus the degradability or Eco-friendliness of materials is decided by the conditions of its use and disposal.

This can be further endorsed by the fact that there are infinite number of applications where long life time is essentially required and usually this can not be achieved by the so called ecofriendly traditional like material wood, paper and cellulosic materials. The table below depicts the average durability required for various application where plastics are being used extensively and successfully.

Expected durability of some materials

Material	**Expected Durability (years)**
Cable	50-60
Underground pipes	30-50
Automotive compotes	15-30
Aircrafts & Boats	10-20
Office equipments	20-30
Televisions & computers	10-20
Paintings & coatings	1-10
Window frames & Door cladding	20-50

Further, without plastics, 400 percent more material by weight and 200 percent more material; by volume would be needed to make packaging, while the volume of packaging would more than double.

a. For every seven trucks needed to deliver paper grocery bags to the store-only one truck in needed to carry the same number of plastics grocery.

b. Plastic members, made with recycled plastic, holds nails and screws better than wood, is virtually maintenance free and lasts for 50 years.

c. Foam polystyrene containers take 30 percent less total energy to make than paperboard containers.

d. By using plastic in packaging, American product manufactures save enough energy each year to provide energy to a city of 1 million homes for three and half years.

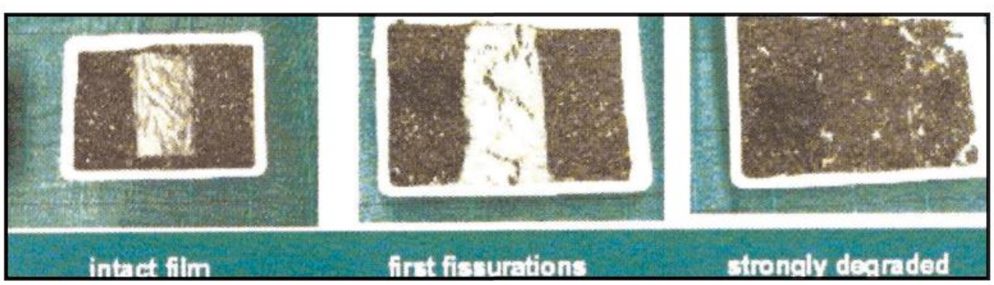
Requirement of Biodegradability

All advantages and benefits mentioned above become an issue from the point of view of environmental pollution generated by one time use disposable packaging materials. Certainly, we need to make much more efforts to make thermoplastics stable for certain applications but at the same time the biodegradability is essentially required for short lifecycle plastic materials as shown in the table below.

Expected durability of common commodity plastic materials

Materials	Generally Expected Durability (Days)
Carry Bags	30-100
Milk Pouches	30-100
Mulching Films	40-125
Disposable Food container (Food Packaging)	30-100

One biodegradable plastic film must degrade in a prescribed fashion resulting in the generation of carbon di oxide and water leaving behind some residual biomass as is shown in figures below some examples of biodegradable films from Enviro case are also shown alongside.



ideal trend of biodegradation

With Envirocare ™ Ag 1000: Mulch film becomes brittle after the desire lifetime

Without Envirocare™: Mulch film remains intact after use

Examples of biodegradation of products from Envirocare TM

International Status of Biodegradable Polymers and their Functional Advantages

Polyhydroxy alkanoates (PHA), are hydro-biodegradable polymers and can be made by fermentation of sugar. Since this process is expensive and inefficient, work is currently in progress to genetically modify oilseed rape (Brassica napus) to produce seeds containing PFIAs. Polylactic acid is another hydro-biodegradable polymer and can also be produced from sugar or corn¬starch. However, it is doubtful whether such materials could satisfy the world packaging requirements without the raw material coming into competition with food application. It seems inevitable that, even if acceptable yields of polyesters could be obtained from food crops, plastics production would be in competition with food production. In the long-term, a more acceptable ecological strategy would be to utilize the agro wastes themselves (e.g. molasses) to produce biopolymers. Since the time of the first forays into the market, biodegradable plastics have matured greatly. New polymers offering improved properties, one of which is true susceptibility to microbial attack, have entered the marketplace. In addition, standards have been developed which assess the propensity of a material to degrade biologically. Biodegradable products are no longer pitched at eliminating landfill issues but rather are targeted to specific applications such as the collection of leaf and yard waste destined to composting operations and food contact applications. In this end use, a truly compostable bag, compatible with the operation may afford economic benefit and / or improved quality of finished compost.

The use of such type of polymers in the body as temporary inclusions such as sutures and supporting meshes which require to dissolve and biodegrade over a relative short period of time requires the design of new material which, unlike the present range of bio-inert polymers, can be bioassimilated into the body after they have served their purpose. Biodegradable polymers have made possible the introduction, of mulching films where non-biodegradable polymers cannot be used. Biodegradable mulch from natural sources has been used since time immemorial to provide an insulating layer round the roots of vegetables and soft fruits.

Biodegradable and compostable plastics are available in the market from many sources. A few of them are as follows.

- Bayer - Germany has introduced a novel biodegradable polyester amide. The resin is semi-crystalline and can be injection moulded or extruded on conventional machinery. The resin is made of hexamethylene diamine, butane diol, and adipic acid. The film is translucent to transparent. Biodegradation begins when material comes in contact with humus. Target markets are trash bags, plant pots, food packaging and disposable utensils.

- Eastman Chemical Co. - TN began making copolyester 14766, sold as Eastar BioCOPE, a year ago. Expected end uses include lawn and garden bags, food packaging, and horticultural applications. When composted, the material breaks down to carbon dioxide, water and biomass at a rate comparable to newspaper. It is semi crystalline, translucent to transparent as film, with a modulus lower than PE, and oxygen-barrier properties slightly better than PE.

- BASF, Ludwigshafen, Germany has a biodegradable COPE, Ecoflex, said to have properties comparable to low density PE. Ecoflex films are tear resistant and water resistant. Unlike LDPE, they allow water vapour permeation. DuPont, Geneva, Switzerland announced last year the commercial release of its Biomax hydro / biodegradable polyester. As a modified PET, it is only marginally more expensive to produce than conventional PET. Biomax has a melting point of about 200°C. Elongation is from 50 to 500%. Strength may also be adjusted from that of LDPE to 50% of the strength of DuPont's Mylar polyester film. The company is marketing the product in the U.S. and Europe.

- Symphony Environmental Ltd, Hertfordshire, England, launched sales of a polyethylene based degradable plastic in which degradation is controlled by an additive which can be preset to ensure degradation is complete in as little as 60 days or as long as five years. Novamont SpA, Novara, Italy says the firm has four formulations of Mater N., a nontoxic, starch-based polyester and wants to increase this to fit the resin to a broader realm of niche products. Current applications include golf tees and animal toys.

- Environmental Polymers Group (EPG), a license of BTG, London., intends to further develop special grades of polyvinyl alcohol which are biodegradable in hot or cold water. These will be used in extruded blown film applications. EPG technology has two components : proprietary low shear extrusion technology and formulating technology for PVOH-based biodegradables. Firm officials say films produced will have equivalent or better physical properties than films made from PVC or PE.

- Idroplast SPA, Montecatini Terme, Italy, produces Hydrolene based on PVOH. Solubility in water occurs based on water temperature, so the material must be stored in paper and then in PE or PP sheets,. It is bubble extruded using modified extruders. Printing can be done by silk printing, offset, and lithography without pretreatment. Targets are packaging for agricultural products, seeds and disinfectants.

Some commercial examples of starch based biodegradable polymers are shown below.

Company	Brand Name
Biotech GmbH	Bioplast
VTT Chemical Technology	COHPOL
Groen Granulaat	Ecoplast
Japan Corn Starch Limited & Grand River Technology	Evercorn
Novamont SpA	Mater Bi
Starch Tech Re NEW	
Supol GmbH	Supol
Novon International	Novon

Water Soluble – Biodegradable Polymers

Water soluble polymers are used as detergent builders, scale inhibitors, flocculants, thickeners, emulsifiers and paper sizing agent. Conventional water soluble polymers persist in oceans, lakes and other water depositories. To avoid accumulation of recalcitrant substances in waterways, the commercial development of water-soluble biodegradable polymers are urgently needed. Water-soluble biodegradable polymers are synthesized by modifying starch and cellulose. Carboxy methule cellulose (CMC) is a family of water-soluble polymer. Water soluble polysaccharides, manufactured by microbial fermentation are also used as biodegradable polymers. Xanthan is the most widely used microbial polysaccharides. Poly (amino acid) with free carboxylic groups, such as poly (aspartic acid) and poly (glutamic acid) are also common among water soluble biodegradable polymers.

Additives for Plastics to promote Degradation

Some additives manufacturing companies are also working towards developing additives which will make conventional plastics degradable or disintegratable. Such additives offer a scope for modifying the properties of conventional resins like polyethylene, polypropylene, polyvinylchloride etc. Ciba Speiality chemicals has developed additives for degradable, controlled-lifetime agricultural polyolefin products, They claim that after harvesting the degradable mulch film which will left in the ground while a nondegradable film must be collected, transported to a collection centre and disposed of by burial, landfilling or incineration. So collection and disposal cost can be saved.

Challenges in Biodegradable Polymers

a Market Trends of Biodegradable Polymers

The European market for biodegradable plastics is small, about 7,000 tonnes/year, according to Greg Bohlmann of SRI Consulting. This includes about 3,800 tonnes of compost bags, 1500 tonnes of loose-fill packaging, 700 of paper coatings and 500 of food packaging.

b Costs and Commercial Availability

Price economics of currently available biodegradable polymers (Nov. 2002)

•	Lactic acid based biopolymers	: 1.5 to 3.0 US $ per pound
•	PHB based polymers	: 4 US $ per pound
•	Starch based biopolymers	: 2.25 – 2.90 US $ per pound
•	Price of conventional thermoplastics	
-	Polyethylene	: 700 – 800 USD/MT
-	Starch filled polyolefins	: 550-825 USD/MT
-	Polypropylene	: 520 – 540 USD/MT
-	Poly (vinyl chloride)	: 440 – 460 USD/MT
-	Polystyrene	: 550 – 590 USD/MT

c Being higher priced materials, widespread applications of biodegradable polymers as substitute for petrochemicals derived polymers is beset with limitations in commodity application.

NIMITLI programme on biodegradable polymers

In order to derive the fullest benefit from the indigenous Science and Technology system, the Government of India has mounted the New Millennium Indian Technology Leadership Initiative (NMITLI). This is a farsighted programme and seeks to capture for the country a global leadership position, in few selected niche areas. The onerous task of managing the NMITLI programme has been entrusted to Council of Scientific and Industrial Research (CSIR).

Agricultural byproducts constitute one of the most important classes of renewable and sustainable feedstock for the production of polymeric materials. Natural polymers such as modified starch and cellulose have been examined as biodegradable materials. India possess several agricultural products and byproducts having a large agricultural based economy. One of the NMITLI programme also aims to examine such low cost raw materials such as bagasse, Molasses and Waste grain as a precursor for producing value added biodegradable polymeric materials such as cellulose acetate, poly (latic acid), etc.

Recommendations and Conclusions

Many packaging manufacturers have exploited the 'green conscious' consumer with exaggerated claims to 'Environmentally Friendly' biodegradable packaging materials without a proper understanding of the absolute principle of 'biodegradable' materials. The replacement of traditional packaging plastics (LLDPE, LDPE, HDPE, PS & PP) by synthetic biodegradable polymers groups (polyesters viz. PLA, PCL etc.) is currently expensive proposition. Although scientific literature are replete with several publications and patents of different kind of formulations, to achieve the biodegradability either thought blending with natural biodegradable material or by the sue of only additives or biodegradable fillers, *real biodegradation* (absolute conversion of material to water and carbon dioxide leaving some biomass residues) is achieved or demonstrated only in a few selected cases. There are several factors which determine the degradability of material in the environment e.g. temperature, humidity, pH, soil enrichment, availability of sunlight, mechanical factors etc. Sellers of biodegradable plastics should be capable of supporting their claims through appropriate certification, labeling programme and must be willing to provide information indicating that their products meet recognized standards or be willing to demonstrate through field of testing that their products will meet the buyer's expectations. Buyers of biodegradable, compostable plastics should seek evidence that the product being offered has been certified or meets recognized standards or degrades in his specific conditions in a manner that meets his needs.

The following are the major recommendations

1. To set up a Centre for study of Polymer Degradation and Life Cycle analysis (PDLCA) in a well reputed institution to systematically explore all facets of polymer usage and its impact on the environment.

2. Setup in one or two locations, basic test facilities for certifying the bio or environmental degradability of materials for defined end applications. Here NCL is willing to play a lead / catalytic role in helping set up such facilities

3. Develop and establish Indian Standards for testing and evaluation of degradability of polymers (bio and environmental) and provide hands on training to representatives of industry for the same.

4. BIS should constitute a committee on biodegradability and bio-polymers and adopt such standards.

5. Conduct training and awareness programs on all aspects of bio and environmental degradation of polymers and life cycle analysis

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