BIODEGRADABLE PLASTICS

Introduction

Although plastics as we know them today are a relatively recent invention, they have become an important part of modern life.

The age of plastics

Today, 200 billion pounds (100 million tons) of plastics are produced worldwide every year. Plastics are used for packaging, building materials, and virtually every type of consumer product. Past ages of human society have been called the Stone, Bronze, Copper, Iron, and Steel Ages, based on the material that was relied upon the most during that time. Today, the total volume of plastics produced worldwide has surpassed that of steel and continues to increase. Without a doubt, we have entered the Age of Plastics.

Some common plastic items include: sunglasses, tooth brushes, super glue, paint brushes, tennis shoes, Frisbees, 2-liter bottles, Honda CRX's, Astroturf, photographs, street signs, pens, automobile paint, video tapes, rubber bands, balloons, bicycle tires, umbrellas, guitar strings, carpeting, shower doors, hearing aids, Scotch Tape, fishing lines, trash bags, and toilet seats. Plastic can be found in everything from clothing to machinary.

It is important to understand the nature of plastics, and the consequences of their production and use. Virtually all plastics are made from nonrenewable resources, such as oil, coal or natural gas, which will eventually become exhausted. Plastics waste is increasing, adding to the already burdensome problems of waste management. And the use of plastics continues to grow, raising the important question, how can we balance convenient living with concern for ecology? To understand this concern, it is helpful to understand what plastics are.

Why green plastics?

Green plastics are the focus of an emerging industry focused on making convenient living consistent with environmental stability. One reason to make a shift toward the use of green plastics is the availability of raw materials. Green plastics can be made using polymers that come from agricultural and marine feedstocks. These are abundant natural resources that are constantly being replenished. This, in turn could revitalize rural economy, both agricultural and marine, by providing additional demand for currently underutilized land or low-valued biomass commodities.

Another favorable property of green plastics is their biodegradability, making them a natural material for use in such applications as compostable collection bags, such as for food or yard waste.

But bioplastics have to possess adequate physical properties. Their properties have to be managed and controlled with technological means through the development of adequate formulations and plastics processing. The commercial ventures already under way in the United States, Canada, Europe, and Japan indicate that there is confidence technological advances are possible. The key to solving technical problems is often simply knowing what the problems are.

Bioplastics also have to be cost-competitive. Commercially available biopolymers are typically more expensive than synthetic polymers, often significantly so. Currently only starch competes with synthetic polymers in terms of cost.

Interest in the development of bioplastics will grow largely to the extent that there is real interest in and concern over the environment. Societal concern over the environment is already being reflected in governmental restrictive legislation on the use of plastics, particularly aimed at plastic packaging. Legislation has begun at the local, state, federal, and international levels, and legislation will undoubtedly increase in the future. New legislation will likely contain restrictions aimed at materials that are neither recyclable nor biodegradable. Labeling legislation may lead to an "ecolabel," based on a product's raw material usage, energy consumption, emissions from manufacture and use, and waste disposal impact. Most of all, what is needed is a paradigm shift.

Making it a reality

Ignoring nature's way of building strong materials, we have, for many applications, over-engineered our plastics for stability, with little consideration of their recyclability or ultimate fate, and ended up transforming irreplaceable resources into mountains of waste.

There is another way. We can take nature's building materials and use them for our purposes, without taking them out of nature's cycles. We can be borrowers, not consumers, so that the process can continue indefinitely. If society is indeed, becoming more and more committed to resource conservation, environmental preservation and sustainable technologies, bioplastics will find their place in this Age of Plastics.

The widespread use of these new plastics will depend on developing technologies that can be successful in the marketplace. That in turn will partly depend on how strongly society is committed to the concepts of resource conservation, environmental preservation, and sustainable technologies. There are growing signs that people indeed want to live in greater harmony with nature and leave future generations a healthy planet. If so, bioplastics will find a place in the current Age of Plastics.

Plastics

Plastics are a class of material that has one or more polymers as its primary ingredient, that is shaped by flow when it is processed (usually using heat), and that is solid in its final form. Plastics can be made up of many different kinds of polymer, and can be processed in many different ways, but as long as they satisfy these three conditions, they are *bona fide* plastics.

The general "recipe" for any kind of plastic is a combination of three ingredients: a polymer, one or more plasticizers, and one or more additives. These ingredients can then be processed into different shapes, resulting in a wide variety of different materials with different properties.

Polymers

Polymers are long molecules. They are one of the basic components of all plastics.

Synthetic polymers

Synthetic polymers are polymers that are man-made. Most synthetic polymers are manufactured from petroleum.

Some examples of synthetic polymers include:

- **polystyrene** is the polymer found in styrofoam, used for everything from packing materials and insulation to drinking cups.
- **polyvinyl chloride**, widely known by its abbreviation PVC, is used in a lot of building material (and is well-known as being ubiquitous in piping).

These materials are generally not biodegradable, and because they are made from petroleum, once the basic materials for creating them are used up, we cannot make any more.

Biopolymers

Biopolymers are polymers that occur in nature. Carbohydrates and proteins, for example, are biopolymers. Many biopolymers are already being produced commercially on large scales, although they usually are not used for the production of plastics. Even if only a small percentage of the biopolymers already being produced were used in the production of plastics, it would significantly decrease our dependence on manufactured, non-renewable resources.

Some examples of biopolymers include:

- **cellulose** is the most plentiful carbohydrate in the world; 40 percent of all organic matter is cellulose!
- **starch** is found in corn (maize), potatoes, wheat, tapioca (cassava), and some other plants. Annual world production of starch is well over 70 billion pounds, with much of it being used for non-food purposes, like making paper, cardboard, textile sizing, and adhesives.
- **collagen** is the most abundant protein found in mammals. Gelatin is denatured collagen, and is used in sausage casings, capsules for drugs and vitamin preparations, and other miscellaneous industrial applications including photography.
- **casein**, commercially produced mainly from cow's skimmed milk, is used in adhesives, binders, protective coatings, and other products.
- **soy protein** and zein (from corn) are abundant plant proteins. They are used for making adhesives and coatings for paper and cardboard.
- **polyesters** are produced by bacteria, and can be made commercially on large scales through fermentation processes. They are now being used in biomedical applications.
- A number of other natural materials can be made into polymers that are biodegradable. For example:
- **lactic acid** is now commercially produced on large scales through the fermentation of sugar feedstocks obtained from sugar beets or sugar cane, or from the conversion of starch from corn, potato peels, or other starch source. It can be polymerized to produce polylactic acid.
- **triglycerides** can also be polymerized. Triglycerides make up a large part of the storage lipids in animal and plant cells. Over sixteen billion pounds of vegetable oils are produced in the United States each year, mainly from soybean, flax, and rapeseed. Triglycerides are another promising raw material for producing plastics.
- These natural raw materials are abundant, renewable, and biodegradable, making them attractive feedstocks for bioplastics.

Plasticizers

A plasticizer is a substance that can be added to material to increase its workability, flexibility, or pliability. Plasticizers are one of basic ingredients of all plastics.

Additives

An additive is a substance that can be added to material to change its properties, usually to make the end product more desirable in some way. Additives are one of basic ingredients of all plastics.

The pure polymer resin by itself may not always have the physical properties needed in the final product, it may be strong but too brittle, flexible but too elastic, or flexible and elastic but just plain ugly. Just like the polymer material itself, additives come in different varieties: some can be found in the environment, while others are manufactured. The amounts and types of additives used in manufacturing plastics are another factor that influence how environmentally-friendly they are.

Green Plastics

Green Plastics, sometimes also called Bioplastics, are plastics that are biodegradable and are usually made mostly or entirely from renewable resources. Frequently there is also a focus on environmentally friendly processing. Green plastics are the focus of an emerging industry focused on making convenient living consistent with environmental stability.

Like all plastics, bioplastics are composed of a polymer, combined with plasticizers and additives, and processed using extrusion or thermosetting. What makes green plastics "green" is one or more of the following properties:

1. they are biodegradable
2. they are made from renewable ingredients
3. they have environmentally friendly processing
4. Because different compounds can satisfy some or all of these criteria to different degrees, there are different "degrees of green" in green plastics. To evaluate how "green" a plastic material is, you need to ask three questions:
5. how quickly can the plastic be re-integrated into the environment after it is no longer being used?
6. how quickly are the ingredients that go into making the plastic created in the environment?
7. how much pollution or waste is created during the process of actually making the plastic?

Traditional plastics fail on all three of these points.

1. Biodegradability

Biodegradation is a process where something breaks down into simple compounds as a result of the action of microorganisms (like bacteria, fungi, or algae). The term biodegradation is actually a contraction, short for "biotic degradation." Something is biodegradable if it *can* be broken down by this kind of process.

In order to say that something "biodegrades", it therefore has to meet the following requirements:

1. it has to break down (this is simply "degradation")
2. it's molecules have to break down from complex molecules into simpler ones (this is "chemical degradation")
3. the breaking down of its molecules has to be accomplished by microorganisms.
4. In order to prevent misinformation in advertising, standards organizations have made even more strict requirements for something to be labelled as biodegradable. In addition to the above list, something can only be labelled as "biodegradable" if:
5. The biodegradation of the material has to be scientifically measurable. Since most biodegradation produces CO_2 as a by-product, usually this is measured by the amount of CO_2 produced.
6. The biodegradation of the material has to be fast enough to have a significant effect in a reasonable amount of time. For example, the ISO standard requires 60% biodegradation within 180 days for a material to be called biodegradable; the Europenan Norm EN13432 is more strict, requiring 90% biodegradation within 90 days.

Types of Biodegradation

Because biodegradation requires microorganism to do something to a material, usually the material has to be broken up into smaller pieces first. As a result, most biodegradable materials *become* biodegradable after the action of another kind of degradation.

Hydro-biodegradable

Hydro-biodegradable materials are first broken down by interaction with water (a process called hydrolysis), and then are further broken down by microorganisms.

Photo-biodegradable

Photo-biodegradable materials are first broken down by interaction with sunlight (a process called photolysis), and then are further broken down by microorganisms.

Oxo-degradable

Some companies have been claiming that they have created an additive that can be added to traditional plastics to make them biodegradable. These products become what is called **oxo-degradable**, and sometimes is incorrectly identified as **oxo-biodegradable**.

Although this allows the plastic to return to the environment, these products are not biodegradable. Instead, the additive allows the plastic material to break down physically when exposed to water, into pieces small enough to be accidentally ingested by microbes. However, the microbes are not able to actually break this material down further. The end result is therefore a material that combines biomass with polymer residue. The plastic never decomposes as a result of interaction with the organisms. This process is therefore more accurately called "disintergration" rather than "biodegradation".

For bioplastics to become practical, they must have properties that allow them to compete with the current plastics on the market: bioplastics must be able to be strong, resiliant, flexible, elastic, and above all, durable. It is the very durability of traditional plastics that has helped them in the marketplace, and has been a major goal of plastics research throughout the years. However, it is exactly this durability that now has people increasingly worried. Now that we wrap our sandwiches in bags that will still be around when the sandwich, and even the person who ate it, are long gone, many people are wondering: have we gone too far?

There is a lot of current research going on concerning methods of decomposition. There is also research on controlling the time-line of biodegradation. One goal of this research is to make a product that is programmed-degradable: in other words, a product that allows you to control when and how it degrades, while insuring that the product remains strong while it is still in use.

2. Renewability

A renewable resource is a natural resource that is created in the environment faster than it is used up by people. Many people think of "renewability" as a fixed trait: some things (like trees, grass, and wind) are renewable, while others (like oil and coal) are not. In fact, whether a resource is renewable depends on both how fast it is replenished and how fast people use it. As a result, some resources are *more* renewable than others, and some resources may or may not be renewable depending on how they are used.

Rate of Renewal

The rate of rewal (sometimes also called the "sustainable yield") of a resource tells you how quickly it can be replenished by the environment.

Solar energy, tides, rainfall, and winds are considered *perpetual resources* for energy because they renew much faster than they could ever be used. (Can you imagine us "using up" the wind, so that we would have to wait until the earth made more?)

Living organisms provide the majority of resources that are generally considered "renewable", because they generally renew themelves within a reasonable amount of time relative to how quickly they are use. Agricultural feedstocks and marine feedstocks are two major categories of living organism feedstocks. Within this category, some organisms renew faster than others: for example, it takes much longer to grow a new tree than it does to grow grass.

Most of the resources that are considered "non-renewable" are based on coal, oil, natural gas, and other substances that take so long for the environment to create that almost any use of these resources at all will cause them to be used up before any more is created. Petro-chemical feedstocks are feedstocks derived from petroleum principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics.

Rate of Use

Imagine you live in a small village by a river. A turbine on the river spins, and it can generate enough electricity for the entire village every day. Clearly, their hydroelectric power is a completely renewable resource. However, as the size of the village grows, their energy use grows. If eventually the needs of the village far outstrip the energy that can be provided by the turbine, then the hydroelectric energy from the river is no longer a renewable resource for the village: the rate of use has exceeded the rate of replenishment.

The same issue exists for the use of plants. As long as our use of (for example) corn remains moderate compared to the amount of corn produced, corn is a renewable resource. However, if our use of corn increases dramatically *without* a corresponding increase in corn crop production, then corn will cease to be a renewable resource: we will use it all up, and we will either have to cease production until the corn renews itself or (worse) it will become extinct, so it will not replenish at all.

3. Processing

When making plastics, the initial mass of polymer, called resin, is processed into different shapes using a variety of methods, including: extrusion, injection molding, compression molding, transfer molding, and casting. Different processing techniques result in the wide variety of forms that plastic can take: ranging from thin films and elastic sheets, to resiliant panels and hard, solid three-dimensional shapes.

HISTORY OF BIOPLASTICS

The use of natural polymers is not entirely a new idea. In one form or another, green plastics have been around for a long time.

Early History

Natural resins-like amber, shellac, and gutta percha-have been mentioned throughout history, including during Roman times and the Middle Ages. Native Americans were developing and refining techniques for making ladles and spoons from animal horns long before there was any European contact. In Europe, molded horn jewelry and snuff boxes were popular in the eighteenth century.

The 1800's

Significant commercialization of bioplastics only began in the middle of the nineteenth century... The American inventor, John Wesley Hyatt, Jr., was looking for a substitute for ivory in the manufacture of billiard balls, and in 1869 patented a cellulose derivative for coating non-ivory billiard balls. That attempt, however, was affected by the coating's flammability; balls were occasionally ignited when lit cigars accidentally came into contact with them. Hyatt continued working on the project and soon developed celluloid, the first widely used plastic, now most widely known for its use in photographic and movie film.

The 1900's

The history of plastics changed dramatically in the early 1900s, as petroleum emerged as a source of fuel and of chemicals. The early bioplastics were simply displaced by plastics made from synthetic polymers. World War II brought on a large increase in plastics production, a growth which continues to this day.

The 1920's

In the 1920s Henry Ford experimented with using soybeans in the manufacture of automobiles. Ford was partly motivated by a desire to find non-food applications for agricultural surpluses, which existed then as they do now. Soy plastics were used for an increasing number of automobile parts, like steering wheels, interior trim, and dashboard panels. Finally Ford gave the go-ahead to produce a complete prototype "plastic car." Ford, a master at generating publicity, exhibited the prototype with great fanfare in 1941, but by the end of the year was no longer publicizing the "plastic car," probably for a variety of reasons. World War II played a role: armament work took precedent over almost everything else, and steel shortages limited all non-defense production. Today plastic automobile parts are common, but the use of plastics made from renewable raw materials got side-tracked.

The 1960's

One well established bioplastic that has survived the growth of the synthetic plastics industry is cellophane, a sheet material derived from cellulose. Although production peaked in the 1960s it is still used in packaging for candy, cigarettes, and other articles.

The 2000's and Beyond

Demand for materials like plastics is continually growing and will not be abated. Today, the plastics industry is an important component of our economy: The U.S. plastics industry includes over 20,000 facilities that produce or distribute materials or products, employ over 1.5 million workers, and ship over $300 billion in products each year.

The magnitude of the plastics industry, however, is itself a cause for concern. The pressures of increasing waste and diminishing resources have lead many to try to re-discover natural polymers and put them to use as materials for manufactor and industry. As a result, there is increasing interest in the promise of a new generation of green plastics.