Novamont (Italy)

Bioplastics in Food Packaging:
Innovative Technologies for Biodegradable Packaging

FKur Kunststoffe Gmbh

EarthShell Corporation (USA)

NODAX (USA)

Lillian Liu
San Jose State University
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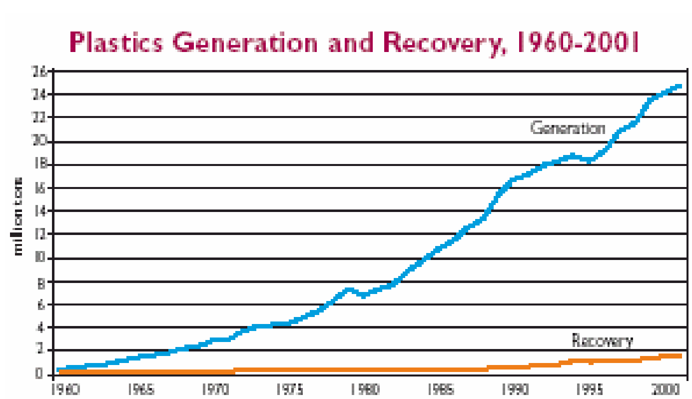
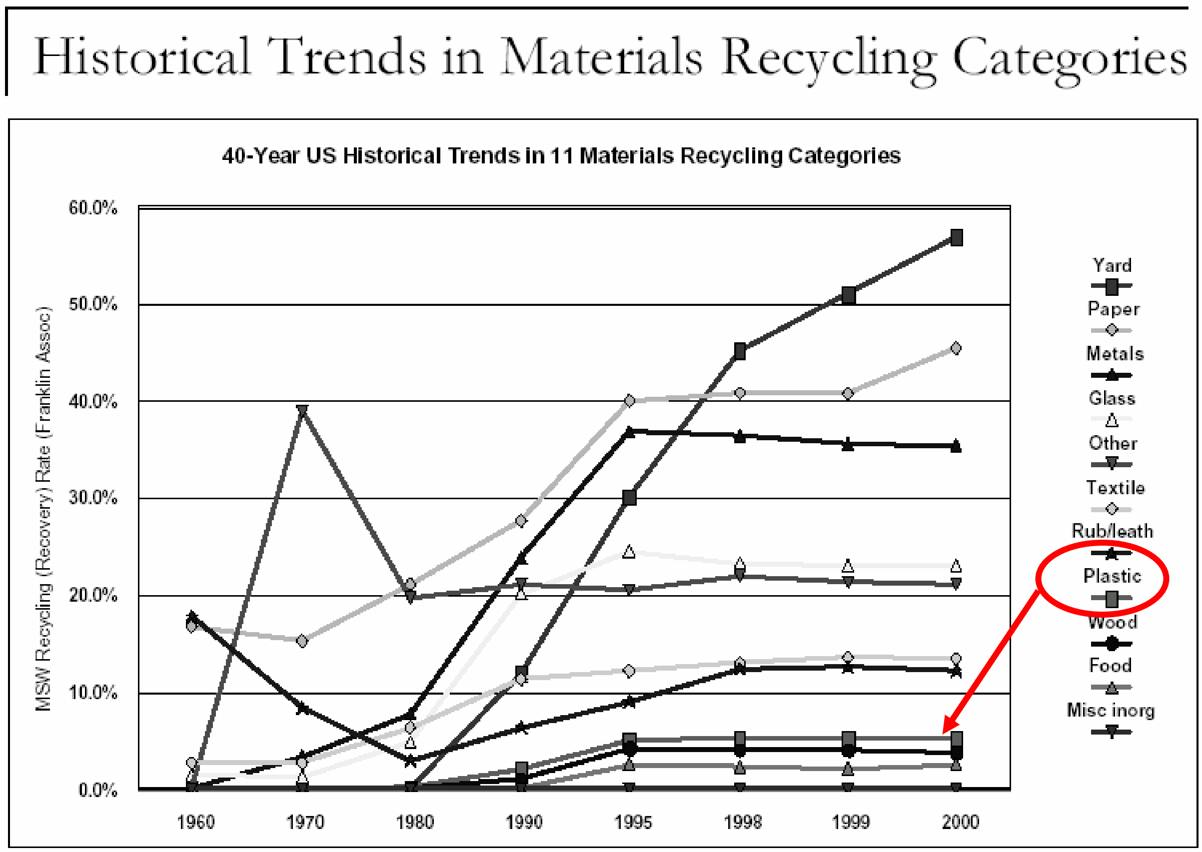
Introduction

In 2001, the United States generated approximately two hundred thirty million (230 million) tons of waste (before recycling) – or approximately 4.4 pounds per person each day. Of this municipal waste, plastics currently account for approximately 11 percent, with plastic containers and packaging being the chief source, accounting for more than 11 million tons in 2001 (or about 5 percent) of the total waste generated that year.

Recovery methods for plastics include recycling, reuse, energy recovery, and composting. In food packaging, re-use and recycling of discarded packaging materials is severely limited, as the collected items contain an increasing proportion of unique materials consisting of multi-layered structures developed for purposes of achieving optimal barrier properties. These multi-layered materials are extremely difficult – if not impossible – to separate into their respective individual layers for recycling. Further compounding this problem (in the United States), as shown in the following graphs prepared by the U.S. Environmental Protection Agency, is the slow rate of plastics recovery when compared against the exponential growth of plastics generation over the past four decades.



Source: "Characterization of Municipal Solid Waste in the United States: 2001 Update," U.S. Environmental Protection Agency, Office of Solid Waste



Source: *"Assessment of OSW's 35% Municipal Solid Waste Recycling National GPRA Goal for 2005,"* U.S. Environmental Protection Agency.

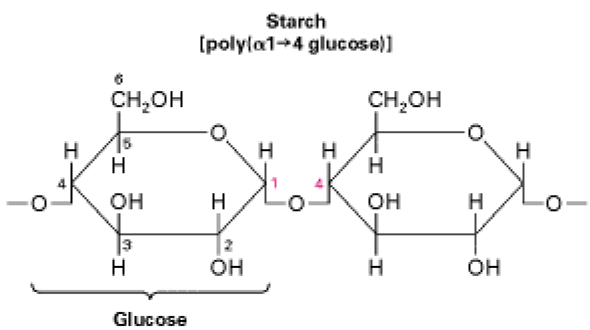
Recovery of packaging materials is often difficult due to lack of collection and processing infrastructure, resulting primarily from a lack of consumer interest and education. Environmental awareness has been growing, however, over the relentless rise in demand for pre-packaged disposable meals, and consumers have increasingly targeted food manufacturers and packagers to improve their environmental performances. *Datamonitor* statistics show that more than one-third of European consumers live alone and are spending €140 billion a year on food, drinks and personal care products; single people spend 50 percent more per person on consumer-packaged goods than a two-adult household. Similar trends have been observed in the U.S. and other economically developed nations, and underscore why the environmental impact of food packaging is a concern of increasingly global magnitude.

Because of this growing problem of waste disposal and because petroleum is a non-renewable resource with diminishing quantities, renewed interest in packaging research is underway to develop and promote the use of "bioplastics." Bioplastics is a term used for packaging materials derived from renewable resources, and which are considered safe to be used in food applications. In general, compared to conventional plastics derived from petroleum, bio-based polymers have more diverse stereochemistry and architecture of side chains which enable research scientists a greater number of opportunities to customize the properties of the final packaging material.

The primary challenge facing the food industry in producing bioplastic packaging, currently, is to match the durability of the packaging with product shelf-life. Alone or working in combination, environmental temperature, relative humidity, presence of active bacterial and spoilage microorganisms, ultraviolet exposure, etc. are the usual modes of degradation in food quality and spoilage. These factors that cause deterioration of the food product are also factors that influence the rate of degradation of the bioplastic material, and special care must be taken to develop bioplastic materials which address these concerns. More importantly, processes must be developed such that innovative developments in the properties of bioplastics materials can be implemented for industrial-scale applications.

Major Bioplastics in Development Today

A number of bio-based materials and their innovative applications in food-related packaging have gained much attention over the past several years. These new materials include starch, cellulose, and those derived from processes involving microbial fermentation. Bioplastic development efforts have focused predominantly upon starch, which is a renewable and widely available raw material. Starch is economically competitive with petroleum and has been used in several methods for preparing compostable plastics. Corn is the primary source of starch for bioplastics, although more recent global research is evaluating the potential use in bioplastics for starches from potato, wheat, rice, barley, oat and soy sources.

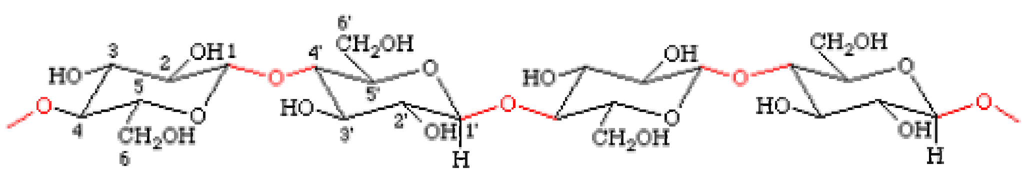


Starch is a biopolymer formed from glucose units linked together via α-1,4 glycosidic linkages.

As a packaging material, however, starch-based bioplastics are extremely brittle. Starch alone cannot form films with satisfactory mechanical properties (high percentage elongation, tensile and flexural strength) unless it is plasticized, blended with other materials, chemically modified, or modified with a combination of these treatments. Common plasticizers used include glycerol and other low-molecular-weight polyhydroxy-compounds, polyethers and urea.

Starch-based thermoplastic materials have been commercialized over the last several years and currently dominate the market of bio-based, compostable materials. Food-related applications include films for food wrapping and thermoplastics for food packaging and other food containers such as bowls, plates, cups and egg trays. Thermoplastic starch has been shown to demonstrate good oxygen-barrier properties, but the hygroscopic nature of starch dictates this material is unsuitable for high-moisture and liquid food products.

Cellulose is the most abundantly occurring natural polymer on earth and – like starch – is also comprised of glucose monomer units. Unlike starch, however, the glucose units in cellulose are joined together via β-1,4 glycosidic linkages, which enable cellulose chains to pack tightly together and form strong inter-chain hydrogen bonds.



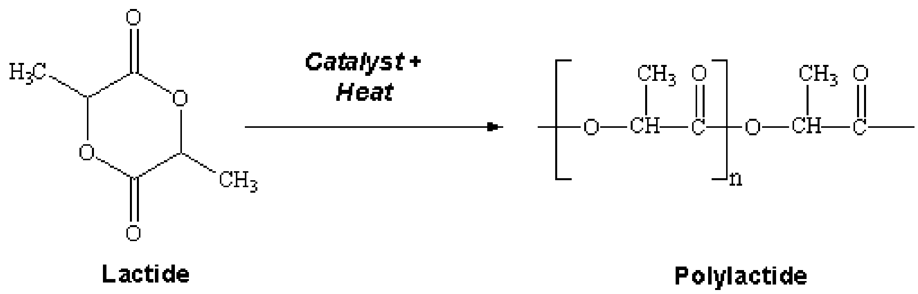
Alternating orientations of the D-glucopyranose rings along the cellulose backbone allow for the strong hydrogen bonding interaction between cellulose chains.

Cellulose is found in all plant material and is thus a very inexpensive natural resource. It is, however, difficult to use in packaging because of its hydrophilic nature, poor solubility characteristics, and highly crystalline structure. The alternating hydroxyl side-chains along the cellulose backbone are responsible for the poor moisture-barrier properties of cellulose-based packaging materials. They also contribute to the highly crystalline structure of cellulose which, in turn, results in a packaging material that is brittle and demonstrates poor flexibility and tensile strength. As a result, academic and industrial research has been focused in recent years on the development of cellulose derivatives for use in packaging applications.

Cellulose acetate is one such cellulose derivative. Although cellulose acetate was first prepared in the late 1800's and has been traditionally used in the production of synthetic fibers and as a film base in photography, its "Generally Recognized As Safe" (GRAS) standing with the FDA has prompted the food packaging industry to more aggressively develop innovative applications for cellulose acetate. As such, cellulose acetate is commonly used for wrapping baked goods and fresh produce. Although cellulose acetate requires the addition of plasticizers for production into films, the resulting product demonstrates good gloss and clarity, good printability, rigidity and dimensional stability. While these films can tear easily, they are tough and resistant to punctures. Cellulose acetate films, however, possess relatively poor gas and moisture barrier properties and are known to undergo hydrolysis to produce acetic acid in what is commonly referred to as the "vinegar syndrome." These properties have prevented more widespread use of cellulose acetate films in today's food packaging applications.

Like cellulose acetate, many other cellulose derivatives possess excellent film-forming properties, but industrial-scale application of this technology has yet to be implemented. This is a direct consequence of the crystalline structure of cellulose making the initial steps of derivatization difficult and costly. Continued research and innovation in this area is required to develop more cost-efficient processing technologies for the production of these cellulose derivatives in bioplastics-based packaging.

Some of the most innovative research today, however, has been underway in the area of bioplastics synthesized via microbial fermentation of polysaccharides. These efforts have resulted in the development of polylactides (PLAs) and poly-hydroxyalkanoates (PHAs). Also known as polylactic acid, PLA is a biodegradable, thermoplastic, aliphatic (non-aromatic and non-cyclic) polyester derived from lactic acid. This lactic acid source of PLA is itself produced from the fermentation of agricultural by-products such as cornstarch or other starch-rich substances like maize, sugar or wheat.



This picture shows a schematic view of the ring-opening polymerization reaction of polylactide from lactide, a dimer of lactic acid.

PLA can be easily produced in a high-molecular-weight form through ring-opening polymerization of lactide using a (stannous octoate) catalyst. The resulting thermoplastic film material offers good moisture-barrier properties and is able to withstand the rigors of injection molding and blow- or vacuum-forming processes. PLA is currently utilized in the production of loose-fill packaging, food packaging and disposable foodservice tableware items.

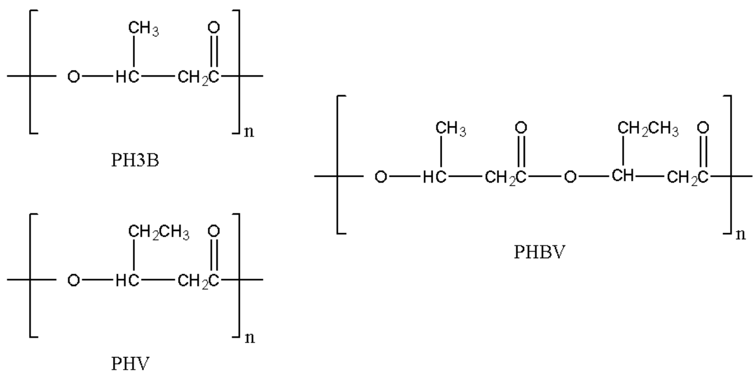
Another bioplastics innovation resulting from the application of microbiological techniques are poly-hydroxyalkanoates (PHAs). PHAs are linear polyesters produced via bacterial fermentation of sugars or lipids. There are more than 100 different known monomers that can be combined within this family to yield materials with extremely different properties. As such, properties of PHAs depend upon the composition of the monomer unit, the microorganism used in fermentation, as well as the nature of the carbon source used during the fermentation process. The most common type of PHA is poly-hydroxybutyrate (PHB), which is the most popular PHA used in food-packaging.

Although they tend to have a lower glass transition, melting temperature, and degree of crystallinity relative to PHBs, in general, PHAs behave as elastomers with crystals acting as physical cross-links. In addition, PHAs offer a low moisture-vapor permeability that is comparable to that of low-density polyethylene (LDPE). Recent application developments based on medium-chain length PHAs include biodegradable cheese coatings.

Like PHA, PHB is produced by microorganisms (such as *Alcaligenes eutrophus*) and is utilized as an energy storage molecule within the microorganism's cellular structure. Microbial synthesis of PHB starts with a condensation reaction between two molecules of acetyl-CoA. The resulting product is acetoacetyl-CoA, which is subsequently reduced to hydroxybutyryl-CoA. It is this latter compound that is used as the monomer unit from which polymerization of PHB begins.

Microorganism filled with polymer material.
Source: Metabolix website (www.metabolix.com).

PHB has properties resembling those of polypropylene (PP) in relation to melting temperature (175-180°C) and mechanical behavior; however, it is stiffer and more brittle than PP. Thus packaging made from PHB offers poor impact resistance, which is a leading factor prohibiting more extensive use of PHB in food packaging applications. Another major limiting factor of PHB is its relatively expensive production costs when compared with plastics produced from petrochemicals. Because it offers the benefits of biodegradability, though, market expectations remain high for the development of PHB-based materials that have good potential for replacing PP in bottles, bags, and film applications.



*The poly-3-hydroxybutyrate (P3HB) form of PHB (*top left*) is the most common type of polyhydroxyalkanoate (PHA), but many other polymers of this class are produced by a variety of microorganisms; these include polyhydroxyvalerate (PHV,* bottom left*) and its PHBV copolymer (*right*).*

With continued market anticipation for these environmentally-friendly bioplastics, a number of companies have dedicated new efforts – or renewed previous efforts – to the development of commercially-viable and sustainable food-related packaging applications using starch, cellulose, and microbially-produced biopolymers. A few examples of these companies are listed in the table below and reflect not only the diversity of applications for bioplastics in food packaging, but also the recognition by industry across the globe for the need to produce environmentally-responsible packaging materials:

Company	Country	Starch-based	Cellulose	Microbial (PLA/PHA/PHB)	Comments
Bioenvelop	Canada	x			Product: *BioP* moisture-barrier coating films for biodegradable food containers and utensils.
EarthShell Corp.	USA	x			Foam laminate product; primarily serving food-service industry with food containers and serviceware.
EverCorn, Inc. (subsidiary of Japan Corn Starch Co., Ltd.)	Japan	x			*EverCorn* resin used in the following food-related applications: disposable serviceware and utensils, lamination or coatings for paper/paperboard, foam products for trays, food containers and other packaging material, and films for food wrapping.
National Starch Company	UK	x			Packing (packing peanuts) applications for shipping and distribution.
Novamont	Italy	x			*Mater-Bi* line produced from maize starch for applications in food as extrusions, films, thermoforms, injection-molded and foam products.
StarchTech, Inc.	USA	x			Loose-fill packing material produced from starch (from corn and potatoes). Dissolves in water.
VTT Chemical Technology	Finland	x			Starch is first derived as a hydrophobic ester and then formulated to bioplastic or a water dispersion for food packaging applications. *COHPOL* product for injection molding and dispersion formulations (for paper and board coating).
FKur Kunststoffe GmbH	Germany		x	x	*Biograde* PLA- and cellulose-blends for food packaging applications; supports blow- and injection-molding processing.
Metabolix	USA			PHA	Focuses on food packaging applications, including disposable food containers and utensils. Can be utilized as cast film, cast sheets for thermoforming, and supports injection molding and melt-extrusion processes for paper and board coatings.
NatureWorks LLC	USA			PLA	*NatureWorks PLA* and *Ingeo* product lines for food packaging (bakery, deli/meat, produce, confectionary, food wrapping, dairy) and serviceware applications.
NODAX	USA			PHA	Benefits of *Nodax* ™ include anaerobic and aerobic degradability, hydrolytic stability, good odor and oxygen barrier properties, good surface properties for printability, a wide range of customizable mechanical properties (elastic and soft vs. hard/stiff).

Table 1. Sample companies involved in bioplastics for food-related packaging applications. (Source: company websites, accessed November 2005 through February 2006.)

Summary

Without question, the challenges surrounding plastics waste treatment are multi-faceted and complex – and, as numerous studies have indicated, are further being compounded as time progresses. It will be up to future generations of society to produce the necessary resources to address this growing environmental concern with viable, long-term solutions. Truly innovative global research and development has resulted in today's emerging field of bioplastics. By combining the disciplines of agricultural biology, food packaging, and microbiology, new biodegradable packaging solutions made from renewable plant resources are helping to address this environmental concern of rampant worldwide growth in plastics waste.

It is important to recognize that although past and recent efforts have thus far yielded significant strides in the field of bioplastics, continued research in this field is clearly needed if economically-viable development and sustainable production processes are to be widely implemented throughout the world. As with any emerging technology, continued innovation and global support is essential in order for bioplastics to fully demonstrate its socioeconomic benefits and further challenge the *status quo* of traditional petroleum-based plastics.

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