DEGRADABLE PLASTICS

Proceedings
of Symposium on
DEGRADABLE PLASTICS
June 10, 1987
Washington, D.C.

Sponsored by The Society of the Plastics Industry, Inc.

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The Society of the Plastics Industry, Inc. is a trade organization of more than 1,900 members representing all segments of the plastics industry in the United States. SPI's operating units and committees are composed of resin manufacturers, distributors, machinery manufacturers, plastics processors, moldmakers, and other industry-related groups and individuals. Founded in 1937, SPI serves as the "voice" of the plastics industry.

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REMARKS OF C. E. O'CONNELL

President, The Society of the Plastics Industry, Inc.

Good morning . . . and welcome to what we believe will be a very enlightening day of presentations and dialogue on the subject of degradable plastics.

Today promises to be more than a purely technical event. Thanks to several events in recent months, degradability has become an integral part of a larger discussion—that of solid waste management and litter control. It is in the context of this larger issue that we come together today—to discuss not only how some plastics can be made to degrade, but also whether some should be made to degrade.

For more than a month this spring, national attention focused on a garbage barge—the scow without a country—that was unable to find a place to drop its cargo . . . every landfill between New York and South America, it seemed, was full or otherwise unwilling to accept the load. Legislators, reporters and environmentalists across the country eagerly took the opportunity to use the barge . . . as a symbol of the nation's emerging solid waste disposal crisis.

Even before the barge saga began, we at SPI were feeling pressure from various publics wrestling with the solid waste issue.

Legislators, for instance, in more than a dozen states, have introduced bills targeted specifically at post-consumer plastics . . . materials they often consider to be particular problems in the waste stream. Sometimes, in their search for answers, they have latched onto the idea of degradability as a possible solution.

In New Jersey, for instance, one lawmaker is seeking to ban non-degradable egg cartons . . . another, non-degradable tampon applicators. Berkeley, California—like the state of Michigan a year ago—is considering a ban on all non-biodegradable fast food packaging. In Oregon, the legislature is debating a ban on plastic grocery bags and nondegradable diapers. And Senator John Chafee of Rhode Island—who will be our lunch speaker today—has introduced a bill in Congress that, among other things, would ban non-degradable six-pack loops nationwide. Already 11 states require that these items be degradable . . . and the list goes on.

In the popular press, as well, attention is focusing on degradability. Numerous stories in recent months have reported on the dangers of plastics items in the marine environment. Others have featured certain products, like garbage bags or agricultural films, that are being made from degradable resins. Because of stories such as these, levels of expectation are being raised as to what degradability can or should achieve.

As the interest in solid waste, litter and degradability has grown, we have become aware of how little definitive information we as an industry have assembled on degradability—not only the technology behind it, but also the potential applications for it.

Legislators, reporters and environmentalists frequently are asking us questions to which we have no firm answers . . . questions about whether plastics can be made to degrade . . . whether they should be made to degrade . . . and in what applications it would be advisable to make them degrade.

The answers are not going to be easy to find . . . but our purpose in coming together today is to lay the foundation for developing some of those answers.

The idea of making plastics degradable is not a new one. Back in the early 1970s, protection of the environment was a high priority which resulted in the adoption of many beneficial laws and industry practices. It was about this time that "biodegradable" became a buzz word . . . which for many people implied an easy solution to a myriad of problems, including that of litter.

An emotional sense of well-being often accompanied the concept of degradability . . . and it persists even today among those who view it as a panacea in alleviating both litter and waste disposal problems . . . it could be a placebo rather than a panacea.

Quite a bit of research was done back then on degradability and plastics . . . and in many cases, technological developments were spurred by public and political pressures.

Today, that pressure has resurfaced—and is building rapidly. Once again, concerns about the environment are dominating legislative agendas as well as the editorial pages of daily newspapers.

Let's look for a moment at the reasons behind this interest in degradable plastics. Just what is it that the public is expecting from degradability? The answer, I believe, is two-fold.

First, it is seen as a solution to the persistent problem of unsightly litter. When products of all types . . . including plastics . . . are carelessly littered on roadsides and beaches, we all agree that they create an aesthetic problem. And, particularly in marine environments, this litter is seen as more than unsightly . . . it is believed to be an environmental problem that threatens the safety and health of many ocean mammals and seabirds.

Our belief is that education is the key to eliminating litter—it is, after all, primarily a problem of behavior—people who litter do so either because they don't think or don't care. But with a well thought out and implemented public awareness and education program, we believe that we can get the thoughtless to think . . . and the careless to care . . . with the result being a marked reduction in litter of all sorts.

To this end, SPI has been working with the Center for Environmental Education . . . a conservation organization dedicated to protecting marine wildlife . . . to develop public service advertisements and educational materials geared toward the maritime, commercial fishing, and plastics industries—those industries believed to be key players in the marine pollution problem.

But education programs are not likely to result in immediately observable solutions . . . so some groups, in hopes of seeing more short-term results, are seeking to ban materials that they feel are more persistent in litter—and therefore less desirable in the environment—namely plastics. The perceived need is for materials that degrade quickly in the environment when they are littered. However, even most "traditional" materials, like paper, glass and aluminum, don't meet this criterion.

Some of the legislation that has been proposed calls for plastics to degrade within 90 to 120 days . . . but surely those who would ask for such a requirement do not realize that this is a goal that cannot be met by any of the so-called "traditional" packaging materials . . . and so, in effect, plastics are being singled out. Certainly aluminum and glass . . . and even paper . . . do not "disappear from view" in such a short period of time. They may, in fact, persist for months or even years before the natural forces of wind . . . rain . . . rust and decay . . . eliminate them from sight.

Likewise, those who wish to ban certain plastics might not realize that they could be replacing superior-performance with possibly less desirable materials . . . that do not degrade nearly as fast as they wish to believe.

The second reason behind the push for degradable packaging materials has to do with the solid waste disposal crisis that I mentioned earlier. According to a recent study, one out of every four states is expected to run out of landfill capacity by 1990. Because it is extremely difficult to site new, politically acceptable landfills and resource recovery facilities, municipalities are looking for ways to extend the useful lives of their existing landfills. One way, some decision-makers figure, is to make the solid waste that goes into the landfills degrade faster, therefore making more room.

Now the logic behind this motivation may be faulty . . . and it can be argued that nondegradability may even be an advantage in landfills—because, for instance, degrading waste can cause the build-up of explosive methane . . . or can cause hazardous leachate or groundwater contamination. But when faced with a crisis, the mere perception that degradability can ease landfill burdens may be enough to cause a public outcry for action from the plastics industry.

So it is with these perceptions in mind that we come together today to rekindle the plastics industry's interest in examining applications and markets for degradable plastics . . . where there may be a need. At the same time, we must keep in mind several questions that must be carefully examined before we can determine where degradability truly is feasible, and not just technically possible.

For instance:

- What really are "appropriate" applications?
- In what types of products would the desirability of degradability outweigh the need for durability or integrity in a package, for instance?
- What effect would chemical modifications in a polymer have on the ability of a food or beverage package to assure safety from microbial contamination?
- What impact would these chemical modifications have on the recyclability of these polymers?
- What would be the by-products of decomposition of these materials? Would the perceived environmental benefit of degradability truly outweigh the possible hazard of undesirable by-products in the ground or air?
- What would be the true effects of degradable plastics on easing litter problems or landfill burdens?

We also must keep in mind that while most of the debate we hear today concerns packaging materials, only one-quarter of plastics are used in packaging. Many of the other applications are in markets like building and construction . . . or transportation . . . or medicine . . . applications where durability is more than a benefit—it is an absolute necessity.

Remember, too, that durability in packaging materials is not the only reason that the users of plastics packaging chose them over "traditional" materials—their light weight and virtually limitless design possibilities are unmatched by competitive materials. But even more important are the safety advantages provided by their shatter resistance . . . which has made glass bottles virtually obsolete in both bathroom and laundry products.

During the next few hours, we will hear from researchers who can explain to us what is meant by the term degradable . . . and what is known about making different polymers degrade. We'll hear presentations of papers from people who have developed technologies to make certain plastics degrade . . . and from others who are marketing products that take advantage of these technologies.

I hope that by the end of the day we will have enough information to go away thinking about plastics, and particularly plastics packaging, in a new way.

We are being asked to think about product design from the cradle to the grave . . . and as a responsible industry, we must give serious thought to the ultimate disposal of our products after their useful life is finished.

I doubt that we will come away with many answers today . . . but as far as I am concerned, that is not really our goal. If we can come away with an appreciation for the difficult questions . . . and an awareness of the perceived needs . . . we will be that much closer to determining just where degradability is truly feasible, both today and in the future.

BIOGRAPHY

Charles E. O'Connell

Chuck O'Connell became the fifth president in the nearly half-century history of The Society of the Plastics Industry, Inc. on May 1, 1985.

At the time of his selection to head SPI, one of the nation's largest trade associations, Mr. O'Connell was senior vice president of chemicals for Gulf Oil, based in Houston. He entered the industry in 1956 in his hometown of Kansas City when he joined Spencer Chemical Company, later acquired by Gulf.

Mr. O'Connell worked as a plastics salesman for Gulf in Chicago, returning after a few years to Kansas City to be district manager, sales manager and eventually vice president of Gulf's Plastics Division. He was transferred to Houston in 1967 and through several promotions reached his senior v.p. post at Gulf in 1983. As senior vice president of chemicals he was responsible for all U.S. operations—including plastics. During these years, Mr. O'Connell participated in a wide range of SPI activities as his company's representative. He was a member of SPI's Board and Executive Committee in the mid-1970s.

An alumnus of the University of Kansas where he earned a bachelor of arts degree, Mr. O'Connell was in the U.S. Coast Guard from 1951 through 1954. He and his wife Mary are parents of five children. They are residents of McLean, Virginia, a suburb of Washington, where SPI headquarters are now located.

DEGRADABLE PLASTICS IN EUROPE

Peter Claus
The Association of Plastics Manufacturers in Europe

SYNOPSIS

Degradable plastics find use in applications requiring eventual disintegration and disappearance of the material for the function served, such as in agricultural mulch film and in surgical sutures. A proposed regulation in Italy will prohibit the use of non-biodegradable materials for shopping bags, retail pouches, and, in a later stage, for all pre-packaging, in an effort to reduce litter as well as domestic waste. Given as an argument for political moves in a period of government shifts and elections, a number of towns and cities in Italy have now banned the use of plastics containers and packaging in a premature and ill-founded application of the regulation. These developments reflect a lack of understanding and misappropriation by political and government bodies of the concept and practical applicability of degradable plastics.

Short-term uses of plastics, mainly packaging, account for 20% of the consumption of plastics in Europe in 1986—3.7 million metric tons. European domestic waste is estimated to be 100 million metric tons in 1986, of which plastics comprise about 7%, short-term use articles being about 4%. The amount of domestic waste disposal methods used in Europe vary by country, for example landfill is the most prevalent method used in the U.S., whereas incineration is the most prevalent method in Japan. EEC waste management policies are being developed.

THE VIEWS ON PLASTICS IN DOMESTIC WASTE:

- Plastics in domestic waste are an advantage rather than a problem for modern waste disposal methods.
- Mandatory restrictions of uses for plastics as a measure for waste reduction are discriminatory and unecological.
- Incineration with heat recovery is the realistic waste disposal method, with plastics an energy bonus.
- In some cases, waste light fraction separation for refuse derived fuel (RDF) use or for secondary material use may be economic—not on any large scale.
- Economic material recycling requires consistent quality, and regular adequate supply of plastics wastes—typically industry and trade sourced.
- Littering is caused by socially irresponsible attitudes, and must be cured at source, not by doctoring symptoms—irrespective of materials in question.

APME VIEWS ON PLASTICS DEGRADABILITY (1)

- Common plastics are considered photodegradable to variable degrees—not biodegradable.
- By far most plastics uses require consistent material properties over a flexible lifetime, for reliable and safe service.
- Food grade materials, representing 50% of plastics outlets in West Europe, must be
  - — Impermeable, impervious to outside media and agents
  - — Mechanically resistant
  - — Chemically and biologically inert
  - — Readily processable and competitive

  What scope for enhanced degradability?

APME VIEW ON PLASTICS DEGRADABILITY (2)

- Degradable plastics, like other commercial materials, will find uses requiring their price/performance profile.

  Under the state-of-the-art, they offer no general solution to waste and litter problems, and must not be imposed as such by official authorities.
- For market acceptance, predictable performance of degradable plastics requires control of
  - — Degradation process and circumstances
  - — Effects on users and the environment
  - — Performance specifications, with test methods for compliance and quality control

Peter Claus

Peter Claus is Director of the Association of Plastics Manufacturers in Europe (APME).

Founded in 1976 under Belgium law, APME is a West European non-profit association. APME represents the plastics manufacturing industry in the European member countries of OECD.

WHAT PRICE CONVENIENCE? THE NATIONAL ENVIRONMENTAL COMMUNITY'S CONCERN WITH THE FATE OF PLASTICS

Michael J. Bean
Environmental Defense Fund

OVERVIEW

There is increasing concern within the environmental community and within governments about the fate of plastics in the environment. As plastic products take over a greater share of the markets for soft drink containers, grocery bags, and myriad other containers, they will comprise a growing share of the general litter problem and the associated solid waste disposal problem.

The concern with plastic wastes, however, is not merely an aesthetic one. There is mounting evidence that plastic wastes present a hazard to living wild resources, particularly in the marine environment. Buoyant, nearly indestructible, and often virtually invisible to many marine organisms, plastics threaten to take an increasingly heavy toll of marine birds, turtles, mammals and fish through entanglement with lost or discarded fishing gear, plastic strapping bands, and other debris. Ingestion of small plastic particles by marine animals has also been documented for an extraordinary number of species with sometimes staggering frequency. More than 50 marine bird species have been shown to eat plastic particles found at sea; one recent study of an Hawaiian albatross colony found that 90 percent of the chicks in the colony had indigestible plastic in their gullets.

The mounting evidence of risks to the environment from persistent, non-degradable plastic waste seems certain to create strong pressures for change. The major focus is likely to be on increasing the recycling opportunities for plastic products. Today, the recycling of plastics lags woefully behind that for the materials they are replacing in the marketplace; the most promising means of reducing the environmental hazards of plastic is by recycling, and thus reducing the volume of plastic capable of entering the environment.

A second means of reducing the environmental hazards of plastic may be through designing them to degrade in the environment. About a dozen states now require such degradability for beverage ring carriers. The important environmental questions that must be asked are whether the products of degradation are themselves environmentally safe and whether degradation can occur rapidly enough to reduce significantly the hazards of plastics in the environment. The obvious marketing question is whether plastic products made to degrade can continue to serve their intended function in the marketplace.

Without significant progress in the recycling of plastic wastes or other solutions—like engineering the degradability of plastics—more draconian solutions may not be far over the horizon. These may take the form of differential taxes to encourage the use of alternative materials or even outright product bans. There is growing interest in the latter in state legislatures and even in the Senate dining room.

BIOGRAPHY

Michael J. Bean, Esq.

Michael J. Bean, Esq., graduate of Yale Law School, has been chairman of the Wildlife Program of the Environmental Defense Fund since 1977. He is the author of "The Evolution of National Wildlife Law." Since 1984, he has been involved in efforts to develop legal strategies for controlling plastic pollution in marine environments.

Proceedings of Symposium on Degradable Plastics, The Society of the Plastics Industry, Inc., Washington, D.C., June 10, 1987

AN SPI OVERVIEW OF DEGRADABLE PLASTICS

presented by

Regina Johnson

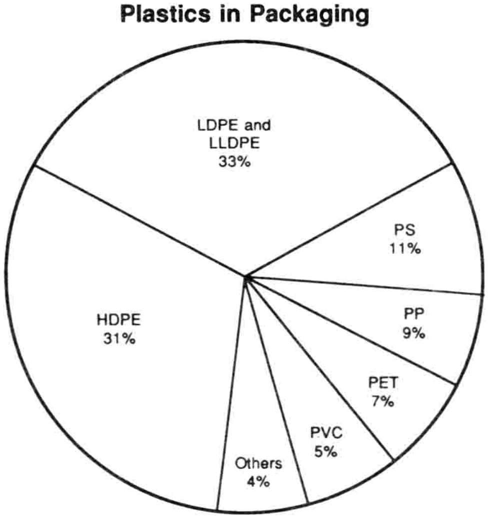
Dow Chemical Company

Plastics, relatively new materials, have become almost as ubiquitous in use as such centuries-old materials as glass, metals, paper, wood, and masonry. Plastics are synthetic polymers, as opposed to natural polymers such as cellulose, starch, and natural rubber, and have replaced the old materials in many applications. Since their introduction into commerce in 1868 when cellulose nitrate was used to make eye glass frames, the types of plastics have proliferated to become the materials of choice in hundreds of old and new uses. The growth of plastics was accelerated by World War II when plastics became critical to electronics and communications, particularly in hot, humid environments where many other materials deteriorated or decomposed. Plastics' light weight, inertness, safety, permanence and economics are the properties largely responsible for their value. In the U.S. today, the volume of plastics used exceeds that of steel.

Plastics is a generic term like "metals." Plastics can be as different from one another as is iron from aluminum or lead from gold. Some are transparent, some flexible, some rigid, but generally they are light weight, inert, resistant to microbial attack and safe in use. All are synthesized from petrochemicals, air, and other natural substances to create long-chain molecules whose structure determines each plastic's unique properties. Scientists have learned to control the synthesis and thus, within limits, tailor-make plastics with properties and cost needed for various applications.

In 1986, 75 percent of the 45 billion pounds of plastics sold in the United States were converted to long life applications such as in transportation, health care, and construction markets, and 25 percent were utilized in packaging and other short life uses. (1) The 11.5 billion pounds used in packaging consisted of the following plastics:

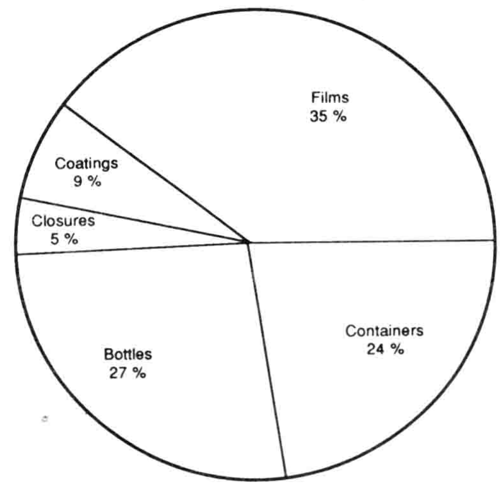
Plastics in Packaging



Source: *Modern Plastics*, January, 1987; pages 56-62

These plastics were used in the following industrial, institutional, and consumer packaging applications:

Plastics in Industrial, Institutional and Consumer Packaging



Source: *Modern Plastics*, January, 1987; pages 56-62

Films for wrapping and laminating, and for bags were made from all six of the major packaging plastics. In many applications, plastics films have replaced coated papers, metals, and glass packages and have permitted innovative packaging applications like the "boil in the bag," which none of the other materials could. In addition to their economic benefits, the plastics provide transparency, inertness, i.e., resistance to the packaged item and the surrounding environment, and an excellent barrier to the transfer of odors, gases, and moisture. Polyethylene is the most used plastic for films where toughness and moisture barrier properties are needed. It is the film from which trash bags are made. PET films provide barrier to gases and may be used at higher temperatures, i.e., boil in the bag. Much of the film is converted to bags or pouches which frequently are used with other materials, such as the plastic film bag containing cereal inside of a paperboard box.

Bottles also utilize the same six plastics as films. Plastics have become the preferred material for a number of reasons, a principal one being safety. Plastic bottles rarely break when dropped, thus eliminating sharp cutting fragments. Plastic bottles are typically eight to ten times lighter than glass which enhances handling and markedly reduces transportation energy and costs. Again, polyethylene is most used for its toughness, moisture barrier, inertness and low cost if transparency is not required. Milk, bleach, and automotive chemicals are packaged in polyethylene bottles. When transparency is important, polystyrene, PVC, and PET are used. Combined requirements of transparency and gas barrier utilize PVC or PET. The plastic beverage bottle is made from PET which retains the carbonation, and some cooking oil bottles take advantage of the protection from oxygen provided by PVC.

Containers other than bottles include boxes, cups, tubs, and pails used by food service establishments for sandwiches and meals. Plastics have replaced metal and coated papers for many of these uses. Polyethylene, polypropylene, and some forms of polystyrene are now used in place of coated paper for tubs to package cottage cheese and other dairy products because of their light weight and resistance to permeation by microorganisms. Tough polyethylene pails have replaced steel for various liquid products ranging from foods to building materials because of their resistance to oxidation and excellent strength-to-weight ratio. Because of their moisture barrier properties and resistance to breakage, transparent polystyrene and PVC are made into boxes and jars formerly made of metal or glass to contain products from medications to hardware items. Foamed polystyrene has replaced paper for egg cartons and trays for packaged meats and, because of its excellent insulating properties, it also is used to make the popular hot or cold drink cup and food service clam shells.

Nearly 10 percent of plastics used in packaging is as coatings on other materials, much of it on paper. For instance, both sides of the familiar paperboard milk carton are coated with polyethylene to protect the paper and the milk. To provide protection from deterioration, paper or metal foil used for packaging is often coated with plastic where there is contact with moisture, grease, oils, or chemicals. In food packaging applications, the plastic is the inner or food contact surface because of its inertness and compatibility with foodstuffs. Without a plastic coating, traditional materials like paper could not be used for bags, pouches, and boxes which are so important to packaging of foods.

The last category of packaging made of plastics is closures like screw caps and snap lids. Most of these, which were formerly made of metal, are now made from polypropylene or polystyrene. Versatile plastics have eliminated the rusty binding of steel screw caps, and in many cases, reduced the need for gasketing material. Snap-on lids, such as those furnished with cans of coffee grounds, provide a closure which was not possible without plastics.

The above examples illustrate why plastics have replaced traditional materials like papers, metals, glass, and wood in many established packaging applications and have permitted innovative new packaging which is not possible with traditional materials alone.

The unique properties of importance to use in packaging are the following:

Lightweight. Compared to glass and metal and, in some instances, paper, plastics permit lighter packaging resulting in savings in energy, transportation costs, and disposal weight.

Protection. Plastics have unique barrier properties. Some protect against the passage of either moisture or gases, some only moisture and some mainly certain gases. These properties enable design of packages which need to "breathe" or those which require a totally captive atmosphere.

Inertness. Because of their excellent chemical resistance, plastics are utilized as the product contact surface with coated packaging materials as well as in an all-plastic package. Similar to glass, plastics do not react with most foodstuffs to impart taste or odor, and they protect other materials on which they are coated.

Safety. Plastics packages do not shatter and rarely break when dropped, a safety feature which was paramount when plastics replaced glass for shampoo, bleach, and beverage bottles. The edges of broken plastics containers are not sharp or hard enough to cause injury.

Transparency. Most plastics are transparent when in the form of thin films, but some are only translucent or opaque in thicker sections such as bottles. When product visibility is important, PET, PVC, polystyrene and polycarbonate are clearly as transparent as glass. Plastics surpass paper and metals in transparency.

Permanence. Except for a few specialty polymers, plastics are resistant to attack by microbes and moisture. This property, along with chemical resistance, make plastics useful in hostile warm and humid environments. Military, construction, transportation, and communications uses of plastics require permanence as do many packaging applications. Plastics do not deteriorate unless exposed to high temperatures or intense ultra violet light. Factors affecting the degradation of plastics will be discussed later.

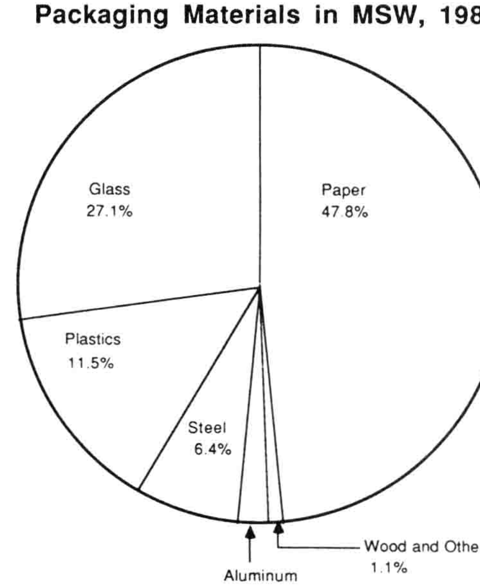
Versatility. Plastics can be tailor-made to offer a broad versatility of design and functionality for packaging. Some are rigid and can support loads, some are flexible for squeeze bottles, some can be stretched, some are sterilizable, and some provide insulation in the form of foams.

Cost Effectiveness. In reviewing the key properties of plastics which have lead to their wide-spread use, performance and cost, or more correctly total economics of use, are very important. Like other applications, a plastics package cannot survive in the marketplace if it is not more cost effective than a rival. Although a plastic material may be more expensive than its non-plastics counterpart, combinations of the superior properties summarized above can result in more cost effective packaging systems.

PLASTICS IN MUNICIPAL SOLID WASTE

An analysis of municipal solid waste (MSW) discarded in 1984, performed for the U.S. Environmental Protection Agency, shows that 32.7 percent by weight of the 133 million tons was packaging materials (2). This percentage has declined slightly since the mid-1960s, probably because lighter packaging materials like plastics have replaced heavier ones such as glass. In 1984, the packaging portion consisted of materials as shown in the following figure:

Packaging Materials in MSW, 1984



Source: Franklin Associates, Ltd., September 1986

Total discarded plastics to MSW in 1984, including plastics from packaging, appliances, housewares, etc., were estimated to be 9.6 million tons or 7.2 percent of the total. These estimates are for net discards and do not include materials which were recovered or recycled.

The same study (2) estimated that in 1984, 95 percent of MSW was landfilled and only 5 percent was incinerated. The portion of MSW disposed of by incineration is projected to grow to 30 percent to 40 percent by the end of the century (3). The incentives for the growth of incineration are the recovery of energy from discarded resources and a rapidly diminishing number of acceptable landfill sites.

Presently, MSW being placed in landfills consists of nearly 30 percent inorganics and plastics (2) which are not biodegradable and, therefore, will occupy some of the volume for a very long time, and about 70 percent organics (not including plastics) which may degrade over varying lengths of time. Some fills have reportedly completed decomposition in three to four years while others have continued decomposing for over twenty years (4). "Glass, plastic, and aluminum refuse in a fill will remain relatively unaltered for twenty years and, depending on the moisture content, paper products may also remain intact for that length of time. Steel, most woods, cloth, and organic wastes will be partially to totally decomposed within 20 years." (4) Decomposition of MSW does not occur completely or rapidly enough to permit re-use of landfill sites for disposal of more MSW.

Plastics pose no unusual problems in landfills. Like ceramics and glass, the plastics do not biodegrade or decompose in the dark oxygen-free environment of a landfill.

Almost 80 percent of the MSW in the U.S., including the 7.2 percent plastics, can be burned to generate energy. The fuel value of the waste is near 4,500 Btu/pound, similar to wood. Plastics provide the richest source of energy on a weight basis in MSW. For example, polyethylene generates over 18,000 Btu/pound, similar to petroleum products from which it was made.

Although there are 74 modern energy-from-MSW plants operating nationwide, the U.S. is far behind many developed countries in the use of MSW as a source of energy (5). Japan now burns 70 percent of its waste and more than half of the wastes in Sweden and Switzerland are burned to generate steam, hot water, or electricity. Waste-to-energy incineration systems can make a valuable contribution to alleviating the landfill crisis. The residue from incineration occupies one-tenth the volume of the original MSW.

Another way to reduce the quantity of discards is to recycle them. Paper is the most recycled material; however, more than 70 percent of discarded paper becomes solid waste. Industrial plastics wastes are recycled at a high level, but post-consumer plastics products are recycled to a very modest extent. Some polyethylene bottles are being recycled to make products including plastic lumber and traffic cones, but the quantity is very small. The most notable recycling of plastics is the soft drink bottle made of polyethylene terephthalate or PET. In 1984, 800 million of these bottles, equal to 20 percent of the bottles produced, were recycled (6). This eliminated 100 million pounds of plastic discards.

The plastics industry along with bottlers, packaging manufacturers, and state and federal organizations, are funding work through the Plastics Recycling Foundation. The Foundation is sponsoring development of technology to permit and promote the recycling of plastics.

LITTER

Some single-use articles, primarily packaging, are disposed of improperly and become litter. Anti-littering laws and valiant efforts by organizations such as Keep America Beautiful have only reduced but not eliminated littering. Once primarily a problem on land, litter also has become a problem in the world's lakes and in the oceans. Aesthetics and protection of wildlife are the driving forces behind efforts to eliminate litter.

Unsightly litter is an old problem, whereas harm to wildlife is a more recent concern. Birds, mainly water fowl and sea birds, have been found entangled in discarded fishing lines and plastic loop carriers. Birds also may eat small plastic articles and plastic pellets causing blockage of their digestive systems and eventually, starvation. Floating plastic bags have been found in the stomachs of sea turtles which apparently mistook the bags for jelly fish. Sea lions have become ensnared in discarded cargo strapping now made mostly of plastic. Lost or discarded fishing gear, such as gill nets, may continue to entrap sea life below the surface. In addition, carelessly discarded infant diapers lined with plastic are unsightly on land or water and, because of improper disposal and incomplete sewage treatment practices, feminine hygiene plastic tampon applicators are found in rivers or on beaches.

One frequently offered suggestion to solve our litter problems is to make the littered items of materials which will deteriorate or degrade at the end of their useful life. However, of the usual packaging materials found in the littered environment, glass is not degradable; aluminum, like plastics, degrades very slowly; steel cans may rust to disintegration; and paper may decompose over time.

Environmental conditions are very important. Steel will not rust if kept dry and away from oxygen, and paper will not decompose unless moist.

Very visible plastics litter has received much attention from legislators, regulators, and the public. These voices are mandating or encouraging that plastics be made more degradable to make them disappear not only from litter, but also from landfills. Presently, 11 states require that plastic loop carriers be degradable, and Federal legislation has been proposed to extend that requirement to the national level. Other proposed Federal legislation would require that the EPA study the effects of plastics dumped on land or in the water.

DEGRADABILITY

Plastics are not inherently biodegradable and scientists historically have sought ways to make them more resistant to other kinds of degradation. Early environmental awareness in the 1960s fostered research to make plastics more degradable. A number of methods were discovered which accelerated photodegradation and have been adopted commercially on a limited scale.

While these plastics used for packaging are not inherently biodegradable, they are susceptible to ultra violet (UV) light or photodegradation. If they photodegrade to small enough molecules, they may be susceptible to biodegradation. Some specialty plastics, such as those used in surgical sutures, are biodegradable and scientists have researched ways to make packaging plastics biodegradable. Two such approaches, one using degradable fillers and the other a new polymer, will be discussed later.

Materials deteriorate or degrade via physical, chemical, and biological actions. They may be physically stressed, chemically attacked, or consumed by mirobes. All three of these actions have been studied in efforts to accelerate photodegradation or to impart biodegradation in plastics, the two kinds of degradation suggested for removal of plastics products from litter or solid waste.

Photodegradation is degradation resulting from exposure to light. In the case of plastics polymers, photodegradation results from the UV portion of the spectrum, the erythmal radiation which also causes sunburn of the skin. This is the visible portion of the sun's rays with wavelengths in a narrow range between 290 and 320 nanometers (nm) (7)(8). These wavelengths do not appreciably penetrate window glass, but do possess energy sufficient to attack polymer molecules. They are not present to an appreciable extent in artificial light (9). Attack of the molecules may be by UV energy alone or may require the presence of oxygen, in which case, the process is called photooxidative degradation.

Plastics owe their toughness and integrity to their molecular structure which consists of large, usually very long chain molecules. If these large molecules are reduced in size, the plastic article loses strength, becomes brittle, and may fall apart if stressed. UV radiation can cause a chemical reaction resulting in chain scission of the long polymer chains, and physical stress from wind or weight may break it apart. Molecular modification and the use of photo-sensitive additives have both been shown to accelerate photodegradation. Much of the work has been limited to laboratory data, but a few commercial uses have evolved, namely the loop carrier, agricultural mulch films, and more recently, trash bags.

Biodegradation is the assimilation or consumption of substances by living organisms. It can include destruction by rodents or other macroscopic life forms, but when applied to waste it includes only microorganisms such as bacteria and fungi. Biodegradation is catalyzed by enzymes and its rate depends greatly upon environmental conditions such as temperature, moisture, oxygen, and a population of suitable microorganisms. These microorganisms secrete enzymes which require a very moist environment to reach the food source. With plastics, the enzyme must breakdown the polymer molecules to products small enough to be assimilated by the microorganisms for digestion (10). While natural polymers like starch are biodegradable, most synthetic ones are not. Some exceptions will be discussed later. New strains of microorganisms are continually evolving by mutation and natural selection processes, but thus far none have evolved which will consume synthetic, water-resistant, high molecular weight polymers.

Except for the loop carriers, packaging has not employed materials modified for accelerated degradability. In opposition to those who would encourage degradability, there are those who question its true value because of the following: biodegradation is not relevant to the decay of litter because it is a slow process and requires moisture and burial; biodegradation in landfills may have only marginal benefit since it does not remove all materials or even all biodegradable materials in a reasonable time; and while photodegradation may have limited value in reducing litter, it is not relevant to landfills because of the lack of UV radiation.

Two commonly expressed concerns about degradable plastics are possible premature failure of the package and the possible contamination of the contents. In addition to the need for a known and controllable lifetime, the following are important considerations if a modified degradable plastic is to be used for packaging:

1. Provide acceptable performance.
2. Utilize conventional manufacturing technology.
3. Present acceptable economics.
4. Not adulterate the contents.
5. Its degradation products should not be toxic.
6. Be resistant to microorganisms in use.
7. Be disposable with conventional technology.
8. Will not be recycled.

Items 1 through 3 above are particularly critical to the successful commercialization of a modified material. A package will not be acceptable if it does not perform its intended function of delivering and protecting the contents. Unmodified plastics for packaging have been thoroughly characterized regarding barrier properties, inertness to the packaged product, non-adulteration of contents (especially foodstuffs), printability, and other properties; modified resins and the effect of additives to promote degradability will have to be subjected to the same thorough characterization. Package manufacturing technology has been developed with unmodified resins and may need to be itself modified to operate with new materials. The procedure of evaluating and qualifying changed plastics in product manufacture and performance is costly and time consuming.

POLYMER PHOTODEGRADATION TECHNOLOGY

Very pure polymers are not sensitive to that portion of the sun's UV radiation which reaches the earth, namely wavelengths of 280 to 400 nm. As a result, very pure polymers are not susceptible to photodegradation (9,11). In real life, however, plastics articles contain some molecular alterations or imperfections created during processing and fabrication. In polyethylene, thermal processing results in some carbonyl impurity which does absorb UV light from the sun. For greater sensitivity, photo-sensitive additives might be used. It is this susceptibility of impurities and additives to UV absorption, leading to polymer degradation, which forms the basis for the systems which have been offered commercially. A discussion of these systems follows.

Ketone Carbonyl. Carbonyl groups absorb UV energy in the range of 270 to 360 nm (12). If the pure polymer molecule is modified by introducing carbonyl groups (simply, a carbon monoxide molecule) it can be made photo-sensitive to UV radiation reaching the earth. With carbonyl molecules distributed at intervals along the long polymer chain, it can be postulated that UV energy could break the chain at each carbonyl and make the polymer brittle. One method of such molecular alteration has been described by Guillet (9). Guillet introduces carbonyl by incorporating ketone molecules which contain a carbonyl group into the polymer chain. The ketones used absorb UV energy to 330 nm. This range of wavelengths is not present in incandescent light, only barely in fluorescent light, but appreciably in the sun's rays. Window glass screens most of this range of wavelengths. Plastics modified by this method should, therefore, not be expected to photodegrade under artificial light or behind window glass.

Guillett's work with the ketone method of introducing carbonyl is more fully described in patents (13). The technology is offered commercially for license and as a masterbatch plastic resin by EcoPlastics, Ltd. of Ontario, Canada. The masterbatch provides a concentrated form of the ketone copolymer to be mixed with a larger quantity of unmodified resin. Presently, only the polyethylene form is being sold, but a polystyrene version is reported to be available, as well. Material now being sold is used in Europe for trash bags and grocery sacks and is being field tested in agricultural mulch film, some of which is sold in Canada. Use of the masterbatch adds 8 percent to 10 percent to the cost of the film (14).

EcoPlastics reports that their Ecolyte masterbatch modified plastics have physical properties similar to unmodified plastics and that lifetime can be controlled if environmental exposure conditions are known. Food and Drug Administration sanction of Ecolyte plastics for use in contact with foods has not been requested.

Carbon Monoxide Carbonyl. Another method of incorporating carbonyl groups, which is applicable to only low density (not linear low) polyethylene, is to copolymerize carbon monoxide with ethylene in the polymer manufacturing process. The level of carbon monoxide incorporated is typically less than 2 percent. The photodegradation reaction is similar, although not identical, to that with ketones. Again, the polymer chain breaks at the CO groups to form shorter, weaker chains. This method is used by several plastics resin manufacturers, namely, Dow Chemical, DuPont, and Union Carbide Corporation, who offer such resins for sale. These modified polymers have not yet been sanctioned for direct contact with foods by the Food and Drug Administration.

The intensity of UV radiation absorbed by the material determines the rate at which chains will be broken. Thus, a plastic article shaded from the sky will not photodegrade as rapidly as one that is not. Similarly, latitude and the seasons have a substantial effect. Except at lower latitudes, winter time rates will be slower than summer. Articles will degrade more rapidly near the equator than in northern latitudes. A study by Jonas (15) conducted in Oregon, reported embrittlement of plastic loop connectors made from an ethylene-carbon monoxide copolymer to be up to five times faster in the middle of summer than in the fall and winter. These geographic and seasonable variables may present a problem of tailoring the plastic to give an acceptable degradation rate and controlling distribution of packages.

These methods of introducing carbonyl as an integral part of the polymer molecule avoid the potential leaching or loss of additives which may occur with additive systems. Since these carbonyl systems require UV radiation, the degradation process will be retarded if the article is screened from the sun's ray. Unless exposed to the sun for a sufficient length of time to result in gross molecular scission, carbonyl modified plastics will not become biodegradable in a landfill. Potts (16) reported that polyethylene must be broken down to a molecular weight of 500 or less before it will support microorganisms. Polyethylene articles are typically made from polymers having molecular weights of 20,000 or higher.

Additional methods for accelerating photodegradation employ additives, either singly or in combination, which are claimed to be synergistic or to yield chemicals which continue the degradation process in the absence of light.

Ampacet. The Ampacet Corporation of Mt. Vernon, New York, markets a proprietary additive containing masterbatch called "Poly-Grade" for polyolefins. Masterbatch is offered in natural and white or black. White and black are utilized by one manufacturer of trash bags in the U.S., while the natural is sold in Europe (17). Poly-Grade is not FDA-sanctioned for use in contact with foods.

Princeton Polymer Laboratory. This laboratory does not offer masterbatch or resin, but does offer technology and license under a U.S. patent (18). Claimed to be suitable for use in polyolefins and polystyrene, a dual additive system is used for synergism. The dual additives are selected from two classes of chemicals:

1. A photo activating material such as benzothiozol or benzophenone, and
2. A prooxidant, typically a transition metal salt such as zirconium stearate or nickel acetate.

Antioxidant—Photoactivator. During thermal processing, plastics may be degraded by oxygen by the formation of peroxides. To prevent this thermal oxidative degradation, additives known as antioxidants are incorporated in the plastics resin formulation. These antioxidants scavenge the oxygen so it cannot degrade the polymer molecule. Interestingly, some antioxidants containing certain metal salts act to stabilize polyolefins if present at high concentrations, but act as photodegradation catalysts at lower concentrations. Professor Scott (19) stated, "Studies of mechanisms of antioxidant action have led to the development of antioxidants which act by catalytically destroying hydroperoxides during polymer processing and subsequent exposure to ultraviolet light. They are, however, destroyed at the end of the photooxidation induction period and subsequently catalyze the photodegradation process."

Scott's antioxidant-photoactivator system was further refined in conjunction with Gilead as described in two recent patents (20). The improvement utilized a two-additive system, one being a complex of iron which is a peroxide decomposing antioxidant, and UV stabilizing compound. A typical compound is ferric dibutyldithiocarbamate. The second is a metal ion deactivating compound which also acts as a photostabilizer. Nickel or cobalt complexes such as cobalt dibutyldithiocarbamate are suggested. It is claimed that by varying the relative amounts of the iron complex versus the cobalt or nickel complex, the lifetime of the plastic article, such as film, can be controlled providing the amount of UV exposure is known.

In practice, UV energy is absorbed by the metal complexes, thus releasing the metal ions which then act as catalysts to break the polymer chains. It is claimed that this breaking of polymer chains will continue in the absence of sunlight or oxygen (21).

Polyethylene films, primarily for agricultural mulch using this technology, are offered in the U.S. by Ideamasters, Inc. of Miami, Florida, under the tradename PLASTIGONE. This technology does not apply to other than the polyolefins. Although only films are presently marketed, the company may supply masterbatch in the future (24). Food and Drug Administration sanction for use in contact with foods has not been requested.

POLYMER BIODEGRADATION TECHNOLOGY

Efforts to make plastics biodegradable have pursued two courses, one to make the polymer itself susceptible to enzyme attack, and the other to incorporate biodegradable additives. The second approach does not necessarily make the polymer biodegradable.

An extensive study and review by Potts (7) revealed that some synthetic polymers do support microbial growth. Such polymers include some aliphatic polyesters, polyester diol based polyurethanes, and polylactides made from lactic acid. These three classes of polymers do not possess properties necessary for packaging materials, but have found use in some specialty applications where biodegradability is desirable. Polycaprolactone, an aliphatic polyester, has been used to make seeding pots for automated reforestation planting. Polylactides and polyglycolate, also an aliphatic polyester, have been used for degradable surgical sutures and devices. To date, biodegradable polymers possessing properties and economics suitable for packaging applications have not been developed. Enzymes do not attack these high molecular weight polymers but do catalyze the biodegradation of low molecular weight fragments inherent in most synthetic plastics or produced by aggressive photo or oxidative degradation.

One recent development of aliphbatic polyesters claims a polymer which is biodegradable and possesses properties similar to some polyolefins. Other attempts to impart biodegradability to polyolefins utilize starch as a filler.

PHBV—Biodegradable Plastic. PHBV is an acronym for poly (hydroxybutyrate-valerate). These are aliphatic polyester copolymers produced during fermentation of sugars. Their existence has been known for more than 50 years, but extraction and purification from fermentation bacteria has only recently been perfected. Holmes (23) states that these polymers are biodegradable and resemble polypropylene in properties.

PHBV is marketed by Marlborough Biopolymers, Ltd. (MBL), a subsidiary of ICI in England. MBL is producing the polymer in ton quantities in the U.K. for applications development work in surgical devices, personal hygiene products, and packaging. Medical grade material is expensive, but less pure material "with properties intermediate between polypropylene and PVC can be extracted using more basic technology." The rate of biodegradation depends upon form and environment, but is reported to range from several days for a film in anaerobic effluent to nine months for a bottle in soil.

Starch—U.S. Department of Agriculture. Research at laboratories of the USDA has discovered technology for the incorporation of gelatinized starch in copolymers of ethylene and acrylic acid (EAA) and polyethylene. The method is described by Otey (24,25) and in U.S. patents (26). This combines a natural biodegradable polymer, starch, with a synthetic non-biodegradable polymer. Compositions containing up to 60 percent starch have been made into blown films using small laboratory equipment. As the starch level is increased, the physical properties of films decreases. Starch levels of 40 percent or more demonstrated mold growth associated with biodegradability in laboratory tests. Field studies have not been conducted. It is expected that microorganisms will consume the starch particles leaving a porous plastic article which may disintegrate or deteriorate so it, too, may become biodegradable.

Preparation of film requires the mixing of starch, water, and EAA copolymer with the addition of a base such as ammonia. Polyethylene may be added to this mixture, but the EAA is essential for compatibility. This mixture may then be extruded into a blown film.

This technology recently (1986) has been licensed by Agri-Tech Industries of Gibson City, Illinois. Agri-Tech will use facilities of the business development unit at the University of Illinois to do development and pilot plant scale-up of the technology, possibly leading to a venture which would supply resins (27).

Starch—St. Lawrence ECOSTAR. Other technology for the use of starch as a biodegradable filler in plastics was reported by Griffin (28). Griffin claimed the addition of an autooxidant would degrade the synthetic polymer if buried. This technology was commercialized in the U.K. by Colorall, Ltd. for use in grocery sacks. Subsequently, the worldwide rights to the patents (29) have been acquired by the St. Lawrence Starch Company, Ltd. of Ontario, Canada, which offers a masterbatch presently for only polyethylene. Masterbatch for other plastics may be offered in the future.

The technology utilizes starch which is treated with a silane coupling agent to provide compatibility with the synthetic polymer, such as polyethylene. To this is added a small amount of an unsaturated ester, such as corn oil, to serve as the autooxidant. In a buried article made of this mixture, the starch is consumed by soil fungi leaving a porous structure, while the corn oil reacts with metal salts in the soil to form peroxides. Allegedly, the peroxides break the synthetic polymer chains into fragments small enough so that they too can be biodegraded. Following burial, a polyethylene film containing 15 percent starch decomposes in six months and one with 6 percent starch in three to five years (30).

A polyethylene masterbatch containing 60 percent starch plus corn oil and desicant sells for about double the price of polyethylene. There is no commercial use of ECOSTAR in the U.S., but a Canadian company is planning to use it for trash bags. St. Lawrence is preparing to utilize ECOSTAR in polyethylene bottles for corn oil and syrup in Canada and is awaiting approval from the Department of Health and Welfare. Compliance with U.S. FDA regulations has not been investigated.

The molecular modification and additive systems described above have been demonstrated and are presently used commercially only with polyethylene. The applicability or effectiveness of such systems has not been demonstrated in most of the other plastics used for packaging.

CONCLUSION

Some of the methods reviewed above have been available for more than 15 years, but have found very limited applicability, particularly in packaging. They have been used where degradability serves a useful purpose such as in surgical sutures, agricultural mulch film, and loop carriers, or where they provide a marketing uniqueness as in trash bags and grocery sacks. Loop carriers are a special case since their physical configuration may entrap wildlife.

Manufacturers and users of plastics packaging point out that only a small percentage of items are littered, and since it is not known which specific item will become litter, they ask why all should be faced with the added cost. Why, for example, they ask, should plastic beverage bottles be made degradable when only a minor portion are littered and degradability would not only add cost but also preclude recycling? Why, in fact, they ask, must plastics be degradable when glass and metal containers are not? Similar reasoning may be applied to all packaging, the large majority of which is collected for proper disposal where degradability provides no benefit for incineration and is of questionable value in landfill.

Degradability could be beneficial for those items discarded on the oceans; however, the methods described above have not been shown to be effective in the submerged marine environment. If degradability in the sea were possible, the distribution system would have to be controlled so as to not penalize items disposed on land with the added cost. Degradability would be most cost effective if it could be applied selectively to only those items where it provides a benefit.

Synthetic polymers presently used for packaging plastics are not biodegradable and unless modified, degrade only slowly in sunlight. Following is a list of factors which must be taken into account when considering whether plastics can, and should, be made degradable for given applications.

1. Methods to accelerate degradability of plastics are mostly untried in critical applications with generally uncontrolled environmental exposure such as packaging. It is not known if these modified plastics will satisfy the requirements of the Food and Drug Administration.
2. Photodegradability is relevant only to litter and depends upon exposure to UV radiation.
3. Biodegradability is relevant only to landfill since burial and moisture are required. It has questionable value because the process is slow and the landfill will not be returned to use in a reasonable time.
4. All things must go somewhere. Unmodified plastics do not degrade. Degradation products of degradable materials are not well characterized, so their toxicity and environmental effects are unknown.
5. Plastics modified to be degradable will cost more. As specialty materials, they will require separate handling and lose the economy of scale.
6. Additional costs will be incurred because of restrictions on distribution. Photodegradable articles for northern latitudes may need to be different from those shipped to southern latitudes. Seasonal differences also may need to be considered.
7. Performance must be characterized and use controlled to prevent premature failure of the package which could lead to product loss or product contamination.
8. Materials which degrade become a lost resource. Degrading plastics may eventually return carbon to the carbon cycle but incineration is a quicker method of accomplishing this with the added benefit of energy recovery.
9. Plastics articles modified for accelerated degradability will not be recycled since their remaining life would be unknown. They may, in fact, impede recycling since some modified material accidentally mixed with nonmodified would introduce the degradability trigger into the entire mix.
10. The impression that an article is degradable might result in more litter.

The technology to make some plastics photodegradable and/or biodegradable has been demonstrated and commercialized in a few applications. Degradability can be beneficial and cost effective if it is applied selectively, but for most applications degradability is undesirable. For each plastics application, one must ask—is degradability beneficial?—particularly in light of the factors summarized above.

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BIOGRAPHY

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Regina Johnson was graduated from the University of Texas at Austin in 1975 with a BS in Chemical Engineering. Since that time, she's been with Dow Chemical Company, Freeport, Texas, where she has held several technical positions. She is currently a development leader in the Polyethylene Technical Services and Development Department. Johnson also serves as chairman of SPI's Ad Hoc Committee on Degradable Plastics.