Solutions for sustainability

The Paradox of Biodegradability

Summary/Abstract

As scientists, environmentalists and manufacturers continue to push biodegradability to the forefront of the plastics disposal debate, the "paper or plastic" grocery store dilemma of yore may soon be replaced with consumers mulling over the question, "compost or landfill?"

The "correct" answer lies in the ultimate disposal of the product - a fate that is unknown to the manufacturer and depends in large part on consumer location, politics, public perception and, above all, cost.

And therein lies the modern plastic paradox – how does the polymers industry create more environmentally-friendly products when the ultimate disposal environment is unknown until the consumer is finished using the product. And how much are consumers willing to pay – in dollars as well as convenience – to address the problem of plastics disposal. Compounding this uncertainty is the mixed messaging consumers are receiving from the convergence of science and sales. While terms such as *bioplastic*, *biodegradable plastic*, *degradable* and *compostable* are often interchanged in consumer advertising, the chemical and biological processes those words describe are distinct and occur only under certain conditions in certain environments.

Background

According to the University of Hannover in Germany, there are over 300 types of "bioplastic" today made from renewable resources such as corn, sugar cane and soy. But "bioplastic" has a particular meaning that may or may not relate to a polymer's biodegradability. The distinction between a plastic that is degradable and one that is biodegradable is significant. A degradable plastic will simply break down into smaller fragments, often microscopic in size, through chemical and mechanical processes. *Biodegradation* is "the process by which organic substances are broken down into smaller compounds using the enzymes produced by living microbial organisms. The microbial organisms transform the substance through metabolic or enzymatic processes." While the term is obviously appropriate in reference to plant and animal matter, biodegradation can also include "artificial materials that are similar enough to plant and animal matter to be put to use by microbes."[1]

It is this similarity to organics that makes it possible for otherwise stubborn hydrocarbon-based and synthetic plastics to undergo biodegradation – with a little help from additives.

The Packaging Recovery Organization of Europe (E-PRO) notes that the term bioplastics is often used as a catchall for different plastic types, creating confusion about two critical aspects of a polymer - its composition and its end-of-life. "The composition and the end-of-life are independent aspects that should not be confused. The biodegradability of plastic is independent of its composition… bio-based plastics are not always biodegradable," and "biodegradable plastics are not always made of renewable resources. Traditional petroleum based plastics can be biodegradable. Moreover, it should be noted that not all biodegradable materials are compostable."[2]

Because biodegradability "is an end of life option and harnesses microorganisms present in the selected disposal environment, one must clearly identify the 'disposal environment' when discussing or reporting on the biodegradability of a product – like biodegradability under composting conditions (compostable plastic), under soil conditions, under anaerobic conditions (anaerobic digestors, landfills) or under marine conditions," explains Ramani Narayan, Department of Chemical Engineering and Materials Science at Michigan State University.[3]

Even when a product's intended disposal environment is clearly evident to consumers, making proper disposal a habit requires good marketing – and good science to support it. "Ever since the introduction of "biodegradable plastics" in the late 1980s, confusion and skepticism about claims and product performance have prevailed," notes the Biodegradable Products Institute. "Although touted as 'environmentally friendly,' several so-called biodegradable plastic products did not biodegrade as expected. And yet manufacturers of these products were able to make claims of biodegradable because no scientifically based test methods and standards existed."[4]

While an apparent rush to market hampered the plastics industry's early biodegradable efforts, things began to change in 2002, says BPI, when specifications and tests were developed to separate scientific fact from marketing fiction. In granting use of its Certified Compostable label, BPI says it uses independent laboratories to test products, and its scientists "check the data to verify that the products meet requirements in ASTM Specifications D6400 or D6868. The ASTM Specifications used by the BPI resulted from eight years of intensive work by leading scientists, resin producers and the composting industry."[5]

As the science of biodegradable plastics has evolved, so too have testing and certification protocols. ASTM subcommittee, D20.96, *Environmentally Degradable Plastics and Biobased Products,* now boasts a total of 21 active and eight proposed standards. ASTM standards D6400 and D6868 pertain specifically to the labeling of plastic items and plastic packaging designed for disposal in a municipal or industrial composting facility, with D6400 including a provision for post-degradation eco-toxicity testing consistent with the Organisation for Economic Co-operation and Development's OECD 208, *Terrestrial Plant Test: Seedling Emergence and Seedling Growth Test*.[6]

According to E-PRO, "A distinction needs to be made between plastics that can be composted at home and those which require an industrial process. A certain level of temperature, heat, water and oxygen is required by active micro-organisms for efficient and effective biodegradation. A product is compostable according to the internationally recognized standard EN 13432 only when specific conditions (temperature, humidity level, time) are met in the composting system. These conditions are significantly different in home composting than in industrial facilities. Many products which meet EN13432 in industrial composting facilities will not do so in home composters."[7]

While the focus in composting has obviously been on the commercial/industrial sector, standardization and testing efforts are beginning to include the home consumer. ASTM's D20.96 subcommittee recently initiated work item WK35342, *Specification for Home Composting of Biodegradable Plastics*. Such a standard makes sense from both an economic and an education perspective, according to D20.96 member Robert Whitehouse, Ph.D., senior customer applications development manager, Metabolix Inc. "Home composting reduces the amount of volume of trash for curbside collection and associated landfill fees," says Whitehouse. "Municipalities have the same interest since their served costs are reduced from less trash collection and landfill options. Education is equally important, because the home consumer may have very little knowledge regarding plastic materials that can be biodegraded through the home composting process, hence they need to have the packaging marked by the brand owners so that items can be distinguished from non-biodegradable materials." Whitehouse says the proposed standard will have several types of potential users, including resin producers, packaging converters, retailers/brand owners and consumers.[8]

Marketing a compostable plastic product demands a great deal of clarity, cautions environmental attorney Elizabeth Poole. **"**Unqualified compostable claims should only be used on a product that breaks down into, or otherwise becomes part of, usable compost in a safe manner in approximately the same time as the materials with which it is composted. Such claims should be qualified if composting facilities are required and not available to a substantial majority of consumers where the product or service is sold. (The FTC informally considers a substantial majority to be 60%.)"[9]

At the same time it is considering home composting standards for the first time, ASTM is also reevaluating a longstanding plastics recycling education effort. Recognizing that the stalwart Resin Identification Code (RIC) classification system has confused consumers and not kept pace with changing plastics disposal options, ASTM's D20 committee initiated work item WK37080 - *New Practice for Marking Plastic Manufactured Articles for End of Life Purposes*. According to the work item abstract, "The recycling community has for 20 years attempted to use the Resin Identification Code system to help educate consumers on which products are accepted in municipal waste programs. Unfortunately, the RIC system was never intended for that purpose. In response to the request of the municipal recycling organizations, we are proposing a practice that will more efficiently assist public education."[10]

Developing a Taste for Petroleum-Based Plastics

Biodegradation of a plastic material occurs when microbes in a particular environment metabolize the molecular structure of the plastic polymer. While the process is natural and fairly rapid for plant-based materials, petroleum-based plastics had historically been written off as non-biodegradable. The problem, quite simply, is that microbes just don't have a taste for conventional plastic. Thus, for the better part of the last two decades, scientists have worked to make traditional plastics a more appealing meal for microbes. The result has been numerous proprietary organic formulations that, when added to hydrocarbon-based plastics, make the entire plastic item biodegradable through microbe activity.

Regardless of their type or application, biodegradable plastics are created in one of two ways:

- Polymers are produced from renewable plant-based resins or a combination of plant and petroleum resins.
- An additive, usually a proprietary chemical formulation, is added to traditional petroleum-based resins.

In both cases, biodegradation begins when one or more environmental conditions are present such as heat, pressure, moisture, mechanical stress or UV exposure. The ultimate biodegradation of a plastic – and its impact on the environment in the process – depends on both its chemical composition at manufacture and its final resting place after consumer use. A fully-compostable bag derived from PLA sources requires the high-heat and oxidative conditions of a commercial compost facility to fulfill its promise. Bury that same bag in a predominantly anaerobic landfill and its decomposition may be dramatically slowed or completely halted. Similarly, a petroleum-based plastic bottle with a biodegradation additive formulated for metabolism by anaerobic microorganisms might linger in a compost facility for decades or even centuries. Depending on the formulation, this can be overcome.

Depending on the polymer and additives, biodegradation can either be direct to humus, water and carbon dioxide, or it can be a two-step process where the material must disintegrate prior to biodegradation. This step – initiated by organic additives - breaks down plastic's characteristic long monomer chains through hydrolysis, allowing microbes to colonize in the material and initiate the biodegradation process.

Because plastic packaging and other consumer products have an expected shelf life and service life and must exhibit certain physical properties consistent with their intended use (e.g., strength, temperature range), the biodegradable compound is often just one component in a masterbatch additive. Unlike traditional commonly recycled plastics such as HDPE, biodegradable plastics must be designed with a critical eye toward shelf life and biodegradation rates. "Designing plastics and products to be completely consumed (as food) by such microorganisms present in the disposal environment in a short time frame is a safe and environmentally responsible approach for the end of life of these single use, short life disposable packaging and consumer articles," says Narayan. "The key phrase is 'complete.' If they are not completely utilized, then these degraded fragments, which may even be invisible to the naked eye, pose serious environmental consequences."[11]

For plastics producers, there's no easy way around this all or nothing proposition. Depending on the masterbatch used in production, consumers who might want to play it safe and dispose of a biodegradable plastic (e.g., PLA and other starch-based materials) in a municipal recycling stream could unwittingly contaminate the recycling stream. With no control over the consumer's end-game and no single biodegradable solution, the plastics industry risks undermining recycling efforts as well as polluting the environment further if biodegradables don't reach a post-consumer location that is consistent with their composition. [12]

A Little Trash Talk

Regardless of its origin, use or composition, practically every plastic item eventually ends up as some form of waste somewhere on the planet. In the United States alone, plastics accounted for about 12 percent of the 250 million tons of municipal solid waste generated in 2010, making plastics the fourth highest waste category behind paper, food scraps and yard trimmings. About 136 million of the 250 million tons of total MSW were landfilled in 2010, with the remaining 114 million tons going to recycling, composting and energy recovery (incineration).[13] Looking just at plastics in the U.S.:

- 31 million tons of plastic waste were generated in 2010, representing 12.4 percent of total MSW.
- In 2010, the United States generated almost 14 million tons of plastics as containers and packaging, almost 11 million tons as durable goods, such as appliances, and almost 7 million tons as nondurable goods, for example plates and cups.
- Plastics also are found in automobiles, but recycling of these materials is counted separately from the MSW recycling rate.[14]
- 51 million tons of plastic resin were produced in 2010.[15]

While solid waste generation increased from 3.66 to 4.43 pounds per person per day between 1980 and 2010, the recycling rate skyrocketed from less than 10 percent of MSW to about 34 percent over the same three decades. Correspondingly, disposal of waste to landfills dropped from 89 percent of MSW generated in 1980 to about 54 percent of MSW in 2010 with actual landfill tonnage staying nearly flat across those three decades.[16]

In terms of waste stream recovery efficiency, automotive batteries led the charge in 2010 with a recycling rate of 96 percent, followed by newspapers (72 percent), steel cans (67 percent), yard trimmings (58 percent), aluminum cans (50 percent), tires (36 percent) and glass containers (33 percent). While 29 percent of PET bottles and jars and 28 percent of HDPE bottles were recycled in 2010, plastics overall achieved a recycling rate of only eight percent. You don’t have to dig very far in a landfill to figure out why – beyond bottles, plastic packaging is seldom recovered, and in many cases it’s simply not commercially recyclable. This is significant considering that nearly one-third of all MSW in the U.S. came from packaging-related materials in 2010.

Of the six primary container/packaging materials cited by EPA, plastics were recycled the least with a recovery rate of 13.5 percent, trailing paper/paperboard (71 percent), steel (69 percent), aluminum (36 percent), glass (33 percent) and wood (23 percent). Yet, plastic ranked second only to paper in terms of total weight in the packaging/container segment of the overall municipal solid waste stream. Given the comparatively light weight of most plastic packaging, there’s clearly a huge volume of plastic items in the MSW stream.[17]

The Dangers of Degradation

Plastics seem to have undergone a uniquely notorious evolution among items that end up in the waste stream. With the birth of the modern environmental movement in the 1970s, activists successfully branded plastics as a non-degradable, permanent blight on the global landscape. Once produced, they would simply exist forever. "Plastics in daily use are generally assumed to be quite stable," explains Katsuhiko Saido, Ph.D. But Saido and others have found that “plastic in the ocean actually decomposes as it is exposed to rain and sun and other environmental conditions, giving rise to yet another source of global contamination that will continue into the future.” Saido explained that polystyrene begins to decompose within one year, releasing components that are detectable in the parts-per-million range. Those chemicals also decompose in the open water and inside marine life.[18]

According to Saido, “Each year as much as 150,000 tons of plastic debris, most notably Styrofoam, wash up on the shores of Japan alone. Vast expanses of waste, consisting mainly of plastic, float elsewhere in the oceans. The so-called Great Pacific Garbage Patch between California and Hawaii was twice the size of Texas and mainly plastic waste.”[19]

Saido, a chemist with the College of Pharmacy, Nihon University, Chiba, Japan, said his team found that when plastic decomposes it releases potentially toxic bisphenol A (BPA) and PS oligomer into the water, causing additional pollution. “Plastics usually do not break down in an animal's body after being eaten. However, the substances released from decomposing plastic are absorbed and could have adverse effects. BPA and PS oligomer are sources of concern because they can disrupt the functioning of hormones in animals and can seriously affect reproductive systems.”[20]

“About 44 percent of all seabirds eat plastic, apparently by mistake, sometimes with fatal effects. And 267 marine species are affected by plastic garbage – animals are known to swallow plastic bags, which resemble jellyfish in mid-ocean, for example,” according to a 2008 study by oceanographer and chemist Charles Moore of the Algalita Marine Research Foundation.[21]

Modern Science Embraces an Old Idea

While polymer and additives manufacturers continue to develop, evaluate and tweak proprietary eco-friendlier plastics options, some of the biggest names in global consumerism have already invested millions in the science – and marketing – of biodegradable plastics. Coke introduced its *PlantBottle*, comprised of 30 percent plant sugars, in 2009. Not to be outdone in any aspect of the century-old cola wars, Pepsi unveiled its own green bottle two years later. Comprised of switch grass, pine bark and corn husks, the 100-percent renewable feedstock bottle marked the beginning of what Rocco Papalia, Senior Vice President, PepsiCo Advanced Research, said would be a successful symbiotic relationship between the company’s beverage and food businesses. “This bottle far surpasses existing industry technologies and helps us address the petroleum issue because we anticipate being able to manufacture the bottle for our beverage business by using the agricultural waste from our foods business. For example, our Tropicana business generates 1.3 billion pounds of orange peels every year. Eventually, we'll use this and other agriculture waste to make our beverage bottles and other packages."[22]

Pepsico subsidiary Frito Lay set the snack packaging eco bar rather high in 2009 with the launch of its Sunchips fully compostable packaging, which the company says will completely biodegrade within 14 weeks in a suitable compost operation.[23] And several major U.S. automobile manufacturers now incorporate partially bio-based plastics in many of their interior components.[24]

Sharing a ride with plant-based plastics may strike modern consumers as a remarkable 21st century concept, but it's actually a throwback to the 1930s when, in the midst of building his namesake automobile empire, Henry Ford found time to construct numerous plastic parts out of agricultural materials. His renewable plastic efforts culminated in 1941 with the "soybean car", a vehicle with a steel frame enclosed by 14 plastic panels made from common agricultural sources. The car weighed 33 percent less than a conventional all-steel vehicle. In a 1934 *Modern Mechanix* article, Ford explained his penchant for agri-plastic. One day "we shall grow annually many if not most of the substances needed in manufacturing. When that day comes… the present unnatural condition will be naturally balanced again. Chemistry will reunite agriculture and industry. They were allowed to get too far apart and the world has suffered by the separation."[25]

While today's auto industry – and the global proliferation of plastics - are both attributable to the rise of petroleum, natural materials such as rubber and shellac have been used to make plastic items for centuries. In the 1850s, Alexander Parkes of Birmingham, England developed the first thermoplastic, *Parkesine*. New York printer and inventor John Wesley Hyatt followed in 1869 with the first commercially successful thermoplastic, patented as the now-ubiquitous "celluloid" that gained widespread use in early photo and cinema applications.[26] By this time the industrial revolution was on, and petroleum was quickly becoming its primary fuel source. By the mid-20th century petroleum-based plastics were the rule, and plant-derived polymers faded quietly into obscurity.

With environmental awareness on the upswing, rising oil prices and growing concerns over the sustainability of a petro-plastic economy, renewable resources are once again being considered for wholesale plastics production. Viewed through the lens of modern science and industry, bio-based plastics may be much more appealing today than they were a century ago.

Today's plastics producers are recognizing the need to approach biodegradability with the end user – and end of product life – in mind. ENSO Bottles has developed a biodegradable PET bottle that it claims is recyclable and will biodegrade in both landfill (anaerobic) and composting (aerobic) environments. ENSO account manager John Barnes in a 2009 *Plastics Today* article said his firm's product, which uses a proprietary additive called EcoPure®, has the same physical properties as traditional PET so it won't contaminate the recycling stream.[27] Additionally, John Lake, chief executive officer of BioTec Environmental, owners of the EcoPure technology, has stated, "we've blended EcoPure with a number of resin systems and done ASTM D-5511 testing that shows very promising results."[28]

Skeptics, including the Association for Postconsumer Plastics Recycling, say that even if biodegradable PET bottles pose no contamination threat to the recycling stream, their biodegradability puts them at odds with a recovery effort based on consumer behaviors that took decades to mold. Giving the consumer the choice to either recycle a PET bottle or discard it could reverse what the recycling industry and many environmentalists consider a good habit. Further, material that would be reused in a recycling effort drops permanently out of the plastic supply chain when it biodegrades. In a 2008 position statement, APR noted that "repeated use of molecules through recycling leads to less environmental burden than single use of molecules. Repeated use of molecules should lead to more efficient use of natural resources and complement overall sustainability efforts."[29]

Sustainability might not be as clearcut as recycling advocates hope, since many plastics suffer degradation during both their useful product life and while in the recycling stream. Additionally, polymers that are recycled don't boomerang in the recycling stream forever - they may eventually comprise a product that is not recyclable or they can permanently drop out of the recycling stream for any number of reasons, including improper disposal.

Common Ground – the Need for Standards

While recycling proponents and biodegradable advocates may not see eye-to-eye on the future impact of biodegradable plastics, they do agree on one key point – the need for quality assurance testing through applicable, objective standards. In the United States, the American Society for Testing and Materials (ASTM) has provided several standards for biodegradable plastics, including ASTM 6400/6868 which stipulate pass/fail tests for compostability, a minimum 60 percent biodegradation within 180 days in specified composting conditions, and third-party certification.[30]

ASTM 6954 provides a standard testing guide for oxo-biodegradables, where "Each degradation stage is independently evaluated to allow a combined evaluation of a polymer's environmental performance under a controlled laboratory setting. This enables a laboratory assessment of its disposal performance in, soil, compost, landfill, and water and for use in agricultural products such as mulch film without detriment to that particular environment."[31]

Additional ASTM performance standards include:

- ASTM D7475-11, Standard Test Method for Determining the Aerobic Degradation and Anaerobic Biodegradation of Plastic Materials under Accelerated Bioreactor Landfill Conditions
- ASTM D5988-03, Standard Test Method for Determining Aerobic Biodegradation in Soil of Plastic Materials or Residual Plastic Materials After Composting
- ASTM D5526-94, Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions

In Europe, the most widely-cited authority is EN13432, which stipulates requirements for packaging recoverable through composting and biodegradation as well as a test scheme and evaluation criteria for the final acceptance of packaging. EN 14995 broadens the scope of plastics when used in non-packaging applications and provides for the evaluation of compostability.[32]

Some say biodegradation can pose an air pollution risk. Plastics that end up in a landfill – if encouraged to biodegrade anaerobically – would release methane, a greenhouse gas, as part of the biodegradation process. If the landfill boasted a waste-to-energy system, the methane could be captured and used to generate electricity. With no recovery, a greenhouse gas estimated to be 21 times more potent than CO_2 could be released into the atmosphere during anaerobic biodegradation.[33]

With new greenhouse gas regulations on the horizon, proponents of biodegradation argue that not only can landfill methane be captured, it can become an enduring and efficiently produced fuel source. According to the EPA, 576 of the 2,400 municipal solid waste landfills in the U.S. capture methane for energy production, and another 510 "could turn their gas into energy, producing enough electricity to power nearly 682,000 homes."[34]

Science and Salesmanship

Separating science from marketing is rarely easy. Remember the cola giants' bio-bottle wars? Consumers may have the impression that Pepsi's 100 percent bioplastic green bottle is also 100 percent biodegradable. While it is recyclable – no small feat for a plant-based PET bottle – PepsiCo says it is not biodegradable in its current composition.

For those plastics that are bona fide biodegradables, Adam Lowry of *Treehugger.com* urges that a failure to link these plastics with the ability to recover them only reinforces "a false sense of responsibility that we are doing good by the environment when we really aren't. If the composting infrastructure is not in place to recover the bio-material from that corn-based cup, it's really no better than the ubiquitous red plastic keg cup. Here's the problem: Most biodegradable cups are made from PLA (polylactic acid) plastic. PLA is a polymer made from high levels of polylactic acid molecules. For PLA to biodegrade, you must break up the polymer by adding water to it (a process known as hydrolyzing). Heat and moisture are required for hydrolyzing to occur. So if you throw that PLA cup or fork in the trash, where it will not be exposed to the heat and moisture required to trigger biodegradation, it will sit there for decades or centuries, much like an ordinary plastic cup or fork."[35]

Steve Mojo, executive director of the Biodegradable Products Institute, explains that there are two primary misconceptions driving consumer confusion. "Eighty-five percent of consumers think that bio-based/renewable also means biodegradable, and 60 percent think biodegradable products magically disappear when you throw it away," he said.[36]

"The challenge all companies will face will be finding a way on the packaging to convey their message — especially when people are buying the product, not the packaging," he added. "It is confusing to consumers and it is going to get more so as many people don't understand what those words really mean."[37]

To help consumers wade through the confusion, the plastics industry has to do more than provide information. It needs to instill confidence in the technology. The Plastics Environmental Council (PEC) is one of several diverse groups working to this end. The consortium of businesses, independent scientists and academics, engineers, landfill/compost operators and environmental groups is studying landfill degradation rates of plastics treated with biodegradable additives. The study is expected to yield a new landfill biodegradability standard in 2013 that Board Chairman Robert McKnight says "will inspire confidence in these additives from businesses, consumers and regulators."[38]

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