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ASTM STANDARDS HELP DEFINE AND GROW A NEW BIODEGRADABLE PLASTICS INDUSTRY

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impact of standards

Introduction

For 100 years ASTM has provided the mechanism by which industry, government, and academia come together to develop consensus standards. Through these standards, industry and governments (and their regulatory agencies) can operate in a clear, safe, and effective manner for the benefit of the general public. The ASTM process has continuously evolved over these 100 years to provide state-of-the-art, scientifically credible standards that are used throughout the world. It was, therefore, inevitable that when industry introduced degradable and recycled plastics in response to the new environmental and sustainable development drivers, they turned to ASTM to help set the standards in this area.

In this paper, we showcase the important role ASTM standards played in helping define and grow a new biodegradable plastics industry. The standards helped overcome the confusion and misunderstandings in this new area. They provided a level, well-defined field whereby companies could introduce new degradable products, governmental agencies could monitor and confirm degradability claims, and consumers could safely use and dispose of the products with a clear understanding of the environmental benefits of degradable products. This paper also demonstrates the synergistic value and utility of ASTM's Institute for Standards Research (ISR) in helping perform the necessary R&D to write standards in emerging technology areas such as degradable plastics.

Background

Emerging societal concerns and a growing environmental awareness throughout the world triggered the search for new materials and processes that enhance the environmental quality of products. Companies throughout the world have or are initiating the design and engineering of new products with holistic environmental evaluations beginning with the acquisition of raw materials, continuing through product use/reuse, and ending with disposal. Sustainable development and eco-efficiency are terms that have the attention of major international companies. In this context, biodegradability and recyclability have become important considerations in the design of new products.

Designing biodegradable polymer alternatives and ensuring that they end up in an appropriate disposal system can enhance the environmental quality of many products. For example, composting is an environmentally sound approach that recycles biodegradable waste into useful products and minimizes the amount of waste disposed in landfills. Composting biodegradable polymers and paper waste along with other compostable materials like yard, food, and agricultural wastes generates high quality soil amendment products. Compost amended soil creates the beneficial effects of increasing soil organic carbon, increasing water and nutrient retention, reducing chemical inputs, and suppressing plant disease. The composting infrastructure, which is a key consideration in the ultimate disposal of biodegradable polymers, is growing in North America and Europe. In the United States, close to 3,000 facilities compost yard waste, about 150 compost sludge, 30 compost food and food processing waste, and 20 compost mixed waste. In particular, yard waste composting facilities have shown dramatic growth; since 1988 an average of 470 new yard waste composting facilities have opened each year. Figure 1 (next page) conceptually shows a cradle-to-grave closed loop of design, use, disposal, and re-use of annually renewable resources.

Another major area of concern is marine plastics (single-use disposable plastics used in ships, plastic fishing nets and other similar items). The International MARPOL treaty (the U.S. is a signatory to the treaty along with other large and small countries) prohibits the dumping of non-degradable plastics in the sea, but degradable plastics that have the degradability attributes of paper could be an acceptable proposition. For example, plastic ring connectors that hold cans and bottles were causing the deaths of marine animals which resulted in U.S. Public Law 100-56. U.S. Public Law 100-56 requires degradable ring carriers for bottles and cans.

Table 1. Environmentally Degradable Plastics Standards

COMPOSTING ENVIRONMENT

1. Standard Test Method for Determining the Aerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewage Sludge [D 5209]
2. Standard Test Method for Determining the Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions [D 5338]
3. Standard Practice for Exposing Plastics to a Simulated Compost Environment [D 5509]
4. Standard Practice for Exposing Plastics to a Simulated Compost Environment Using an Externally Heated Reactor [D 5512]
5. Standard Test Method for Determining Weight Loss from Plastic Materials Exposed to a Simulated Municipal Solid Waste (MSW) Aerobic Compost Environment [D 6003]
6. Standard Test Method for Determining the Aerobic Biodegradation in Soil of Plastic Materials or Residual Plastic Materials After Composting [D 5988]
7. Guide to Assess the Compostability of Environmentally Degradable Plastics [D 6002]—ISR Program
8. Standard Test Method for Determining Weight Loss from Plastic Materials Exposed to a Simulated Municipal Solid-Waste (MSW) Aerobic Compost Environment [D 6003]
9. Standard Test for Determining Aerobic Biodegradation of Radiolabeled Plastic Materials in Compost Environment [D 6340]—ISR Program
10. Standard Test Method for Determining Aerobic Degradation of Plastic Materials in a Full Scale Composting Environment [New Standard, in Committee Ballot]—ISR Program
11. Specifications for Compostable Plastics [D 6400]—ISR Program
12. Standard Practice for Preparing Residual Solids Obtained After Biodegradability Standard Methods for Toxicity and Compost Quality Testing [D 5951]—Fate & Effect Testing
13. Standard Practice for Water Extraction of Residual Solids from Degraded Plastics for Toxicity Testing [D 5152]—Fate & Effect Testing

ANAEROBIC DIGESTION / PROCESSES

14. Standard Test Method for Determining the Aerobic Biodegradation of Plastic Materials or Residual Plastic Materials After Composting in Contact with Soil [D 5988]
15. Standard Test Method for Assessing the Aerobic Biodegradation of Plastic Materials in an Activated-Sludge-Wastewater-Treatment System [D 5271]
16. Standard Test Method for Determining the Anaerobic Biodegradation of Plastic Materials in the Presence of Municipal Sewage Sludge [D 5210]
17. Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under High-Solids Anaerobic Digestion Conditions [D 5511]
18. Standard Test Method for Determining Anaerobic Biodegradation of Plastic Materials Under Accelerated Landfill Conditions [D 5526]
19. Standard Practice for Exposing Plastics To a Simulated Landfill Environment [D 5525]

OTHER

20. Standard Practice for Weathering of Plastics Under Marine Floating Exposure [D 5437]
21. Standard Test Method for Determining the Aerobic Biodegradability of Degradable Plastics By Specific Microorganisms [D 5247]
22. Standard Practice for Heat Aging of Oxidatively Degradable Plastics [D 5510]
23. Standard Test Method for Determining Hydrolytic Degradation of Plastic Materials in an Aqueous Solution [D 6118]

PHOTODEGRADATION ENVIRONMENT

24. Practice for Determining Degradation End Point in Degradable Polyolefins Using a Tensile Test [D 3826]
25. Practice for Operating Xenon Arc-Type Exposure Apparatus with Water for Exposure of Photodegradable Plastics [D 5071]
26. Practice for Operating Fluorescent UV and Condensation Apparatus for Exposure of Photodegradable Plastics [D 5208]

A Challenge/Opportunity

As the industry began implementing approaches to design biodegradable materials and products, questions about the practicality, efficacy, and the effects of such products on the environment were raised. The U.S. Federal Trade Commission (FTC), a group of state attorneys general, state legislatures, and the U.S. Congress became very concerned about the various degradability and environmental claims being made, especially as they related to existing waste management practices. Verification of degradability claims and environmental fate and effects of the new degradable products using acceptable well-defined testing protocols were lacking.

The plastics industry failed to take advantage of this opportunity at the beginning by introducing starch filled (6 to 15 percent) polyolefins that were claimed to be biodegradable materials. At best, these materials only disintegrated and did not completely biodegrade. The introduction of these materials resulted in a number of regulatory actions. Eleven states enacted environmental marketing claim laws. A task force of several state attorneys general issued recommendations (Green Report I and II) on advertising related to products and environmental attributes. Between October 1990 and June 1992, 48 separate actions were taken for misleading or deceitful environmental advertising; the highest number of actions were on claims of biodegradable plastics, and the use of the terms biodegradable and recyclable.

Thus, it became increasingly clear that standard test methods and protocols were sorely needed to establish and quantify the degradability and biodegradability of polymers, and to confirm the benign nature of the breakdown products. In order to ensure societal, regulatory, and market acceptance of biodegradable polymers, the ultimate biodegradability of these materials needed to be demonstrated in appropriate waste management infrastructures (like composting where biodegradation can occur). Federal and state governments looked to their Environmental Protection Agencies to set the standards to regulate this nascent industry. The EPAs, in turn, looked to industry to provide well-defined standards and measurements that could be used to regulate the industry.

Standards Development for Environmentally Degradable Plastics

It was in this confused and vexing regulatory climate that ASTM Committee D-20 on Plastics undertook the development of standards in the area of degradable plastics. ASTM's proven, century old, voluntary consensus process involving a balanced participation of government, industry, and academia was well suited to bring order and understanding in this new area.

Committee D-20 formed Subcommittee

Figure 1.

Sustainable Design, Use, Disposal, and Reuse of Resources

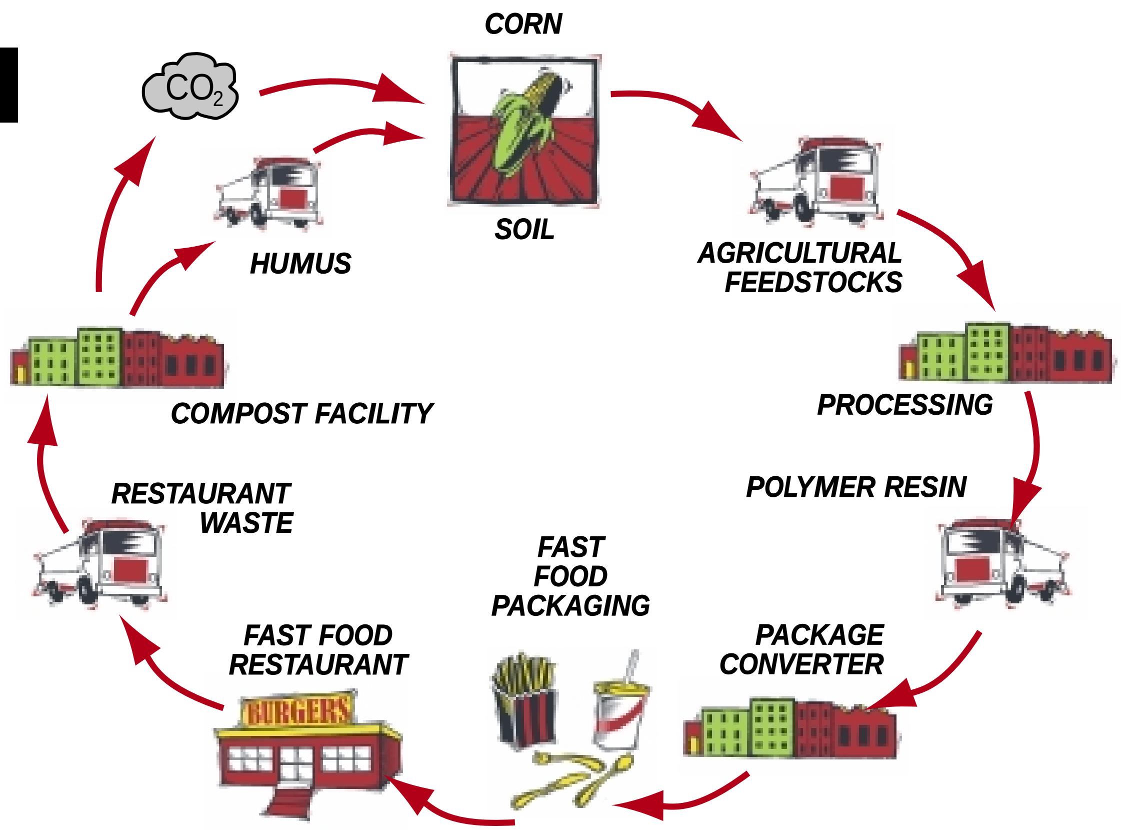


Table 2. ASTM & ISO Definitions on Environmentally Degradable Plastics

degradable plastic, n—a plastic designed to undergo a significant change in its chemical structure under specific environmental conditions resulting in a loss of some properties that may vary as measured by standard test methods appropriate to the plastic and the application in a period of time that determines its classification.

biodegradable plastic, n—a degradable plastic in which the degradation results from the action of naturally-occurring micro-organisms such as bacteria, fungi and algae.

photodegradable plastic, n—a degradable plastic in which the degradation results from the action of natural daylight.

oxidatively degradable plastic, n—a degradable plastic in which the degradation results from oxidation.

hydrolytically degradable plastic, n—a degradable plastic in which the degradation results from hydrolysis.

compostable plastic, n—a plastic that undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds, and biomass at a rate consistent with other known, compostable materials and leaves no visually distinguishable or toxic residue.

D20.96 on Environmentally Degradable Plastics to address the issue of standards for degradable polymers. The scope of the subcommittee was the promotion of knowledge, and the development of standards (classifications, guides, practices, test methods, terminologies, and specifications) for plastics that are intended to environmentally degrade. Over 170 members representing a broad spectrum of interests ranging from producers, converters, users, consumers, and general interest joined the subcommittee. Industry, government, academia, and national laboratories were represented on the subcommittee. Interestingly, the large majority of the members joining were new to ASTM and its consensus process. Thus the ASTM process was, once again, called upon to provide the framework to bring order and understanding in the form of standards to yet another emerging industry.

Recognizing the complexity and diversity of the standards development activity in this area, a modular standards development protocol was adopted. This is exemplified in Figure 2 (next page) and addresses:

- The environment to which plastic will be exposed (simulating a real-world disposal system or environment);
- The test method to ensure degradability (mechanical and chemical property loss) and biodegradability (microbial assimilation/degradation);
- The fate and effects of the degraded products; and
- Classification based on intended application.

The subcommittee is divided into sections to address these and other aspects of degradability. the sections under D20.96 are:

- Biodegradable (D20.96.01);
- Photodegradable (D20.96.02);
- Chemically degradable—hydrolytic and oxidative (D20.96.03);
- Environmental fate (D20.96.04);
- Terminology (D20.96.05); and
- Classification and marking (D20.96.06).

Using the protocol described in Figure 2 (next page), the subcommittee has, to date, 26 approved standards on the books. These standards cover various photo and bio environments that plastics may be exposed to, and methods to quantify the degradability. Table 1 (page 37) lists the developed standards. Table 2 (above) lists the definitions crafted by the subcommittee. These definitions are now International Organization for Standardization (ISO) standards as well. The standards measure biodegradability under different environmental/disposal conditions including composting, soil, marine, wastewater treatment, and anaerobic digestion. The original standards activity was started in ASTM with CEN (European Committee for Standardization), DIN (Deutsches Institut für Normung), and ISO standards closely following the ASTM standards with only minor variations. The majority of the standards address the composting disposal environment, given the importance of composting as an ecologically sound disposal method that generates useful soil amendment products, important for sustainable agricultural practices.

ASTM Institute for Standards Research Degradable Polymers Research Program

As Subcommittee D20.96 started writing standards in this new degradable polymers area, it became increasingly clear that a certain amount of research needed to be conducted before good credible standards could be written. Through the ASTM Institute for Standards Research, Subcommittee D20.96 instituted the Degradable Polymers Research Program to provide the basis for scientific substantiation of disposability statements for degradable polymeric materials in full scale disposal systems. The goal was to determine the behavior of degradable polymeric materials in real disposal systems, and how that correlates with ASTM and other laboratory tests in order to assure that such materials are safe for disposal and effectively degraded. A more important goal was to write standards based on the results of the research conducted. Composting was selected as the first disposal/waste management system for study. As discussed earlier, composting is an important waste disposal option. Furthermore, the Federal Trade Commission (FTC) and state attorneys general found the greatest number of problems were with compostability claims.

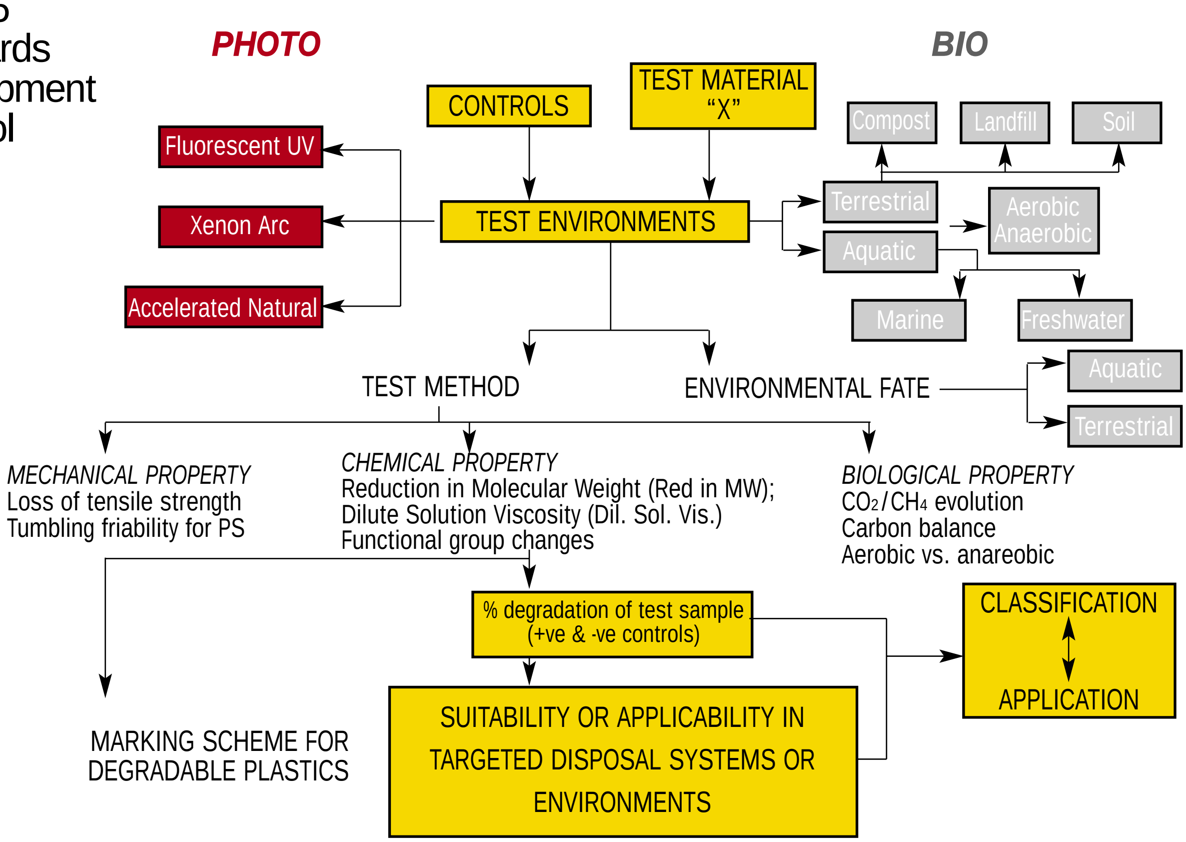
The Degradable Polymers Research Program was funded by industry, including some large multinational companies, government agencies, and trade/consumer organizations as shown in Table 3 (next page). This testifies to the importance of this new environmentally degradable polymer materials area. It is also testimony to the vision and creativity of ASTM in making ISR a forum that facilitates such diverse interests to come together and conduct R&D that would help in writing good, technically sound standards.

Experimentally determining the fate of a polymeric material during composting involved determining first the physical and chemical stability of the materials and second, whether the materials had the potential to be completely biodegraded. This process started with screening level evaluations that were followed by confirmatory studies conducted in pilot, and full-scale composting systems. Similar approaches were used to understand the fate of a material in compost amended soil. In both cases there was a need to determine if persistent residues or intermediates were produced. In order to generate these data, the Advisory Committee on Degradable Polymers Program (ACDP) (see Table 3, next page) and ASTM Subcommittee D20.96 developed a tiered testing strategy for assessing the compostability of polymeric materials.

The ACDP tested a broad range of degradable materials, including synthetic materials and polymers derived from natural resources using the tiered testing strategy, including laboratory-, pilot-, and full-scale studies. The quantitative data generated in these studies formed the basis for the recommendations that the ACDP provided to the degradable polymer industry. These recommendations focused on the usefulness of the tiered testing strategy, drawing upon the results with specific polymeric materials as case studies. The ACDP, in conjunction with the ASTM Subcommittee D20.96 prepared standard D 6002, Guide to Assess the Compostability of Environmentally Degradable Plastics. This guide provides a systematic approach to determining the compostability of a plastic or any other material that could enter the municipal solid waste stream. The scheme is cost effective because information is generated from lower-level, less expensive tests to higher-level, more expensive ones. The strategy covers the three aspects of compostability: biodegradability, ecotoxicity, and composting processability (the mechanical behavior of the material in a compost process). A detailed report on the composting trial has been issued. Several other important test methods like the testing with radiolabeled materials, test methods for performing pilot and full-scale

FIGURE 2.

D20.96 Standards Development Protocol



composting, and specifications for compostable plastics evolved from the program, and are under various stages of balloting.

Impact of the Environmentally Degradable Plastic Standards

The technical standards, definitions, and test methods that have emerged from the ASTM and ACDP biodegradable polymer programs have had important commercial and societal impacts. As discussed earlier, the biodegradable polymer industry suffered a severe setback a decade ago when the first generation polyolefin-starch materials did not degrade as claimed. Through the seminal work and technical leadership of ASTM Subcommittee D20.96 and its ISR-ACDP program, the degradable plastics industry now has the tools it needs to ensure the credibility of claims for current and future generations of degradable plastic products.

The ASTM and ACDP biodegradable polymer programs have generated information on the performance of a benchmark set of materials that have been used by industry in comparing the performance of many newly developed materials. For example, the ACDP reported that the results obtained for the same material at each tier within the ASTM standard guide shows that for all materials compared, without exception, the degradation results obtained in a higher-level test equaled or exceeded those obtained in a lower-level test. This means that the laboratory scale ASTM D 5338, Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions, was more conservative than the pilot-scale tests that, in turn, were more conservative than the full-scale tests. These observations have important ramifications with regard to environmental claims and the cost of generating data to support those claims. On the basis of the ASTM and ACDP program results, a material developer is able to generate a reliable and credible data package based upon relatively rapid laboratory- and pilot-scale tests that would be accepted by the governmental regulatory agencies and the general consumer.

Thus, from a state of confusion, misunderstandings, and legal actions by the attorneys' general task force and the FTC, the degradable plastics industry has begun to successfully introduce degradable plastics in the marketplace based on the technical strength and clarity of the developed ASTM standards and the ISR-ACDP program. Examples of this success can be found in U.S. Public Law 100-56, which requires degradable ring carriers for bottles and cans that cites ASTM D 5208, Standard Practice for Operating Fluorescent Ultraviolet (UV) and Condensation Apparatus for Exposure of Photodegradable Plastics, and D 3826, Practice for Determining Degradation End Point in Degradable Polyethylene and Polypropylene Using a Tensile Test, as the test methods to use to verify and confirm degradability. The state of Wisconsin's Department of Transportation in its procurement guidelines for erosion mat stakes cites ASTM D 5338 as its measure of biodegradability. That ASTM standard also forms the basis for the new standard D 6002, Guide for Assessing the Compostability of Environmentally Degradable Plastics. The presence and acceptability of the standards are attracting many companies to develop degradable plastics for a variety of applications.

In the United States, multinational companies such as Cargill-Dow (a joint venture of Cargill and Dow Chemical), Eastman Chemical, DuPont, Monsanto, Union Carbide, and National Starch and Chemical are commercializing biodegradable plastics. In addition, there are a number of small- and medium-size companies that are also actively pursuing commercialization of degradable plastics. The 170-member strength of subcommittee D20.96 is indicative of this strong activity in the area of degradable plastics.

On the international level, the ASTM standards have led the way for the CEN, DIN, and ISO standards. Asian countries such as Japan, Taiwan, and Korea are using the ASTM standards as the basis for developing and using biodegradable plastics. Some of the major international companies involved in biodegradable plastics are Bayer and BASF (Germany), Novamont (Italy), Showa High Polymer, Mitsui Toatsu, and Shimadzu (Japan).

These companies and their new biodegradable thermoplastic technologies target a broad list of applications such as:

- Starch-based loose fill and rigid foam pack-

Table 3. Sponsor Members of Advisory Committee on Degradable Polymers Program (ACDP)

Cargill
Dow Chemical
DuPont
Eastman Chemical
Ecochem
US Army Natick RD&E
KimberlyClark
Mobil Chemical
Novamont
Novon International
Procter & Gamble
Zeneca Bioproducts
National Com Growers Association
Association of the Nonwovens Fabrics Industry (INDA)

Standard Specification for Compostable Plastics A Milestone Achieved

A major milestone was met with the approval of the Specification for Compostable Plastics (D 6400). This standard establishes criteria (specifications) for plastics and products made from plastics to be labeled compostable. It establishes whether plastics and products made from plastics will compost satisfactorily, including biodegrading at a rate comparable to known compostable materials. This specification is comparable to what is being developed by the European Committee for Standardization (CEN) in Europe today, and in harmony with the Deutsches Institut für Normung (DIN) standard, moving the industry closer to global standards. The specification is based on and references three other D20.96 standard documents for the testing and identification of plastics that will biodegrade and compost satisfactorily. They are:

D 6002, Guide for Assessing the Compostability of Environmentally Degradable Plastics—Outlines recommended procedures and a general approach to establish the compostability of plastics. It provides a three-tiered criteria-based approach that includes rapid screening tests, laboratory and pilot scale composting assessment, and field/full scale assessment.

D 5338, Test Method for Determining Aerobic Biodegradation of Plastic Materials Under Controlled Composting Conditions—Determines the degree and rate of aerobic biodegradation of plastic materials on exposure to a controlled-composting environment under laboratory conditions.

D 6340, Test Method for Determining Aerobic Biodegradation of Radiolabeled Plastic Materials in an Aqueous or Compost Environment—Determines the rate and degree of biological oxidation of carbon in plastic materials when placed in a composting environment containing simulated municipal solid waste or an aqueous environment under laboratory conditions. It applies to plastics the biodegradation rate of which is slow and requires test periods of as long as 365 days.

These documents are based on the results of the work of Subcommittee D20.96 on Environmentally Degradable Plastics and several years of research conducted by ASTM's Institute for Standards Research at the request of D20.96.

aging;

- Packaging materials for single- or limited-use disposable packaging and film applications;
- Disposable nonwovens and hygiene products;
- Consumer goods—items such as cups, plates, cutlery, containers, egg cartons, combs, razor handles, toys, etc.;
- Coatings for paper and film; and
- Marine plastics—fishing lines, nets, pots etc., plastics used in ships (MARPOL treaty).

Film applications in single-use disposal packaging and select non-packaging disposal applications represent the best opportunity for biodegradable plastics. The film applications that are the most promising and having immediate potential are in:

- Lawn and leaf compost bags;
- Agricultural film; and
- Retail carry-out packaging bags (tee-shirt and other merchandise bags, garment bags, grocery bags, etc.).

One of the most promising applications for the use of biodegradable plastics is lawn and leaf waste compost bags. Steady growth in the yard waste-composting infrastructure in recent years has created a renewed demand for biodegradable compost bags. The EPA reports that 20 percent of the 32.8 million metric tons of yard trimmings generated in 1993 were delivered to central composting facilities. This amounts to approximately 6.6 million metric tons (14 billion lb) of yard trimmings collected primarily in polyethylene bags, but also in kraft paper compost bags or in bulk. Based on this amount of yard trimmings, the potential annual market for compost bags is 450 million 30-gallon (114 L) bags (assuming that one 30-gallon compost bag holds on average 30-33 pounds (13.5 to 15 kg) of yard waste). This translates to 56 million pounds (25 000 metric tons) of resin (estimating that one pound of resin yields eight 30-gallon bags of 1.5 mil thickness) (1 kg of resin yields 18 bags of 38 micrometre thickness). It is estimated that yard waste composting grew to 20 billion lb (9 million metric tons) in 1994, providing an 83 million lb (38,000 metric ton) market potential for compost bags. The market for compost bags will continue to grow as the composting infrastructure expands. Centralized yard waste composting facilities have grown from 651 in 1988 to 2,980 in 1992 and continues to grow. This dramatic increase in the number of composting facilities is complemented by increased throughput by existing facilities, resulting in further demand for compostable bags.

Twenty states now mandate composting of lawn and leaf waste, and many more will follow this trend. in addition, because of their biodegradability, state regulations increasingly require the use of paper bags instead of plastic. Biodegradable plastic bags are lighter, and have better strength and water resistance than paper. In the future, it is likely that the composting of other waste streams, such as food waste, will be required. This will also increase the size of the market for biodegradable plastics.

Conclusions

ASTM standards have helped define and grow a new degradable plastics industry—that was not accepted by the consumer and was looked upon warily by regulators—to a strong, thriving industry attracting large multinational companies commercializing biodegradable plastics worldwide. This paper showcases the impact of not only the ASTM standards, but ASTM itself and its ability to continuously evolve to respond to current needs with programs such as ISR, which was so vital for the degradable plastics standards.

Companies, researchers, and consumers will continue to turn to ASTM and its team to help define and grow the next generation of products, technologies, and services as the degradable plastics industry has. **SN**

Acknowledgement

The development of degradable plastics standards and its significant role in growing the degradable plastics industry would not have been possible without the selfless work of members of Subcommittee D20.96, the ISR Advisory Committee on Degradable Polymers Program, and the superb staff of ASTM and ISR, particularly its Staff Managers Kathie Morgan (Committee D-20) and Ann McKlindon (ISR).