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Report to the Chairman, Committee on Governmental Affairs, U.S. Senate

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DEGRADABLE PLASTICS

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The Honorable John Glenn
Chairman, Committee on Governmental Affairs
United States Senate

Dear Senator Glenn:

In your letter of January 19, 1988, you asked us to conduct a study of federal government activities that encourage the research and development (R&D) of degradable plastics. As agreed to in subsequent discussions with your office, this report

- identifies the extent of federal and private sector efforts relevant to developing standards for degradable plastics and
- describes federal agencies' support of degradable plastics R&D.

Results in Brief

Overall, we found that the federal government and the private sector are making only limited efforts to develop standards for degradable plastics. Along with the growing interest in commercializing degradable plastics, scientists and management officials in both government and industry recognize that standards need to be developed before these plastics can have widespread use. Such standards would include uniform definitions and methods of testing to evaluate product performance and would help assure consumers of a satisfactory product. They would also facilitate manufacturers' compliance with existing and potential legislation mandating the use of degradable plastics.

Furthermore, we found that federal agencies' support of degradable plastics R&D has been limited. Federal expenditures in fiscal year 1988 total $1.7 million for 12 projects emphasizing the development of new degradable plastic materials. These projects include very basic research and applied R&D intended for specific uses. The federal agencies supporting these activities, however, are not among those that could undertake the formulation of standards. In addition, virtually no testing of degradable plastics has been done; the limited testing that is planned or is being conducted may help to evaluate product performance but does not ensure the establishment of standards for degradable plastics.

Background

The mounting problems posed by the permanency of plastics in municipal solid waste, litter, and marine pollution have led to a search for solutions, including the use of degradable plastics. Unlike traditional plastics, which may persist in the environment for centuries, degradable plastics are intended to disintegrate in a matter of months through degradation by sunlight (photodegradation) or microorganisms (biodegradation). They thus may be able to reduce the life span of litter in the landscape and at sea; they may also diminish the amount of plastics accumulating in landfills. In addition to their potential environmental benefits, degradable plastics offer new opportunities for the use of agricultural commodities. Cornstarch, in particular, is a leading ingredient.

Need to Develop Standards for Degradable Plastics

We found widespread concern among officials and scientists about the current lack of standards. Definitions of such basic terms as biodegradation and photodegradation have not yet been agreed upon, nor have uniform methods of testing been developed. Very little testing of degradable plastics has been done to support the development of standards. Testing remains necessary to resolve two basic technical uncertainties about the performance of degradable plastics in the environment: the rate of degradation and the safety of the end products. Issues relating to the rate of degradation include the possibility that degradation may occur before the product has served its purpose or that it may occur too slowly to provide an effective solution to environmental problems. Safety-related issues include the potential toxicity of chemicals leaching from degradable plastics and the size of the plastic fragments resulting from degradation.

Among government agencies with the capability to standardize or test new materials and products, the Environmental Protection Agency (EPA), National Institute of Standards and Technology (NIST), and Food and Drug Administration (FDA) reported few or no activities involving degradable plastics. EPA has laboratories capable of addressing the technical uncertainties but has not targeted resources on these concerns, primarily because of other priorities. NIST is planning one experiment to evaluate degradable plastics but has no program underway. FDA has not approved any additives that are intended to increase the degradability of plastic food-packaging materials. However, the agency has recently been contacted by, and is working with, companies that are interested in food-packaging uses of degradable plastics.

In the private sector, the American Society for Testing and Materials (ASTM) is preparing to develop formal definitions and methods of testing.

ASTM, supported by private firms, describes itself as the world's largest source of voluntary consensus standards. It operates through numerous technical committees. One of these, the Committee on the Permanence Properties of Plastics, is chiefly responsible for ASTM's efforts to develop uniform definitions and methods of testing. These activities have begun so recently, however, that their contribution to developing standards for degradable plastics is difficult to evaluate at present.

Federal R&D for Product Development

Four federal agencies are conducting or supporting basic or applied research related to the degradability of plastics and product development. The Departments of Agriculture (USDA), Defense (DOD), and Energy (DOE) and the National Science Foundation (NSF) are supporting 12 R&D projects at a total funding level of $1.7 million in fiscal year 1988.

- USDA is spending $941,000 for degradable plastics research aimed at developing new nonfood, nonfuel uses for agricultural commodities, particularly corn.
- DOD's R&D program, accounting for $575,000, is focusing on developing an alternative to nondegradable plastics for use at sea.
- DOE has provided $150,000 to develop wood- and starch-based substitutes for petroleum-based plastics.
- NSF has awarded a grant for $63,000 to improve the technology for developing plastics based on cornstarch and wood.

In addition, although supporting no direct R&D, the Department of Commerce has completed a technical study; further studies are underway at EPA and the Office of Technology Assessment (OTA). The Commerce Department established the Interagency Task Force on Persistent Marine Debris, which assessed the problem of plastics at sea and recommended ways of mitigating it. EPA, in response to the Marine Plastic Pollution Research and Control Act of 1987 (P.L. 100-220, sections 2001-2305), is conducting a study on methods to reduce plastics pollution. OTA, too, is evaluating different technologies and long-term strategies for reducing and managing municipal solid waste. Both EPA and OTA are assessing the potential role of degradable plastics in addressing these concerns.

Several bills, including S. 2298, which you have proposed, have been introduced in the Congress and in state legislatures to promote or mandate the use of degradable plastics. Sixteen states already have enacted legislation requiring the use of degradable plastics in six-pack yokes. The majority of these state laws, however, provide no definitions, time

frames, or requirements for the safety of the end products of degradability.

Matter for Consideration by the Congress

Given the consensus on the need to develop standards for degradable plastics and the currently limited efforts within the federal and private sectors to formulate such standards, the Congress may want to consider the following approach if it wishes to promote degradable plastics: Select an agency (or agencies) which, in cooperation with the private sector, would undertake the development of standards, including uniform definitions and methods of testing for degradable plastics. EPA and NIST would be appropriate agencies for such activities because of their extensive experience in testing for environmental effects and product performance. If such standards are developed, the Congress may want to incorporate them in any legislation promoting the use of degradable plastics.

Our report does not attempt to evaluate the relative merits of product degradability versus other approaches (such as recycling) to alleviating the solid waste problem associated with traditional plastics. Reports by EPA and OTA will compare degradable plastics with other alternatives in developing an overall strategy. Efforts to promote the use of degradable plastics, according to an OTA official, should take into account their effectiveness in reducing solid waste and their compatibility with alternative approaches.

Our report is based on information obtained from federal officials, project officers, academic researchers, trade associations, and industry representatives. In addition, we reviewed technical literature, legislation, and reports by specialized task forces. Because of our report's informational nature, we did not obtain agency comments on a draft of this report. Our audit work was conducted between February and July 1988.

We are sending copies of our report to the heads of federal agencies contacted during this review and to others upon request. This report was prepared under the direction of Flora H. Milans, Associate Director. Major contributors to this study are listed in appendix IV.

Sincerely yours,

J. Dexter Peach
Assistant Comptroller General

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Abbreviations

ASTM	American Society for Testing and Materials
DOD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
FY	fiscal year
NIST	National Institute of Standards and Technology
NOAA	National Oceanographic and Atmospheric Administration
NRRC	Northern Regional Research Center
NSF	National Science Foundation
OTA	Office of Technology Assessment
R&D	research and development
SPI	Society of the Plastics Industry
USDA	U.S. Department of Agriculture

Technology and Uses for Degradable Plastics

The numerous advantages of plastics—their strength, durability, lightness, flexibility, and low cost—have led to their widespread use. They are employed extensively in the packaging industry, transportation, agriculture, commercial fisheries, and other market sectors. They have been used to replace glass in bottles, metal in automobiles, and natural fibers in large nets used in commercial fishing. The use of plastics is especially evident in packaging, which accounted for about 11.5 billion pounds, or 25 percent, of total plastics usage in 1986.

The very success of plastics, however, has created problems with their disposal as litter or municipal solid waste. Their strength and durability, which enable them to endure for long periods of time, pose aesthetic or environmental problems. As an example of the extent of marine pollution, the Woods Hole Oceanographic Institution reported as many as 46,000 pieces of plastic per square mile at sea. Ten miles of plastic netting from Asian commercial fishing operations alone are lost every day at sea, creating a hazard to marine life. Ingestion of plastic by marine animals has been documented among seabirds, fish, turtles, and whales. A report prepared by the Office of Technology Assessment (OTA) concluded that tens of thousands of seabirds and an estimated 100,000 marine mammals die each year by ingesting or becoming entangled with plastic debris.[1]

The growing share of plastics in municipal solid waste is also stirring concern about their disposal. The percentage of the waste composed of plastics nearly doubled between 1976 and 1984, equaling 7.2 percent, or about 9 million tons. The growing reliance on plastics, coinciding with a steep decline in the number of landfill sites where the wastes may be deposited, has led to mounting concerns about the looming crisis in plastics waste disposal.

Consideration is being given to degradable plastics as one means of alleviating such problems. Unlike traditional plastics, which may last 200 to 400 years, degradable plastics may deteriorate in a matter of months. Degradable plastics may thus be able to reduce the life span of litter in the landscape and at sea; they also may diminish the amount of plastics accumulating in landfills. Technical uncertainties about the performance of degradable plastics, however, have stirred some questions about their ability to alleviate these problems. (For a discussion of technical uncertainties, see app. II). As a result, some experts contend that recycling

[1]Office of Technology Assessment, Wastes in Marine Environments (OTA-O-334), April 1987.

and incineration may be more effective responses to the environmental problems posed by plastics.

In addition to their potential environmental benefits, degradable plastics offer new opportunities for the use of agricultural commodities. Cornstarch, in particular, is a basic ingredient for making a degradable plastic. Assuming that cornstarch could penetrate 5 percent of the packaging market, the National Corn Growers Association has estimated that this use could consume more than 19 million bushels per year. Proposed legislation in the Senate (S. 2298) observes that degradable plastic products made from agricultural commodities can also reduce U.S. reliance on imported oil, a principal ingredient in traditional, durable plastics.

The private sector has responded to this growing interest in degradable plastics. The Society for the Plastics Industry, a trade organization of more than 1,900 members representing all segments of the plastics industry in the United States, held a symposium on the subject in June 1987. The symposium was attended by a wide range of representatives from large corporations, small manufacturers of degradable plastics, and environmental and research-oriented organizations. In addition, manufacturers have marketed some degradable plastic products, although such products tend to be somewhat more expensive than nondegradable plastics.[2] Companies are also conducting research and development (R&D) to test the performance of new degradable plastics.

In addition, local, state, and federal governments have promoted the use of degradable plastics. Local and state governments across the country have proposed bills to ban such nondegradable plastic products as fast-food packaging; certain wrappings for fruit, cheese, and meat; six-pack yokes; egg cartons; grocery bags; and liquor bottles. As of July 1988, two local jurisdictions—Berkeley, California, and Suffolk County, New York—have enacted legislation prohibiting nondegradable fast-food packaging. Sixteen states have enacted legislation requiring the use of degradable plastics in beverage containers.

At the federal level, on April 2, 1987, 30 Senators requested that the President assist in developing a coordinated strategy to resolve marine problems resulting from plastic debris. Subsequently, the Department of Commerce organized an Interagency Task Force on Persistent Marine

[2]A Congressional Research Service Issue Brief, "Degradable Plastics" (June 8, 1988, IB88067), stated that on average, degradable plastic products cost about 8 to 14 percent more than conventional plastic goods.

Debris, an 11-agency task force addressing the potential role of degradable plastics. Since January 1988, several bills have also been introduced in the House and Senate to promote or mandate the use of degradable plastics.

Ways of Making Degradable Plastics

Current technology produces plastics that are considered nondegradable because they degrade only over long periods of time (from 200 to 400 years). These nondegradable plastics are synthesized from petrochemicals to create long chains of repeating molecules known as polymers. The synthetic polymers account for much of the strength and durability of plastics. In addition, they are chemically inert and resistant to attack by microorganisms. Scientists have sought to make them resistant to other kinds of degradation as well.

Environmental concerns in the 1960s, however, fostered research to make plastics more degradable. This early research focused on materials that could be broken down by sunlight. Research since has been broadened to include blends of synthetic and natural polymers. Unlike synthetic, petroleum-based polymers that have traditionally been used in making plastics, natural polymers such as starch are susceptible to attack by microorganisms.

Photodegradation and biodegradation are the two most often considered ways of degrading plastics. The former relies on the sun's ultraviolet light to decompose the physical and chemical structure of the plastic. The latter makes use of microorganisms to break the plastic into smaller fragments or to disintegrate it completely.

Photodegradation requires the use of certain chemical additives in plastic that are sensitive to sunlight. These chemicals, such as carbon monoxide, are included at intervals in the polymers. Sunlight is able to decompose the plastic at these points, resulting in shorter molecular chains which render the plastic brittle and hasten its disintegration. Given an initial exposure to sunlight, one particular type of photodegradable plastic, using an "auto-oxidant/photoactivator system," is claimed to continue degrading even in the absence of sunlight or oxygen. This characteristic may enable the plastic to decompose even if it is buried in a landfill.

Biodegradation requires the blending of natural and synthetic polymers and their exposure to a moist environment with an active microbial population. The natural polymer is recognized as food by bacteria and fungi,

which release enzymes that help to disintegrate it. One approach to biodegradation, which is already being commercialized, involves the inclusion of starch as the natural polymer. The starch degrades completely, reducing the remaining plastic to smaller fragments that may in turn become susceptible to further biodegradation. A second approach involves a biodegradable plastic that is produced through the use of microorganisms. A third approach to biodegradable plastics relies on the use of cellulose, specifically wood fibers. Additional methods are being developed to produce a variety of degradable plastics. With the need for moisture and microorganisms, biodegradation of surface litter may be limited and is more likely to occur in landfills or on the seabed.

Technical Innovation

The technologies for producing degradable plastics, according to the technical director for a large company entering the degradable plastics market, are in a state of considerable flux and improvement. A scientist directing the polymers division of a large chemical corporation told us that researchers need to learn how to "unzip" polymers as effectively as they have learned how to make them virtually indestructible. In an effort to improve degradable plastics, companies are reviewing older techniques and searching for innovations. Following are two among many examples of the innovative research underway.

The bond between synthetic and natural polymers is a limiting factor in the current technology but is considered capable of improvement. Plastics and natural polymers such as starch are basically incompatible. As a result, the present blends in biodegradable plastics are generally able to incorporate no more than 6 to 10 percent of the natural polymer in the finished product. Blends that attempt to include a higher percentage lose a proportionate amount of strength.

Research sponsored by the Department of Energy (DOE) is aimed at developing a bond to hold the synthetic and natural polymers together more effectively. It involves efforts to manipulate the synthetic polymer, the natural polymer, and a compatibilizer or "glue," each engineered to interlock with the other. Development of an improved bond will enable scientists to boost the percentage of the natural polymer to levels as high as 25 to 35 percent with no loss of strength. In turn, the by-products of bacteria acting to degrade the natural polymer may also attack the remaining synthetic polymer more effectively.

Research sponsored by the Department of Defense (DOD) relies on special strains of microorganisms to produce a plastic that degrades completely

into carbon dioxide and water. Scientists are investigating numerous types of these microorganisms capable of producing a variety of these degradable plastics. By controlling the food consumed by the microorganisms, scientists are able to stimulate the production of fatty materials with plastic properties. They are also learning how to direct the microorganisms' production of such plastics to obtain polymers with specially designed characteristics.

Uses for Degradable Plastics

The current uses of degradable plastics are limited to a few products and have been commercialized only to a minimal extent. The products include six-pack yokes, plastic bags for carrying trash, and mulching films for agriculture. Expectations about the potential market point toward specialized uses. An overview presented at the Society of the Plastics Industry (SPI) June 1987 symposium concluded that degradability can be beneficial and cost- effective if it is applied selectively. Manufacturers of degradable plastics believe that markets can be expanded in packaging, agricultural films, and other areas requiring short-term uses for plastics.

Degradable six-pack yokes are useful in reducing litter and the risk to wildlife of entanglement in the loops. Several large plastics manufacturers have responded to the problem of six-pack yokes by marketing a degradable plastic material (a resin) that can be used in making the yokes. The resin incorporates additives that are photodegradable. These degradable packaging materials are mandatory in numerous states.

Degradable plastic bags have been developed but have obtained only a limited share of the market. Degradable plastic trash and grocery bags, for example, are sold by only a few companies on a local or regional basis. The National Corn Growers Association, in an effort to promote degradable plastic grocery bags incorporating cornstarch, has begun distributing samples.

The use of plastic mulching films in agriculture has become widespread. The films are designed to reduce the number of weeds, loss of fertilizer, the rotting of fruit, and other problems. The National Agricultural Plastics Association estimated that, in 1985, about 125 million pounds of plastic mulch films were sold in the United States. The Association estimates that farmers are using up to 500 pounds of nondegradable plastic film per acre and paying more than $100 per acre for its removal. Although biodegradable plastics have not yet been used extensively for this purpose in the United States, they may be employed more widely

because of the cost of removing the nondegradable plastics from the fields.

Packaging is an area that may be appropriate for degradable plastics. About 25 percent of the plastics sold in the United States is used in packaging and other short-life applications. Plastics are applied in packaging for wrapping and laminating; they are also used in bottles and numerous other containers for carrying and protecting food. Some packaging used for fast foods has an estimated service life of only 3 minutes but may persist as litter for centuries. As a result, applications in packaging may become an attractive market for degradable plastics.

Objectives, Scope, and Methodology

In a letter dated January 19, 1988, Senator John Glenn, Chairman of the Senate Committee on Governmental Affairs, asked us to conduct a study of federal government activities in the area of degradable plastics. We subsequently agreed with the Chairman's office to (1) identify the extent of federal and private sector efforts relevant to developing standards for degradable plastics and (2) describe federal agencies' support of degradable plastics R&D.

Our report does not attempt to evaluate the relative merits of product degradability and other approaches (such as recycling) to alleviating the solid waste problem associated with traditional plastics. We restricted our scope in this regard because studies underway at the Environmental Protection Agency (EPA) and OTA will evaluate degradable plastics in conjunction with other approaches to achieving solid waste management objectives.

During our review, we contacted officials and scientists in the federal government and the private sector. We talked with officials and scientists in the Department of Agriculture (USDA), DOD, DOE, and the National Science Foundation (NSF), as well as EPA, NIST, the Department of Commerce, and the Food and Drug Administration (FDA), to identify federally funded R&D and activities relating to standards for degradable plastics. In the private sector, we contacted officials and scientists in companies, trade associations, and the American Society for Testing and Materials (ASTM) to identify concerns about the need for standards. We further contacted officials in Suffolk County, New York, and Berkeley, California, to obtain their legislation banning nondegradable plastics.

In addition, we reviewed a wide range of popular and technical literature on plastics and the development of degradable plastics.[3] Federal managers and scientists associated with degradable plastics projects furnished us with detailed information on their activities. Manufacturers of degradable plastics provided brochures, technical analyses, and samples of their products. We also reviewed existing state and local laws relating to degradable plastics.

We coordinated our study with OTA, which is preparing an extensive analysis of municipal solid waste issues and the role of plastics. Because of its informational nature, we did not obtain agency comments on a draft of this report. Our analysis was performed from February to July 1988.

[3]An especially useful document is the Proceedings of the SPI Symposium on Degradable Plastics, Society of the Plastics Industry, June 10, 1987, Washington, D.C.

The Need to Develop Standards for Degradable Plastics

Greater interest in degradable plastics has led to the recognition of the need to develop standards for them. This development would include agreed-upon definitions of such basic terms as photo- and biodegradation. It would also include the formulation of accepted methods of testing to evaluate performance characteristics. Such standards would help assure consumers of a satisfactory product and facilitate manufacturers' compliance with state and local government legislation and potential federal legislation requiring the use of degradable plastics for specific applications.

Very little testing, however, has been undertaken to date to determine the performance characteristics of degradable plastics and help in establishing standards. As a result, technical uncertainties involving the timing and rate of degradation and the safety of the end products remain unsettled. The federal and private sectors possess the resources to resolve these uncertainties but have begun only recently to respond to the problem. Certain federal agencies—most notably EPA, the National Institute of Standards and Technology (NIST), and FDA—are capable of evaluating the performance of degradable plastics but are involved in this area to only a limited extent. ASTM, the principal private organization responsible for developing standards, is beginning to formulate definitions and methods of testing. In addition, a trade association is conducting a limited testing program for degradable plastics. The testing that is planned or underway may help to evaluate product performance but does not ensure the establishment of degradable plastics standards.

This appendix discusses the need to develop standards for degradable plastics. It reviews the main technical uncertainties that have been identified. It also examines the resources and activities committed to standards development by EPA, NIST, FDA, and the private sector.

Lack of Standards

Private and federal officials and scientists have expressed concern about the current lack of standards. Officials we spoke with considered the absence of uniform definitions and methods of testing to be a source of confusion regarding degradable plastics. The director of the plastics department at a major corporation described the situation of degradable plastics as "a state of chaos." Another official with a large corporation involved in developing degradable plastics said that inconsistent definitions of biodegradability in particular are causing considerable confusion. The technical director for an industry trade association stated that degradability needs to be defined and uniform methods of testing need to be developed. A scientist conducting research on degradable plastics

at the Massachusetts Institute of Technology described the problem as follows:

"Most of the biodegradability studies are very ill-defined, not quantitative and not standardized as to what is biodegradable. The community in this area has not reached satisfactory standards or procedures allowing for uniform comparison of biodegradability. There is a need for further development of policies and procedures for this critically important area."

Standards, according to various officials, also need to be developed as a basis for effective legislation. Officials are concerned that the current lack of standards may lead to unrealistic or confusing legislation. One technical director of a degradable plastics program at a major corporation stated that legislators are trying to write laws with no suitable guidelines, as exemplified by Italy's legislation banning nondegradable packaging; Italy's law does not clarify what is meant by degradability or what standards are to be met. This official is concerned that a similar situation, in which producers would not know whether they were in compliance with the law, could develop in the United States.

Although 16 states have enacted legislation requiring the use of degradable plastics in six-pack yokes, few of the states have provided definitions, time frames, or requirements for the safety of the end products of degradability. Legislation in a majority of these states is relatively simple and nontechnical. Nine of these states provide no definitions of degradability, 10 states specify no time frame, and 11 states provide no requirements regarding the safety of the end products. The definitions, when provided, refer mainly to general processes, including photo- and biodegradation, while giving no further details. Time frames, when specified, vary between 120 days in Florida and 5 years in Minnesota. Of the five states with end product safety requirements, only two states require that both the particle size and chemical composition of degradable plastic fragments be established as safe.

Areas of Technical Uncertainty

Along with the lack of standards, two important technical uncertainties associated with degradable plastics remain to be addressed: (1) the initiation and rate of degradation and (2) the safety of the end products resulting from it. Some scientists and industry officials are concerned that degradation may occur before the product has served its purpose or that it may occur too slowly to provide an effective solution to environmental problems caused by persistent plastics. Safety-related issues include the potential toxicity of chemicals leaching from degradable

plastics into the environment or into food from plastic packaging. In particular, chemical additives used in plastics to improve their durability and other properties may be released during degradation.

These technical uncertainties also have implications for other approaches to addressing solid waste management problems. Their resolution would contribute to decision-making about the best mix of strategies in this area. These other strategies include recycling, incineration, and waste stream reduction.

The limited amount of testing of degradable plastics accounts in part for these technical uncertainties. A scientist conducting research on degradable plastics for DOD and the Department of Commerce told us that there has been virtually no testing and, consequently, no demonstration that the materials will perform properly in degrading. He stated:

"Neither the exact sequence nor the time scale for any of the natural stages of deterioration of any of the plastics have been determined, especially with regard to performance in the marine environment."[1]

He also told us that future research should focus on experimentation to demonstrate effective degradation.

Control over the initiation and rate of degradation remains uncertain. Diverse environmental conditions play important roles. Plastics may be dumped into the ocean, where they float or sink, scattered as litter on the surface of the land, buried in a landfill, mixed with soil as a mulching film, or used as a container or a lining in contact with food. Consequently, exposure to the two primary agents affecting the start and rate of degradation, sunlight and bacteria, may differ to a considerable degree.

As a result, the technical challenges for degradable plastics are avoidance of a premature failure and disintegration within a suitable time frame once they are no longer needed. According to the overview presented at SPI's June 1987 symposium, degradable plastics in proposed applications such as packaging have not been carefully tested to ensure that the contents are not lost or contaminated through an early failure of the packaging. It further noted that, on the other hand, some plastics may degrade too slowly in landfills. A representative for an environmental group, citing the dangers posed by nondegradable plastics to

[1]Report of the Interagency Task Force on Persistent Marine Debris, May 1988, p. 105.

marine life in particular, emphasized the need to determine whether degradation can occur rapidly enough to reduce the hazards of plastics in the environment.

The safety of the end products resulting from degradation is also a concern. According to a manufacturer of degradable plastics, it is important to distinguish between (1) the breakdown of a plastic object into small, dispersible, undegraded plastic fragments by the action of microorganisms on fillers such as starch and (2) the true breakdown of the polymers to natural end products that may safely enter the environment.

The SPI degradable plastics overview stated that the end products of degradable plastics are not well understood, so their toxicity and environmental effects remain unknown. Effects on groundwater and soils are not well known and could add to the burden already placed on the environment by materials degrading in landfills. According to a state environmental official, biodegradable products in landfills will form undesirable products such as methane gas, one of the major problems with all current landfills. In addition, the leaching of degradable plastic additives into the environment and contamination of foods in contact with packaging materials have been cited as potential hazards.

Some manufacturers of degradable plastics have stated that they are able to control the rate of degradation and the safety of the end products. On the basis of field trials, a manufacturer of an agricultural mulching film, for example, indicated that the time for degradation of the film is predetermined and can be varied according to the location, season, and time of application. The manufacturer claims that predictable times ranging between 3 weeks and 12 months have been achieved. According to a manufacturer of the bacteria-produced plastic that is claimed to disintegrate completely into carbon dioxide and water, it is stable in storage and harmless during degradation. In general, however, such claims have not eliminated the concerns about the technical uncertainties associated with degradable plastics.

Limited Efforts to Resolve Technical Uncertainties

In spite of the need to address technical uncertainties and develop standards, only limited efforts are underway. Among the federal agencies that we contacted, EPA could address the technical uncertainties through several of its laboratories but has not targeted resources on these concerns, primarily because of other priorities. NIST and FDA have indicated

recent but limited involvement in this area. Regarding the private sector, ASTM is beginning to develop formal definitions and methods of testing. One trade association is conducting tests to evaluate the performance of degradable plastics. In general, however, activities related to standards development for degradable plastics are somewhat limited in both the public and private sectors.

Federal Activities

Among the many government agencies becoming concerned with degradable plastics, EPA, NIST, and FDA have responsibilities that relate to the development of standards and testing of new materials and products. EPA conducts a variety of studies that relate to the degradability and safety of many products, including plastics. NIST's Polymers Division is directly concerned with testing and evaluating plastics. FDA, charged with protecting the public safety where food is concerned, has recently begun to work with companies interested in the use of degradable plastics in food-related packaging. The extent of these agencies' activities is discussed in further detail below.

Environmental Protection Agency

Several laboratories within EPA's Office of Research and Development are capable of conducting tests to address the technical uncertainties about degradable plastics, but no testing in this area is underway, primarily because of other priorities. The Deputy, Office of Environmental Processes and Effects Branch, said that the Office of Research and Development has a major program concerning the stability and transport of chemicals in the environment. The testing of degradation rates and the safety of end products of plastics, according to the Deputy, would be consistent with previous work that EPA has done. The Deputy indicated that such a task would be relatively easy to perform and could be conducted in a cursory or a very thorough manner.

Several of EPA's laboratories described their ability to address the technical uncertainties. The Gulf Breeze Laboratory (Gulf Breeze, Florida) would be able to evaluate the biodegradation of plastics. The Environmental Research Laboratory (Athens, Georgia) could address both bio- and photodegradation. The Robert S. Kerr Environmental Research Laboratory (Ada, Oklahoma) conducts research on the mechanisms and rates of degradation of chemicals in groundwater and could apply this expertise to degradable plastics in general.

A fourth EPA laboratory, the Risk Reduction Engineering Laboratory (Cincinnati, Ohio), conducts a program involving the biodegradation of

hazardous wastes. It evaluated various plastics and their biodegradation in the early 1970s.[2] The Deputy Director stated that social concerns are broadening from hazardous waste to include municipal solid waste problems and that the laboratory has the capability to address the technical uncertainties.

EPA officials said that although the laboratories possess the capability, no tests of degradable plastics are underway. The laboratories are faced with numerous other research and testing priorities. As a result, any effort involving degradable plastics would probably be somewhat limited. An EPP official involved in developing methods of testing told us that the responsibility for progress toward standardization resides with the private sector, unless the federal government mandates degradable plastics and the standards to be met. At that point, according to this official, EPA would have to become more involved in activities relating to standards development.

National Institute of Standards and Technology

The Polymers Division within NIST, which has about 40 scientists with expertise in plastics, is planning to undertake one very small-scale project to test degradable plastics. The Group Leader, Chemical Performance and Standards, in this division has requested samples and is planning very limited testing. The tests will involve burying starch-based degradable plastics in soil and exposing them to selected strains of microorganisms.

According to the Deputy Director, Polymers Division, for NIST to expand its testing, one of three developments would have to occur: (1) the designation of a lead agency for degradable plastics and funding from that agency provided to NIST, (2) a budget initiative from within NIST, or (3) a congressional mandate. The Chief, Program Office, said that no determination has yet been made whether NIST would undertake an expanded degradable plastics program. She added that since NIST receives more than 40 percent of its funding from other agencies, it might be able to obtain funding elsewhere to support an effort in this area.

Food and Drug Administration

FDA has not approved any additives that are intended to increase the degradability of plastic food-packaging materials. However, the agency

[2]One of these studies, An Investigation of the Biodegradability of Packaging Plastics (Aug. 1972), concluded that the then-current packaging plastics were not biodegradable at practical rates.

has recently been contacted by, and is working with, companies that are interested in food-packaging uses of degradable plastics. The burden of proof for the safety and functionality of a new product, as well as the analysis of environmental impact, rests with the manufacturer.

To assess the safety of the indirect food additives that might impart degradability to plastic food-packaging materials, according to FDA, information is needed on (1) the effect of degradability on the shelf life of the package and (2) the potential migration of the additive from the package to the food. To assess the environmental impact of degradable plastics used for food-packaging material, information is needed on (1) whether a polymer is degradable and, if so, under what conditions and in what time frame; (2) the potential for increased environmental introduction of degradation products and additives from a degrading polymer; (3) the potential effects of small pieces of the degrading polymer in terrestrial and aquatic ecosystems; and (4) the impact of degradable polymers on recycling programs. The agency will determine the extent to which FDA resources are needed to develop testing methods for predicting the environmental impact of degrading plastics.

Private Sector Activities

Private sector activities are being planned primarily through ASTM. These activities have begun so recently, however, that their contribution to developing standards for degradable plastics is difficult to evaluate at present.

ASTM Activities

ASTM is a scientific and technical organization that develops standards on the characteristics and performance of materials and products. It describes itself as the world's largest source of voluntary consensus standards. It operates through 140 main technical committees designed to provide a balanced representation among producers, users, and consumers.

One of its committees, known as the D-20 Committee on the Permanence Properties of Plastics, is chiefly responsible for ASTM's recent efforts to develop standards for degradable plastics. The chairman of the D-20 Committee said that his committee has just begun to address the question of developing degradable plastics standards. The subject was broached for the first time at a committee meeting in March 1988. Members have agreed that they would like to develop a set of standards and

methods for testing that would conform with ASTM's criteria. Two officials were appointed at the March meeting, one to develop definitions and one to develop standards and methods of testing.

The official concerned with definitions indicated that he is involved in defining five principal terms: biodegradability, photodegradability, environmental degradability, biodeterioration, and enhanced degradability. The main purpose for ASTM's work in defining these terms is to distinguish different manufacturers' products. The terms and definitions under development will be circulated among manufacturers and customers for comments and revisions.

The official concerned with standards and methods of testing indicated that the principal effort so far has consisted of a letter sent to about 40 companies and individuals inquiring whether they have or are aware of any standards relating to degradable plastics. He found no relevant standards but wanted to establish this fact as a starting point for further ASTM efforts to discuss and develop them.

With regard to methods of testing, ASTM's function is to provide a peer review process through which appropriate tests can be suggested, made known to other scientists, and evaluated for effectiveness. A plastics industry spokesperson believes that scientists need to identify the specific conditions (such as landfills and marine environments) to be replicated for degradable plastics testing; he would then like to see perhaps a half-dozen methods formulated and subjected to ASTM review.

The chairman of the D-20 Committee said that prior ASTM work on the permanence properties of plastics is relevant to degradable plastics. The committee's extensive experience with outdoor weathering of plastics, for example, is considered relevant, as is its work on the resistance of plastics to microorganisms. The D-20 Committee has developed and published three standard practices for performing experiments on the resistance of plastics to fungi, bacteria, and algae.

A scientist involved in developing and manufacturing degradable plastics expressed some concerns about these earlier ASTM procedures for exposing plastics to fungi and bacteria. He believes that the procedures need to be reassessed because of advances in the knowledge of biodegradation during the 15 years since the publication of these ASTM procedures. In expressing his concern that ASTM procedures may not accurately reflect the degradability of the plastic being tested, he stated:

"A major end result of the differences between ASTM test conditions and environmental circumstances is that materials that are apparently not degradable by ASTM procedures may actually be degradable, and on the contrary, materials that support limited growth of microbes in the laboratory may not be fully degradable when placed in the environment."

In spite of ASTM's efforts to develop uniform definitions and methods of testing and its prior activities that may be relevant to degradable plastics, industry officials and scientists have expressed uncertainty about ASTM's future role in developing degradable plastics standards. They stated that ASTM reflects the views of its member companies and that many of these companies are doubtful about or opposed to degradable plastics. As a result, they question the degree of ASTM's commitment and its rate of progress in developing standards. One official associated with a company developing degradable plastics stated that ASTM may lack sufficient incentive to address the technical uncertainties and formulate standards. Estimates of time frames for ASTM's standards development range from 2 to 5 or more years, depending on the standards to be developed and the resources committed to the effort.

Other Private Sector Activities

In addition to ASTM's activities, at least one trade association is involved in testing degradable plastics. The Missouri Corn Growers Association has arranged for the University of Missouri to conduct tests intended to provide a more rigorous definition of degradability and to determine what by-products are leached from the plastics as they degrade in compost piles. Results of soil burial tests are expected in early 1989. The leaching assessment will conform with the EPA's Priority Pollutant Test, a procedure that screens for the presence of 132 different chemicals and heavy metals.

Federally Funded Research Related to Degradable Plastics

Four federal agencies are conducting or supporting basic or applied research directly related to degradable plastics. Scientists associated with the R&D projects recognize the need to test and develop standards for degradable plastics. Two other agencies with relevant expertise are funding no direct R&D projects, although they are conducting technical studies.

Federal R&D for Product Development

USDA, DOD, DOE, and NSF are supporting 12 R&D projects directly related to degradable plastics, at a total funding level of $1.7 million in fiscal year 1988. Expenditures for each agency are shown in table III.1.

Table III.1: Degradable Plastics R&D, by Agency, FY 1988

Agency	Number of projects	FY 1988 funding	Share of total (percent)
USDA	4	$941,000	55
DOD	4	575,000	33
DOE	3	150,000	9
NSF	1	63,000	3
Total	**12**	**$1,729,000**	**100**

The types of degradable plastics being investigated are derived from three different sources: starch, wood, and certain microorganisms (including bacteria and fungi) that are capable of directly producing polymers. Nearly two-thirds of the federal R&D spending is for corn-starch-based plastics, with microorganism-derived plastics accounting for slightly more than one-fourth of the total.

The 12 projects span the spectrum from very basic research, with a wide range of potential applications, to applied R&D intended for specific uses. Particular forms of degradable plastics being studied include films (for use as agricultural mulch, trash bags, and similar products) and molded products (such as containers and packaging for food). Films account for about 42 percent and molded products for about 20 percent of federal R&D; the remaining 38 percent consists of projects in which the forms are not separately identified.

Scientists conducting federally funded R&D recognize the technical uncertainties associated with degradable plastics and the need for standardization. As a result, a few have already incorporated testing as a basic part of their R&D; others are planning to conduct more extensive testing within the next year. USDA is planning to test its starch-based materials; DOD projects have included a limited amount of testing of the

bacteria-produced plastic and a starch-based trash bag; one DOE project (which is also receiving funding from NSF) is planning extensive testing. This testing may help to evaluate product performance but does not entirely meet the testing needs for degradable plastics standards.

Two agencies, Commerce and EPA, are supporting no direct R&D, but they are conducting technical studies of degradable plastics. Commerce is funding two projects for about $160,000. EPA began a study in early 1988, and an OTA study is also underway.

The following section briefly summarizes the R&D projects currently being conducted or supported by federal agencies. It also describes the testing that is being conducted or planned. A compendium at the end of this appendix provides further details on each individual project.

Department of Agriculture

USDA accounts for about 55 percent of federal funding for degradable plastics R&D. Its research emphasizes the use of cornstarch. The focal point for USDA's activities is the Northern Regional Research Center (NRRC) in Peoria, Illinois. Two NRRC projects account for slightly more than $900,000 of USDA's expenditures. One project is directed toward degradable plastic films and is funded at $552,203 for fiscal year 1988. A new project, begun in February 1988, expands on NRRC's research in degradable plastic films by moving into molded products such as plastic cups and seedling pots; it is funded at $350,000 for fiscal year 1988. The remaining $40,000 is being used to support two research projects at the Universities of Illinois and New Hampshire, which are exploring the degradation rates of agricultural mulching films.

NRRC requested funding in June 1988 for a project that would develop methods of testing degradable plastics and subject their new products to these tests. The Project Manager plans to bring together specialists in microbiology, biochemistry, and polymer chemistry to devise more effective testing that simulates conditions in landfills. The tests would compare the degradability of different NRRC formulations and determine their relative lifetimes in municipal solid waste. The Project Manager would like to develop tests that can yield reliable results in a matter of days rather than months. The proposed project would be funded at about $150,000 per year and would be completed in September 1990.

A private firm, Agritech of Ceutopolis, Illinois, is working closely with NRRC. Agritech is primarily an R&D company that is just beginning to market degradable plastic products. The company received the rights to

the exclusive use of three USDA patents from NRRC. The patents all relate to NRRC-developed products for degradable plastic films employed as agricultural mulch. Agritech has improved the products and is applying for patents of its own. To date, its work has been mostly with degradable plastic films, but it will assist the Center in its new research involving degradable molded plastics.

Department of Defense

DOD is funding four projects, three by the Navy and one by the Army, that together account for one-third of all federal R&D on degradable plastics. One Navy project is focused on the use of cornstarch; the other three projects involve the production of degradable plastics by means of microorganisms. The Navy project on cornstarch-based plastic, sponsored by the David Taylor Research Center of Annapolis, Maryland, is aimed at developing a biodegradable plastic trash bag for use at sea. It is being funded at $126,000, including $61,000 to support in-house activities (1 staff-year) and a $65,000 subcontract let to the Research Triangle Institute of North Carolina for R&D activities. Samples of various products are being exposed to ocean conditions. One basic concern is the size of the remaining plastic particles after degradation has occurred.

Two additional Navy projects, funded through grants by the Office of Naval Research, involve very basic research on bacteria producing a degradable plastic. The Navy awarded the University of Massachusetts $215,000 and the Massachusetts Institute of Technology $168,000 for fiscal year 1988. Written justifications for the awards include references to potential applications in degradable plastic products, but the Navy's program manager indicated that practical applications are probably several years away. Scientists at the University of Massachusetts have begun to test a plastic in low-salt environments but have not yet subjected it to a high-salt environment that would simulate marine conditions. The scientist at the Massachusetts Institute of Technology has not yet started testing but expects to begin by the end of 1988. Tests will involve burying samples in soil and exposing them to salt water.

An Army project, conducted at its Research Development and Engineering Center in Natick, Massachusetts, is also concerned with bacteria capable of producing a degradable plastic; its research is further exploring the use of fungi in this regard. The plastic is being converted into both films and fibers, which in turn can be processed for various applications, including food packaging. Funding is set at $66,000 for fiscal year 1988. The principal investigator said that testing is considered an

integral part of the R&D. He has buried samples in a specified soil mixture with precise temperature and humidity controls. Samples have been taken at regular intervals to evaluate their loss of tensile strength. He has found that some of the materials degrade very quickly and some very slowly. He has also begun to identify the factors controlling the rates of degradation. He believes that with more experimentation he will be able to manipulate the material well enough to control the rate of degradation to a considerable extent. He is also planning to extend the testing from soil to different environments, including the marine environment.

Department of Energy

DOE's Energy Conservation and Utilization Technology Division has provided $150,000 to the Solar Energy Research Institute in Golden, Colorado, for R&D primarily involving wood. The Institute is seeking to develop innovative, inexpensive, lightweight materials to replace petroleum- and natural gas-derived plastics. A small in-house research effort at the Institute is combined with the efforts of researchers at local universities and three subcontractors. The three subcontractors are modifying wood fibers to produce plastics; one researcher is also investigating starch-based plastics. The projects are being conducted at the University of Wisconsin, Virginia Polytechnic Institute, and Purdue University. (As noted below, the scientist at Purdue is also receiving funding from NSF for related research.)

The Director of the Solar Energy Research Institute's Biobased Materials Program recognizes the need for testing to evaluate the rates of degradation and the safety of end products. The principal investigator for one of the three projects being managed by the Institute is planning a series of tests; the other two projects need to conduct further work with product development before preparations for testing are made. Specifically, the principal investigator of the project at Purdue is planning an extensive series of tests to evaluate the biodegradability of the plastics being developed. The tests will be performed with aerobic and anaerobic microorganisms[1] in environments with and without nutrients (water, sugar, and other normal nutrients for the microorganisms) and in different media (landfill or compost, garden soil, sewage sludge, sea water, and pure culture). Tests in a pure culture have the advantage of being easily quantifiable, meaning that results can be reproduced under completely controlled conditions. Tests will include several types of control samples as well as samples containing various percentages of starch

[1] Aerobic and anaerobic microorganisms exist, respectively, with and without oxygen.

combined with petroleum-based polymers. Several technical methods will be used to evaluate the results.

National Science Foundation

NSF is funding one project directly related to degradable plastics. In the Biochemical and Biomass Engineering Division, a grant for $63,000 was awarded to Purdue University for R&D involving grafts of starch and wood with petroleum-based plastics. In NSF's Metallurgy, Polymers, and Ceramics Division, the Director for the Polymers Program reported no current projects related to the subject. He explained that NSF is oriented toward basic rather than applied research and regards degradable plastics as fitting into the latter category. He believes that enhancing the durability of plastics (as substitutes for ceramics and metals) is a better use of research funding. He added that his group has received virtually no proposals focusing on degradable plastics.

Technical Studies and Agency Coordination

In addition to the direct R&D work supported by federal agencies, several technical studies on issues related to degradable plastics have been completed or are underway. These have been undertaken by the Department of Commerce, EPA, and OTA.

Department of Commerce

No R&D related to degradable plastics is being funded in Commerce's fiscal year 1988 budget. Commerce, however, has provided about $160,000 for two technical studies related to degradable plastics. The National Oceanographic and Atmospheric Administration (NOAA), at the request of 30 Senators, provided about $100,000 to support an Interagency Task Force on Persistent Marine Debris. The task force, composed of 11 agencies,[2] has prepared a report assessing the problem of plastics at sea and ways of mitigating the problem. The report, which was submitted to the White House Domestic Policy Council in May 1988, contains two recommendations pertaining to degradable plastics R&D. The first proposes that NIST work with ASTM and other industry associations to develop standards and criteria for what constitutes "biodegradable" and "photodegradable." The second proposes that EPA, FDA, and NOAA work with plastics manufacturers to examine the reaction of degradable plastics in the environment, including potential environmental effects as the plastic degrades.

[2]Participants in the interagency task force included USDA, DOD, EPA, Commerce, Interior, State, Transportation, Health and Human Services, the Council on Environmental Quality, the Office of Management and Budget, and the Marine Mammal Commission.

In addition to the Interagency Task Force, NOAA is funding a project through its Marine Entanglement Research Program within the National Marine Fisheries Service. The project is a review of current degradable plastics technologies and their applicability to plastics debris in the marine environment. A $60,000 contract has been let to the Research Triangle Institute in North Carolina to conduct the review. (NOAA and the Navy are coordinating their respective contracts with the Institute.) The contract calls for a literature analysis, evaluation of existing technologies, and an economic assessment of degradable plastics. It will also identify, if appropriate, further R&D that might be warranted, but it does not provide for original R&D by the contractor.

Environmental Protection Agency

At present, EPA is supporting no direct R&D related to degradable plastics at its laboratories. As mandated by the Marine Plastics Pollution Research and Control Act of 1987 (P.L. 100-220, sections 2001-2305), however, the agency is studying methods to reduce plastics pollution. As part of its study, EPA is required to investigate the feasibility of making articles from degradable plastics.

Specifically, EPA is required to take into account (1) the risk to human health and the environment that may be presented by fragments of degradable plastic articles and the properties of the end products of degradation, (2) the efficiency and variability of degradation due to different environmental and biological conditions, and (3) the cost and benefits of using degradable articles.

EPA has selected a contractor to carry out the portion of the study relating to degradable plastics. The contractor plans to review the relevant technical literature and monitor ASTM's efforts to develop definitions and methods of testing for degradable plastics. The reporting deadline for the study is June 1989.

Office of Technology Assessment

OTA began a study of municipal solid wastes in late 1987 and is due to report to Congress in March 1989. The study is focusing on the federal role in municipal solid waste management, including opportunities for reduction and recycling and for making incineration and landfilling safer. It covers all of the major materials in the waste stream (such as plastics, paper, glass, metal, rubber, and yard waste). OTA is analyzing the environmental risks and costs associated with municipal waste management technologies (including recycling), institutional barriers, and incentives.

Specifically concerning plastics, the report will describe what types and amounts are entering the waste stream and the current status of plastics recycling and degradable plastics. OTA will examine the technical, market, and institutional factors that may influence the use of these emerging technologies. Available information on the impact of degradable plastics on other disposal options, including landfills, incineration, and recycling will be discussed.

Compendium of Federal R&D Projects and Studies

Department of Agriculture

Project Title: Property Enhancement of Cereal Starch for Agricultural Use

Manager: Dr. W. Doane, Plant Polymer Research, Northern Regional Research Center, Peoria, IL

Funding: FY 1987: $544,971; FY 1988: $552,203

Timing: Started October 1985; expected completion, September 1989

Description: Increase the compatibility of starch with synthetic polymers to provide composites with properties acceptable for use as semipermeable membranes, biodegradable agricultural mulch, and other biodegradable plastics.

Project Title: Cornstarch-Based Biodegradable Molded Plastics

Manager: Dr. W. Doane, Plant Polymer Research, Northern Regional Research Center, Peoria, IL

Funding: FY 1988: $350,000

Timing: Started February 1988; expected completion, February 1991

Description: Develop process for injection-molded products. The project expands upon the Center's research in degradable plastic films by moving into molded products such as plastic cups and seedling pots.

Project Title: Micro-Environmental Modifications to Enhance Economic Yield and Quality of Vegetable Crops	Manager: Dr. J. Gerber, Dept. of Horticulture, University of Illinois, Urbana, IL Funding: FY 1988: $8,000 Timing: Started October 1986; expected completion, September 1989 Description: Field-test an already developed degradable plastic and adapt the product to Illinois; specifically, determine the effect of environmental parameters, agricultural chemicals, and plant canopy development on the use and efficacy of biodegradable and photodegradable mulch materials.
Project Title: Environmental Modification for Intensive Crop Production in Northern States	Manager: Dr. O.S. Wells, Dept. of Plant Science, University of New Hampshire, Durham, NH Funding: FY 1988: $30,585 (for degradable plastics research and other activities) Timing: Started October 1987; expected completion, September 1992 Description: Develop a containerized growing system for early production of tomatoes and peppers; monitor photodegradable plastic to determine rate of degradation and amount of labor saved by elimination of need for its removal.

Department of Defense

Project Title: Biopolymer Applications for Military Materials	Manager: Dr. David Kaplan, Army Natick Research, Development, and Engineering Center, Natick, MA Funding: FY 1987: $75,000; FY 1988: $66,000 Timing: Started March 1986; expected completion, September 1990 Description: Research is focused on bacteria and fungi capable of producing a plastic that is easily degradable and multifunctional. The product itself is being converted into both films and fibers, which in turn can be processed for various applications, including food packaging.

Project Title: Polymeric Hydroxybutyric Acid From Photosynthetic Bacteria	Managers: Dr. Robert Lenz, Polymers Science and Engineering Dept., and Dr. Clinton Fuller, Dept. of Biochemistry, University of Massachusetts, Amherst, MA Funding: FY 1987: $260,000; FY 1988: $215,000 Timing: Started November 1986; expected completion, February 1990 Description: Characterize biosynthetic pathways for bacterial production of poly(beta)hydroxybutyric acid; determine possibilities for biosynthesis of related polymers and conditions for producing polymers of different molecular weight distributions. Justification for research includes potential applications in degradable plastic products.
Project Title: Strategies for Biopolymer Engineering of Polyhydroxybutyric-Like Materials	Manager: Dr. Anthony Sinskey, Dept. of Biology, The Massachusetts Institute of Technology, Cambridge, MA Funding: FY 1987: $79,000; FY 1988: $168,000 Timing: Started March 1987; expected completion, March 1990 Description: Determine molecular genetics and enzymology of microbial production of polyhydroxybutyrate in order to control the chain length and composition of this biopolymer; characterize the physical and rheological properties of new biopolymer produced by modification in the biosynthetic pathway. Justification for research includes potential applications in degradable plastic products.
Project Title: Enhanced Degradable Plastics for Marine Waste Disposal	Manager: Dr. Todd Olson, David Taylor Research Center, Dept. of the Navy, Annapolis, MD Funding: FY 1987: $35,000; FY 1988: $126,000 Timing: Started December 1987; expected completion, September 1991 Description: Develop a cornstarch-based, biodegradable plastic trash bag for use at sea. About $61,000 is being spent in-house to cover salary, travel, and administrative costs for 1 staff-year. A $65,000 contract has been let to Dr. Anthony Andrady (Research Triangle Institute, NC) to conduct the research.

Department of Energy

Project Title: Biobased Materials

Manager: Dr. Helena Chum, Chemical Conversion Research Branch, Solar Energy Research Institute, Golden, CO

Funding: FY 1987: $50,000; FY 1988: $150,000. Funding provided by DOE's Energy Conversion and Utilization Technologies.

Timing: Started August 1986; expected completion, not yet determined

Description: A small in-house research effort funded at about $50,000 is combined with the efforts of researchers at local universities and three subcontractors. The in-house effort aims at developing innovative, inexpensive, lightweight materials to replace totally or partially petroleum- and natural gas-derived commodity plastics. THE THREE SUBCONTRACTS ARE LISTED BELOW.

Project Title: Starch- and Lignin-Based Plastics

Manager: Dr. R. Narayan, Laboratory of Renewable Resources Engineering, Purdue University, West Lafayette, IN

Funding: FY 1988: $30,000

Timing: Started January 1988; expected completion, 3 to 4 years

Description: Synthesize grafts of starch and lignins with polystyrene and other vinyl polymers.

Project Title: Cellulose Derivatives From Steam-Exploded Hardwoods for Structural Materials

Manager: Dr. Wolfgang Glasser, Virginia Polytechnic Institute and State University, Blacksburg, VA

Funding: FY 1988: $34,550

Timing: Started January 1988; expected completion, 3 to 4 years

Description: Derive plastic materials from specially prepared wood fibers. The project aims to decrease the cost of these biomass-derived plastics.

Project Title: Plastic Wood

Managers: Dr. Ray Young and Dr. R. Rowell, Dept. of Forestry, University of Wisconsin, Madison, WI

Funding: FY 1988: $31,065

Timing: Started January 1988; expected completion, 3 to 4 years

Description: Investigate moldable wood products from chemically modified wood fibers by using innovative technology.

National Science Foundation

Project Title: New Synthetic Routes to Cellulosic Graft Copolymers

Manager: Dr. R. Narayan, Laboratory of Renewable Resources Engineering, Purdue University, West Lafayette, IN

Funding: FY 1988: $63,000

Timing: Started May 1987; expected completion, October 1988

Description: Synthesize grafts of lignins with polystyrene and other vinyl polymers.

Department of Commerce

Project Title: Interagency Task Force on Persistent Marine Debris

Manager: Dr. David Cottingham, Executive Secretary

Funding: $100,000 (based on Executive Secretary's estimate)

Timing: Started April 1987; completed April 1988

Description: The task force consisted of 11 agencies. Its report, entitled Report of the Interagency Task Force on Persistent Marine Debris, assesses the problem of plastics at sea and ways of mitigating it. The report was submitted to the White House Domestic Policy Council in May 1988.

Project Title: Marine Entanglement Research Program	Manager: Dr. James Coe, NOAA, National Marine Fisheries Service, Seattle, WA Funding: FY 1988: $60,000 Timing: Started December 1987; expected completion, June 1988 Description: The project is a technical review of current degradable plastics technologies and their applicability to plastics debris in the marine environment. A contract has been let to Dr. Anthony Andrady (Research Triangle Institute, NC) to conduct the review.

Environmental Protection Agency

Project Title: A review mandated by the Marine Plastics Pollution Research and Control Act (P.L. 100-220, sections 2001-2305)	Managers: Dr. Susan Mooney, Office of Solid Waste, and Dr. David Redford, Office of Marine and Estuarine Protection Funding: Unknown Timing: Started spring 1988; expected completion, June 1989 Description: EPA is required to investigate the feasibility and desirability of making articles from degradable plastics; it is also required to investigate the safety of the end products resulting from degradation of the plastic. EPA has assembled a task force to conduct the review.

Office of Technology Assessment

Project Title: Municipal Solid Waste Management

Manager: Dr. Howard Levinson, Oceans and Environment Program

Funding: Unknown

Timing: Started November 1987; expected completion, April 1989

Description: Evaluation of how different technologies for reducing and managing municipal solid waste can be used in an environmentally safe and cost-effective long-term strategy.

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