United States
Environmental Protection
Agency

Waste Management Division
Region 1 (HER-CAN6)
Boston, MA 02203-2211

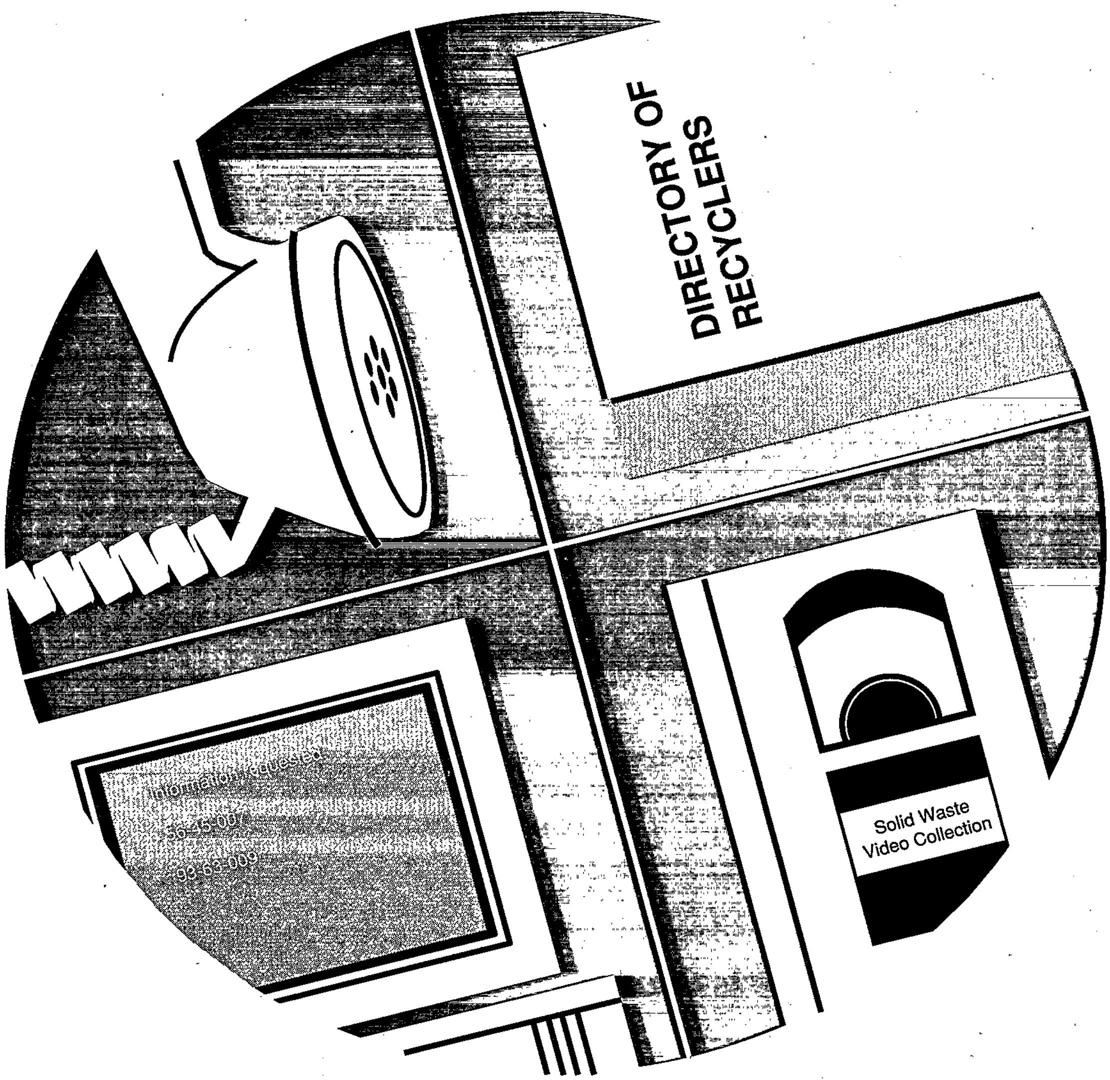
EPA/901/5-92-001
May 1992

Research Library for Solid Waste

EPA

Compendium of Materials on Municipal Solid Waste

Defining Degradability



Printed on Recycled Paper

DISCLAIMER: THE ENCLOSED MATERIALS HAVE BEEN PREPARED BY THE USEPA, REGION 1, SOLID WASTE PROGRAM TO DISSEMINATEINFORMATION FROM THE RESEARCH LIBRARY FOR SOLID WASTE OR FROM OTHER SOURCES. INCLUSION OF INFORMATION ABOUT AN ORGANIZATION, A PRODUCT, A TRADE NAME, OR A SERVICE DOES NOT REPRESENT ENDORSEMENT BY THE USEPA NOR DOES IT REPRESENT EPA OPINION, POLICY OR GUIDANCE UNLESS THIS IS SPECIFICALLY INDICATED. USERS OF THIS INFORMATION SHOULD CONDUCT THEIR OWN EVALUATION OF THE INFORMATION PRIOR TO DEVELOPING CONCLUSIONS OR OPINIONS.

FOR FURTHER INFORMATION CONTACT:

THE RESEARCH LIBRARY FOR SOLID WASTE
(617) 573-9687

DEFINING DEGRADABILITY

TABLE OF CONTENTS:

Introduction:

The term 'degradable' and its 'photodegradable' and 'biodegradable' variants are widely used with varying degrees of appropriateness, depending upon the source and the purpose. Defining degradability is much more than a mere academic exercise. The definition rendered or accepted has an impact on the processes chosen to produce many consumer goods. It has an impact on advertising, marketing, industrial design or redesign, and the management of wastes, as well as on choices that are made by the ultimate end user of these products: the consumer. Consider that some 5,700 "green" consumer products, many bearing claims of "degradability" or "biodegradability," were marketed in 1989 alone. ("Why Biodegradable Claims May Not Mean Much," by John F. Wasik, **San Francisco Chronicle**, Sept. 24, 1990).

Society will ultimately require some standard for evaluating claims of degradability. Thus, generic and open-ended definitions will compete in the future, as they have in the past, with those bearing a higher degree of specificity. This Compendium offers examples of definitions for the term "degradable" and, in doing so, provides a brief history of definitions which began in the 1970s.

In the 1970s, the very same debate that now exists concerning the degradability of consumer goods was taking place. The issues at that time were plastics and waste nuclear materials. At least in the case of plastics, many of the same solutions were proposed, researched, and discussed, principally in a dialogue among packaging industries and in a second dialogue between some industries and some government agencies. "It is almost inconceivable," wrote John H. Abrahams, Jr. of the Glass Container Manufacturers Association, "that you can instill in a product that costs only a few pennies to create, the intelligence to perform 100 percent and then, at a given point, to automatically disappear and destroy itself." (**Utilization of Packaging Wastes**, in Reuse and Recycle of Wastes: Proceedings, 3rd New England Regional Conference, University of Rhode Island, 1970).

"Degradable plastics can now be produced," countered an unsigned editor in the periodical, **Chemical Week**, "but until manufacturers are convinced there is a market for them, progress toward commercialization will continue to be very slow." ("Degradables Are Still Debatables," **Chemical Week**, December 12, 1973).

Twenty years later, we are still searching for effective waste management options for many substances within the municipal waste stream. This Compendium is an attempt to make people aware of the various definitions that are either currently in use or have, at one time, been accepted to define the term "degradable."

Standard reference sources, academic sources, and specialized solid waste reference sources are included, as are Federal working definitions, definitions embedded in State statutes or regulations, and definitions used by international solid waste governmental agencies and voluntary associations. The definitions in this Compendium are intended to represent a wide spectrum of sources and purposes.

DEFINITIONS

Standard General and Specialized Reference Sources

biodegradability: The characteristic of a substance that can be broken down by microorganisms. (**McGraw-Hill Dictionary of Scientific and Technical Terms**, 4th ed., 1989).

biodegradability: The susceptibility of an organic material to decomposition as a result of attack by microorganisms. The term is applied especially to detergents and insecticides, which vary widely in this respect. For ecological reasons, a high degree of biodegradation is desirable to minimize the adverse environmental effect of such materials. Sewage is highly biodegradable, and present methods of treatment are based on this property. Phosphate compounds and chlorinated hydrocarbons such as DDT* are not biodegradable, and it is largely for this reason that their use is restricted. Biodegradable plastic containers have been developed to ameliorate the solid waste problem. (**Glossary of Chemical Terms** by Clifford A. Hampel and G. G. Hawley, Van Nostrand Reinhold, 1976.)

biodegradability: The susceptibility of a substance to decompose by microorganisms, specifically the rate at which detergents and pesticides and other compounds may be chemically broken down by bacteria and/or other natural environmental factors. Branched chain alkylbenzene sulfonates are much more resistant to such decomposition than are linear alkylbenzene sulfonates in which the long straight alkyl chain is readily attacked by bacteria. If the branching is at the end of a long alkyl chain (isoalkyls), the molecules are about as biodegradable as the normal alkyls. The alcohol sulfate anionic detergents and most of the nonionic detergents are biodegradable. Among pesticides the organo-phosphorous types while highly toxic are more biodegradable than DDT and its derivatives. Tests on a number of compounds gave results as follows: Easily biodegraded: n-propanol, ethanol, benzoic acid, benzaldehyde, ethyl acetate. Less easily biodegraded: ethylene glycol, isopropanol, o-cresol, diethylene glycol, pyridine, triethanolamine. Resistant to biodegradation: aniline, methanol, monoethanolamine, methyl ethyl ketone, acetone. Additives that accelerate biodegradation of polyethylene, polystyrene and other plastics are available. (**Hawley's Condensed Chemical Dictionary**, Revised 11th ed., Van Nostrand Reinhold, 1987).

* DDT is the acronym for dichlorodiphenyltrichloroethane.

biodegradable: Susceptible to being degraded by natural action, usually microbial, that usually leaves no harmful residue in the environment. (**International Dictionary of Medicine**, Wiley, 1986.)

Solid Waste Reference Sources

biodegradable: Waste material which is capable of being broken down by bacteria into basic elements. Most organic waste, such as food remains and paper, is biodegradable. (**Handbook of Solid Waste Management**, ed. by David G. Wilson, Van Nostrand Reinhold, 1977).

biodegradable: Any biodegradable substance is capable of being broken down by microorganisms such that its objectionable qualities, as waste, are eliminated. Thus for example pesticidal properties of pesticides, taste and odor of chlorophenols, etc. would be lost. A compound that undergoes only slight degradation in a reasonable period of time is not biodegradable. (**Solid Waste Management Study Report**, Vol. 2, by Raytheon Service Co. for Department of Public Works, Commonwealth of Massachusetts, 1972).

Federal Sources

biodegradation: Degradation that occurs through the action of microorganisms such as bacteria, yeast, fungi, and algae. Debate continues regarding the most appropriate definitions for [these] degradation processes as well as regarding the operational or performance standards for such processes. The absence of accepted definitions has been cited as a factor impeding the development of degradable plastics. The American Society for Testing and Materials (ASTM) has organized a committee to define terms for plastics degradation and to develop standards for testing and measuring "degradability." (**Methods To Manage and Control Plastic Wastes: Report to Congress**, EPA/530-SW-89-051, 1990).

biodegradation of organic compounds: Biodegradation, as a theoretical concept, refers to the process by which an organic compound is converted to carbon dioxide, water, and other inorganic constituents by the action of living organisms. In practice, several qualifying terms are used to modify this concept. . . The main consideration in biodegradability is whether or not an organism exists that can break down, metabolize, or oxidize the parent compound, either on first exposure to it or after a suitable acclimation period. . . In real world situations, the extent of degradation within a fixed time limit is a very important consideration in any working definition of biodegradability. (**Biodegradation and Treatability of Specific Pollutants** by

Edwin F. Barth and Robert L. Bunch, Wastewater Research Division, ORD, EPA. EPA-600/9-79-034, October, 1979).

biodegradability: Strictly speaking, biodegradable materials are those whose chemical structures make them susceptible to assimilation by microorganisms such as molds, fungi, and bacteria when buried in the ground or otherwise contacted with the organisms under conditions conducive to their growth. Some non-biodegradable plastics are erroneously believed to be biodegradable because they often contain biodegradable additives that will support the growth of microorganisms without causing the plastic itself to become assimilated. The term 'biodegradable' is often used indiscriminately to refer to various types of environmental degradation, including photodegradation. Because a polymeric material is degraded by sunlight and oxygen does not necessarily mean that the material will also be assimilated by microorganisms. The term 'biodegradable' should be reserved for that type of degradability that is brought about by living organisms, usually, microorganisms. **(An Investigation of the Biodegradability of Packaging Plastics**, EPA-R2-72-046, 1972.)

biodegradation: If the chemical compound was susceptible to natural degradation, cessation of human use would result in the disappearance of the newly recognized toxicant from ecosystems. By contrast, if the compound was nonbiodegradable, its harmful effects would continue for months, years, or decades, because of the absence of an effective means to rapidly eliminate the offending chemical from natural ecosystems. **(Degradation Mechanisms: Controlling the Bioaccumulation of Hazardous Materials** by Charles J. Rogers and Robert E. Landreth, Solid and Hazardous Waste Research Laboratory, ORD, EPA. EPA-670/2-75-005, January, 1975).

degradable: The term 'degradable' means the ability of a material to be reduced to environmentally benign subunits within the shortest period of time consistent with the material's intended use but in no event greater than a period of 5 years. **(A Bill To Encourage the Development and Use of Recyclable Consumer Plastics...** 101st Congress, 1st Session, House of Representatives.)

photodegradation and biodegradation: See Attachments: **(Environmental Fact Sheet: The Facts On Degradable Plastics** from EPA's Report To Congress On Methods To Manage and Control Plastic Wastes, by OSWER, EPA/530-SW-90-017D, February, 1990.)

photodegradation, biodegradation, and other degradation processes: See Attachments: **(Report To Congress: Methods To Manage and Control Plastic Wastes**, by OSWER, EPA/530-SW-89-051, February, 1990.) pp. 5-76 to 5-80.

State Legislative Definitions

biodegradable: A material has the proven capability to decompose in the most common environment where the material is disposed within one year through natural biological processes into nontoxic carbonaceous soil, water, or carbon dioxide. (**Deering's California Codes Annotated**, 1990 Cal AB 3994, Section 17508.5).

biodegradable material: Material which is capable of being broken down by bacteria into basic elements. (**Vermont Statutes Annotated**, 1989 Supplement, 10 VSA, 1521.)

biodegradable: Degradable through a process by which fungi or bacteria secrete enzymes to convert a complex molecular structure to simple gasses and organic compounds. (**Michie's South Dakota Codified Laws**, Chapter 34A-7, Litter Disposal and Control, 1989).

biodegradation: As used in this section, 'biodegradation' means the conversion of all constituents of: (1) A plastic; or (2) A hybrid material containing plastic as a major component, into miscellaneous component parts by the microbial action of fungi and bacteria upon natural materials such as cornstarch. (**Michie's Burns Indiana Statutes Annotated**, Title 4, Article 13.4 State Procurement, Chapter 4 Specifications: 4-13, 4-4-6, Degradable plastic products.)

biodegradation: When used in connection with recycling, means the conversion of all constituents of a plastic or hybrid material containing plastic as a major component to carbon dioxide, inorganic salts, microbial cellular components and miscellaneous by-products characteristically formed from the breakdown of natural materials such as corn starch. (**Illinois Revised Statutes**, Chapter 111 1/2, Environmental Protection Act, Ill. Rev. Stat., ch. 111 1/2, par 1003.68, 1988).

biodegradable or photodegradable material: Means material which is capable of being broken down by bacteria or light. (**Michie's Delaware Code Annotated**, Title 7 Conservation, Part VII, Chapter 60, Subchapter III, Beverage Containers).

degradable: Degradable means capable of being broken down by biodegradation, photodegradation, or chemical degradation into component parts within 360 days under exposure to the elements. (**Michigan Compiled Laws**, 1989, Chapter 299, Labeling of Plastic Products, 299.481, 1989).

degradable: Degradable means capable of decomposing by biodegradation, photodegradation, or chemical process into harmless component parts after exposure to natural elements for not more than three hundred sixty-five days. (**Code of Iowa 1989**, Title XVII, Chapter 455B, Division IV Solid Waste Disposal, Part 1.)

Professional and Other Sources

biodegradation: Biodegradation is a process wherein micro-organisms secrete enzymes to chemically break down material that they then eat. This can be in the presence of oxygen (e.g. composting) or in the absence of oxygen (e.g. in a landfill). In either case, there must be moisture present and other conditions must be met. (**Degradable Plastics: Myth or Miracle?** by Keep America Beautiful, Inc., Focus: Facts On Municipal Solid Waste, No. 2, March, 1990.)

biodegradable: Any substance that decomposes quickly through the action of microorganisms. (**Hazardous Materials, Hazardous Waste: Local Management Options**, International City Managers Assn., 1987.)

biodegradable materials: Waste material which is capable of being broken down by microorganisms into simple, stable compounds such as carbon dioxide and water. Most organic wastes, such as food remains and paper, are biodegradable. (**Garbage Solutions: A Public Official's Guide to Recycling and Alternative Solid Waste Management Technologies**, by National Resource Recovery Association and the U.S. Conference of Mayors, 1989).

biodegradation: There is no agreed scientific definition of biodegradation--nor any standard laboratory test for biodegradability of solids. ("Biodegradation in Landfills," **Health & Environment Digest**, by the Freshwater Foundation, Vol. 3, #9, November, 1989).

biodegradable: An organic compound that can be degraded or converted to simpler compounds by microorganisms in the natural environment. (**Recycling In the Marketplace**, by Camp, Dresser & McKee, Inc., 1985).

biodegradable: Few people would regard a compound that undergoes only slight degradation as biodegradable. An intermediate position is occupied by the concept of 'activity' loss. This means that if the specific activity that renders the compound objectionable is lost through microbial degradation, the compound would be considered biodegradable. (**Determination of Biodegradability Using Warburg Respirometric Techniques**, by J. V. Hunter and H. Heukelekian in Purdue University Proceedings of the 19th Industrial Wastes Conference, 1964, part 2.)

ENVIRONMENTAL FACT SHEET: THE FACTS ON DEGRADABLE PLASTICS
February, 1990

FROM: U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste
Washington, D.C.

United States Environmental Protection Agency
Solid Waste and Emergency Response (OS-305)
EPA/530-SW-90-017D
February 1990
Office of Solid Waste

EPA

Environmental Fact Sheet

THE FACTS ON DEGRADABLE PLASTICS

FROM EPA'S *REPORT TO CONGRESS ON METHODS TO MANAGE AND CONTROL PLASTIC WASTES*

Discarded plastic products and packaging make up a growing proportion of municipal solid waste. By the year 2000, the amount of plastic we throw away will increase by 50 percent. Current volume estimates for plastic waste range from 14 to 21 percent of the waste stream. By weight plastics contribute seven percent, and less than one percent of plastic waste is currently recycled. Additionally, some plastic items end up as litter that poses ecological risk to the marine environment and aesthetic and economic loss. These facts have led to the exploration of degradable plastics as one possible solution.

Degradable Plastics Defined

Degradable plastics are engineered to be less resistant to degradation than "normal" plastic. The following are currently the most prominent technologies being investigated for consumer products and packaging:

Photodegradation adds a sun-sensitive component that triggers physical disintegration when exposed to sunlight.

Biodegradation adds a natural polymer such as corn starch or vegetable oil that degrades into smaller pieces of plastic when exposed to the appropriate environment.

Do Degradables Fit Into Solid Waste Solutions?

Reduction of Waste: Degradable plastics do NOT reduce the volume or toxicity of waste produced. In fact, for certain applications, additional plastic may be required to offset the weakening effect of adding biodegradable components. The amount of waste may decrease once (and if) degradation occurs, but the amount of waste produced is the same.

Landfilling: Degradation in a landfill occurs very slowly. Even cabbages and carrots have been found in recognizable form in landfills after many years of burial. Enhancing the degradability of plastics will have little if any effect on landfill operation or space.

Recycling: Plastic recyclers fear that degradable plastics will contaminate the recycled plastic waste stream, resulting in products that do not perform well. As we learn more about how degradable plastic bags work, however, they may prove useful in collecting and composting yard waste.

Incineration: Degradable plastics will have little, if any, effect on incineration. In most cases, the waste will be combusted before degradation begins.

If they perform appropriately, degradable plastics may help reduce risks to wildlife and aesthetic damage from items such as six-pack beverage rings, cups, and wrappers. There is, however, some concern as to whether smaller bits of plastic may pose a greater threat to wildlife. Additionally, there is a question as to whether degradability might encourage littering. EPA has initiated a research effort to answer some of these questions.

Where Can I Find Additional Information?

Call EPA's RCRA/Superfund Hotline for a free copy of the Executive Summary of EPA's *Report to Congress on Methods to Manage and Control Plastic Waste* (EPA/530-89-051A). The toll-free number is 1-800-424-9346, or TDD 1-800-553-7672 for the hearing impaired. In Washington D.C., the number is 382-3000 or TDD 475-9652. The Hotline is open from 8:30 a.m. to 7:30 p.m. EST, Monday through Friday. Ask the Hotline for information on ordering the full report.

REPORT TO CONGRESS: METHODS TO MANAGE AND CONTROL PLASTIC WASTES
February, 1990

FROM: U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Solid Waste/Office of Marine & Estuarine Protection
Washington, D.C.

12

From · Report to Congress: Methods to Manage & Control Plastic Wastes.

Degradable products are not included in the integrated waste management system EPA prepared for its policy proposals in its "Agenda for Action," and thus do not have a defined role in current EPA policies. Further, degradable plastic products introduce a new range of environmental issues and their influence on current waste management concerns remains largely undefined. These uncertainties are described in the sections below.

5.5.1 Scope of the Analysis

This section summarizes available information about the current and potential development of degradable plastics and examines possible approaches to increasing the use of such materials. All types of degradable plastics intended for use in plastic product markets are considered here. Issues covered include types of degradation processes and the environmental implications of this waste management technique.

5.5.2 Types of Degradable Plastics and Degradation Processes

Six methods of enhancing or achieving degradation of plastic have been defined in the literature and are described below. The most important technologies, based on available data and apparent market potential, are photodegradation, biodegradation, and biodeterioration.

Photodegradation - Degradation caused through the action of sunlight on the polymer

Biodegradation - Degradation that occurs through the action of microorganisms such as bacteria, yeast, fungi, and algae

Biodeterioration - Degradation that occurs through the action of macroorganisms such as beetles, slugs, etc.

Autooxidation - Degradation caused by chemical reactions with oxygen

Hydrolysis - Degradation that occurs when water cleaves the backbone of a polymer, resulting in a decrease in molecular weight and a loss of physical properties

Solubilization - Dissolution of polymers that occurs when a water-soluble link is included in the polymer [Note: soluble polymers remain in polymeric form and do not actually "degrade." They are included here because they are sometimes mentioned in the literature on degradable plastics.]

Debate continues regarding the most appropriate definitions for these degradation processes as well as regarding the operational or performance standards for such processes. The absence of accepted definitions has been cited as a factor impeding the development of degradable plastics (U.S. GAO, 1988). The American Society for Testing and Materials (ASTM) has organized a committee to define terms for plastics degradation and to develop standards for testing and measuring "degradability."

The absence of accepted definitions for degradation also complicates the ensuing discussion. Plastics engineers have measured degradation according to changes in the tensile strength or the embrittlement of the material. Generally, degradation is considered to have occurred by the time the materials readily collapse or crumble (which is before they have completely disappeared). Field testing necessary to establish the final degradation products, however, has not been performed.

Photo- and biodegradation are discussed in detail below, but a general comment about the processes can be made here. First, the rate of degradation of plastic materials in the environment is a function of both the characteristics of the plastic product and the environmental conditions in which it is placed. The addition of characteristics that increase photodegradability, for example, is an effective waste management step only if the product is exposed to sunlight. Thus, degradable plastics must be matched with an eventual disposal practice (or with disposal problems that are to be mitigated) in order for intended effects to be produced.

In the subsections below, more information is provided about the mechanisms involved for the two primary degradation processes and the commercial activities that are being pursued. A summary of the degradation processes that have been introduced by manufacturers (although not necessarily commercially exploited) for plastic polymers is shown in Table 5-22.

5.5.2.1 Photodegradation

Photodegradation processes are based on the reactions of photosensitive substances that have absorbed energy from a specific spectrum of ultraviolet radiation, such as from sunlight. The reactions may cause a break in the linkages within the long polymer molecules. This shortening of the chains leads to a loss of certain physical properties.

Sunlight is the dominant source of the ultraviolet radiation that will produce photodegradation. Indoor lighting generally will not produce photodegradation both because window glass screens out most ultraviolet radiation from sunlight and because other indoor light sources do not produce much ultraviolet radiation. Because photodegradation is primarily an outdoor process, photodegradable plastic products used primarily indoors can therefore be given "controlled lifetimes." When the products are discarded outdoors – as litter for example – they will degrade more rapidly.

To enhance the photodegradation properties of a plastic, manufacturers have modified or developed new polymers that contain photosensitive substances in the polymer chain. Alternatively, they have used resin additives that are photosensitive and cause degradation of the plastic material. The principal technologies that have been developed for photodegradable plastics are described below.

MODIFICATION OF THE PLASTIC POLYMER – Photodegradation may be accomplished by incorporating a photosensitive link in the polymer chain. The principal method used thus far has been the incorporation of carbon monoxide molecules, also referred to as carbonyl groups, into the polymers. If carbonyl groups absorb sufficient ultraviolet radiation, they undergo a reaction and break the linkage of the polymer chain. Copolymerization with carbon monoxide is the most common method of incorporating carbonyl groups into plastic.

The rate of photodegradation depends on the number of carbonyl groups added or incorporated, although most applications have used a 1% mixture. It has been postulated that if sufficient photodegradation occurs so as to substantially reduce the molecular weight of the plastic molecules, that biodegradation of the residual would be possible. Even if this postulate is true in some circumstances, photodegradation has not been accomplished to the degree necessary to allow subsequent biodegradation of lower-weight chemical molecules. For instance, polyethylene molecules may have molecular weights of 20,000 or higher. Photodegradation reduces this weight, but for biodegradation of the polymer to occur at significant rates the molecular weight must be reduced to approximately 500 (Potts, 1974 as referenced in Johnson, 1987). Such a reduction is not possible without more complete photodegradation than has been yet been achieved by polymer modification.

USE OF PLASTIC ADDITIVES – Several types of additives have been commercially developed for enhancing photodegradability of plastics. One method uses a photosensitizing additive combined with a metallic compound to encourage degradation (Princeton Polymer Laboratory, as referenced in Johnson, 1987). Another method uses antioxidant additives (see Section 2 for a description of antioxidant additives). At low concentrations, antioxidant additives speed the rate of photodegradation.

5.5.2.2 Biodegradation

Manufacturers have developed potentially biodegradable products either by modifying the polymer or by incorporating selected additives. In the latter case, the plastic polymer left behind after degradation of the additive remains intact although it may no longer hold its original shape.

MODIFICATION OF THE PLASTIC POLYMER – Most plastic resins, and all the commodity resins, are nonbiodegradable. More accurately, they are degradable at such a slow rate that they can be thought of as nonbiodegradable.

Some biodegradable resins exist, however, including selected polyesters and polyurethanes. These biodegradable resins were developed for low-volume specialty uses for which biodegradability is desirable, such as some agricultural applications (e.g., seedling pots for automatic reforestation machines). Some of these end products for biodegradable plastics are not materials that reach the MSW stream, so their uses have not represented decreases in the aggregate waste volumes.

As of a 1987 symposium on degradable plastics sponsored by SPI, biodegradable resins appropriate for use in packaging had not been developed (Johnson, 1987). One type of aliphatic polyester, polyester poly(3 hydroxybutyrate-3 hydroxyvalerate), or PHBV, has been developed by ICI Americas in England. It is biodegradable and reputed to have characteristics similar to polypropylene. It is not, however, currently price-competitive with nonbiodegradable plastics. Other techniques for enhancing biodegradation employ additives, as discussed below.

USE OF PLASTIC ADDITIVES -- Most development work on biodegradable additives has centered on the use of starch additives. Starch is highly biodegradable, and upon discard or burial it is consumed by microorganisms in the soil, if an active population of these organisms exists. The degradation of the plastic polymer that remains has not been enhanced by the addition of the starch. Starch may be employed in moderate amounts as a filler, i.e., at 5 to 10% relative to the resin. In some experimental work, it has been incorporated in amounts up to 60% of product volume. Autooxidants are also added to some products. One polymer manufacturer, St. Lawrence Starch, has claimed that on burial, the starch additive is consumed by microorganisms and the autooxidant reacts with metal salts in the soil to form peroxides. These help degrade the polymer itself until it is also biodegradable (Maddever and Chapman, 1987). The field research regarding this phenomenon, however, is extremely limited.

The U.S. Department of Agriculture has experimented with very high starch concentrations. In these volumes, the starch is gelatinized before incorporation into the polymer. Again, the starch in the product is biodegradable, and the remaining lattice of plastic polymer may be sufficiently porous (of low enough molecular weight) to be biodegraded as well (Budiansky, 1986).

5.5.2.3 Other Degradation Processes

Three other degradation mechanisms exist. As noted above, autooxidation operates by producing peroxide chemicals from plastic polymers that then degrade the polymers. Autooxidation additives are incorporated into the polymers and react with trace metals, such as those available in the soil after burial. Manufacturers of these systems assert that this process has been used, along with biodegradable processes, to provide a more complete degradation of polymers.

Hydrolysis occurs when water destroys links in the polymer chains, resulting in a decrease in the molecular weight of the polymers. Chemical groups that are susceptible to this type of attack must be present in the molecule for this to occur. Ester groups, which are present in a number of polymers, are an example of such a group.

Polymers have been developed that are water soluble under certain environmental conditions. Belland Co. has marketed a specialty resin that is soluble within specified pH ranges. This polymer actually washes away, but nevertheless the smaller pieces remain in polymeric form and are not chemically degraded. As a result, soluble polymers may not be considered biodegradable in the same sense as the other degradation mechanisms that are discussed. Outside the specified pH ranges, the material retains its physical properties.

Degrabable Plastic Ring Carriers
Title I of Public Law 100-556 [S.1986]

October 28, 1988

17

PUBLIC LAW 100-556 [S. 1986]; October 28, 1988

DEGRADABLE PLASTIC RING CARRIERS; SAN FRANCISCO BAY NATIONAL WILDLIFE REFUGE

For Legislative History of Act, see p. 3632.

An Act to require that plastic ring carrier devices be degradable, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

TITLE I—DEGRADABLE PLASTIC RING CARRIERS

SEC. 101. FINDINGS. 42 USC 6914b note.

The Congress finds that—

(1) plastic ring carrier devices have been found in large quantities in the marine environment;

(2) fish and wildlife have been known to have become entangled in plastic ring carriers;

(3) nondegradable plastic ring carrier devices can remain intact in the marine environment for decades, posing a threat to fish and wildlife; and

(4) 16 States have enacted laws requiring that plastic ring carrier devices be made from degradable material in order to reduce litter and to protect fish and wildlife.

SEC. 102. DEFINITIONS. 42 USC 6914b.

As used in this title—

(1) the term "regulated item" means any plastic ring carrier device that contains at least one hole greater than 1¾ inches in diameter which is made, used, or designed for the purpose of packaging, transporting, or carrying multipackaged cans or bottles, and which is of a size, shape, design, or type capable, when discarded, of becoming entangled with fish or wildlife; and

(2) the term "naturally degradable material" means a material which, when discarded, will be reduced to environmentally benign subunits under the action of normal environmental forces, such as, among others, biological decomposition, photodegradation, or hydrolysis.

SEC. 103. REGULATION. 42 USC 6914b-1

Not later than 24 months after the date of the enactment of this title (unless the Administrator of the Environmental Protection Agency determines that it is not feasible or that the byproducts of degradable regulated items present a greater threat to the environment than nondegradable regulated items), the Administrator of the Environmental Protection Agency shall require, by regulation, that any regulated item intended for use in the United States shall be made of naturally degradable material which, when discarded, decomposes within a period established by such regulation. The period within which decomposition must occur after being discarded shall be the shortest period of time consistent with the intended use

18

of the item and the physical integrity required for such use. Such regulation shall allow a reasonable time for affected parties to come into compliance, including the use of existing inventories.

TITLE II—SAN FRANCISCO BAY NATIONAL WILDLIFE REFUGE

SEC. 201. ENLARGEMENT OF REFUGE.

Section 2 of the Act entitled "An Act to provide for the establishment of the San Francisco Bay National Wildlife Refuge", approved June 30, 1972 (16 U.S.C. 668dd note), is amended to read as follows:

"SEC. 2. There shall be included within the boundaries of the refuge the following:

"(1) Those lands, marshes, tidal flats, salt ponds, submerged lands, and open waters in the south San Francisco Bay area generally depicted on the map entitled 'Boundary Map, Proposed San Francisco Bay National Wildlife Refuge', dated July 1971, and which comprise approximately twenty-one thousand six hundred and sixty-two acres within four distinct units to be known as Fremont (five thousand five hundred and twenty acres), Mowry Slough (seven thousand one hundred and seventy-five acres), Alviso (three thousand and eighty acres), and Greco Island (five thousand eight hundred and eighty seven acres). Said boundary map shall be on file and available for public inspection in the offices of the United States Fish and Wildlife Service, Department of the Interior.

Public information.

Fish and fishing

"(2) Up to 20,000 acres in the vicinity of the areas described in paragraph (1), and similar to the areas described in paragraph (1), which the Secretary determines are necessary to protect fish and wildlife resources.".

SEC. 202. TOTAL AREA OF REFUGE.

16 USC 668dd note.

Subsection (a) of section 3 of such Act is amended in the second sentence by striking "twenty-three thousand acres" and inserting "43,000 acres".

SEC. 203. AUTHORIZATION OF APPROPRIATIONS.

16 USC 668dd note.

Section 5 of such Act is amended—

(1) by inserting "(a)" before "There"; and

(2) by adding at the end the following new subsection:

INTERNATIONAL SOURCES

See Attached letters to the Research Library for Solid Waste, EPA Region 1 from:

Asociacion Tecnica Para La Gestion De Residuous Solidos, Spain.

General Secretariat, The International Solid Wastes and Public Cleansing Association, Copenhagen Office, Denmark.

Polish Association of Sanitary Engineers and Technicians, Poland.

The Swedish Association of Solid Waste Management, Sweden.

Istituto Di Ingegneria Sanitaria, Politecnico Di Milano, Italy.

[NOTE: ATTACHMENTS FOLLOW]

ATEGRUS : ASOCIACION TECNICA PARA LA GESTION DE RESIDUOS SOLIDOS

MIEMBRO NACIONAL DE ISWA
MIEMBRO DE: CLEAN WORLD
AGHTM
ISWM
APWA

RESEARCH LIBRARY FOR SOLID WASTE
U.S. ENVIRONMENTAL PROTECTION AGENCY
Region 1
HEE-CAN 6
John F. Kennedy Federal Building
Boston, MA 02203 USA

CLEAN WORLD

11th. July 1990

Dear Mr. Friedman,

I make reference to your letter of the 23rd. May.

For me the term "biodegradable" means something - that can be destroyed bioligically .

Yours sincerely,

ATEGRUS
SECRETARIO GENERAL
Representante Español en la ISWA
Firmado: JULIAN URIARTE JAUREGUIZA
CHAIRMAN ISWA'92

P.S. Please note our new address.

x21

page

THE INTERNATIONAL SOLID WASTES AND PUBLIC CLEANSING ASSOCIATION.

General Secretariat

Jeanne Møller
Ingeniørhuset
V. Farimagsgade 29
DK-1606 Copenhagen V.
Denmark
Telephone +45 33 15 65 65
Telefax. +45 33 93 71 71

15 June, 1990
JM/SM

Fred T. Friedman
Research Librarian
United States Environmental Protection Agency
J.F. Kennedy Federal Building
Boston, Massachusetts 02203-2211

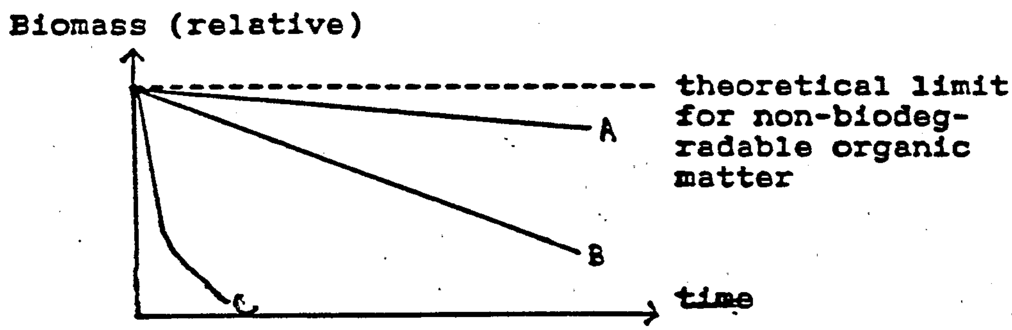
Dear Mr. Friedman:

We have asked three of our engineers to provide us with a term for "biodegradable" and the following is their exact definition.

CHARACTERIZATION OF BIODEGRADABLE ORGANIC MATTER:

Organic matter may serve as an energy and carbon source in a biological system. In environmental engineering microbial biodegradation is of special interest.

A main characteristic for biodegradable organic matter is the role of biodegradation relative to the length of time biodegradation is considered, ie. residence time, tr, in a system.



If change in the biomass is approximately zero during the residence time in question, the organic matter may be regarded as non-biodegradable.

X 22

THE INTERNATIONAL SOLID WASTES AND PUBLIC CLEANSING ASSOCIATION.

General Secretariat

Jeanne Møller
Ingeniøerhuset
V Farimagsgade 29
DK-1606 Copenhagen V
Denmark
Telephone +45 33 15 65 65
Telefax +45 33 93 71 71

It is important that the same organic matter may be considered biodegradable if (tr) increases.

Yours sincerely,
for Jeanne Møller
General Secretary

Susan McCarty

Susan McCarty

23

POLYTECHNIC INSTITUTE, Institute of Sanitary Engineering
65-246 Zielona Góra, ul. Podgórna 50; skr. poczt. 47. Telefony: centrala 48-31 (łączy wszystkie n-ry wewn.). Rektor 707-35; Prorektor d/s Nauki 703-82; Prorektor d/s Nauczania i Wychowania 722-06; Dyrektor Adm. 39-44. Telex 043-22-15. Konto bank. NBP II O.M. Zielona Góra nr 97026-521-189-31.
POLAND

Nasz znak IIS/EK Wasz znak ....

Zielona Góra, 3 July 1990

Dotyczy:
Subject: term: "biodegradable"

Research Library for Solid Waste
U.S. Environmental Protection Agency
Region 1
HEE-CAN6
John F. Kennedy Federal Building
Boston, MA 02203, USA

Attn.: Mr Fred T. Friedman,
Research Librarian

Dear Mr Friedman:

Authorized by the Secretary General of the Polish Association of Sanitary Engineers and Technicians Mr Ryszard Paruszewski, I would answer your letter of 23 May 1990.

You asked about the definition of the term "biodegradable". The answer cannot be a unique one, and should be rather descriptive than in some few words only. I looked through different sources, and here the results:

1/ Oxford Advanced Learner's Dictionary of Current English, by A.S. Hornby. Oxford University Press 1974.
Biodegradable:(of substance) that can be broken down by bacteria.

2/ Glossary on Solid Waste, by P.K.Patrick. WHO Regional Office for Europe, Copenhagen 1980.
Biodegradable: Capable of being broken down physically and/or chemically by the action of microorganisms.

3/ Handbook of Industrial Waste Disposal, by R.A.Conway, and R.D. Ross, Van Nostrand Reinhold New York 1980.
Some techniques of experimental determination of biodegradability with references (3-1, 3-2, 3-3 p.143) are described in the book.

4/ Compost Engineering, by Roger T.Haug. Ann Arbor Science Publisher Ann Arbor 1980, pp.248.
Haug introduced the degradability coefficients, but he does not give a definition for "biodegradable" substances.

5/ Podstawy Ochrony Środowiska (Fundamentals of Environment Protection - in Polish), by B.Głowiak, E.S.Kempa, and T.Winnicki. PWN

Science Publishers Warsaw 1985, pp. 45 and 59:
Biodegradable substances: organic matter which can be degraded by the action of microorganisms under natural, aerobic conditions in a quantity of 50% of the input during 48 hours.

Remarks: Natural conditions means: in soil, in water, in wastewater The contrary of biodegradable is: refractory or resistive.

6/ Gospodarka odpadami miejskimi (Management of Municipal Refuse - in Polish), by Edward S. Kempa. ARKADY Publishing House, Warsaw 1983, pp.88-89.
For biodegradable substances I used the contractual term "FOS" - fermentable organic substance, which is a part of VDS. In our studies on the composition of municipal refuse from various Polish towns and cities, the FOS varied from 0.38 to 0.50 (with a weighted aver. 0.43-0.45) of VDS. In the analytical procedure it is assumed, that TOC makes 0.47 FOS. The analytical procedure is described in:

EAWAG-ISWA [Edit. E. Grabner]: Methoden zur Untersuchung von Abfall stoffen (in German). Duebendorf 1977. Procedure K-3028.

Could you please let me know whether you are satisfied with my informa tions. Should you have further questions, please do not hesitate to ge in contact with me.

Yours sincerely,

Dr. Edward S. Kempa,
Professor in Environmental
Engineering.

cc.: Mr Ryszard Paruszewski
Secretary General
c/o Polskie Zrzeszenie Inżynierów
i Techników Sanitarnych

Czackiego 3/5

00-950 Warszawa

25

SVENSKA RENHÅLLNINGSVERKS-FÖRENINGEN

United States Environmental
Protection Agency
Att. Fred T. Friedman
Region I
J.F.Kennedy Federal Buildning
Boston
Massachusetts
USA

RECEIVED

AUG 15 90

WASTE MANAGEMENT DIVISION

Malmoe, Sweden 1990-08-03

Dear collegue,

By request I will send you following definition of the term "biodegradable".

Biological material which is possible to break down in a unaffected process.

Please let us know if we are totally wrong in our interpreting

Best regards

Yours sincerely

Bo Audelius

Postadress/Postal address:
Svenska Renhållningsverks-Föreningen
Östergatan 30
211 22 MALMÖ

Telefon/Telephone:
Nat: 040-10 40 45
Int. +46-40-104045

Telefax:
040-97 10 94

Postgiro/Postal account:
472 41 69-0

Bankgiro/Banking account:
985-9877

Organisationsnummer:
556260-8553

26

ISTITUTO DI INGEGNERIA SANITARIA
VIA FRATELLI GORLINI, 1 - 20151 MILANO (ITALIA)
TEL. (02) 4520354-4520543 - TELEX: 333467 POLIMI-I

IL DIRETTORE

Mr. Fred FRIEDMAN - (Research Librarian)
Reserch Library for Solid Waste
U. S. Environmental Protection Agency
Region 1
HEE - CAN 6
John F. Kennedy Federal Building
Boston, MA 02203 U.S.A.

MILANO, the 19th of October 1990

VS. RIF. ____________

NS. RIF. VIII.32

Dear Mr. Friedman,

with reference to Your letter of the 23d of May 1990, I have at present the opportunity to supply You with a definition of the term "biodegradable".

Hoping that such definition will be useful to You for Your project, I send my best wishes and regards.

Yours sincerely
(Luca Bonomo)

→

27

043/17 - 2.000 - 3.88 - (210x297)

Biodegradability is a general term usually indicating the aptitude of a substance to undergo a degradation process operated by living organisms, that is, a degradation resulting from bacterial animal and vegetable metabolism.

We could practically define "biodegradable " as the aptitude of a soluble organic compound to undergo a microbiological degradation, mostly due to bacteria. However, from a quantitative point of view, this is not a specific definition, as it doesen't reveal anything about the reaction's speed and the destination of the reaction products.

The "complete biodegradability" o "mineralisation" is the transformation (conversion) of complex organic compounds into final inorganic products such as CO_2, H_2O and mineral salts, through the metabolic processes related to the growth of microorganisms.

The "functional biodegradability" is the microbial transformation (conversion) of a substance into intermediate products, whose characteristics differ from those of the original products.

The intermediate products are generally less toxic (this process could be defined as "detoxification"), or in some rare cases, more toxic.

On the contrary, the term of "bioremoval" is intended to mean the removal of a substance from a solution, a suspension or an aerosol state, resulting from a combined or "borrowed" action of physical, chemical or biological feature (e.g. the bioflocculation supported or activated by microorganisms).

The quantitative measure is equivalent to the time of half conversion, (t_{50}; t 1/2), which is needed in order to obtain the falling off of half of the original product. On the base of this parameter it was possible to draw some biodegradability scales as the following one:

Proposal for the quantification of biodegradability

Denomination	t 1/2 (year)
Biodegradable	0,01 - 0,1
Moderately biodegradable	0,1 - 0,8
Persistent	> 1
Permanent	> 1