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POLYMER WASTE MANAGEMENT—BIODEGRADATION, INCINERATION, AND RECYCLING

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ABSTRACT

Increasing volumes of synthetic polymers are manufactured for various applications. The disposal of the used materials is becoming a serious problem. Unlike natural polymers, most synthetic macromolecules cannot be assimilated by microorganisms. Although polymers represent slightly over 10% of total municipal waste, the problem of nonbiodegradability is highlighted by overflowing landfills, polluted marine waters, and unsightly litter. Existing government regulations in Europe and anticipated regulations in the United States will greatly limit the use of polymers in large volume applications (packaging, water treatment, paper and textile sizing, etc.) unless acceptable means of waste management are available. Total management of polymer wastes requires complementary combinations of biodegradation, incineration, and recycling. Biodegradation is the most desirable long-term future solution and requires intensive research and development before it becomes practical. On the other hand, incineration and recycling can become operational in a relatively short time for the improvement of the situation at present and in the near future.

Solid waste management is becoming increasingly difficult as traditional landfills are becoming scarce and, more importantly, environmentally undesirable. Among the problems is the ever-increasing volume of polymer wastes [1–4]. Most of the solid polymers (plastics) are used as protective coatings, structures, and packagings. They are designed and manufactured to resist environmental degradations, including biodegradations. Since plastics are more economical than metals, woods, and glasses in terms of manufacturing costs, weight-to-strength ratio, and the amounts of energy and water required, as well as in most cases causing less environmental harm, the use of plastics is likely to increase. This makes polymer waste management an urgent problem, needing environmentally compatible and friendly solutions, both short and long term, as soon as possible [1-3].

In addition to conservation, direct waste management means are needed. Recycling, incineration, and biodegradation are possibilities. Among the advanced countries, Japan has made the most progress by far, both in terms of national policies and practice. Incineration has been and will continue to be the major means of waste management (Table 1). In Europe, Germany is actively pursuing mechanical recycling. In the United States, due to the lack of a national policy, there is hardly any practice of polymer waste management other than landfill, which is quickly becoming impractical.

In Japan, currently 11% of polymer wastes are recycled mechanically. This is limited mostly to industrial scrap. Consumer waste plastics recycling has been tried, but mostly abandoned. There do not seem to be any future plans in this area. Although around 65% of municipal solid wastes (MSW) in Japan is incinerated, only 15% is coupled with power generation. It is MITI's plan to increase plastic waste-to-energy conversation to 70% by the end of the 21st century and thus reduce the need of landfills to less than 10%. Recycling of industrial polymer scraps is being practiced, to a very limited extent, in Europe and the United States. This can be expected to increase as legislative incentives and economic benefits become more favorable. MSW consumer wastes contain polyethylene, polypropylene, polystyrene, and poly(vinyl chloride), which are incompatible with each other. As a result, only low performance and low market value products such as garden tires, fences, and planters can be manufactured. Compatibilization of these polyolefins is needed in order to make MSW plastics recycling practical.

Chemical recycling is potentially useful for certain polymers. At the present time, only poly(ethylene terephthalate) has been practically recycled [5]. Pyrolysis is another method by which small molecules can be obtained from polymer waste. New catalysts have to be developed for more efficient processes [6]. Little attention seems to have been directed toward catalytic pyrolysis of polyolefins, which should be similar to petroleum cracking processes.

Incineration is a common form of general waste disposal. Japan expects to eventually take care of up to 70% of its polymer wastes through incineration for energy processes [7]. In the United States, Connecticut is the only state in which 40-60% of its solid MSW is incinerated. However, because the MSW are not sorted,

TABLE 1. Plastics Waste Management in Japan

	Current, %	21st Century (MITI), %
Material recycling	11	20
Thermal recycling	15	70
Landfill	37	<10

40% of it ends up as ashes after incineration, and is difficult to dispose of [8]. Sorting polymer wastes before incineration will become necessary in the future. Since the combustion of relatively pure polyolefins generates too much heat for traditional furnaces, newer high temperature furnaces with ceramic liners might be needed. This will add significantly higher costs to the already very large costs for building incineration-to-energy plants. Gathering, sorting, and transportation are additional to the plant costs for incineration.

These facts, together with the growing concern over the greenhouse effect generated by the large volume of CO_2 produced, have caused almost insurmountable political barriers for building new incinerators in the United States.

Various forms of degradation can be used for polymer waste disposal. The most environmentally compatible is biodegradation, a subject of increasing research interest [9-19].

Most of the current large volume polymers are not biodegradable. Thus biodegradation for waste disposal can only become a reality when new biodegradable polymers and facilities for biodegradation become available. If biodegradations can be controlled and useful products can be obtained, they become bioconversion or

TABLE 2.

Pro	Con
Recycling (material, mechanical)	
Available processes	Product downgrade
Source reduction	Not easily adopted for mixed plastics
Suitable industrial scraps	High costs of gathering and sorting
Not final disposal	Not efficient for food packaging
Politically favored	Not a final disposal
Can be done on any scale	
Incineration	
High efficiency for sterilization	High plant cost
Energy generation	High gathering and sorting costs
Semifinal disposal	Could produce high water and gas pollution
Available technology	Political barrier
	Only applicable to relatively large scale
Biodegradation-Bioconversion	
Environmentally compatible and friendly	No enough reactors/plants
Completes the carbon and nitrogen cycles	Requires new plastics, additives, etc.
Can be on any scale	Has to overcome the public's misconceptions
	Needs to develop new products

biorecycling processes. Among the promising approaches to new useful biodegradable polymers are biopolymers, modified biopolymers, and blends.

Poly-R-3-hydroxyalkanoates are energy storage materials for bacteria and have been the subject of increasing research interest and limited commercial production [20–28]. Their biodegradation is being studied in detail [29–33]. If the processing of these polymers can be mastered, and if the costs of production can be lowered, they can become important biodegradable polymers.

Cellulose acetates are used for various applications. Recent results on their biodegradation [34, 35] have increased their importance as biodegradable materials. Starch derivatives, on the other hand, have not received as much attention.

Among the synthetic polyesters, polycaprolactone lacks the necessary high temperature properties, and polylactate cannot yet be produced cheaply. It is premature for these to become major polymers.

Blends of starch and degradable polymers are now commercially available [36–41]. Disposal facilities are needed for these to be commonly used.

SUMMARY

There are pros and cons for all three approaches (Table 2). Ideally, complementary practices of all three and conservation would be the most environmentally friendly in the long run.

REFERENCES

[1] S. J. Huang, *Polym. Mater. Sci. Eng., 63*, 633 (1990).
[2] J. Tallman, *Waste Age, 18*, 141 (1987).
[3] B. Wessling, *Kunstoffe, 83*, 7 (1993).
[4] A. M. Thayer, *Chem. Eng. News*, p. 7 (January 30, 1989).
[5] R. Calendiene, M. Palmer, and P. von Bramiers, *Mod. Plast.*, p. 64 (1980).
[6] J. A. Fiji, *Environ. Sci. Technol., 2*, 308 (1993).
[7] *Plastic Wastes. Disposal and Recycling, Past, Present and Future in Japan*, Plastic Waste Management Institute, Tokyo, 1992.
[8] K. Johnson, *New York Times*, p. B1 (January 30, 1989).
[9] R. Leaversuch, *Mod. Plast. Int., 17*, 94 (1987).
[10] S. J. Huang, in *Encyclopedia of Polymer Science and Engineering*, Vol. 2, 2nd ed., Wiley, New York, 1985, pp. 220–243.
[11] S. J. Huang, in *Comprehensive Polymer Science*, Vol. 6 (G. Allen and J. C. Bevington, Eds.), Pergamon Press, London, 1989, pp. 567–607.
[12] D. L. Kaplan, J. M. Mayer, D. Ball, J. McCassie, A. L. Allen, and P. Sterhouse, in *Biodegradable Polymers and Packaging* (C. Ching, D. Kaplan, and E. Thomas, Eds.), Technomics Publishing, Lancaster-Basel, 1993, pp. 1–44.
[13] G. Swift, *Acc. Chem. Res., 26*, 105 (1993).
[14] R. Lenz, *Adv. Polym. Sci., 107*, 1–40 (1993).
[15] A.-C. Albertsson and S. Karlsson, in *Comprehensive Polymer Science*, First Supplement (G. A. Allen, S. L. Agarwal, and S. Russo, Eds.), Pergamon Press, London, 1993, p. 285.

[16] J.-C. Huang, A. S. Shetty, and M.-S. Wang, *Adv. Polym. Technol., 10*, 23 (1990).
[17] T. F. Cooke, *J. Polym. Eng., 9*, 171 (1990).
[18] P. J. Hocking, *J. Macromol. Sci.—Rev. Macromol. Chem. Phys., C32*, 35 (1992).
[19] J. E. Potts, R. A. Clendinning, W. B. Ackart, and W. D. Niegisch, in *Polymers and Ecological Problems* (J. Guillet, Ed.), Plenum Press, New York, 1973, p. 61.
[20] E. A. Dawes and P. J. Senior, *Adv. Microb. Physiol., 10*, 135 (1993).
[21] Y. Doi, *Microbial Polyesters*, VCH, New York, 1990.
[22] A. J. Anderson and E. A. Dawes, *Microbiol. Rev., 54*, 450–472 (1990).
[23] P. A. Homes, S. H. Collins, and L. F. Wright, US Patent 4,477,654 (1984).
[24] A. Steinbüchel, *Biomaterials: Novel Materials from Biological Sources*, Stockton Press, New York, 1991, pp. 123–214.
[25] H. Brandly, R. A. Gross, W. R. Lenz, and R. C. Fuller, *Adv. Biochem. Eng./Biotech., 41*, 77 (1990).
[26] R. H. Marchessault, T. L. Blulim, Y. Deslandes, G. K. Hamer, W. J. Orts, P. R. Gundarajan, M. G. Taylor, S. Bloembergen, and D. A. Holden, *Makromol. Chem., Macromol. Symp., 19*, 235 (1988).
[27] G. J. M. de Konig, in *Unconventional and Nonfood Uses of Agricultural Biopolymers* (M. L. Fishman, R. B. Friedmand, and S. J. Huang, Eds.), American Chemical Society, Washington, D.C., 1994, In Press.
[28] M. K. Cox, in *Abstracts, 3rd International Scientific Workshop on Biodegradable Plastics and Polymers, November 1993, Osaka*, Japan Biodegradable Plastics Society, p. 32.
[29] Y. Doi, Y. Kanesawa, M. Kunioka, and T. Saito, *Macromolecules, 23*, 26 (1990).
[30] Y. Kawaguchi and Y. Doi, *Ibid., 25*, 2324 (1992).
[31] D. Jendrossek, I. Knoke, R. B. Habibian, A. Steinbüchel, and H. G. Schlegel, *J. Environ. Polym. Deg., 1*(1), 53 (1993).
[32] H. Nishida and Y. Tokiwa, *J. Environ. Polym. Degrad., 1*(1), 65 (1993).
[33] N. Nishida and Y. Tokiwa, *Ibid., 1*(3), 235 (1993).
[34] C. M. Buchanan, R. M. Gardner, and R. J. Komarck, *J. Appl. Polym. Sci., 47*, 1709 (1993).
[35] J.-D. Gu, D. T. Eberiel, S. P. McCarthy, and R. A. Gross, *J. Environ. Polym. Degrad., 1*(2), 143 (1993).
[36] C. Bastioli, V. Bellotti, L. Del Giudice, and G. Gilli, in *Biodegradable Polymers and Plastics* (M. Vert, J. Feijen, A. Albertsson, G. Scott, and E. Chiellini, Eds.), Royal Society of Chemistry, 1992, pp. 101–111.
[37] C. Bastioli, V. Bellotti, L. Del Giudice, and G. Gilli, *J. Environ. Polym. Degrad., 1*(3), 181 (1993).
[38] Y. Yoshida and M. Tomori, in *Abstracts, 3rd International Scientific Workshop on Biodegradable Plastics and Polymers, November 1993, Osaka*, Japan Biodegradable Plastics Society, p. 72.
[39] M. Koyama, H. Kameyama, and Y. Tokiwa, *Ibid.*, p. 71.
[40] S. Takagi, M. Koyama, H. Kameyama, and Y. Tokiwa, *Ibid.*, 71.
[41] *Michigan Biotechnology Institute Product Informations*, 1993.