EPA-670/2-75-058
June 1975

Environmental Protection Technology Series

ENVIRONMENTAL ASSESSMENT OF FUTURE DISPOSAL METHODS FOR PLASTICS IN MUNICIPAL SOLID WASTE

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Grant No. R803111-01-1
Program Element No. 1DB314

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REVIEW NOTICE

FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and

- a search for ways to prevent contamination and to recycle valuable resources.

Among these many areas of concern are plastics and the disposal procedures used for the increasing plastic-containing products in the nation's solid waste streams. Plastics not only behave differently in the various waste disposal processes, but they can potentially add new problems as a result of the additives they contain. As with any changing situation, the best procedure is to try to understand the problem by keeping as well informed as possible. This study evaluates the potential impacts, both desirable and undesirable, of increasing amounts of plastics in the years ahead.

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ABSTRACT

The environmental impact of plastics in solid waste in the United States up to the year 2000 has been assessed. The total solid waste that will be collected from a predicted population of 297 million has been estimated to be 222 million tons per year by the year 2000, based on a waste-generation rate of 4.5 pounds per person per day.

Production of plastics for engineering and consumer items in the United States has been predicted to reach 113 million tons per year by the year 2000. This figure does not include the production of polymer used for synthetic fiber or fabric. Production of these materials normally is considered separately, as is the waste problem associated with their disposal. From 31 to 38 million tons of the plastic produced is expected to reach the solid waste stream, depending on the basis of estimation. The largest amount will go to sanitary landfills, and the next largest amount will be thermally treated using such methods as power generation, heat recovery, incineration, and pyrolysis. Relatively small amounts of plastic are expected to be disposed of in open dumps or as litter. No resource recovery is predicted for plastics in municipal refuse up to the year 2000.

The land-area requirement for plastics is predicted to be 20 percent of sanitary landfills and 3 percent of open dumps in the year 2000. Air pollution as a result of plastics in the landfills and open dumps will be negligible, even if there is still some burning of open dumps in 2000. The contribution of plastics to water pollution also will be negligible, and by introducing aerobic conditions, plastics may lower the BOD of the leachate.

Thermal treatment of plastics will result in some emissions of carbon monoxide, particulates, and hydrocarbons, but these are expected to be only a small fraction of the total U. S. emissions of these materials from other sources. Hydrogen chloride from disposal of

plastics by thermal treatment is predicted to amount to 380,000 tons per year by the year 2000, but this will constitute a minor portion of the total air pollutants in the U. S., which will still be measured in millions of tons.

The difficulty of sorting and processing plastics of different types in municipal refuse is expected to make recycling of plastics negligible up to the year 2000. Plastic is predicted to be a large fraction of the litter up to the year 2000, but as a result of education of the public and the introduction of degradable plastics, it is expected to constitute only about 15 percent of the litter at that time.

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ACKNOWLEDGMENTS

The assistance of Mr. Donald Oberacker of the Solid and Hazardous Waste Research Division of the National Environmental Research Center, Cincinnati, Ohio in collecting data for this analysis is gratefully acknowledged. The help of Mr. Howard Kibbel of the Society of the Plastics Industry in providing data was important to this study. Discussions with Mr. Truett DeGeare, Mr. Stephen Lingle, and Mr. Robert Lowe of the Office of Solid Waste Management Programs, Washington, D.C. also were of assistance. Mr. Norman Broadway of Battelle's Columbus Laboratories assisted in the analysis of the data.

SECTION I

CONCLUSIONS

An assessment has been made of the environmental impact of plastics in solid waste in terms of future disposal methods up to the year 2000. Population growth as projected by the U. S. Bureau of Census indicates a total U. S. population of 297 million by that time. The urban and rural populace of about 285 million have been considered to be the chief contributors to collectable solid waste. The amount of solid waste generated per capita is predicted by this study to decrease from today's 5 pounds per person per day to 4.5 pounds by the year 2000. This decrease will be the result of material and energy conservation, recycling, and education of the public. At the same time, the percentage of the waste generated that will be collected for municipal disposal will increase from the current 75 percent to 95 percent by the year 2000. The net result of these two factors is predicted to be an increase in the total solid waste collected from 139 million tons in 1975 to 222 million tons in the year 2000.

A projection of growth in the U. S. plastics industry indicates that annual production will increase from about 13.3 million tons in 1973 to 113 million tons by 2000 A. D. The latter value represents a median between an estimated maximum of 144 million tons and a minimum of 85 million tons. The rate at which these plastics will enter the solid-waste stream was estimated using the "useful life concept". This approach involves an evaluation of the number of years that will pass before a plastic item is discarded. Hence the useful life may vary from 1 year for a packaging use to 50 years for use in building and construction. On this basis it was estimated that the amount of plastic waste will increase from a 1973 value of 3.4 million to 30.7 million tons per year by the year 2000. Another approach to this estimate, based on production by types of plastic, leads to a value of 37.9 million tons per year of plastic waste by 2000. As a result of resource recovery and recycling efforts, the projection indicates that the percent of plastic in the solid waste will increase from about 2.8 percent in 1975 to 13.4 percent by 2000. The amount of plastic waste collected for disposal is expected to undergo a similar increase from 3.9 million tons in 1975 to 29.7 million tons by the year 2000.

In terms of waste-disposal technology, increasing amounts of the solid waste are expected to go to sanitary landfills, to be treated thermally, or to be processed in resource-recovery handling. At the same time the amount of waste going to open dumps and being discarded as litter will decrease.

These trends will be reflected in the plastics portion of the solid waste, which should follow the same pattern, except that resource recovery is not likely to apply to plastics up to the year 2000. The plastic waste predicted by the two approaches is averaged in the following tabulation:

	Plastics Waste, millions of tons	
Disposal Method	1975	2000
Open dumping	4.1	3.6
Sanitary landfill	0.84	17.8
Thermal treatment	0.55	12.5
Resource recovery	0	0
Litter	0.35	0.05

The environmental impact of the plastics in solid waste differs according to the method of disposal. For disposal in open dumps and sanitary landfills the volumetric contribution of the plastic waste is more important than its weight. Although the number of open dumps is expected to decrease significantly by the year 2000, the increasing percentage of plastic in the solid waste will increase the land requirement that can be attributed to plastics. However, even by the year 2000, plastic waste will probably require only about 3 percent of the land area devoted to open dumping.

The increase in sanitary landfill disposal of all waste means a similar increase in the total amount of plastics disposed by this method, as shown above. The land requirement for the plastics portion is expected to increase about twentyfold between 1975 and 2000. This contribution of plastics will constitute about 20 percent of the land requirement for the sanitary landfills in the year 2000.

The fact that plastics degrade very slowly means that they will have a long lifetime in both open dumps and sanitary landfills. The presence of plastics in these areas will not contribute to the leachate in any significant amount, but the plastics may tend to prolong aerobic conditions where they do not compact effectively. These conditions may result in lowered BOD level.

The burning of refuse in open dumps is expected to be practically eliminated by the year 2000. Consequently, the air pollution resulting from the burning of plastics in the open dumps is predicted to be only about 5,000 tons in total, of which the major portion will be carbon monoxide and hydrogen chloride. Minor amounts of metal compounds also may be emitted.

The thermal treatment of solid waste by ordinary incineration is expected to decrease, while heat recovery and power generation from burning of the refuse will increase. The development of pyrolysis methods should be sufficient by the year 2000 to make this method important in the total. A comparison of the anticipated distribution of solid wastes in these disposal methods for 1975 and for 2000 is given below:

	Solid Waste, millions of tons	
Disposal Method	1975	2000
Incineration	12.5	0.5
Heat recovery	6.0	24.0
Power generation	Negligible	32.0
Pyrolysis	Negligible	6.0

The air-pollutant emissions resulting from these controlled combustion processes applied to solid waste will increase as larger amounts are consumed. The contribution of plastics to these emissions also will increase, but it will still constitute only a small fraction of the total U. S. emissions of carbon monoxide, particulates, and hydrocarbons. With respect to HCl, thermal treatment of plastics is expected to produce some 380,000 tons of this gas by 2000. This amount will still be small compared to other forms of air pollution, but the acidic nature of this gas may necessitate control in the form of water scrubbers.

Resource recovery in general as applied to components of solid waste such as paper, metals, and glass is predicted to increase very substantially, from 2.2 to 65.2 million tons by 2000, but plastics are not expected to be involved. The difficulty of sorting and processing different types of plastics for recycling from municipal refuse is expected to make this type of resource recovery negligible, even to the year 2000.

The amount of litter is predicted to decrease from 4.3 million tons in 1975 to 300,000 tons by 2000, at which time it will constitute only about 0.1 percent of the total solid waste. However, a large fraction of the litter usually is plastic, because of its predominance in packaging materials. Introduction of photodegradable plastics for packaging will reduce the impact of plastics in litter because its decomposition will be enhanced.

Aesthetic, human, and economic factors as applied to the plastics in solid waste are considered to be in proportion to their percentage in the waste disposed by litter, open dumping, and sanitary landfill.

SECTION II

RECOMMENDATIONS

As a result of this analysis of the future environmental impact of plastics it is recommended that the situation be reevaluated in 1980 to compare the actual circumstances with the forecast, and to make any necessary revisions. These forecasts necessarily have increasing amounts of possible error as the time interval becomes greater, and reevaluation will be important in about 5 years.

The rate of refuse generation and the plastics production from 1975 to 1980 should be compared with what has been predicted for that period, so the extrapolation to the year 2000 can be either confirmed or corrected. The progress of resource recovery by 1980 and the use of the newer disposal methods such as power generation and pyrolysis should be evaluated at that time.

During the interim period (from 1975 to 1980), adequate data collection should be made to insure more accurate prediction of future trends than was possible for this analysis. The changes in plastic content of solid waste should be followed to determine whether the forecasts are being borne out in practice. The impact of the educational and legislative programs on the solid-waste stream should be considered during this interim period. This aspect would be particularly important for the litter problem, where the forecast has been based on a successful outcome of these approaches in reducing litter, together with the introduction of photodegradable plastics. Consideration also should be given to the promotion of resource recovery by separation of plastics in refuse at the homeowner source to encourage recycling. This method has not been considered feasible up to the year 2000, but it is possible that by 1980 an educational and economic incentive program may offer more promise for recycling the plastics now being collected in municipal refuse. The data acquisition should also include the air-pollution emissions from the newer incinerators which incorporate steam generation, and from the combined firing of refuse and fossil fuels. These data will be needed to verify the predicted trends toward increased impact of plastics as their concentration in refuse increases and emissions from other sources are reduced.

Another area which needs to be investigated is the effect of additives to plastics on waste and on the methods of handling waste. Although for this study, the amount of these additives (heat and light stabilizers, colorants, flame-retardants, and biodegradable and photodegradable agents) was considered as being negligible, the effects could become important in the future. For example, on incineration or pyrolysis, smoke or corrosive gases such as HCl and HBr may be formed. In some plastics, the additive consists of compounds based on heavy metals, and their release could become sufficient to cause local pollution problems. These pollution possibilities are just beginning to be explored. The by-products formed under the various waste-handling methods are not fully known. An investigation is needed in this area to determine the potential contribution of additives to the pollution problem.

SECTION III

INTRODUCTION

Although plastics account for a small (2-5) percentage of the present solid-waste stream, a large (40-50) percentage of the total plastic production becomes a waste product. With an anticipated growth of 10 percent per year in plastics production and the continued increase of the portion that enters the solid-waste stream plus the possible reduction in other components in solid waste through recycling and resource recovery, the relative amount of plastic in refuse could become much larger. Hence, it is important to evaluate the environmental impact of plastic-refuse disposal by present-day methods and anticipated developments in solid-waste-disposal technology.

During the past 5 years, the United States has modified its concern with regard to the treatment of solid waste from methods of disposal to methods of conserving natural resources (land, air, water, raw material, and energy). This concern has enhanced the development of solid-waste technology which can be expected to alter significantly the distribution of solid waste into various disposal systems. Ultimately, only small percentages of what is now considered to be solid waste will be disposed of without further recovery of energy or material. In accomplishing this ultimate objective, it is important that the processes required for each component of the solid-waste stream be evaluated in terms of their contribution to the overall environment and to the conservation of resources. Thus, an analysis of the rapid growth in the plastics industry versus developments in solid-waste-treatment technology has been made to assess the environmental impact of this component of the solid-waste stream over an extended period of time. The solid wastes considered in this analysis were those generated by households and commercial establishments, since much of the industrial-type wastes are sufficiently segregated to be economically recycled, reprocessed, or otherwise disposed of by the industry in an environmentally acceptable or regulated manner. The volume and mixture of components in household and commercial waste has been of much concern to the waste-disposal technologists.

To provide a basis for comparison of the environmental impact of plastic wastes, the magnitude of the plastic component in the total municipal solid-waste stream was analyzed and projections of these data to the year 2000 were forecasted as was the distribution of waste into various disposal systems.

SECTION IV

ANALYTICAL PROGRAM

The analytical program consisted of three tasks:

A. Quantitative Analysis of the Total and Plastic Component of Solid Waste

B. Analysis of Developments in Waste Disposal Technologies

C. Analysis of Environmental Impact of Plastic Waste for Various Disposal Methods.

QUANTITATIVE ANALYSIS OF TOTAL SOLID WASTE

The method selected to estimate the total amount of solid waste is based upon projected population growth[1] over the period of interest (1974-2000) and changes in the per capita rate of waste generation as discussed here. A number of factors (such as economical, political, social, educational, legislative, medical, and promotional influences) can significantly alter the forecast so that its reliability decreases as the time interval increases. It would be reasonable to expect an increase of 1 percent per year in the uncertainty of any forecasted data; that is, a reliability of ±10 percent in current 1974 population or waste generation could be expected to increase to ±36 percent of the respective numbers by the year 2000. Although the reliabilities are not shown in the tables or in the following discussion, it is important to recognize that the magnitude of the uncertainty increases with time for the numerical data given in the projected forecast.

Our analysis of the total amount of solid waste and the magnitude of the plastic components is presented in Table 1. The data for total solid waste are divided into that generated by the entire U.S. population and that generated by the municipal plus rural portion, of which the latter is most likely to be collectable for common disposal treatments developed in the foreseeable future. Although the population growth, by categories, has been forecasted by the U.S. Bureau of Census, the amount of refuse generated per person is a matter of considerable uncertainty. A linear extrapolation of the amounts collected in various sections of the U.S. for the years 1960-1970 would indicate an amount approximating 9 lb per capita per day by the year 2000.[2] This amount is believed to be excessively high as a result of the rapid increase in collection facilities over the 1960-1970 time period rather than a large increase in the amount of solid waste generated. Therefore, our analysis assumes a constant generation rate for 1970 and 1975. The emphasis on conservation of materials, recycling of specific products and materials, plus government regulations, energy conservation, and public opinion will result in a slight decrease (0.1 lb/capita/day for each successive 5-year period) in the amount of solid waste generated after 1975. However, the percentage of solid waste collected for the municipal plus rural population is expected to continue to increase at a rate of 1 percent per year until 90 or 95 percent is collected. Based upon these parameters, the total annual amount of solid waste generated is expected to increase from 187×10^6 tons in 1970 to 244×10^6 tons by the year 2000, with the collected amount increasing from 125×10^6 tons to 222×10^6 tons over the same period.

QUANTITATIVE ANALYSIS OF PLASTICS PRODUCTION

A projection of growth in the United States plastics industry is required for an analysis of the future contribution of plastic materials to solid waste. The analysis covers a 20-year period; hence, projected plastics consumption to the year 1994 is needed. To obtain the necessary data, a literature search and a telephone survey were conducted.

The prime literature information source used was Predicasts[3], a quarterly abstract service which provides complete coverage of all published data relating to materials produced or consumed in the United States. The section of this publication listing data on polymers (plastics, rubbers, and fibers) was carefully reviewed. The period

TABLE 1. FORECAST OF POPULATION AND AMOUNT OF SOLID WASTE TO THE YEAR 2000

	1970	1975	1980	1985	1990	1995	2000
Population							
Total x 10^6	205	217	232	249	265	280	297
Farm x 10^6 [(a)]	9.8	10.0	10.3	10.7	11.0	11.5	11.9
Urban x 10^6	143.5	161.6	179.7	197.7	215.8	233.9	252.0
Rural x 10^6	51.7	45.4	42.0	40.6	38.2	34.6	33.1
Solid Waste Generated							
Pounds/Capita/Day [(a)]	5	5	4.9	4.8	4.7	4.6	4.5
Total - 10^6 tons/year	187	198	207	218	227	235	244
Municipal + Rural - 10^6 tons/year	178	185	198	209	218	225	234
Solid Waste Collected							
Percent of Municipal and Rural	70	75	80	85	90	95	95
Amount - 10^6 tons/year	125	139	159	177	196	214	222
Plastic Wastes							
Total Amount - 10^6 tons/year	4.3	5.6	7.8	12.3	17.8	24.5	32.8
Percent of Total Solid Waste	2.3	2.8	3.8	5.6	7.8	10.4	13.4
Amount Collected - 10^6 tons/year	2.9	3.9	6.0	9.9	15.3	22.3	29.7

(a) See text for justification of estimates.

covered included the second quarter of 1972 through the first quarter of 1974, the most recent quarterly issue available at the time of the search. The published items containing data judged pertinent to this study were then collected. A review of these items was conducted and the principal journals in which pertinent data most often appeared were then surveyed issue by issue from the last date covered in Predicasts to the present. Journals surveyed in this fashion included Modern Plastics, Plastics World, The Chemical Market Reporter, Chemical Week, Chemical and Engineering News, Modern Packaging, Rubber World, Rubber Age, and Automotive News.

In addition to this literature search, a telephone survey was conducted. The Society of the Plastics Industry (SPI), the Manufacturing Chemists Association (MCA), Predicasts, Inc., and the editorial offices of Plastics World and Modern Plastics magazines were contacted. The phone calls were made to request any unpublished information that might be available as well as to identify any significant reports or data sources not previously found. Accurate 1973 plastics production figures (plastic type) were obtained from the SPI and production figures (end use) were obtained from Plastics World as a result of these calls. No sources of future production figures were obtained that had not already been identified from the literature search.

Two factors affecting future production of plastics are availability of feedstock and the cost or price of the plastics. If supply cannot keep up with demand, not only will consumption be less than anticipated, but also the cost of the material will eliminate its use in some of the lower priced markets.

Celanese Plastics Company marketing experts[4] analyzed current and future projected positions of the commodity resins (polystyrene, ABS, PVC, and polyethylene) as well as the engineering materials (acetal, nylon, polybutylene terephthalate, phenylene oxide-based resin, and polycarbonate). Although the supplies of polystyrene, ABS, and PVC are hardest hit by shortages, a substantial improvement should be seen in 1977 for polystyrene and ABS. Similarly, polyethylene and polypropylene, which are in tight supply, should be more available in 1977. It is anticipated that it will be somewhat longer before PVC production catches up with demand.

Most marketers agree that feedstocks will be short through the end of this decade and perhaps well into the 1980's.[5] However, Owings, manager of marketing economics for Gulf Oil, is quoted in this article as saying that 2-3 million bbl/day of additional feedstock will be added during the next 7 years.

An article on growth of oil-derived products worldwide[6] starts out by saying that prospects for continued growth of the major plastics are assured despite higher feedstock and energy costs. Similarly, an article in the Chemical Marketing Reporter[7] states that, although the plastics business will undergo some gradual but significant changes over the next 5-10 years as basic resin producers struggle to cope with extended raw-material shortages, overall consumption is expected to continue to grow, despite the negative aspects of higher prices, pollution-control problems, and the energy crunch.

Polyvinyl chloride is not only under a cloud because of a shortage in feedstock, but is also under attack because of health and environmental problems. However, even for PVC, a growing market is forecast. Although it is expected to grow by only 2 percent in 1974, it is anticipated to increase by a total of 30-40 percent by 1980.[8] A total production capacity of 7.12 billion pounds is forecast for 1980.

Thus, although sources of materials may change, and production between the present and 1980 may be somewhat less than was previously anticipated, there should be a small growth during that period which will increase after 1980. This is the position taken by Industrial Marketing and the SPI.[9] An article in Industrial Marketing[9] states that although a slowdown may be imminent, plastic producers are optimistic about long-term prospects. Whether or not an actual crisis will occur depends on the severity of the petroleum shortage and the resolution of allocation procedures by Congress or the White House.

Two publications of prime importance to this study were identified and obtained. The most important report is one prepared for the SPI by Stanford Research Institute (SRI), entitled "The Plastics Industry in the Year 2000".[10] Projections of plastics production in the year 2000 are given. Projections are reported in two breakdown categories, total resin production by plastic type and total market consumption by end-use distribution. For both categories, the projections are given as minimum, most probable (or median), and maximum figures.

According to this study, total plastic production by the year 2000 will probably total 113.5×10^6 tons, with the range given as 85.0 to 142.0×10^6 tons.

The second report, entitled "The Role of Plastics in Resource Recovery", was prepared by Midwest Research Institute (MRI) for MCA.[11] Projections are made for total plastics production for the years 1975, 1980, 1990, with a breakdown into the major plastic types (polyethylene, polystyrene, polyvinyl chloride, and polypropylene). The only breakdown by end-use markets is the projected consumption of plastics in packaging applications. However, it should be pointed out that MRI's analysis indicates that plastics packaging accounts for about 72 percent of all plastic waste, so this end-use category is by far the most important. By comparison, the Battelle useful-life concept indicates that either 63 or 85 (average 74) percent of plastic waste is derived from packaging materials.[12] The two different figures arise from different calculated values for total plastic waste (1973 data) based on analyses of, respectively, type of plastic (cf this report, Table 2) or end-use markets (cf of this report, Table 4).* It should be noted that MRI does not give a range of projection figures. However, this report has been quite valuable to the present study since it provided an independent analysis of projected plastic waste, both in terms of absolute amounts of discarded plastics and of percentages of total waste for the years 1980 and 1990.

Additional data on projections of future plastics production were obtained from other published sources. However, no other comprehensive report comparable to the two described above was obtained. Furthermore, most of the figures found turned out to be extracted from one or the other of these two primary sources. Data which appeared to be of independent origin were always for isolated plastic types or end uses. When tabulated, these data were insufficient to calculate totals which could be used to crosscheck the projections of the two main sources. Furthermore, most of these data were for the immediate future (1975-1980). Independent projections beyond 1980 were rare and of little use to this study.

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*1973 packaging volume of 2.91×10^6 tons is divided by either 4.61×10^6 tons (plastic-type analysis) or by 3.44×10^6 tons (end-use analysis). The 4.61×10^6 ton figure is a corrected value for Table 6, Reference 6, based on newly available total plastic production figures (see Table 1 of this report).

The pertinent data from the two prime references[10, 11] cited above, as well as the actual production figures for 1972-1973, are presented in Tables 2-6 and shown graphically in Figures 1-4. Plastics production figures for 1973 are given by plastic type in Table 2. Wastage figures are calculated based on the assumed percentage discard rate per year as derived from the useful-life concept.[12] The total (4.61×10^6 tons) is slightly lower than the figure given in Table 6 of Reference 12 (5.05×10^6 tons), since the earlier figure was based on a slightly higher sales estimate. The data in Table 3 (1970-1973 production figures) are given as background information and for use in graphing the actual production curve.

The most probable plastic production figures for the year 2000 by end-use categories from Reference 10 are listed in Table 4. Also included are the 1970 figures taken from the same reference. Table 4 also contains the actual 1973 data and the calculated waste figures based on the discard rate as derived from the useful-life concept. The total plastic-waste figures are 2.67×10^6 tons for 1970, 3.44×10^6 tons for 1973, and 30.7×10^6 tons for 2000. These figures are 32, 26, and 27 percent of the respective actual and projected production totals. These percentages are higher than those resulting from the MRI analysis (Reference 11, page 6) which average 22 percent. In Table 5, the data from both References 10 and 11 for projected market volume based on end-use categories for the years 1975, 1980, 1990, and 2000 are given. Again, waste plastic volume is calculated based on the percentage discard rate. The rounded percentages used for calculation are taken from Table 6 of Reference 12. The percentage of the "other" category is a calculated weighted average. Plastic-waste figures arising from this method of calculation are 5.4, 8.7, 18.3, and 37.9×10^6 tons, respectively, for the years 1975, 1980, 1990, and 2000. These waste volumes represent 31, 29, 33, and 33 percent of the respective year's projected plastic production figures. Again, these are higher than the 22 percent figure of Reference 11. Also, it should be noted that the waste percentage for the year 2000 is 6 percent higher than the result obtained (27 percent, Table 4) from the direct calculation based on estimated useful life of end-use categories. However, the amounts of plastic waste based on the useful-life concept were calculated from individual production years rather than a summation over the period evaluated. This summation would result in only a small increase in the total waste contribution.

TABLE 2. 1973 PLASTICS PRODUCTICN BY PLASTIC TYPE[a] AND WASTE VOLUME

Type of Plastic	Production x 10^6 Tons	Assumed Percentage Discard/Year	Waste x 10^6 Tons
Ethylene	4.22	65.6	2.77
Styrene[b]	2.51	38.1	0.95
Vinyl chloride	2.28	17.9	0.41
Polyesters[c]	0.52	--	--
Propylene	1.08	27.5	0.30
Phenolics	0.69	--	--
Urethane	--	--	--
Urea - Melamine	0.43	--	--
Acrylics	--	--	--
Epoxy	0.11	--	--
Nylon	0.10	--	--
Cellulosic	--	--	--
Acetate	0.05	--	--
Carbonates	--	--	--
Other	1.30	13.4	0.18
Total	13.29	34.7	4.61

(a) Source: Mr. Howard Kibbel, SPI, private communication.
(b) Includes polystyrene, ABS, SAN, and other styrenics.
(c) Unsaturated polyesters.

TABLE 3. ANNUAL PLASTIC TOTAL PRODUCTION (SPI DATA)

Year	Production x 10^6 Tons
1970	8.36
1971	10.33
1972	11.22
1973	13.31

TABLE 4. PLASTIC WASTE VOLUME BASED ON LIFE EXPECTANCIES OF END-USE CATEGORIES[a]

End Use	Approximate Life, years	Discards Per Year, percent	Volume, 10^6 tons: 1970 Production	1970 Waste	1973 Production[b]	1973 Waste	2000 Production	2000 Waste	Waste Percentage by End Use: 1970	2000
Packaging	1	100	2.25	2.25	2.91	2.91	23.7	23.7	84.3	77.2
Transportation	5	20	0.86	0.17	0.69	0.14	17.0	3.4	6.4	11.1
Furniture/Housewares	10	10	0.79	0.08	1.23	0.12	13.8	1.4	3.0	4.6
Electrical/Electronics	10	10	0.75	0.07	0.82	0.08	10.4	1.0	2.6	3.3
Appliances	10	10	0.28	0.03	0.47	0.05	2.2	0.2	1.1	0.6
Building/Construction	50	2	1.98	0.04	2.57	0.05	28.0	0.6	1.5	2.0
Other	50	2	1.45	0.03	4.61	0.09	18.2	0.4	1.1	1.2
Total			8.36	2.67	13.30	3.44	113.3	30.7	100.0	100.0

(a) Plastic production data taken from: Glauz, R. L., Jr., Kridl, A. G., Schwaar, R. H., and Soder, S. L., "The Plastics Industry in the Year 2000", April, 1973, p. 24. Report prepared by Stanford Research Institute for the Society of the Plastics Industry (SPI).
(b) Private communication from Plastics World.

TABLE 5. FUTURE MARKET AND WASTE BY PLASTIC TYPE

Type of Plastic	Assumed Percentage Discard/Year[c]	Volume, 10^6 tons: 1975[a] Production	1975[a] Waste	1980[a] Production	1980[a] Waste	1990[a] Production	1990[a] Waste	2000[b] Production	2000[b] Waste
Polyethylene	66	4.4	2.9	6.7	4.4	15.5	10.2	33.0	21.8
Polystyrene	38	1.9	0.7	2.8	1.1	6.5	2.5	9.9	3.8
Polyvinyl chloride	18	2.8	0.5	4.0	0.7	9.0	1.6	15.4	2.8
Polypropylene	28	1.2	0.4	1.7	0.5	4.0	0.5	15.4	4.3
Other	13[d]	7.3	0.9	14.9	2.0	20.0	2.6	39.6	5.2
Total		17.6	5.4	30.1	8.7	55.0	18.3	113.3[e]	37.9

(a) Plastic production data taken from: Cross, J. A., and Park, W. R., "The Role of Plastics in Resource Recovery", Midwest Research Institute, May 23, 1973, p. 2. Report prepared for Manufacturing Chemists Association (MCA).
(b) Plastic production data taken from: Glauz, R. L., Jr., Kridl, A. G., Schwaar, R. H., and Soder, S. L., "The Plastics Industry in the Year 2000", Stanford Research Institute, April, 1973, p. 6. Report prepared for The Society of Plastics Industry (SPI).
(c) Percentage of the same plastic from Table 6, page 11 of: Vaughan, D. A., Anastas, M. Y., and Krause, H. H., "An Analysis of the Current Impact of Plastic Refuse Disposal Upon the Environment", July 7, 1974. Report prepared by Battelle's Columbus Laboratories for Office of Research and Monitoring, U. S. Environmental Protection Agency.
(d) Weighted average percentage from same source as (c).
(e) Median value (minimum value = 85.0, maximum value = 144.2).

Projected plastic production and waste volumes for the years 1980, 1985, 1990, 1995, and 2000 are listed in Table 6. The projected production figures for all the years listed except 2000 were obtained from Figure 1. Thus, they are extrapolated values derived from a smoothed curve graphical representation of the projected plastics production data of References 10 and 11 (reproduced in Tables 5 and 6, except for the minimum and maximum figures for the year 2000). Waste volumes were calculated on the basis of both 22 percent and 29 percent rates of discard of annual production. The lower figure represents the MRI estimate while the higher figure represents an average Battelle figure based on the useful-life concept. Both sets of calculations were done for minimum, median (most probable), and maximum projected plastics production figures.

The projected future plastics production figures were plotted in Figure 1, which includes the 1970-1973 production figures to show how the projected curves merge with the actual data. The plots are drawn as curves rather than straight lines because calculated growth curves (not shown) based on either an average compound growth rate of 8 percent per year or on a slowly declining plastic production growth rate (from 13 percent growth in 1971 to 3 percent growth by 2000) follow such a pattern. A declining growth rate is predicted in Reference 11, page 2.

The projected plastic-waste data from Tables 4 and 5 are plotted in Figure 2. Data from Reference 11 are also plotted in Figure 2. In addition, a projected waste figure from a report entitled "Solid Waste Management of Plastics"[13] is plotted. The curve plotted using the Battelle useful-life concept is based on the most probable (median) projected plastics production data from Reference 10.

The data from Table 6 are plotted in Figures 3 and 4. Figure 3 is based on calculations made using the 29 percent discard rate, while Figure 4 is based on the 22 percent discard rate calculations. There is an interesting overlap region on the two graphs. Thus, the area between the minimum and most probable curves of Figure 3 can be superimposed on the area between the most probable and maximum curves of Figure 4, indicating the wide range that is likely to occur in projections of this type. The data presented in Table 1 for plastic waste are based upon the mean figures for the 29 percent discard rate.

TABLE 6. PROJECTED PLASTIC PRODUCTION AND WASTE

Year	Range	Production, 10^6 tons	Waste, 10^6 Tons Based on Indicated Percentage 22[a]	29[b]
	Minimum	22.8	5.0	6.6
1980	Median	27.0	5.9	7.8
	Maximum	31.0	6.8	9.0
	Minimum	33.5	7.4	9.7
1985	Median	42.5	9.3	12.3
	Maximum	52.0	11.4	15.1
	Minimum	46.0	10.1	13.3
1990	Median	61.5	13.5	17.8
	Maximum	76.5	16.8	22.2
	Minimum	63.0	13.9	18.3
1995	Median	84.5	18.6	24.5
	Maximum	107.0	23.5	31.0
	Minimum	85.0	18.7	24.6
2000	Median	113.0	24.9	32.8
	Maximum	144.0	31.7	41.8

(a) 22 percent average rate of discard of plastic production projected in "The Role of Plastics in Resource Recovery", Midwest Research Institute, May 23, 1973, p. 6 (report prepared for MCA).

(b) 29 percent average rate of discard of plastic production projected on the useful life approach of end-use categories.

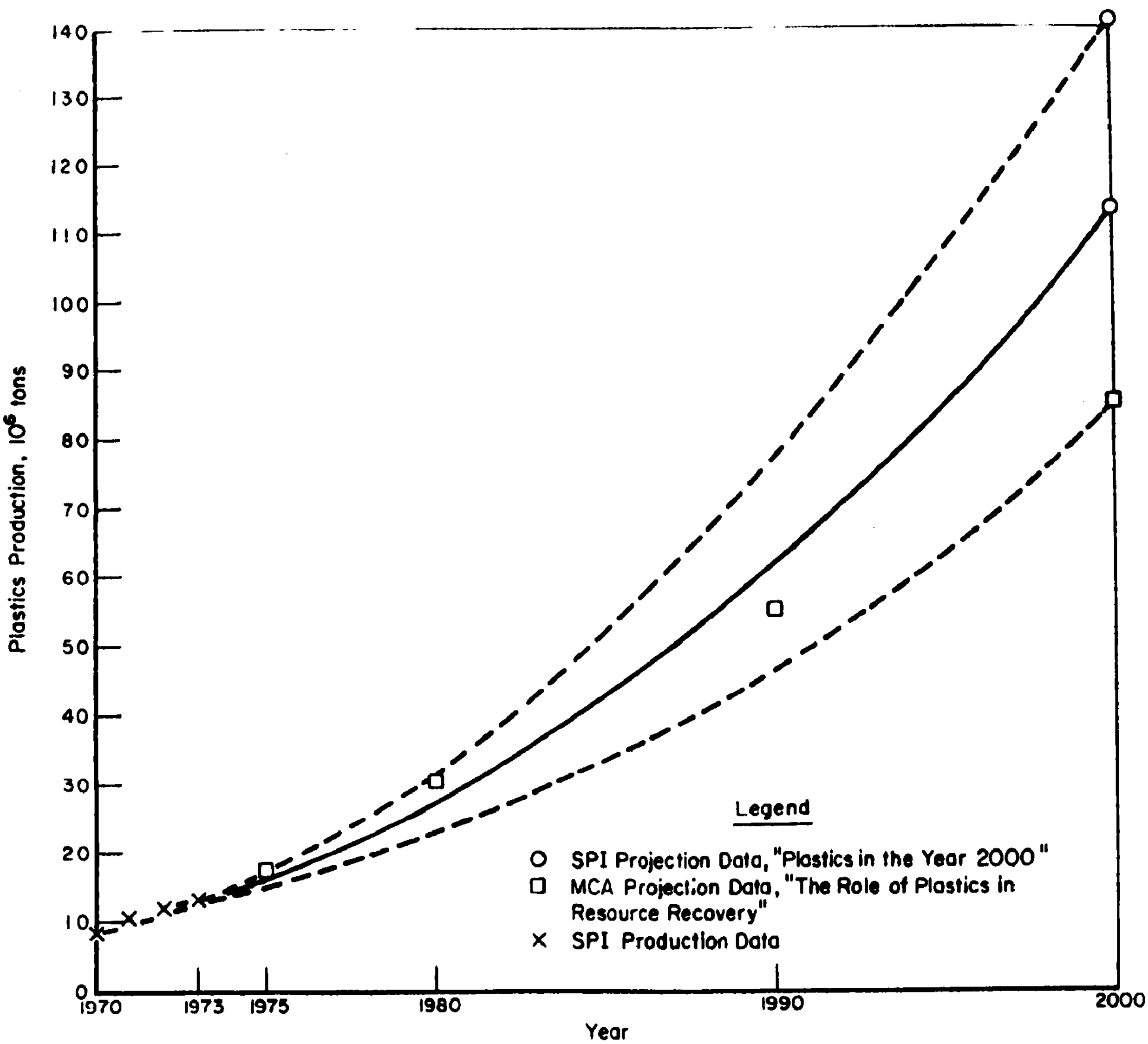

FIGURE 1. PLASTICS PRODUCTION PROJECTIONS TO THE YEAR 2000

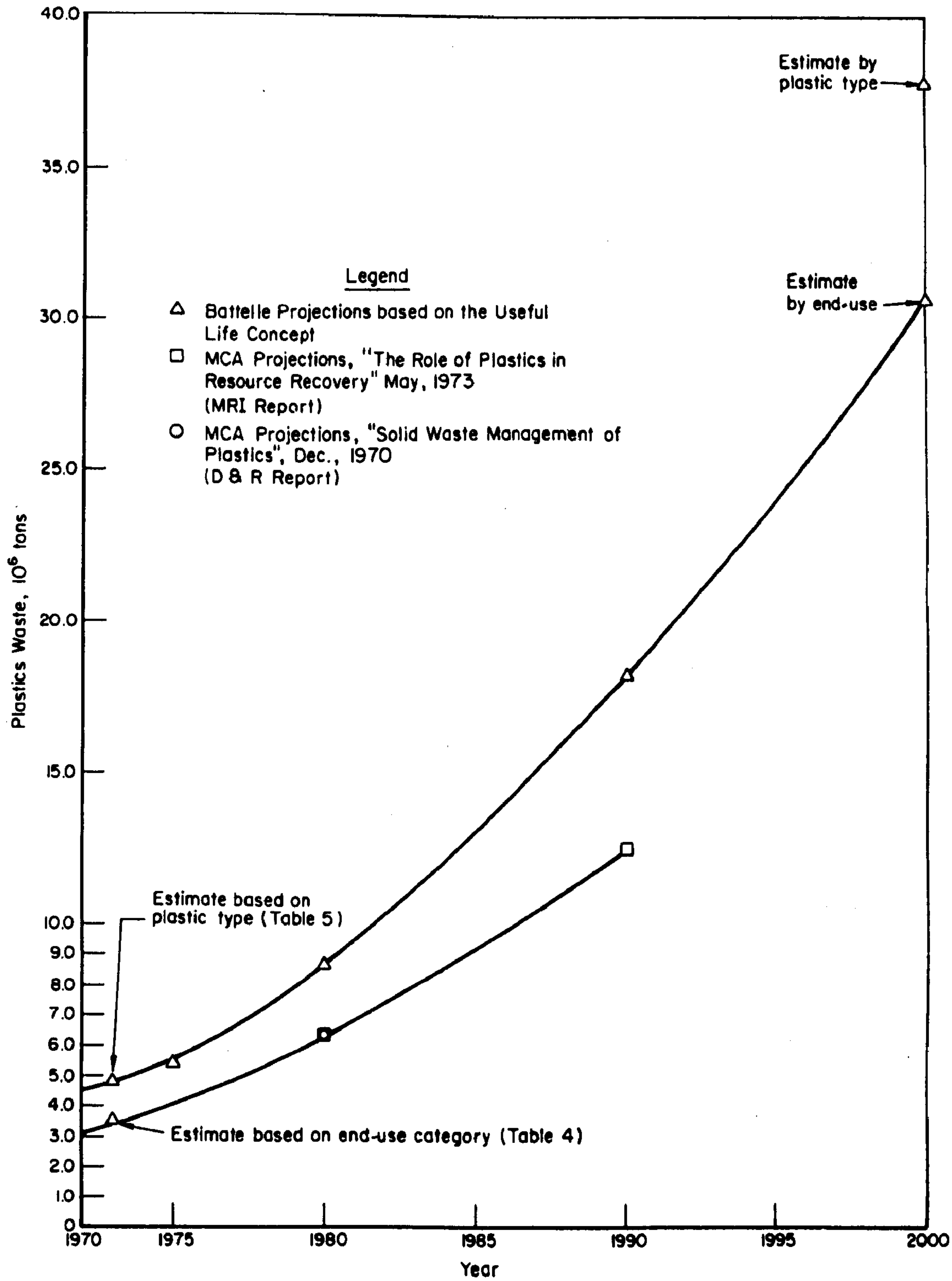

FIGURE 2. PROJECTED PLASTICS WASTE TO THE YEAR 2000

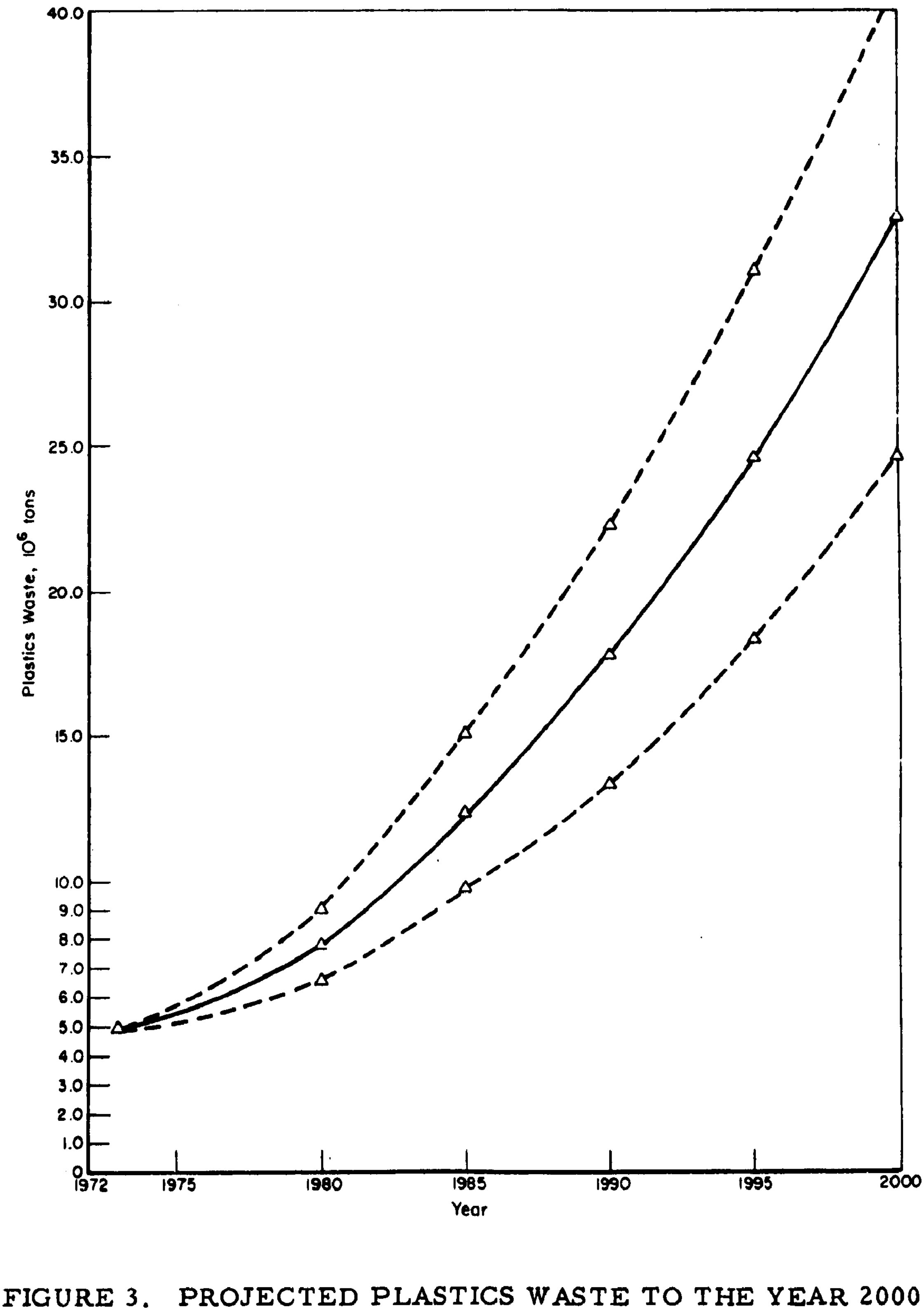

FIGURE 3. PROJECTED PLASTICS WASTE TO THE YEAR 2000 BASED ON A 29 PERCENT DISCARD RATE OF MINIMUM-TO-MAXIMUM PRODUCTION

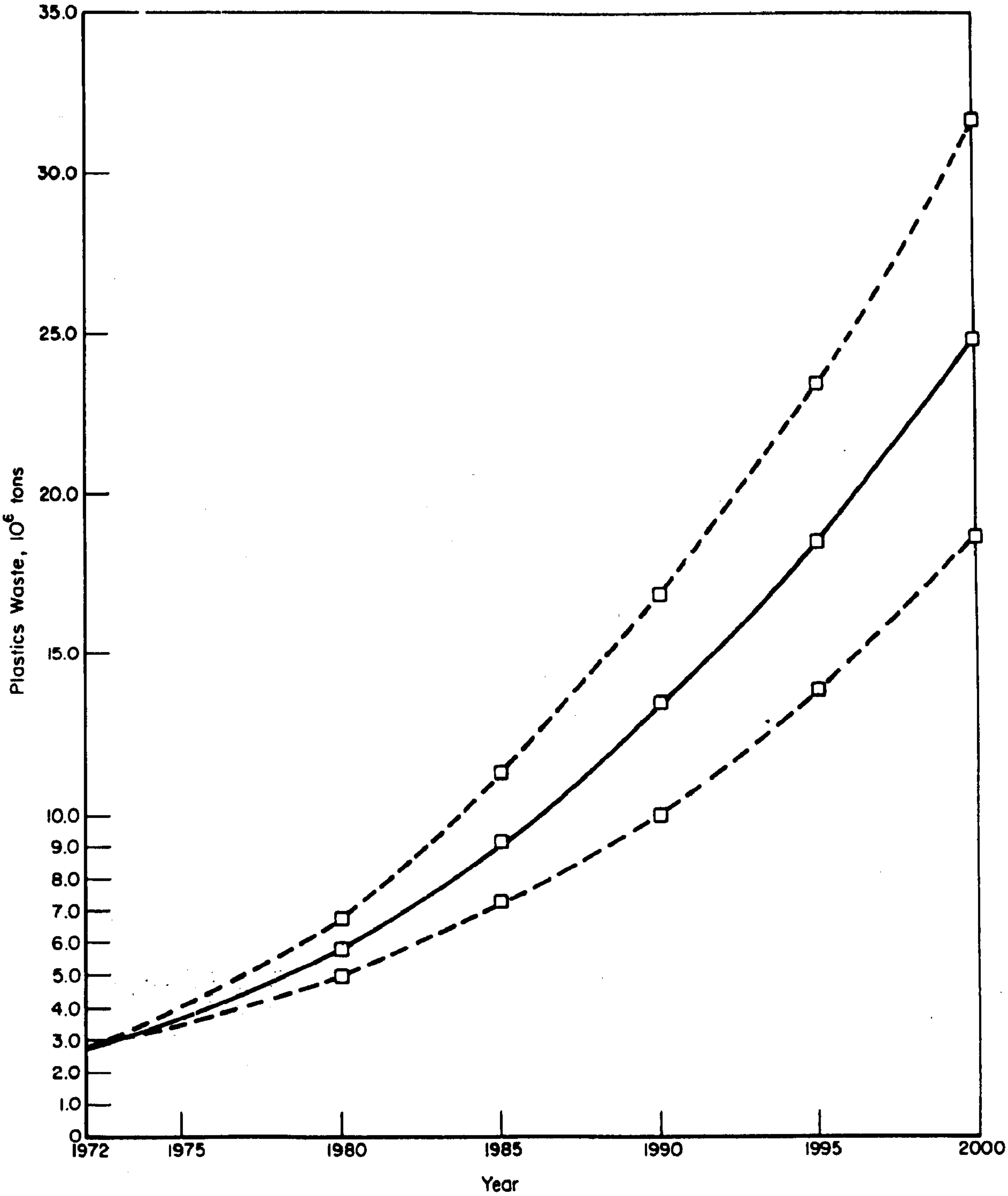

FIGURE 4. PROJECTED PLASTICS WASTE TO THE YEAR 2000 BASED ON A 22 PERCENT DISCARD RATE OF MINIMUM-TO-MAXIMUM PRODUCTION

It should be pointed out that plastics production figures, such as those used for the basis of future projections in the SRI and MRI reports,[10,11] do not include synthetic polymers used for the production of man-made fiber. Since textiles have historically been considered as a separate category from plastics when analyzing the impact of plastics waste upon the environment, they were not included in this study. Textile polymers can be a substantial amount of the solid-waste stream, for in 1973 production of synthetic fibers amounted to 3.4 million tons, equal to about 25 percent of the plastics production that year. Similarly, rubber is another category that becomes part of the solid waste. Production in 1973 amounted to 2.4 million tons of synthetic rubber and 0.6 million tons of natural rubber. At the present time additives in plastics do not constitute an important item, but if the amount of additives is increased in future years, their effects should be evaluated.

ANALYSIS OF DEVELOPMENTS IN THE SOLID-WASTE DISPOSAL TECHNOLOGY

An orderly classification of present and future developments in solid-waste-disposal technology may be grouped into three primary categories: throw-away, thermal treatment, and utilization or resource recovery. The classification is for ease of impact assessments and it will be recognized that some methods of disposal may encompass more than one objective. For example, sanitary landfill with the primary objective of throw-away may simultaneously involve in-land reclamation, while thermal treatment involves volume reduction with or without energy or other product recovery. Furthermore, the only final disposal of solid waste is indeed the landfill (throw-away) method, since residues from other waste-treatment processes, which range from about 8 to 40 percent, may be relegated to landfill. Resource-recovery processes temporarily postpone final disposal until a later time when the materials, either in the original form or transformed into other products, have no further economic value.

Developments in the Throw-Away Methods of Solid-Waste Disposal

Throw-away-disposal methods are the earliest solid-waste-disposal methods and they have seen many changes in the last several decades, progressing from litter, to open dump, to what we have today as the best disposal method in this category – the sanitary landfill.

Litter consists of articles of all types and sizes discarded at random, being most prevalent along roadsides, playgrounds, parks, and beaches.

The persistence of the litter will depend upon the climate, the wind, the effect of convenience-oriented human institutions and activities (which tend to dispense it) and on any efforts which may be made to collect it. Littering problems will be solved by creating an attitude of mind and a behavior pattern in homes, schools, and public places that would prevent its incidence. Public education programs can be used to inculcate this code of behavior. However, improved collection facilities and, if necessary, punitive measures can aid in reducing the incidence of littering. Once collected, litter can be dealt with by the processes of solid-waste disposal. Litter can be prevented if every step is taken to put all waste, irrespective of size and nature, through the solid-waste-disposal systems.

The amount of plastics in the litter varies considerably according to the location of the litter. In Table 7, the plastics fraction is shown to vary from 6 percent by volume to about 10 percent by weight.

TABLE 7. COMPOSITION OF LITTER[14]

Material	U.S. Highways, volume percent	U.S. Cities, weight percent
Paper	59	55.0
Metal	16	18.1
Plastics	6	10.2
Glass	6	4.2
Miscellaneous	13	12.5

The portion of plastics in the litter fraction is generally assumed to increase in the years ahead due to increased usage of plastics in packaging consumable goods. However, the total amount of litter may be expected to decrease significantly through local and state law enforcement and public awareness of the environment.

Disposal by open dumping involves dumping a collection of refuse on land "without any efforts towards altering or modifying its appearance or nature". Open dumping historically has predominated all other forms of disposal methods because of its immediate expediency and low cost. However, because of the associated air pollution, odor nuisance, potential fire hazards, unsightliness, water pollution, and assorted health hazards, open dumping is an unsuitable method for solid-waste disposal. Consequently, recent ecological concern together with the EPA program to close 5000 open dumps, has produced a downward trend in the use of open dumps. Beginning with a little over 74 percent of the total solid waste headed to open dumps in 1970, this study estimates that this fraction will reduce to about 11 percent by the year 2000. Another factor that will influence this trend is urban encroachment on the traditional dumping areas such as natural depressions, flat lands, etc.

Sanitary landfill consists of four main processes:

(1) The sanitary landfill site is selected and a portion of the site is prepared;

(2) The solid wastes are deposited in a controlled manner in the prepared portion, spread, and compacted in thin layers (about 2 feet);

(3) The solid wastes are covered daily or more frequently, if necessary, with at least 6 inches of compacted earth layer; and

(4) The completed sanitary landfill consisting of several cells of daily operations is covered with at least 2 feet of compacted earth layer.

Sites properly selected and operated in this manner meet the criteria for sanitary landfills, that is, "a land-disposal site employing an engineered method of disposing of solid waste on land in a manner that minimizes environmental hazards by spreading the solid waste in thin layers, compacting the solid waste to the smallest practical volume, and applying and compacting cover materials at the end of each operating day."[15]

Through legislation and public acceptance, the number of sanitary landfills are increasing and are expected to become final deposit sites for approximately 40 percent of the municipal and rural solid wastes collected by the year 2000, on a national basis.

Site selection for any sanitary landfill is dependent on three main factors: technical factors, sociolegal factors, and economic factors.

The aspects of the technical factors are the volume and characteristics of the waste to be landfilled, the topography of the land, and the geology and soil condition of the site. A major concern in sanitary landfilling is the potential danger of polluting ground- and surfacewater. Consequently, nonwater-soluble, nondecomposable inert waste materials may be landfilled in low-lying areas with high water tables, near water bodies, or in places with high permeability with less danger to water pollution, while decomposable organic materials and toxic materials are unacceptable in such sites.

The need for site selection for sanitary landfill to comply with the local and state ordinances and zoning restrictions will be increasingly more pressing in years ahead. Urban sprawl presents serious conflict to waste disposal and this conflict will increase in the years ahead as more solid wastes are generated and land for disposal becomes limiting.

Land cost, hauling distance, and availability of cover materials are main economic factors in site selection. Usually land areas that are hardly usable for any other purposes such as low-lying areas which have drainage problems with high potential for surface- and groundwater pollution are reserved for the sanitary landfilling. Hence, the importance of well-engineered sanitary landfill where pollution-control measures are employed, can hardly be overemphasized. Also of economic importance is the available land for landfilling, for the area or volume of land required depend on the character and quantity of the wastes, the depth of the fill, the efficiency of compaction of the wastes, and the desired life of the landfill.

The economic factor associated with hauling distance will vary from locality to locality depending upon capacity of collection vehicles, hauling time, and size and method of collection agency. The larger the quantity of waste hauled per trip and the shorter the hauling time (due to express roads, freeways, etc.), the greater the distance the solid wastes can be hauled for the same cost. The cost of hauling cover materials can be appreciable. A site that has cover material close by will keep these costs at a minimum.

Construction and operation of the sanitary landfill site may simply begin with the clearing of shrubs, trees, and other obstacles that could hinder vehicle travel and landfilling operations. In some instances it may also involve the construction of roads and other structures. Specifically, the prevailing methods of sanitary landfill construction are generally divided into three categories. The choice of construction method depends on the constraints of the particular site.

The trench method (or cut-and-cover method) is used when the groundwater is low, and the soil is more than 6 feet deep, and usually on flat or gently rolling land. Starting at one edge of the first trench, waste materials are dumped. At the end of the day's dumping, spreading, and compacting, the waste is covered with the earth excavated from the second trench on the far side of the dumping edge. A minimum of 6 inches of compacted earth cover on the cell is generally recommended. Spoil material not needed for daily cover may be stockpiled and later used as a cover for an area-fill operation on top of the completed trench fill.

The area method (or fill-and-cover method) can be used in most topographies, but is usually employed in low-lying areas such as marshes or swamps or in land depressions such as abandoned quarries, ravines, or canyons. Waste is dumped on the existing ground surface, spread in horizontal layers, and compacted. At the end of each day's work the waste surface is covered as needed with earth excavated from the area directly in front of the working face of the landfill (progressive excavation). If excavation is not possible, the fill is covered with imported cover material.

The ramp method (or the progressive-slope method) is employed exclusively in filling depressions, such as ravines, canyons, or quarries. In this method, the waste is deposited and spread in layers on the slope of the depression. Cover material is obtained directly in front of the working face and is used to cover the slope sides and top of the waste-cell structure. This technique allows for more efficient use of the disposal site since cover materials are usually available nearby.

Waste treatment prior to landfilling involves methods that reduce the volume of waste. In sanitary landfill, density is the prime consideration. With good equipment, solid waste can be compacted, shredded, or baled to achieve an appreciable volume reduction and to obtain a satisfactory fill material. Improvements in the baling, shredding, compaction, and other operations preceding the actual landfill are all calculated to increase the density (decrease the volume) of wastes to extend the landfill site lifetime.

Such treatment applied to the solid waste takes three forms:

(a) Physical treatment: size reduction and mixing in a pulverizer, or high-density baling

(b) Biochemical treatment, composting by controlled fermentation of the degradable organic content

(c) Thermal treatment: incineration in an enclosed furnace.

Pulverization is a mechanical process for chopping, tearing, and shredding. This is accomplished by passing refuse through a chamber containing swiftly rotating knives or hammers. Pulverization in a hammer mill can reduce 95 percent of the refuse to 25 mm or less, with most of the remainder below 100 mm. Some machines are large enough to accept a piano and strong enough to cut steel as thick as auto wheels. All the machines are designed to reject high-strength materials such as crackshafts, and some reject rubber tires.[16] Pulverization improves the solid-waste density, with resultant reduction in transport cost. Furthermore, a pulverized waste is less objectionable and less likely to ignite or to attract rats and flies. When deposited in a sanitary landfill, the constituents are small and well mixed; thus litter is less of a problem, decomposition is more rapid, and the complete absence of voids prolongs site life and reduces the risk of uneven settlement.[16]

It is estimated that, at the time of collection, about nine-tenths of the volume of residential and commercial refuse is air, and if this can be expelled, subsequent handling cost and space problems can be greatly reduced. This volume reduction has been achieved by plants in Japan, and experimentally in the United States and Britain. The waste volume has been reduced to about 1/7 of the original amount by a high-pressure baling press.[17] The real importance of baling would be the subsequent facility and economy of handling and transporting refuse in large high-density blocks. An added benefit is that settlement during land reclamation would be reduced.

The burning of inflammable materials in the municipal solid waste can reduce the total volume of solid waste to be disposed of to about 16 percent of the incoming material. The residues which are fly ash, bottom ash, and screenings will require subsequent disposal on landfill sites. The high density of incinerator ash makes it an economical material to transport, and because the organic content is very low, it may sometimes be used for filling sites at which there would be a risk of water pollution from crude or pulverized refuse. Ash can cause water pollution, however, because it may contain soluble inorganic salts.

Composting biochemically converts municipal waste into a useful soil conditioner. The volume reduction has distinct advantages over normal landfilling:

(1) Leachate from a compost dump is not as potent and objectionable as that from landfill

(2) Many pathogens and objectionable organisms will have been destroyed in the composting process.

Compost has very little nutrient value, for the nitrogen content is only about 1 percent and phosphate and potash even less. Its most useful characteristic is its humus content, which enables it to improve the performance of soils which lack organic matter.

In spite of this potential technical advantage, however, such a combination of composting-plus-landfilling, thus far, has not gained acceptance in this country, presumably because the added cost of the composting step is still considered unjustifiable. In the future, as landfill sites become less available, the importance of preliminary volume-reduction techniques will increase.

Developments in Thermal Treatment of Solid Wastes

Thermal treatment of solid waste includes both combustion and pyrolysis. The former has been employed for many years as a means of reducing the volume of waste to conserve landfill area. Although burning at landfill sites was general, the practice has been reduced significantly through state and local law enforcement. Open burning has been replaced by municipal incinerators. As a result of the increased concentration of refuse at local sites, the problems associated with disposal of solid waste by incineration became more evident in terms of gaseous and particulate emissions, scenic blights, health and accident hazards, depreciated land values, and public nuisances. Hence, Federal air-pollution regulations were enacted and state or local controls reduced significantly the open burning of refuse with a resulting growth in the number (322) of municipal incinerators constructed. However, since 1967, the number of operating incinerators has declined to approximately 140 because of obsolescence, emission-control regulations, and repair or construction costs.[18] Furthermore, over 95 percent of the operating municipal incinerators have incorporated emission-control systems in the off-gas chambers or stacks. Unfortunately, corrosion is a major problem in these emission-control systems. Also, corrosion has been a major deterrent to the installation of heat-recovery systems in municipal incinerators. Considerable effort has been made to circumvent these problems so that solid waste can be used to conserve other fuels. Hence, although incineration for volume reduction purposes only is decreasing, the combustion of solid waste for heat or power generation is increasing. It is expected that the amount of thermally treated solid waste will increase from less than 10 percent of that generated in 1970 to 36 percent of that generated in 2000, as discussed in the following paragraphs.

The recovery of heat from the incineration of refuse through conversion to low-temperature steam has become attractive in several locations where there is a market for this product. As other forms of fuel become more expensive, solid waste becomes more attractive, even though the most promising use of solid waste as a fuel requires considerable processing. This processing will improve combustion conditions and may be expected to reduce the magnitude of boiler-tube corrosion that results from burning bulk refuse. Hence, although only 5 x 10^6 tons of solid waste was used to provide heat in 1973, this amount is expected to increase to 24 x 10^6 tons by 2000 as central heating and cooling for industrial parks, office complexes, and downtown buildings increases.

The utilization of solid waste as a supplemental fuel for power generation is receiving much attention at the present. Several utility companies are investigating the potential of solid waste as a fuel source and as a benefit to the communities they serve. An analysis[19] of the theoretical and practicable amounts of solid waste that could be utilized in existing coal-fired electric utilities shows that a 20 percent heat value replacement of coal with solid waste would utilize all the waste forecasted to be generated through the year 2000. It is difficult to predict to what extent this potential will be realized. In many areas, it would not be practicable to collect, process, and haul refuse to the point of consumption. Large metropolitan areas and some entire states are developing resource-recovery facilities for solid waste which provides a component equivalent to 70 percent of the waste that is 92 percent combustible. In view of these current developments, the amount of waste utilized in electric power generation is expected to become significant by 1980 and expand to 32 x 10^6 tons per year by 2000.

As a result of the anticipated growth in the utilization of solid waste for heat and energy generation, the growth in resource-recovery operations, plus the enforcement of air-pollution regulations with attendant costs of construction, the incinerator method of reducing the volume of solid waste is expected to decrease markedly in popularity as the existing equipment becomes obsolete. Hence, the disposal of solid waste by incineration will probably remain at a constant level for the next 10 years and then decrease to less than 1 x 10^6 tons per year by 2000.

In contrast, the pyrolysis of solid waste to gas or liquid components plus char products that can be subsequently burned in an environmentally acceptable manner or utilized as a raw material has received much attention and several pilot plants are under construction. It is not expected that this method of disposal will contribute significantly to the disposal of solid waste before 1980, but its use will probably increase after that because of convenience in storage and transfer of the resulting products.

Developments in Resource Recovery

For impact-assessment purposes, resource recovery is narrowly defined in this section to include only the use of materials and products (except energy) reclaimed from solid waste. The energy aspects of the resource recovery are discussed under thermal treatments. Most specialists in solid-waste management tend to agree on some broad areas of solid-waste management, viz: solid-waste generation rates will increase, suitable land for disposal of waste will become less readily available, additional processing of waste will become necessary prior to disposal, and the cost of solid-waste management will increase. Based on these premises, national attention is being focused on resource recovery as an answer to the nation's solid-waste management problems.

Specific advantages of resource recovery are:

(1) The volume of refuse to be disposed after extracting various materials from the waste stream is reduced.

(2) These reclaimed fractions serve as raw products, thus reducing the amount of virgin materials needed.

(3) Less energy is generally required in the total manufacturing process when secondary materials are used.

The different resource-recovery options for utilizing waste materials are reuse, recycling, and reclamation. These are briefly defined as follows:[20] Reuse denotes use of a material or product - as is - more than once. Recycling takes the product and reintroduces it into the production cycle for the production of the same product. Reclamation consists of processing for reuse as a different product. Examples are: a plastic bottle, which is reused when the bottler or the housewife refills it; the same bottle, which is recycled when ground into particles for the manufacture of new soft-drink bottles; and the same bottle, which is reclaimed (or salvaged) when ground up and used to make a totally different product, such as drainage tile.

Reuse of municipal wastes that are disposed of by the "reuse option" as defined here is regrettably insignificant and the future disposal of a sizable quantity by this process is not promising. Firstly, few materials in the municipal wastes could be salvaged and reused without some form of reprocessing. Secondly, the problem of separating these waste materials from a heap of mixed municipal wastes is enormously expensive. Much of the cost of salvaging may be avoided by keeping the desired materials separate at source – a process that would ultimately involve every household.

Beverage-bottle return by consumers is widely practiced today and the efforts to do so will probably increase in the years ahead. Other waste candidates that can be reused as defined here are canning bottles, plastic covers, and cardboard. These are the only widely used materials that may be reused without reprocessing. The fraction of this reuse process in the total solid-waste picture is hard to estimate. Both industrial and government packaging wastes have been reduced by the promotion of reuse designs and specifications. However, there has been little or no attempt to promote this for household items. Thus, reuse is not expected to change municipal solid-waste generation in the foreseeable future.

Recycling is defined as reintroduction of waste materials into the production cycle for the manufacture of the same product. If the waste material, for example, plastics, is to be used as a substitute for virgin raw material, manufacturers require that the salvage waste material must satisfy three requirements:[21]

(1) Homogeneity, because mixed grades of plastic will not possess the required properties for most processes or products

(2) Cleanliness, because contaminants (such as dust, oil, etc.) would degrade the quality of the product

(3) Satisfactory form (granules, pellets, powders, etc.).

Recycling of certain plastic wastes from fabrication plants is practiced. In industrial plants, it is possible to keep different types of plastics (e.g., polyethylene, polystyrene, and polyvinyl chloride) separate at the source. Once the plastics have been discarded into the waste stream, the recovery of the plastic from the mixed waste is a difficult operation, and commercially of doubtful value at present.

The quantity of plastics appearing in the refuse is small, and separating it is neither easy nor economical, and it is difficult to mechanize the process (flotation and elutriation is a possible method under investigation). Further, to make the best use of plastics they should be separated into their various types, e.g., polyethylene, polypropylene, polystyrene, polyvinyl chloride in its rigid form, polyvinyl chloride in its flexible form, and all the others which appear in minor quantities. Thermosetting types would be rejected because they could not be recycled directly. After segregating the recyclable plastics, cleaning and processing is necessary. The plastics are then softened or melted and converted into a suitable raw material form, e.g., granules. The properties and processing characteristics required for a particular application and production method may demand additional treatment. Much exploratory work is being done on all aspects of the reclamation of thermoplastics from refuse. Cost and limitations of use because of difficulties in achieving the quality required are among the major problems yet to be solved. If cleansing to the required level is not possible, other means of dealing with the waste will have to be developed. Therefore, because of the lack of homogeneity and cleanliness, direct recycling of recovered plastics from the municipal waste stream is not promising.

Reclamation (indirect recycle) is defined as processing of the waste material for reuse as a different product. For plastics, this may involve the manufacture of products or the use of the waste material in some other way, having a less demanding specification due to nonhomogeneity and impurities.

Various studies are underway to develop methods of separating the various components of the solid waste into individual reclaimable materials.[5] Scrap metals, paper, glass, and foils have good salvage prospects. However, there are problems with reclaiming plastics. In this country, no method has been developed on reclaiming plastic from the municipal solid waste. In a recent European development, the "remaker"[21] accepted plastic bottles, without precleaning, and many other kinds of thermoplastic wastes after they had been shredded or pulverized, and then transformed them into shoe soles, bicycle saddles, household utensils, and toys. A typical limitation in the use was a requirement that products must have a minimum wall thickness of 1/8 inch. The operation of the machines is said to be somewhat slow compared with those using virgin materials.

Flintoff describes a municipal enterprise in reclamation by the Japanese City of Funabashi.[21] Two types of machinery were installed to produce flowerpots, pipes, and poles from mixed thermoplastic wastes. The most interesting aspect of the project was that the city obtained its raw materials segregated by persuading householders to keep plastic wastes separate from other household wastes.

A process for indirect recycling would normally commence with shredding and mixing of the thermoplastic wastes, and, perhaps, the incorporation at this stage of fillers such as wood chips or wood fibers. This product would then be compacted into granules and fed to an injection-moulding machine for the production of, say, flowerpots, or to an extruder or a press to form profiles or building boards. Thus, reclamation of plastics has some potential for the future if the plastic waste can be salvaged and accumulated in sufficient quantities.

Composting as discussed earlier, is a controlled biochemical conversion of waste to useful soil conditioner, and thus may be considered a reclamation process. Composting has not been a popular means for municipal solid-waste reduction and disposal in the United States. Some reasons are: (1) limited market because of wide use and low cost of chemical fertilizer, (2) high operating and distribution costs, (3) limited number of successful composting installations, (4) reluctance of municipalities to enter commercial ventures, and (5) failure to recognize composting as a method of solid-waste disposal.

At a typical compost plant, ferrous metal would be extracted by electromagnets and there would probably be facilities for hand-picking to remove unsuitable materials such as bottles, man-made textiles, nonferrous metals, and plastics. Pulverization might follow in order to facilitate subsequent bacterial action by reducing particle size and by thorough mixing.

The municipal solid waste may be combined with sewage sludge or other waste types; studies have shown this approach to be a great improvement because of the improved composting characteristics. The improved composting parameters are: carbon to nitrogen ratio, moisture content, aeration, temperature, and particle size. However, plastics cannot be treated by composting since they do not biodegrade within the same time span as the other biodegradable materials.

Projections of Solid-Waste Disposal by Various Methods

Although for many years bury, or burn and bury the residue, were the only methods of solid-waste disposal, recent developments in solid-waste technology brought on by public awareness of our environment, legislation, inflated costs of virgin materials, plus depletion of our natural resources, and the energy crisis have brought about methods to reuse, recycle, and recover much of the value from solid waste which heretofore was lost from the nation's economy with attendant high disposal costs. Solid-waste-disposal technology may now be divided into three major categories: resource recovery, thermal treatment, and landfill. The last method encompasses that which has not been processed plus the residue from the other two.

A national inventory that gives the precise amounts of municipal refuse handled by various disposal methods is nonexistent. Studies have depended largely on best estimates which in all probability differ widely, simply because of great diversity in source of generation, problems of collection, and the fact that some of the waste may never be collected. The three main categories of the municipal solid-waste disposal have received considerable attention during the past 5 years as a result of national interest in the environment, Federal and state legislation regarding air, land, and water pollution, and interest in conservation of materials and resources. We define throw-away or land disposal to constitute litter, open dump, and sanitary landfill; thermal treatment consists of incineration with or without energy recovery, and pyrolysis; while utilization or resource recovery consists of materials recovery and composting.

In the previous section of this report, attempts have been made to estimate the magnitude of the change in various forms of disposal from 1970 to the year 2000, as illustrated graphically in Figure 5.

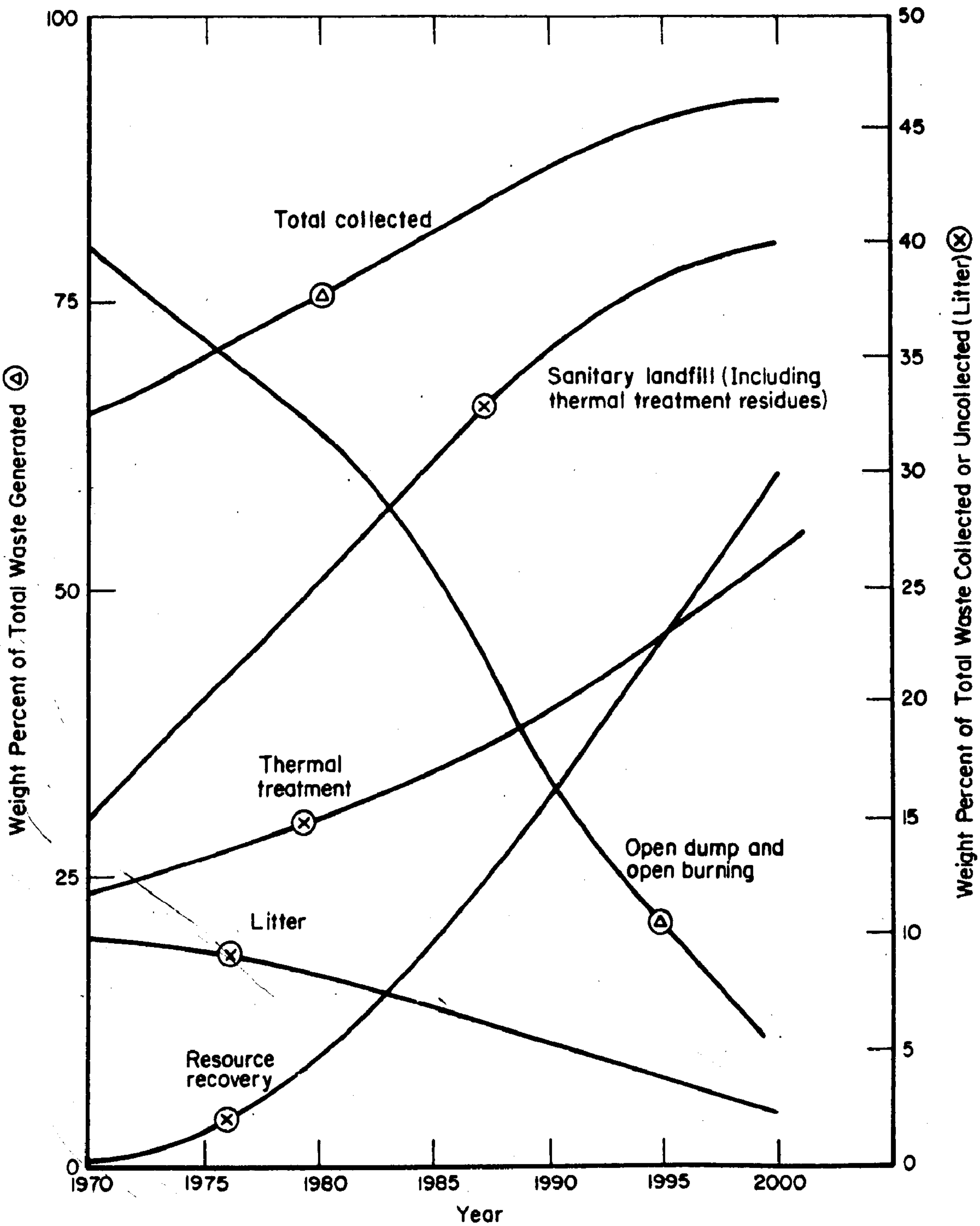

FIGURE 5. PROJECTION OF WASTE DISPOSED BY VARIOUS DISPOSAL SYSTEMS, AS DEVELOPED IN THIS PROGRAM

Estimates for Land Disposal (Throw-Away)

In 1965, a survey by APWA showed that in the U. S. there were about 1175 "noncaptive" sanitary landfills and 19,400 "noncaptive" open dumps.[22] Noncaptive installations were defined as those that are not operated for the disposal of the owner's refuse exclusively. It was estimated that about 91 percent of the sanitary landfills were supported by urban and "semirural", while 9 percent were in rural communities. Also, about 51 percent of the open dumps were supported by the urban and semirural, while 49 percent were supported by the rural. A majority of the rural refuse is disposed of on the privately owned sites, which are largely open dump and not included in this count.

According to Warner et al,[23] in 1966, "79 percent of all U. S. cities with populations over 25,000 utilized landfill with almost 81 percent of the solid waste in these communities disposed of in this manner". The estimate of the sanitary landfill was 6 percent of 12,000 U. S. solid-waste land-disposal sites or about 720 sites. Another estimate by Black[24], who stated that only 5 percent of the 14,000 authorized land disposal sites were sanitary landfills, approximates Warner's estimates.

In 1971, EPA data estimated that 175 million tons of municipal refuse were disposed of on the land[25]: 25 million tons sanitary landfilled, 52.5 million tons open dumped and burned, and 97.5 million tons open dumped without burning. In 1970, about 92 percent (or 171.9 million tons) of the total municipal refuse generated was deposited on or in the land, but this is expected to decrease significantly by the year 2000 to around 47.5 percent or 115.9 million tons. Based upon our evaluation, trends that will effect this change are as follows:

- There will be an increasing efficiency in the municipal refuse collection over the years evaluated. The percentage of the total refuse collected is expected to increase from 67 percent in 1970 to 91 percent by 2000. Furthermore, litter is estimated to decrease approximately linearly, that is, from about 10 percent (or 6.2 million tons) of the uncollected refuse in 1970 to about 2 percent (or 0.4 million tons) by the year 2000.

- Regulations against open dumping with or without burning will reduce this disposal method, with approximately a linear decrease from about 79.7 percent (or 149 million tons) of the total household and commercial refuse generated in 1970 to about 11 percent (or 27 million tons) by the year 2000.

- Wherever possible, it is expected that open-dump sites will be converted to sanitary landfills. The quantity of the refuse placed in sanitary landfill is estimated initially to increase linearly from about 15 percent of the collected refuse in 1970, to about 33 percent in 1987, after which it will begin leveling off as other methods develop. The maturing of other technologies such as energy recovery and other material recovery processes will bring about this leveling effect. Hence, by the year 2000, it is estimated that about 41 percent (or 89 million tons) of the collected municipal refuse will be placed in the sanitary landfill.

The components of solid waste that enter open-dump landfill sites will be in proportion to their respective generation rates, since no processing or resource recovery is expected to be conducted on this fraction. Thus, it is expected that the plastic component will follow its generation rate as shown in Table 1. The impact of plastic on this disposal method is discussed in the next section.

In sanitary landfill and thermal treatment operations, the amounts of various components entering the disposal method will differ from that generated by the amount of materials removed by resource-recovery operations from which the residuals will be relegated to sanitary landfill or thermal treatment for disposal. Assuming metals, glass, and long fibers to constitute the major recoverable materials from solid waste, the cost of processing for recovery purposes would probably be recoverable if 30 percent of the processed waste were obtained as useful marketable material. The remaining 70 percent of the processed waste would go to landfill or be thermally treated for energy recovery. As plastic materials are not considered to be recoverable from household and commercial waste through the year 2000, the amount of plastic in the residue from resource recovery will increase and thus contribute more of an impact upon these disposal methods.

Resource recovery was given a new impetus in 1970 by a law providing Federal assistance to overcome certain technical and product market limitations. It has been estimated that 70 percent of the collected waste is the maximum potential quantity that can be processed for recovery of specific materials and energy values ("roughly equivalent to the waste collected in the U. S. Standard Metropolitan Statistical Areas as defined by the U. S. Department of Commerce").[26] However, the actual recycling rate in the United States today is much lower. Darnay and Franklin provided five reasons for the low recycling rate[27]:

(1) The cost of virgin raw materials to the manufacturer is almost as low as the cost of secondary materials; and virgin materials are usually qualitatively superior to salvage. Consequently, demand for secondary materials is limited.

(2) Natural resources are abundant and manufacturing industries have deployed their operations and perfected their technologies to exploit them. No corresponding deployments and technology to exploit wastes have developed.

(3) Natural resources occur in concentrations while wastes occur in a dispersed manner. Consequently, acquisition of wastes for recycling often is costly.

(4) Virgin materials, even in unprocessed form, tend to be more homogeneous than waste materials. Sorting of wastes is costly and, in an age of affluence and convenience, repugnant to those who would have to engage in it – the urban householders.

(5) The advent of synthetic materials made from hydrocarbons, and their combination with natural materials, cause contamination of the latter, limiting their recovery. The synthetics themselves are virtually impossible to sort and recover economically.

Recent shortages of some natural resources have brought attention to the recovery of materials from mixed municipal refuse. This recovery requires that the products in the refuse be separated into basic materials classes – paper, ferrous metals, clear glass, dark glass, plastic, etc. The traditional technique of separation by hand is too expensive, hence various separation technologies are currently under development.

In 1970, a very small fraction of the collected municipal refuse was being recycled. This study estimates that by the year 2000, about

28 percent (or 42.5 million tons) of the collected municipal refuse will be recycled. This increase will result from: (1) a greater demand for the salvage materials by the industry as virgin materials become more costly, and (2) the development of improved separation technologies.

Thermal treatment of solid waste as a disposal method has considerable merit for purposes of volume reduction and for purposes of energy recovery, as over 70 percent of bulk household waste is combustible. After processing and removing recoverable material, over 90 percent is combustible! The exothermic reaction of combustion provides a heat source that may be converted to low- or high-pressure steam.

In 1965 about 300 municipal incinerators were in operation.[22] By 1971 the number of operating incinerators declined, as shown in Table 8, to approximately 195 because of obsolescence, emission-control regulations, and repair or construction costs.[28] A 1974 survey has shown that the number is now down to 140.[29] Furthermore, over 95 percent of the operating municipal incinerators have incorporated emission-control systems in the off-gas chambers or stacks. Unfortunately, corrosion is a major problem in these emission-control systems. Also, corrosion has been a major deterrent to the installation of heat-recovery systems in municipal incinerators.

TABLE 8. DISTRIBUTION OF REFUSE INCINERATORS BY TYPE AND NUMBER(12)

Type(a)	Number	Capacity, ton/day	Estimate of Volume Processed(b), ton/year
I	8	700	0.17×10^6
II	144	48,000	11.63×10^6
III	43	21,500	5.20×10^6
Total	195	70,200	17.00×10^6

(a) I = No emission control or heat recovery, II = emission control, III = heat recovery and emission control.

(b) Estimate made at 2/3 capacity to correct for downtime and less than 24 hour/day operations.

Incinerators, which do not incorporate emission controls or heat-recovery systems, are in general, constructed of refractory materials resistant to attack by refuse combustion products. However, this equipment may be damaged by overheating.

With improved application of the present technology, municipal incinerators can provide a significant means of disposing the municipal refuse. Economic considerations will force the smaller capacity plants to close. Baun and Parker[20] suggested that something on the order of 200 tons/day represents the minimum economic capacity. Smaller communities may unite in joint efforts to justify a plant of this or larger capacity. It is expected that, because plants of this capacity will have heat-recovery capabilities, incineration merely for volume reduction of solid waste will be less common. In the face of the energy crisis, waste-heat reclamation will become more attractive, especially for larger plants in central locations, operating 24 hours a day.

Projections made in this study stipulate that an increasing percentage of the collected municipal refuse will be thermally processed – from about 11.5 percent (or 14.5 million tons) in 1970 to about 28 percent (or 62 million tons) in the year 2000. As a comparison, Niessen[2] projected the percentage of total collected municipal refuse that is incinerated as follows:

1970 – 14 percent or 30 million tons

1975 – 20 percent or 45 million tons

1980 – 23 percent or 50 million tons.

Although our estimates are somewhat higher than previous projections, we believe that power generation will be a major contributor to the disposal of solid waste. A breakdown of the amounts thermally processed by incineration, heat-recovery combustion, power generation, and pyrolysis is presented at the bottom of Table 9, which presents our forecast of the annual distribution of the total solid waste generated in 5-year increments to 2000. Included in this table are the amounts and percents of plastic handled by the various disposal methods.

TABLE 9. FORECAST OF ANNUAL DISTRIBUTION OF SOLID WASTE GENERATED BY DISPOSAL METHOD TO THE YEAR 2000 IN AMOUNTS (10^6 TONS), PERCENTAGE OF TOTAL, AND PERCENTAGE OF PLASTIC IN DISPOSAL CATEGORY

	1970		1975		1980		1985		1990		1995		2000	
	Amt	%	Amt	%	Amt	%	Amt	%	Amt	%	Amt	%	Amt	%
Open Dump With/Without Burning	149	79.7	145	73.2	133	64.1	112	51.6	82	36.2	51	21.9	27	11.0
Plastics ( )[b]	3.4	(2.3)	4.1	(2.8)	5.1	(3.8)	6.3	(5.6)	6.4	(7.8)	5.3	(10.4)	3.6	(13.4)
Sanitary Landfill	18	9.6	28	14.1	40	19.3	53	24.3	69	30.4	81	34.5	89	36.4
Plastics ( )[b]	0.42	(2.31)	0.84	(2.99)	1.68	(4.2)	3.56	(6.7)	6.90	(10.0)	11.48	(14.2)	17.85	(20.0)
Thermally Treated[a]	14.8	8.0	18.5	9.5	23.8	11.5	33.4	15.2	43.3	19.0	53.6	22.8	62.5	25.6
Plastics ( )[b]	0.34	(2.32)	0.55	(2.99)	1.0	(4.2)	2.25	(6.7)	4.33	(10.0)	7.60	(14.2)	12.50	(20.0)
Resource Recovery	0.2	0.1	2.2	1.1	7.0	3.6	17.4	7.9	31.5	13.9	48.9	20.7	65.2	26.9
Plastics	0		0		0		0		0		0		0	
Litter	5.0	2.6	4.3	2.1	3.2	1.5	2.2	1.0	1.2	0.5	0.5	0.2	0.3	0.1
Total	187	100	198	100	207	100	218	100	227	100	235	100	244	100
Total Plastics	4.3	2.3	5.5	2.8	7.9	3.8	12.2	5.6	17.7	7.8	24.4	10.4	32.7	13.4
(a) Heat Recovery	2.0	1.0	6.0	3.0	8.0	3.9	11.0	5.0	15.0	6.6	20.0	8.5	24.0	9.9
Power Generation	Nil	--	Nil	--	2.0	1.0	8.0	3.6	18.0	7.9	24.0	10.2	32.0	13.1
Pyrolysis	Nil	--	Nil	--	1.0	0.5	2.0	0.9	3.0	1.3	5.0	2.1	6.0	2.4
Incineration	12.[illegible]	7.0	12.5	6.5	12.8	6.1	12.4	5.7	7.3	3.2	4.6	2.0	0.5	0.2

(b) Percentage numbers in ( ) represent the plastic component in the amount disposed of by respective disposal method.

SECTION V

ENVIRONMENTAL IMPACTS OF PLASTICS DISPOSAL

An overall impact of plastic-refuse disposal upon the environment can be obtained by analyzing the effects of major solid-waste-disposal methods upon the major environmental categories. This approach becomes applicable when the distribution of the plastic component within the solid waste among the various disposal methods can be estimated. Unfortunately, while some disposal methods (e.g., incineration) create direct and immediate impacts upon the environment by their specific emissions to the environment, other disposal methods, such as landfill, do not create such direct and/or immediate environmental impacts (except, of course, the physical impact of its weight and volume) because of the much lower rate of plastic degradation and pollutant emission to the environment. A gross and rather simplistic approach that can be used to analyze impacts of plastic disposal (for disposal processes where plastic wastes do not significantly decompose within the normal time frame of solid-waste decomposition) is to assume that the impacts are merely physical, being directly proportional to plastic volumetric and/or weight percentage in the refuse. Such an approach assumes that the presence of plastics may either augment or lessen the environmental impact of the solid-waste disposal. Therefore, the direction of the environmental impact due to plastic will depend on (1) the nature and magnitude of the environmental parameters due to slow releases from plastic degradation, if any, and (2) the relative importance on some numerical scale of specific impacts. The former must be clearly established before any attempt to estimate the latter is possible. Where neither is possible, environmental impact assessment will rely merely on qualitative statements.

Previous sections provide projections of plastic-waste components in the solid-waste generation, and estimates of the quantities that may be disposed of by the respective disposal methods: (1) throw-away or landfill, (2) thermally treated, and (3) resource recovery. The environmental stress of the plastics disposed by these methods is assessed by evaluating contributions to certain environmental impact categories: (1) water pollution, (2) air pollution, (3) land pollution, and (4) aesthetic and human factors. A discussion of the ecological impacts – the biotic and abiotic interactions within and between the impact categories – is necessary to complete the required impact-analysis scenario.

LAND DISPOSAL OF PLASTIC WASTES

The traditional plastics (polyethylene, polyvinyl chloride, and polystyrene) comprise about 90 percent of the plastic wastes found in the municipal solid wastes which are disposed of on and/or under the soil (open dump, litter, sanitary landfill). These materials do not decompose significantly within the normal time frame of solid-waste decomposition, and consequently do not immediately contribute pollutants into the environment except when they are burned. What is not known is the rate of the slow but prolonged emissions or release into the environment from such plastic wastes. On the other hand, if plastics that can degrade under various environmental conditions by various mechanisms – biodegradation, solubility, and photodegradation – would be present in the solid-waste stream in large amounts, then plastic-waste environmental impact will be significant.

Water-Pollution Effects

Environmental parameters used as indicators of ground- or surface-water quality comprise BOD, suspended solids and turbidity, total dissolved solids and COD, macronutrients, dissolved oxygen, and toxic substances. These indicators of water pollution are influenced to a different extent by land-disposal practices applied to solid waste. Under suitable environmental conditions of temperature, moisture and oxygen, organic and inorganic wastes are utilized by microorganisms through aerobic and anaerobic synthesis.

Water entering into the disposal site naturally by rainfall or from adjacent sources moving horizontally through the filled site may initiate surface runoff and leachate of varying chemical compositions.

Depending on the land topography, soil characteristics, and attenuation potential, the leachate may reach surfacewater or percolate through the soil profile to pollute groundwater. Based on the above background on water pollution from land disposal of solid wastes, the respective land-disposal methods are sequentially analyzed.

Litter, a nonpoint source of pollution, creates more surfacewater pollution than groundwater pollution. Its main water-pollution indicator is suspended solids or floating plastic materials in lakes, streams, and rivers. Most litter materials come from consumer packaging goods, and plastics contribute a major portion of this fraction. Consequently, the percentage of plastics in the litter is usually greater than that in other collected solid waste.

It is difficult to predict the quantity of the littering plastics floating in the nation's water bodies since this is influenced by many factors such as climate, wind, topography, and the effect of human activities and closeness to the water body. It is reasonable to assume that the percentage of plastics will be sizeable.

Emissions from litter plastics into the environment will tend to be greatly increased when photodegradable plastics (plastic sensitive to ultraviolet light) are used extensively. Photodegradation is time and temperature dependent and varies with the polymeric structure thickness, and the concentration and content of additives such as pigments, ultraviolet accelerators and promoters, ultraviolet absorbers, and antioxidants.[30] By their constant exposure to sunlight, the litter plastic will absorb ultraviolet energy having wave lengths below 320 microns from the sun. When enough energy is absorbed, the bonds between carbon and hydrogen are broken and oxygen-reactive free radicals are formed. Being constantly exposed to oxygen, these free radicals react with oxygen to produce peroxides and the hydroperoxides which decompose further to produce carbonyl groups, hydroxyl groups, water, and carbon dioxide.[30] The plastics thus broken up into short-chain, low-molecular-weight fragments may become part of the soil or be carried away by natural erosive forces such as rain and wind to surface waters as suspended or dissolved solids.

Open dump water-pollution problems arise more often from runoff than leachate. However, where the dump site is on a high watertable with a pervious soil profile, leachate can be equally as serious. Many open dumps are located in low-lying and swampy areas in attempts to reclaim such areas, but unfortunately, such practices cause water-pollution problems because no attempts are made to contain the water leaving the dump. Major water-pollution indicators which an open dump can contribute are suspended solids, BOD, COD, macronutrients, and toxic materials. There is a lack of data on the ranges of the indicators associated with open dumps. The amount of each will depend on many variable factors such as solid-waste composition at the site, the degree of decomposition, whether anerobic or aerobic, and site characteristics such as topography, soil condition, drainage, etc.

Specific impacts of the plastic fraction in solid waste on water pollution are equally uncertain. Again, because the dump is usually not covered and, thus, exposed to sunlight, photodegradation of the ultraviolet-sensitive plastics will take place. Since most modern plastics are typically inert and nonbiodegradable, they do not by themselves increase the BOD or other dissolved chemicals content of the leachates and runoff from the dump. However, since plastics are light weight and provide a loose packing in the dump, their presence will tend to increase the packed volume of the waste. This packing will improve the aeration and rate of decomposition of the degradable fractions of the solid waste. Furthermore, since leachates resulting from aerobic decomposition are lower in BOD content (about 5 times lower)[12] than their anaerobic counterparts, the presence of plastic appears to be advantageous with respect to BOD level. On the other hand, increased use of plastic bags to contain household and commercial wastes does concentrate the refuse. The bags increase the packing of refuse and encourage anaerobic conditions.

Sanitary landfill is regarded as the most accepted land-disposal method for solid waste because it provides an engineering approach to solid-waste disposal with minimum environmental impact. The greatest water pollution from landfill arises from leachate when it is not contained within the fill and is allowed either to percolate through the soil profile to the groundwater or to run off to the surface-water. Major water-pollution indicators of the leachate from landfill are BOD, COD, dissolved solids, and toxic substances such as phenols and some metal ions.

The leachate from a sanitary landfill is complex and the compositions vary widely. Factors which are considered to have influence on the production and characteristics of leachate include:

- Material in the fill consists of both organic and inorganic or degradable and nondegradable materials, resulting in the production of soluble and insoluble products in the leachate.
- Varying conditions in the fill – such as temperature, dissolved oxygen, pH, moisture – result in different types of decomposition, (aerobic and anaerobic) taking place at different stages of oxidation and permeability of the fill.
- Surrounding soil characteristics will influence the pH, organic matter, etc.
- The incoming solvent water will contribute some changes in the leachate characteristics such as attenuation and dilution, depending on the source and quantity of the influent.

Many studies on the characteristics and amounts of leachates from sanitary landfills have been conducted. Zanoni[31] reviewed the experimental data available and Thornton and Blanc[32] presented "average" values for the characteristics of leachates from sanitary landfills. Zanoni[31] and Stone et al,[33] pointed out qualitative differences between leachates obtained from refuse decomposition under both aerobic and anaerobic conditions. Again it can be stated that leachates resulting from aerobic decomposition are lower in BOD content (about 5 times lower) than those formed anaerobically. Also both organic and inorganic species present in the former are in a higher state of oxidation than in the latter.

The characteristics of the leachate resulting from landfills are given in Table 10.

The presence of plastics in sanitary landfills may be considered to have no immediate impact on the ground- and surfacewater quality, because it does not decompose within the same time frame as do other degradable materials in the fill.

TABLE 10. CHARACTERISTICS OF LEACHATE FROM SANITARY LANDFILLS[12]

Constituent	Minimum Value	Average Value	Maximum Value
pH	5.60	6.55	7.63
$CaCO_3$	650	3,633	8,120
Alkalinity ($CaCO_3$)	730	4,629	9,520
Calcium	115	1,047	2,570
Magnesium	64	181	410
Sodium	85	940	1,805
Potassium	28	959	1,860
Total iron	6	110	305
Ferrous iron	2	24	93
Chloride	96	1,814	2,350
Sulfate	39	248	730
Inorganic phosphate	0.2	7	29
Organic nitrogen	2	163	550
Ammonia nitrogen	0.2	437	845
BOD	81	10,850	33,100

Note: All data with the exception of pH values are in milligrams per liter.

Plastics ultimately decompose; the span of most plastic decomposition is between 10 and 30 years. Plastic degradation in the landfill may take even longer depending on the prevailing mode of degradation, biodegradation, solubility, or photodegradation. Photodegradation should not be significant in covered landfills unless the plastics have absorbed enough ultraviolet energy prior to being covered. The most likely prevailing modes will be biodegradation and solubilization. Most of the products released will form part of the soil. Any part entering the leachate will result in higher COD, dissolved solids, and suspended solids rather than higher BOD. An area of uncertainty, where more data are needed, is the rate of release of decomposition products of plastics to the environment particularly for such plastic types as PVC.

A simplistic approach to analyzing the impact of land disposal of plastics on water pollution was based on the volume effects of the plastic.[12] Since plastics comprise about 5 percent by volume of the waste, it was assumed that the landfill surface area will be increased about the same ratio. Thus more putrescible components of the solid waste would be exposed to more moisture and dissolved oxygen and the rate of decomposition would be increased accordingly. With BOD as a measure of water pollution, the annual BOD produced by landfill was calculated on the basis of 1.85×10^3 tons BOD leachate per ton of landfilled refuse.[31] Five percent of this quantity was assumed to be attributable to the presence of 5 volume percent plastic component of the solid waste. This deduction is misleading because the presence of plastic may tend to lower the BOD of the leachate by promoting aerobic conditions instead of increasing it. As properly assumed, the presence of plastic will increase the area and volume of the landfill site, but it may also provide a loosely packed landfill with trapped air pockets. Such an occurrence will provide an aerobic rather than an anaerobic condition, which will tend to decrease the BOD content of the leachate. If plastics were not present in the solid waste, other materials such as paper could have taken their place thus providing more degradable materials and thus more BOD.

The main effect of plastic disposed in landfills on water pollution will be in the increase of COD, dissolved solids, and perhaps suspended solids of the leachate. However, the lack of a carefully controlled experimental study in this area makes firm conclusions difficult to reach, and research is needed on this aspect of solid-waste disposal.

Air-Pollution Effects

Air pollution from land disposal of municipal refuse results from (1) gas generation from the biodegradation of putrescible components of the refuse, and (2) accidental or deliberate burning of the refuse at the dumps. The various land-disposal methods are assessed on the above air-pollution-emission processes.

Litter contribution to air pollution is considered negligible. Litter is not concentrated in one spot to support fire or encourage decomposition to the extent that air pollution will result. Plastic litter can decompose, but the rate would be very low and the emission quantities insignificant.

Open dumps create air pollution by two processes: (1) anaerobic decomposition of the refuse and (2) accidental or deliberate burning of the refuse.

Since the dump is not covered with soil, gases at different stages of decomposition are emitted with minimum restriction. These gases may consist of decomposition end-products of the degradable nitrogenous, carbonaceous, and sulfurous organic materials, such as ammonia, CH_4, CO_2, moisture, and H_2S or their intermediate products such as organic acids, alcohol, mercaptans, etc. It is important to note that air pollution will not result from an aerobic decomposition process which produces CO_2 as an end-product. The condition existing in the dump is rarely aerobic, however, but usually anaerobic with the production of gases such as H_2S, mercaptans, or alcohols, that are highly odorous even in small concentrations. This is one major reason why the open dump is an environmentally unacceptable disposal method. Methane also may be produced. This gas is explosive in concentrations from 5 to 15 percent by volume and could be a fire hazard when it accumulates in small pockets. The presence of plastic in the dump will improve aeration and thus encourage aerobic decomposition processes, and so, may reduce the production of odorous gases that will cause air pollution.

Open burning of the solid waste on the other hand will contribute to air pollution. Plastics being a high-heat-value material will sustain combustion and contribute to air pollution. Deliberate open burning reduces the volume of solid waste but emits pollutants, such as, particulates, CO, hydrocarbons, HCl, and NO_x, that generally cause adverse public reaction. Many states have banned uncontrolled open burning, and it is expected that by the year 2000, open burning will be an insignificant practice of waste disposal.

Table 11 gives estimated yearly emissions of pollutants from the open burning of plastics, based on the emission factors for open burning of municipal refuse.

The table shows that reasonable reduction in emissions from burning plastic waste may not take place until after 1980.

Sanitary landfilling of municipal refuse may create air pollution when degradable portions of the refuse decompose anaerobically, and the

TABLE 11. AIR-CONTAMINANT EMISSIONS BY PLASTICS DURING OPEN BURNING OF REFUSE

Pollutant	Emission Factor, lb/ton[a]	Annual Pollutant Emissions, thousands of tons						
		1970	1975	1980	1985	1990	1995	2000
Percent Burned		60	50	40	30	30	10	1
Particulates	19.8[b]	20.2	20.3	20.2	18.7	12.7	5.2	0.4
CO	105[c]	107.1	107.6	107.1	99.2	67.2	27.8	1.9
Hydrocarbons as (CH_4)	37[c]	37.7	37.9	37.7	35.0	23.7	9.8	0.7
NO_x	7.4[d]	7.8	7.8	7.8	7.2	4.9	2.0	0.1
HCl	95[e]	96.9	97.4	96.9	89.8	60.8	25.2	1.7

(a) Assuming 81 percent combustible of municipal refuse.[34]
(b) Percent of the open-dump refuse burned. It is assumed that the same percentage is applicable to plastics fraction.
(c) For CO and hydrocarbons the combustible materials in municipal refuse are sufficiently similar in chemical composition to plastics that using the same emission factors is probably warranted.
(d) While some plastics (like urea-melamine) contain nitrogen, the contribution to the total NO_x emission will probably be negligible since in open burning a reducing atmosphere probably is prevalent.
(e) The HCl emission factor from open burning was computed by assuming that all chlorine in PVC is converted to HCl.

gaseous products are emitted to the atmosphere. Sanitary landfill is usually covered with earth, and under the reduced presence of oxygen, the prevailing anaerobic decomposition of the putrescible materials takes place in three phases: liquification, acidification, and gasification. The complex organic compounds (carbohydrates, proteins, and fats) are first liquified by enzyme action and then broken down into organic acids by the action of heterotrophic organisms present in the soil. The final phase is a gasification process during which the organic acids are further broken down into CO_2 and CH_4 gases by methane bacteria.

The presence of plastics in the landfill will have no direct impact on the quantity of gaseous production because plastics by themselves do not decompose. However, the presence of plastics makes the landfill difficult to compact efficiently with ordinary equipment (tractors, draglines, or steel-wheeled compactors).[12] Therefore, the fill tends to contain air pockets, thus encouraging aerobic conditions which generally promote a higher rate of oxidation than do anaerobic conditions. Methane will be produced at much lower rates, and the gases emitted may be diluted with air.

Since plastics are not decomposed within the normal time frame of the solid-waste decomposition, the presence of plastic will tend to delay the reuse of the landfill site. Under the projections shown in Table 9, a significant effect on the ultimate use of the landfill site may not be evident until 1990 when the amount of plastic becomes 10 percent or more.

Land-Pollution Effects

Land pollution results when some activity renders the land unusable. This rarely occurs with most municipal-refuse disposal. Because municipal refuse rarely contains hazardous wastes, most sanitary landfills or open dumps, when completed and allowed to stabilize, may be converted to a playground, parking lot, or agricultural land.

A better approach however, is to classify landfill sites according to the kinds of waste materials to be landfilled at a particular site that will give minimum adverse environmental impact. A typical classification is shown in Table 12. In the years ahead, separation of

TABLE 12. CLASSIFICATION OF WASTE ACCEPTABLE FOR DISPOSAL AT DISPOSAL SITES

Class 1 Disposal Sites - No limitation of type of material, liquid, or solid.

Group 1 Waste

Saline brines	Liquid or soluble toxic chemicals

Class 2 Disposal Sites - Decomposable organic wastes or solid-waste mixtures containing decomposable organic material, and some materials unacceptable at Class 3 sites.

Group 2 Waste

Garbage	Rubbish
Street refuse	Dead animals
Decomposable demolition materials	Sewage-treatment residue
Agricultural prunings and culls	Manures
Industrial rubbish	Cannery sludges
Miscellaneous metals	Paint sludge

Class 3 Disposal Sites - Water-insoluble, nondecomposable, inert solids.

Group 3 Waste

Earth, rock, sand, and gravel	Asphalt-paving fragments
Concrete	Brick and masonry materials
Plaster and plaster products	Inert demolition materials
Steel-mill slag	Glass
Inert plastics	Asbestos materials

wastes into specific site classes will become more widely adopted if the waste material can be separated at the source. It is important to note that plastics are grouped in Class 3 – the water-insoluble, nondecomposable, inert-solids group. The major impact of land disposal of plastic is that larger land area may be required for refuse disposal than would otherwise be required because of its density and compaction effects. Another impact, is the delay in the reuse of the filled site, because of the long time it takes to stabilize.

Litter is a nonpoint source of pollution, and its influence on the land can hardly be termed land pollution, but rather unsightliness.

Open dump refuse usually is not compacted, so the quantity of refuse per unit volume is not as much as that in the landfill, thus requiring greater land area. Densities of refuse in open dumps varies between 420 and 320 lb per cu yd, and height varies widely too. Assuming a height of 20 ft and dump density of 320 lb per cu yd, Table 13 was developed giving the land requirement for the open-dump refuse without plastic through year 2000. The additional land requirement for plastics disposal is also calculated. The land requirement for plastic disposal is a very small portion of the overall land use for open dumping.

A major factor that seems to make open-dump sites unsuitable is lack of structural stability. Open dumps are known to settle as much as 10 ft per year (during the first year) and as little as 2 ft depending on the total depth of the deposit, the amount of precipitation, and the nature of the decomposing refuse. Because it is not compacted, it is prone to produce uneven settling with varyihg bearing strength. The fraction of the plastic is too small to significantly affect the bearing strength of the open dump.

Sanitary landfill is usually compacted, making it possible to include large quantitites of refuse per unit volume. The annual acreage up to the year 2000 is calculated in Table 13 based on density of 900 lb per cu yd and an average height of 30 ft. Because of the increasing quantity of plastic in the landfill there is an increasing land requirement due to plastic. This situation will provide a poor settling characteristic with poor bearing strength of the soil. It will also delay the reuse of the landfilled site.

TABLE 13. OPEN-DUMP AND SANITARY-LANDFILL LAND REQUIREMENT IN ACRES

	1970	1975	1980	1985	1990	1995	2000
Percent Open Dump (without burning)	40	50	60	70	80	90	99
Open Dump (without plastic)	11,298	13,667	14,888	14,354	11,423	11,471	4,494
Plastic Requirement[b]	52	78	116	167	194	181	135
Sanitary Landfill (without plastic)[c]	807	1,247	1,759	2,270	2,851	3,238	3,266
Plastic Requirement	16	32	64	135	261	435	676

(a) Assumed dump density 320 lb per cu yd at 20-ft height.
(b) Assumed plastic density 33 cu. ft/ton.[36]
(c) Assumed sanitary landfill density 900 lb per cu yd at 30 ft.

Ecological Effects

Ecological impacts are those processes which disrupt or change the basic relationships between living organisms and their environment. There is a need to determine whether land disposal of plastics disrupts or changes the basic relationships which exist at the disposal site, or its environs, between living organisms and their environment. Such disruption or changes may result from the leachate and/or gases emitted from the plastic disposed at the sites.

Leachate from sanitary landfills and open dumps reaching stretches of natural surfacewaters (streams, rivers, and lakes) may be sufficiently high in BOD and other pollutants but low in others (such as dissolved oxygen) as to cause fish kills and the destruction of other aquatic life therein. Leachate from sanitary landfills may be contained by proper drainage or collected and treated. Open dumps, however, have been major sources of water pollution, since leachates are usually uncontrolled. There is no direct impact of plastic waste on leachate characteristics as discussed earlier as long as there is no direct emissions by the plastics. Until data are available on the decomposition emissions from plastic waste, no conclusive statement can be made on the ecological impact.

Because sanitary landfills are covered with soil when completed, the site can be used to support plant growth such as grasses and shrubs, even before full stabilization of the site. The site subsequently can be used as a playground or for light-structure buildings. It is not possible to put open dumps into such use because high heat and low dissolved oxygen existing during decomposition do not allow the growth of all plant life. The open dump site must be reclaimed before the site can be put to any use comparable to that of a sanitary landfill.

Decomposition-gas movement in sanitary landfills has been known to cause the destruction of plant life in the immediate vicinity, probably as a result of the exclusion of dissolved oxygen from the root zone by methane and carbon dioxide. Again, there is no direct plastic-waste influence other than its volume and/or weight effects.

Landfill and open-dump encroachment upon the land environment tends to displace the terrestrial fauna and biota previously inhabiting the sites. It is logical to assume that species that are incapable of adapting to the environment existing at the fills will perhaps disappear from that area. At present there is no substantiation of such effects that plastic waste and its decomposition products may have on fauna and biota. The greatest impact however is that of the open dump, which provides habitats for rodents, insects, flies, and other disease vectors. Such an environment may be a threat to wildlife in the vicinity and even to human health. Some plastics, depending on the pigmentation, are fly and insect attractants, and so may promote such infestation.

Aesthetics and Human-Factors Effects

Various methods of refuse disposal have varying degrees of effects on our well-being. Such important effects are the aesthetic, health, and economic impacts. Best disposal methods, as are evident from the preceding sections, are those that are technically efficient, economically sound, and environmentally safe. Specific impacts of the plastic component of the solid waste are presently unclear, and so far as is known, they are insignificant. Some schools of thought feel that plastics are advantageous.[37] The various land disposal methods are sequentially discussed according to their aesthetic, health, and economic impacts. Where possible, plastic impacts are qualitatively discussed.

Litter is ugly, unsightly, and it defaces or mars the appearance of the landscape. The aesthetic impact of plastic waste is significant because (1) it is a significant fraction of the packaging industry which produces nearly all the refuse litter, (2) it is of low bulk density, thus can be blown about in the air, onto natural surfacewaters, or to other less accessible areas of the countryside, where it is not possible or desirable to send in crews of people to pick up the litter, and (3) it has a long life in the environment. Certainly, if it were possible to assess aesthetic impacts quantitatively, that of litter should be found to be more than its volume fraction of the solid-waste. If photodegradable plastics become a sizable fraction of litter plastics in the years ahead, the aesthetic impact will tend to decrease because the life span in the environment will decrease.

Litter is unhealthy. If litter accumulates sufficiently at a spot, it will provide a breeding place for rats, insects, and disease. Accumulated litter is hazardous from the viewpoint of being flammable. It is difficult to put a quantitative figure on this impact since it will depend on factors of human activity and the environment. There is a need to study the potential health effects of the degraded plastics, and this need will become greater with the availability of degradable plastics. As was indicated earlier, the concern will be greatest with the litter because it is usually deposited closer to populated areas than are wastes disposed of by another method. Because of exposure to the atmosphere and to photodegradation, its emission rate per unit weight to the environment may be greater too. No data are available on the air emissions from plastics degradation. For decomposed plastic which remains on the soil (plastic sand), studies on polyethylene and polystyrene have shown that there is no long-term damage to the soil from the accumulation of photodegraded plastic particles.[37]

Litter is costly. One source estimates that about a billion dollars a year is spent to retrieve the newspapers, wrappers, cans, bottles, plastics, etc., tossed carelessly aside. It is further estimated that (1) half of this tax money is spent to clean up parks and recreational areas, (2) $28 million is spent recovering trash from primary highways, and (3) business, industry, and labor together are known to be spending more than $25 million a year to combat litter, both in private effort and in support of organizations like KAB (Keep America Beautiful).[38] A litter-free state attracts industry. West Virginia claims to have attracted 46 new industries that created 5,000 jobs by its clean-up program. A litter-free state also attracts more tourists. In Kentucky, the year after its first antilitter campaign, figures showed that tourists spent an extra $7 million in the state. In general, it will be assumed that the economic impact of plastic will be in direct proportion to its volumetric fraction of the refuse litter. Two approaches have been suggested as means to combat littering – litter laws with strong teeth for enforcement and education against littering. Only 28 states have litter laws; in the years ahead, other states probably will be under increasing pressure to enact such laws. Education through public communication and persuasion to inform citizens that they are individually responsible for the attractiveness of their surroundings will be conducted by government and private agencies.

Open dumps are aesthetically objectionable by their unpleasant appearance and the odors they produce. Urban development near open-dump areas tends to be restricted due to the reduced scenic beauty and psychological, and perhaps physiological, stressful conditions created by the open dump site. People just don't want to live near such surroundings. The contribution of plastics to this impact is assumed to be in direct relationship to their volumetric presence in the refuse. Unless the site is well stabilized, light structures for such activities as playgrounds and parking lots will be the only activities allowed on such sites because of low bearing strength of the soil on the site. The presence of plastic will tend to delay the site stabilization and, thus, the reuse of the site.

Open dumps threaten human health. Their relationship to disease potentials in humans has been reviewed by Hanks.[39] They provide a food source and harborage for rodents, insects, and disease vectors. Hanks observed that open-dump encroachment upon land which hitherto had been a wilderness poses the threat of increased interaction between the wild and "domestic" rodents, thus creating a possibility of spreading disease. It is hard to put quantitative value on the plastics impact which may be in direct proportion to its volume percent in the open dump. As observed previously, the presence of plastics will cause an increase in the acreage for open dumps, and harborage time of rodents may be longer because of the delay in stabilization. Besides odor produced during the biodegradation of the materials in the dump, particulates, odor, intense smoke, and other air contaminants are also produced from the open burning of the refuse. These installations not only produce adverse aesthetic reactions in man, but some of the pollutants emitted are dangerous to health.

The economic impact of open dumping of plastic and other refuse involves collection, transportation, and land cost. No cost is incurred on site management. Plastic economic impact associated with open dumping is assumed to be in direct proportion to its percent in the refuse as shown in Table 9.

Sanitary landfill, when properly designed and operated, is considered the most technically efficient and environmentally safe method of land disposal of refuse. However, when improperly designed and mismanaged it creates aesthetic problems and danger to human and animal life.

The aesthetic impact is associated with odor generation while the possible danger to animal life is caused by leachate. Odor production in landfill is usually not a serious problem since most landfills are covered with soil. However, leachate can create very serious problems if land-selection, drainage-design, and filled-site management are inadequate. Under this condition, leachate may percolate through the soil to contaminate groundwater with metal ions, pathogens, nutrients, etc., making it unsuitable for drinking and recreational purposes. Run-off to the surfacewater may also pose the same danger to water supply. Landfill gases, if not properly vented, can cause asphyxiation and serious explosions when they accumulate in sufficient concentrations near residential areas.

The main human factor of landfill is the economic impact. Land acquisition constitutes the major investment item, amounting to more than half the total capital requirement. The next important cost factor is the cost of transporting wastes from the sources of generation to the landfill site. The importance of the latter has been increased by the present energy crisis.

For landfill within 100 miles of the center of generation, cost of disposal may vary from around $2 to $3 per ton per year, while the capital cost for a 2,000 TPD landfill capacity may be as much as $5,000,000.[40] The differences in land costs from region to region can easily cause the capital costs to vary by a factor of 2 or more. The economic impact of the plastic fraction will be proportional to its volume fraction in the landfills.

Impact of Resource Recovery

The environmental impacts of resource recovery of plastic wastes create no major pollution problems for air, water, or land, but rather it effects some definite economic impacts. Efficient recycling of plastics that are currently disposed on the land will perhaps result in a cost saving in the manufacture of new end-products. However, major problems in salvaging plastics for reuse and recycling include the heterogeneity of the wastes and the diversity of types of plastics in the municipal refuse, lack of cleanliness, and the fact that they are usually present in forms not directly usable without reprocessing. Therefore, this study assumed that plastic recovery will occur only at the manufacturing end where different types and forms of plastics can easily be separated for recycle, and not at the postconsumer end of the spectrum, where such separation is presently technically inefficient, and economically unsound.

Various studies are under way to develop methods or processing and separating the various components of the refuse into reclaimable materials. Because of low specific gravity, plastics may present problems in pulverization, and may be entangled in the refuse-processing machinery. This aspect of plastic may be an adverse impact on its recovery.

Because current plastic waste does not decompose readily, its impact on composting is economically adverse since it has to be sorted out. When photodegradable and biodegradable plastics appear in the municipal refuse stream, the requirement for sorting out the plastics may no longer be necessary, thus providing some cost-saving.

AIR-POLLUTION IMPACT OF THERMAL TREATMENT

The disposal of solid waste by thermal treatment includes ordinary incineration, burning to generate electrical energy, process steam, or to provide central heating, and pyrolysis. With the possible exception of pyrolysis, these thermal processes will result in emissions to the atmosphere that come under regulation as air pollutants. The contribution of plastics to these emissions can be calculated on the basis of the plastic composition and its percentage in the solid waste. Some pyrolysis treatment of solid waste is designed to convert the refuse into useful chemical products that can be returned to the stream of industrial feedstocks, and this pyrolyzed portion would not be expected to become a source of air-pollutant emissions.

To determine the extent to which the plastics contribute to emissions, one must know the emission factors for the various pollutants. Studies made by the U. S. Environmental Protection Agency have resulted in the following incinerator-emission factors for air pollutants which are under control regulations at the present time.[18, 41]

Pollutant	Incinerator-Emission Factor, lb/ton
Carbon monoxide	35.0
Particulates	14.9
Nitrogen oxides (as NO_2)	3.9
Sulfur oxides (as SO_2)	2.5
Hydrocarbons (as CH_4)	1.5

Although these emission factors have been derived from measurements made on incineration processes that do not include heat recovery and power generation, the addition of a boiler to the unit, as projected for future years, will not have significant effect on the emission factors. Consequently, the calculations made for this report have been based on the same factor for all forms of controlled burning of plastics.

The initial data from the experience with combined firing of pulverized coal and solid waste at the Meramec Station of the Union Electric Company in St. Louis indicates that the amounts of gaseous components of the emissions were not affected by the waste.[42] Particulate emissions were increased, but this effect is considered to be the result of poor precipitator performance and firing difficulties, rather than any inherent contribution of the solid waste. In this report the incinerator emission factor has been used for solid waste that would be consumed in combined firing in future years.

Because it has not come under regulation as yet, HCl is not included in the list of official emission factors. However, Achinger and Baker[18] arrived at an emission factor of 6 pounds per ton from their data compilation. Recent data on HCl obtained by the Battelle's Columbus Laboratories at the Harrisburg, Pennsylvania, incinerator result in an emission factor of 5.1 pounds per ton.[43] Hence, an HCl emission factor of 5 to 6 pounds per ton of solid waste appears to be reasonable. As the amount of chlorine-containing plastic that is burned increases, this factor will become larger.

Carbon Monoxide Emissions From Plastics

Inasmuch as all plastics contain considerable carbon, they are potential contributors to the carbon monoxide emissions from incinerators.

If the CO emission factor of 35 pounds per ton of waste is used for the plastic components, on the assumption that its contribution is proportional to the amount of plastic in the waste, the values shown in Table 14 are obtained. In this table the emission factors have been applied to the plastic component of solid waste as projected to the year 2000.

TABLE 14. EMISSIONS FROM CONTROLLED COMBUSTION OF PLASTICS IN SOLID WASTE

	1970	1975	1980	1985	1990	1995	2000
Waste Burned, 10^6 tons	14.8	18.5	22.8	31.4	40.3	48.6	56.5
Plastic Content, percent	2.32	2.99	4.2	6.7	10.0	14.2	20.0
Plastic Burned, 10^6 tons	0.34	0.55	0.96	2.1	4.0	6.9	11.3
CO Emissions, 10^6 lb	11.9	19.2	33.6	73.5	140	241	396
Particulates, 10^6 lb	5.1	8.2	14.3	31.3	59.6	103	168
Hydrocarbons, 10^6 lb	0.51	0.83	1.44	3.15	6.0	10.4	17.0

Current CO emission in the United States from all sources is estimated to be about 150 million tons per year. The CO emissions from burning of plastics, as projected for 1975 will be about 10,000 tons. Hence, today's contribution from plastics is negligible. In future years, the CO emissions from this source are expected to increase to about 200,000 tons by the year 2000. The CO emissions from automobiles in the U. S., which is the largest source at present, will decrease in future years as stricter regulations are applied. Hence the impact of plastics on the total CO emissions will become greater as the time passes. However, it is expected that the total CO from other sources will still be measured in millions of tons when the plastics contribution reaches the 200,000-ton level.

Particulate Emissions From Plastics

The emission factor for particulates from incineration processes is 14.9 pounds per ton of waste. There is some question as to whether this number is strictly applicable to the plastic components, as they appear to burn well, with a high-Btu flame. Boettner[44] presented data on laboratory-scale incineration of plastics that showed no residual ash from combustion of polyethylene, polystyrene, or major types of polyvinyl chloride. This implies that the small metallic content, from catalysts and additives, is completely volatilized and will appear as oxides in the flue-gas stream. There could be some unburned carbon particulate if the combustion of the plastic occurred in a zone where insufficient air was present at the time. Although it may be high, the emission factor of 14.9 pounds per ton was used for Table 14. On this basis the 1975 value of 8.2 million pounds is trivial compared to the 26.2 million tons that are generated in the United States at the present time. The projected level for the year 2000 reaches only 84,000 tons, which will still be only a small fraction of the U. S. total, even with stricter control on other sources.

Hydrocarbon Emissions From Plastics

Since the chemical structure of plastics is based on carbon-hydrogen compounds, there is a possibility that some hydrocarbons from the decomposition of the plastic will survive the combustion process. Hence it may be assumed that hydrocarbons will be produced in proportion to the amount of plastics in the refuse. Using that basis, the hydrocarbon factor of 1.5 pounds per ton of waste was applied to obtain the values shown in Table 14. The 1975 emissions of 830,000 pounds will be insignificant compared to the 35 million tons of hydrocarbons emitted from other sources, chiefly automobiles. Even by the year 2000, when the projected emissions from burning of plastics will be 8500 tons, and auto emissions are greatly reduced, the plastics contribution will still constitute a small part.

HCl Emissions From Plastics

The unique contribution of plastics to air pollution from combustion of solid waste results from the HCl produced by the combustion of polyvinyl chloride (PVC). It has been shown by Boettner et al,[44] that all of the chlorine is released from PVC on combustion and appears as HCl. Other sources of HCl are present in the solid waste, as there is chloride in the plant and food waste, in addition to that which occurs as inorganic salts. The formation of HCl from organic sources would take place readily during incineration. To form it from the inorganic compounds requires volatilization and reaction with incinerator flue gases such as SO_2 and CO_2. That these reactions occur is evidenced by the chemical changes observed in the incinerator deposits, where chlorides are converted to sulfates as exposure time increases.[45]

The projections for HCl emissions as the result of the controlled combustion of PVC are shown in Table 15. In 1975 about 26,000 tons of HCl will be generated in this fashion. This amount is small when compared to that of the major pollutants presently under regulation. However, the amount of HCl will increase in future years as the percentage of PVC in the waste increases.

TABLE 15. PROJECTED HCl EMISSIONS FROM CONTROLLED COMBUSTION OF POLYVINYL CHLORIDE (PVC)

	1975	1980	1990	2000
PVC in Waste, 10^6 tons	0.5	0.7	1.6	2.8
PVC Burned, 10^6 lb	90	154	563	1300
HCl Produced, 10^6 lb	52.5	90	329	760

During the period 1975 to 2000, the amount of HCl generated will be greater than that of the other pollutants, namely CO, particulates, or hydrocarbons. However, it has been claimed that more HCl is emitted to the atmosphere from coal-burning power plants than from municipal incinerators.[46] Fortunately HCl can be removed from flue gases very efficiently by water scrubbers, and the emissions could be controlled readily in this fashion.

An air-pollution problem could develop in the immediate vicinity of an incinerator as a result of HCl emission. This might occur if insufficient dispersal of the stack gases were to cause the ambient concentration of HCl to exceed the 5-ppm level designated as the allowable limit for health.[47]

Nitrogen Oxide Emissions From Plastics

Only a relatively small amount of the U. S. plastic production comprises nitrogen-containing plastics, which would be the source of nitrogen oxide emissions. These plastics would be the polyurethanes, urea-melamines, nylons, and acrylate materials. It was estimated that in 1973 these plastics constituted only 0.1 percent of the total solid waste.[12] No breakdown in these plastic categories was available for projection to future years, but it is reasonable to assume that they will still represent a very minor contribution in future years as well. The 1973 estimate showed that if all the nitrogen in the polyurethane waste incinerated was converted to nitrogen oxides, the total would only have been 1200 tons. This can be compared to the total incinerator emissions of 16,780 tons of nitrogen oxides or the total from all sources of 22,800,000 tons.[18]

Other Emissions From Plastics

Only small amounts of plastics contain sulfur (such as polysulfones) and the contribution to sulfur oxide emissions from such materials would be negligible.

Several other air pollutants could be formed by combustion of special plastics, or as a result of some additive in the plastic. Thus, HBr might result from bromine compounds added as flame retardants. Acrylonitrile materials may form some HCN. However, the amounts of these materials would necessarily be small, and could be a problem only if a large quantity of one such plastic were being burned at one time, and stack emissions were swept down to ground level rapidly enough to create a toxic concentration in the vicinity of the source.

SECTION VI

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-670/2-75-058		

4. TITLE AND SUBTITLE ENVIRONMENTAL ASSESSMENT OF FUTURE DISPOSAL METHODS FOR PLASTICS IN MUNICIPAL SOLID WASTE	5. REPORT DATE June 1975 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) D. A. Vaughan, C. Ifeadi, R. A. Markle, and H. H. Krause	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	10. PROGRAM ELEMENT NO. 1DB314 (ROAP 21BFS, Task 017) 11. ~~CONTRACT~~/GRANT NO. R803111-01-1
12. SPONSORING AGENCY NAME AND ADDRESS National Environmental Research Center Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Production of plastics for engineering and consumer items in the United States has been predicted to reach 113 million tons per year by the year 2000. This figure does not include the production of polymer used for synthetic fiber or fabric. From 31 to 38 million tons of the plastic produced is expected to reach the solid waste stream, depending on the basis of estimation. The largest amount will go to sanitary landfills, and the next largest amount will be thermally treated using such methods as power generation, incineration, and pyrolysis. Small amounts of plastic are expected to be disposed of in open dumps or as litter. Resource recovery for plastics in municipal refuse up to the year 2000 is expected to be insignificant. Air pollution as a result of plastics in the landfills and open dumps will be negligible, even if there is still some burning of open dumps in 2000.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Plastics *Impact Waste disposal	*Plastic waste Solid waste Future trends *Environmental effects Sanitary landfills	11I 13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	86
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975-657-594/5402 Region No. 5-11