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Plastics Recycling in the Industrial Sector: An Assessment of the Opportunities and Constraints

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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PLASTICS RECYCLING IN THE INDUSTRIAL SECTOR: AN ASSESSMENT OF THE OPPORTUNITIES AND CONSTRAINTS

ABSTRACT

T. Randall Curlee
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Sujit Das

This report addresses numerous issues related to plastics recycling in the industrial sector: manufacturing and post-consumer plastic waste projections, the estimated energy content of plastic wastes, the costs of available recycling processes, institutional changes that promote additional recycling, legislative and regulatory trends, the potential quantities of plastics that could be diverted from the municipal waste stream and recycled in the industrial sector, and the perspectives of current firms in the plastics recycling business.

Post-consumer wastes are projected to increase from 35.8 billion pounds in 1990 to 48.7 billion pounds in 2000. Plastic packaging is expected to account for about 46% of all post-consumer plastics during the coming decade and remain the by-far largest single contributor to the waste stream. The product category with the largest projected percentage increase is the building and construction sector, which is projected to increase from 2.0% of the total in 1990 to 8.0% in 2000. Manufacturing nuisance plastics are projected to account for about 4% of total plastic wastes.

The total energy inputs required to manufacture the resins that are projected to appear in the solid waste stream in 1990 are estimated to exceed 1,378 X 10^{12} BTUs. If all manufacturing nuisance plastics and post-consumer plastics are incinerated, the product heat of combustion from those plastics is projected to be about 644 X 10^{12} BTUs in 1990. The estimate for total energy inputs is equivalent to about 1.8% of what total U.S. energy consumption was in 1985. The estimate for product heat of combustion is equivalent to about 0.8% of the 1985 estimate for total energy consumption.

Recent estimates of the costs of recycling plastic wastes suggest that data are not sufficiently detailed or validated to draw definitive conclusions. Given the caveats, two recently introduced secondary processes appear to be economically viable if the appropriate materials are available. Although the costs of secondary technologies appear favorable, no good information is available to suggest the potential size of the market for the lumber-like materials being produced. Neither is there information about how the prices of lumber substitutes may decrease as the production of those products increases.

Significant changes have occurred recently in terms of the institutional structures and regulations that impact on plastics recycling. In the majority of cases, these changes promote additional recycling. For example, mandatory moves to curbside collection of plastics and subsidies for the development and use of new recycling technologies have made plastics recycling more economically attractive. In some cases, however, the institutional and regulatory trends have

questionable implications for plastics recycling and are reflective of the continuing uncertainty about plastics in general.

This report presents several scenarios in which specific technical, economic, institutional, and regulatory conditions are assumed. Given the most probable scenario, the quantity of plastics available for recycling will grow tremendously. If curbside collection of segregated household plastics becomes the norm and if economically viable technologies are available to recycle commingled plastics containing 50% contaminants, most manufacturing nuisance plastics will become recyclable. In addition, about 50% of the post-consumer plastic waste stream -- i.e., about 24 million pounds in 2000 -- will be a candidate for recycling.

This assessment concludes that there are significant opportunities for the industrial sector to recycle plastic wastes during the coming decade. Most technical, economic, institutional, and regulatory trends point toward more possibilities and greater incentives for additional recycling activities. There are, however, potential barriers. Technologies that can accommodate dirty commingled plastics require further development, especially tertiary technologies that could produce high-valued pre-polymers. Separation technologies also require further development if some of the larger waste streams are to be recycled in a secondary or tertiary sense. Market constraints may limit significantly the potential for secondary products, especially those products that compete with wood or concrete. Finally, regulatory programs, which will impact on the collection of plastics and the economic viability of recycling operations, are currently being developed at the federal, state, and local levels. Unfortunately, the specifics of these regulations are highly uncertain at this time.

The lack of information about potential secondary markets is one of the most severe handicaps faced by government and private-sector decision makers. If, on the one hand, lumber-like materials have a large potential market, regulators may select to divert plastics away from the municipal waste stream in a form that will be appropriate to these technologies. In that case, alternative technologies, such as tertiary processes may be de-emphasized. On the other hand, if the potential market for these lumber-like materials is small, the development of alternative recycling technologies becomes more important.

PLASTICS RECYCLING IN THE INDUSTRIAL SECTOR: AN ASSESSMENT OF THE OPPORTUNITIES AND CONSTRAINTS

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1. INTRODUCTION

The industrial sector has historically recycled in excess of 75% of its waste plastics in either a primary or secondary sense -- i.e., clean scrap has been used in place of virgin resin or the scrap has been used to manufacture products with less demanding physical and chemical properties. More recently, a limited quantity of industrial waste has been recycled in a tertiary sense. Tertiary recycling refers to processes such as pyrolysis and hydrolysis that convert the waste polymers to useful chemicals or fuels. A fourth alternative, quaternary recycling, refers to incineration with heat recovery and has not been used extensively with respect to the recycling of separated plastic wastes.

The portion of manufacturing waste that has not historically been suited for recycling has been disposed of by landfill or incineration. These plastic wastes, which have commonly been referred to as manufacturing nuisance wastes, may be heavily contaminated with other materials or may consist of hard-to-recycle thermosets. Thermosets differ from the more popular thermoplastics in that their interlinking bonds prevent melting and reforming into new products. Although the size and composition of manufacturing nuisance plastics have been estimated, those numbers are now somewhat dated. Further, the technical, economic, institutional, and regulatory environment within which the industrial recycling of these wastes may occur is changing rapidly.

While the additional recycling of industrial waste may offer additional economic and environmental payoffs, an even greater potential exists with the recycling of post-consumer wastes. Recent trends toward more source separation of plastics, improved technologies to separate plastics from other materials in the municipal waste stream, and government mandated recycling programs all suggest that the quantity of plastics available for recycling as a segregated waste will grow. In addition, the total use of plastics continues to grow at a rapid rate. The identification of the quantities, qualities, and sources of post-consumer wastes, and in particular the divertable portion of the post-consumer stream -- which in this report will be referred to as divertable plastic waste (DPW) -- is important for planning in the industrial sector. Particular R&D areas may be shown to be most effective in promoting additional recycling of this portion of the waste stream.

The following section of this report gives updated estimates of the quantities and qualities of manufacturing nuisance plastics. Also presented is information on the current uses of plastics and how the post-consumer plastic waste stream is expected to change between now and the year 2000. Section 3 gives estimates of the energy contents of manufacturing and post-consumer plastic wastes during the coming decade. Section 4 presents recent information on the costs of recycling as compared to the costs of disposal. Recent institutional changes that have helped to promote plastics recycling in the industrial sector are summarized in Section 5. Legislative and regulatory trends that directly or indirectly promote additional recycling are discussed in Section 6. Several scenarios depicting probable future technical, economic, institutional, and regulatory conditions are discussed in Section 7. Those scenarios are then overlaid on the information presented in Section 2 on post-consumer waste to suggest the quantities, qualities, and sources of DPW in future years. Section 8 focuses on the current plastics recycling industry and discusses the problems and opportunities for additional recycling as currently perceived by the industry. Conclusions are summarized in the final section.

2. PLASTIC WASTE PROJECTIONS

Curlee (1986) presents projections of the future uses of plastics in various product categories, manufacturing nuisance plastics, and post-consumer wastes for the years 1984, 1990, and 1995. This section updates those projections and extends the projection to the year 2000. In addition, some additional disaggregation of the projections is given for two important product sectors -- transportation and packaging. For the most part, the methodology used in this section is the same as detailed in Curlee (1986, Chapter 4 and Appendix B). The interested reader is referred to that document for details of the methodology. A general overview of the methodology and specific changes made in this update are documented herein. The objective of this section is to present information about the sources, quantities, and likely qualities of future plastic waste streams. This information will be helpful in the later assessment of the applicability of different recycling technologies to different plastic waste streams.

2.1. PROJECTED U.S. RESIN PRODUCTION AND USE

2.1.1. Methodology

Projections of U.S. resin production and use of specific resins in major product categories were made using time series analysis. Historical production of all resins and the use of resins in nine major product categories were regressed against time and a constant. The relationships were then used to project the future production and use of plastics in the United States.

2.1.2. Results

Figure 2.1 illustrates the historical growth of total resin production (including polyurethane) in the U.S. for the years 1974 through 1987 and gives projections of future production through the year 2000.[1] While there have been significant downturns in production during this historical period, the general trend is up sharply. For example, total resin production increased from about 37 billion pounds in 1980 to more than 55 billion pounds in 1987. According to the projections, total resin production will exceed 62 billion pounds in 1995 and approach 72 billion pounds by the year 2000.

Figures 2.2a and 2.2b illustrate the historical use of plastics in several major product areas during the years 1974 to 1987 and give projections for those product areas through the year 2000. [Note that because the Society of the Plastics Industry's Facts and Figures of the U.S. Plastics Industry (from which the historical data were obtained) excludes the use of polyurethanes in their data series, Figures 2.2a and 2.2b do not include polyurethanes. Polyurethanes are considered separately in a later figure.] The packaging and the building and construction sectors are by far the largest of the sectors considered. Resin usage in the packaging sector has increased from 10.0 billion pounds in 1980 to 15.2 billion pounds in 1987. By 1995 resin usage in that sector is projected to increase to 19.5 billion pounds and by 2000 to 22.6 billion pounds.[2] Resin usage in the building and construction sector increased from 6.4 billion pounds in 1980 to 11.3 billion pounds in 1987. The use of plastics in building and construction applications is projected to increase to 15.2 billion pounds in 1995 and to 17.8 billion pounds in 2000. The use of plastics in the other major product areas has been relatively flat in recent years.

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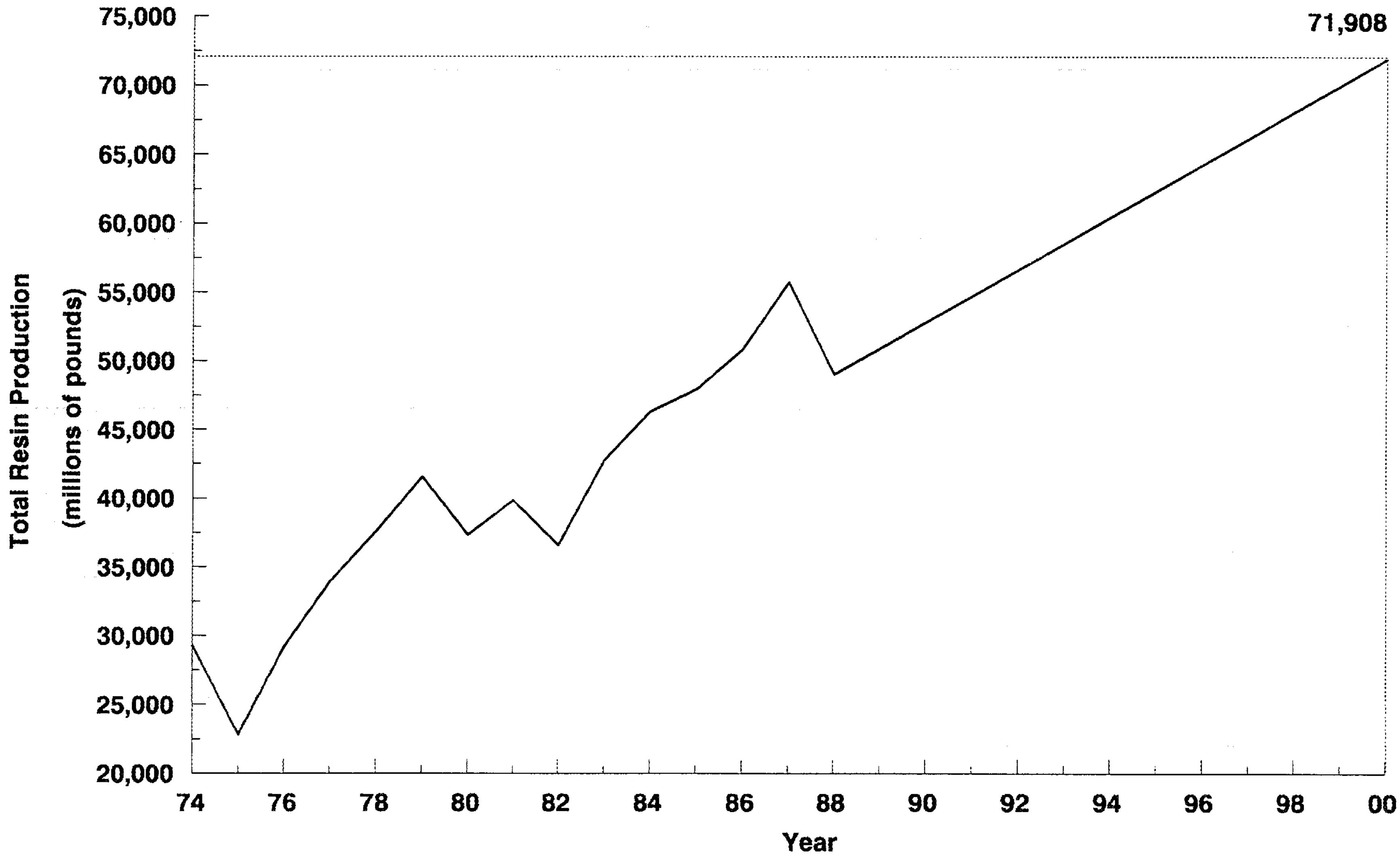
[1]See Appendix A for the numbers corresponding to the graphical presentations given in this section. Also see Appendix A for explanation of the data sources and results of the regression runs on which the projections are based.

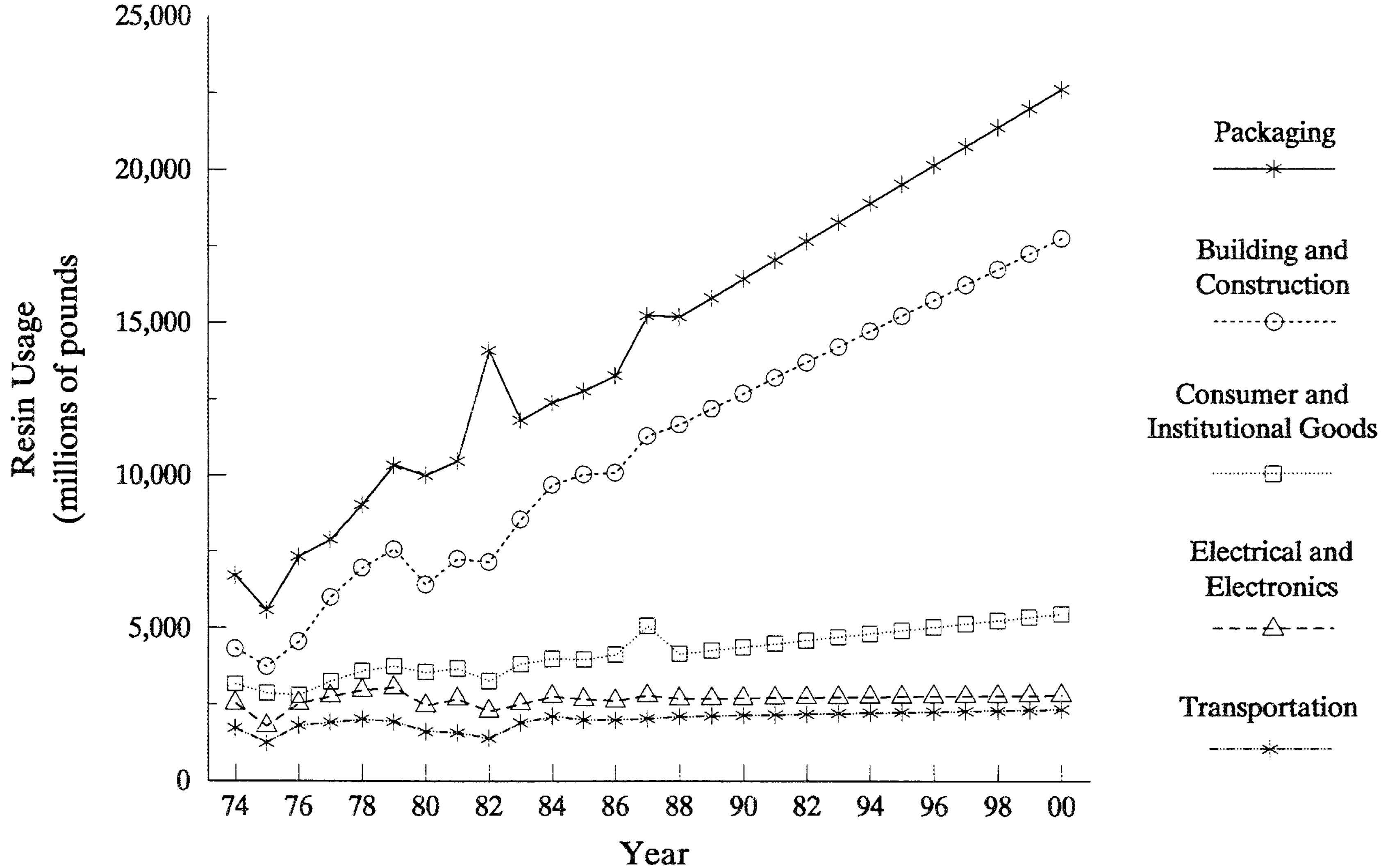
[2]Note that the projections given in this section assume that no significant structural changes will occur, such as changes in technology or changes in regulations that might impact on the use of plastics in specific product categories.

FIGURE 2.1. TOTAL U.S. RESIN PRODUCTION



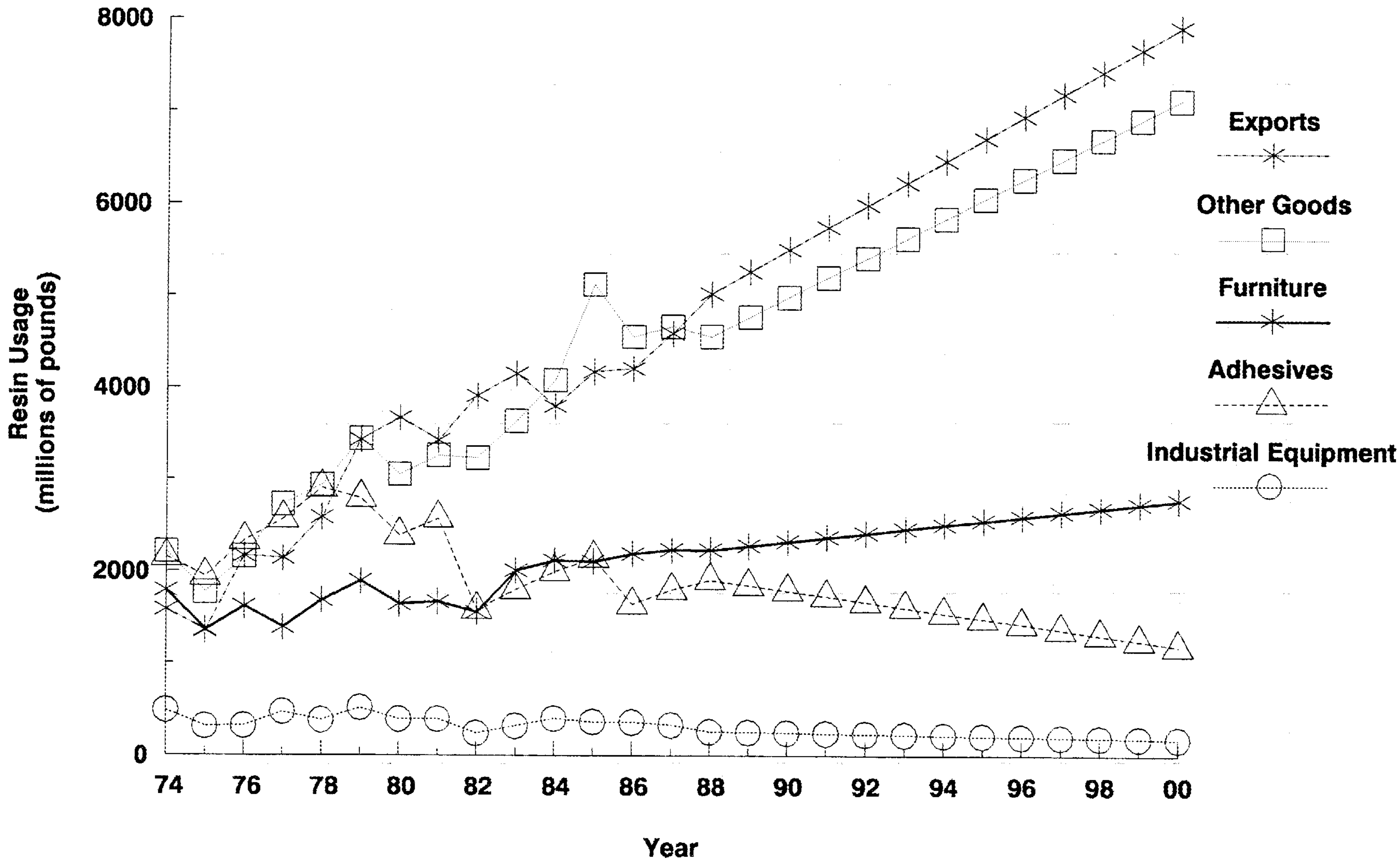
Note: Projected Values are from 1988 and onwards

FIGURE 2.2a. RESIN USAGE BY PRODUCT TYPE



Note: Projected Values are from 1988 and onwards.
Excludes the use of polyurethane

FIGURE 2.2b. RESIN USAGE BY PRODUCT TYPE



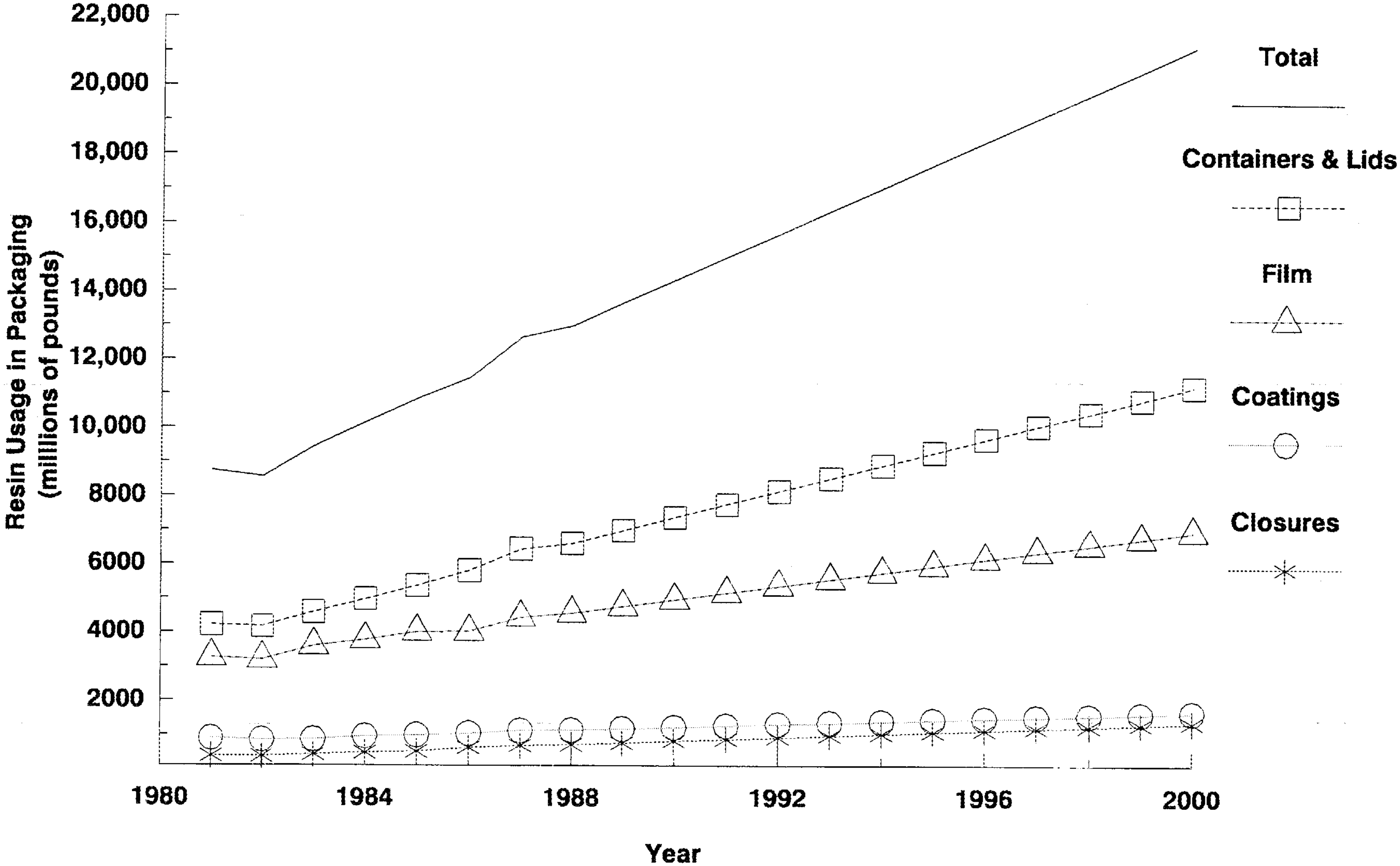
Note: Projected Values are from 1988 and onwards
Excludes the Use of Polyurethane

Figure 2.3 and Table 2.1 further disaggregate the use of plastics in the large and controversial packaging sector. Data on the historical usage of plastics by packaging type is taken from Modern Plastics, and the projections are made using the same methodology used to make the above mentioned projections of total usage of plastics in the polyurethane sector. The projections of total usage of plastics in the polyurethane sector are lower than in Figure 2.2a. In the latter case a different source, SPI's Facts and Figures of the Plastics Industry, was used which reports higher historical usage in the packaging sector.

Containers and lids account for the largest percentage of plastics used in the sector and have increased from 4.2 billion pounds in 1981 to 6.4 billion pounds in 1987. About 9.3 billion and 11.2 billion pounds are projected to be used for containers and lids in 1995 and 2000, respectively. Films account for the second largest percentage, increasing from 3.3 billion pounds in 1981 to 4.4 billion pounds in 1987. The film segment of the packaging sector is projected to increase to 5.9 billion pounds in 1995 and to 6.9 billion pounds in 2000. The packaging sector as a whole is expected to consume more than 21 billion pounds of plastics in 2000.

Figure 2.4 summarizes the actual and projected usages of polyurethanes in different sectors over the same time frame. Total production of polyurethanes is only about 4% of total resin production. However, polyurethanes pose special problems for recycling and therefore are important to consider as a separate resin stream. The two largest uses of polyurethanes are in the furniture and fixtures sector and the building and construction sector. The furniture and fixtures sector accounted for 0.8 billion pounds in 1985 and is projected to account for 1.3 billion pounds by 2000. The building and construction sector consumed 0.4 billion pounds in 1985 and is

FIGURE 2.3. RESIN USAGE IN PACKAGING APPLICATIONS



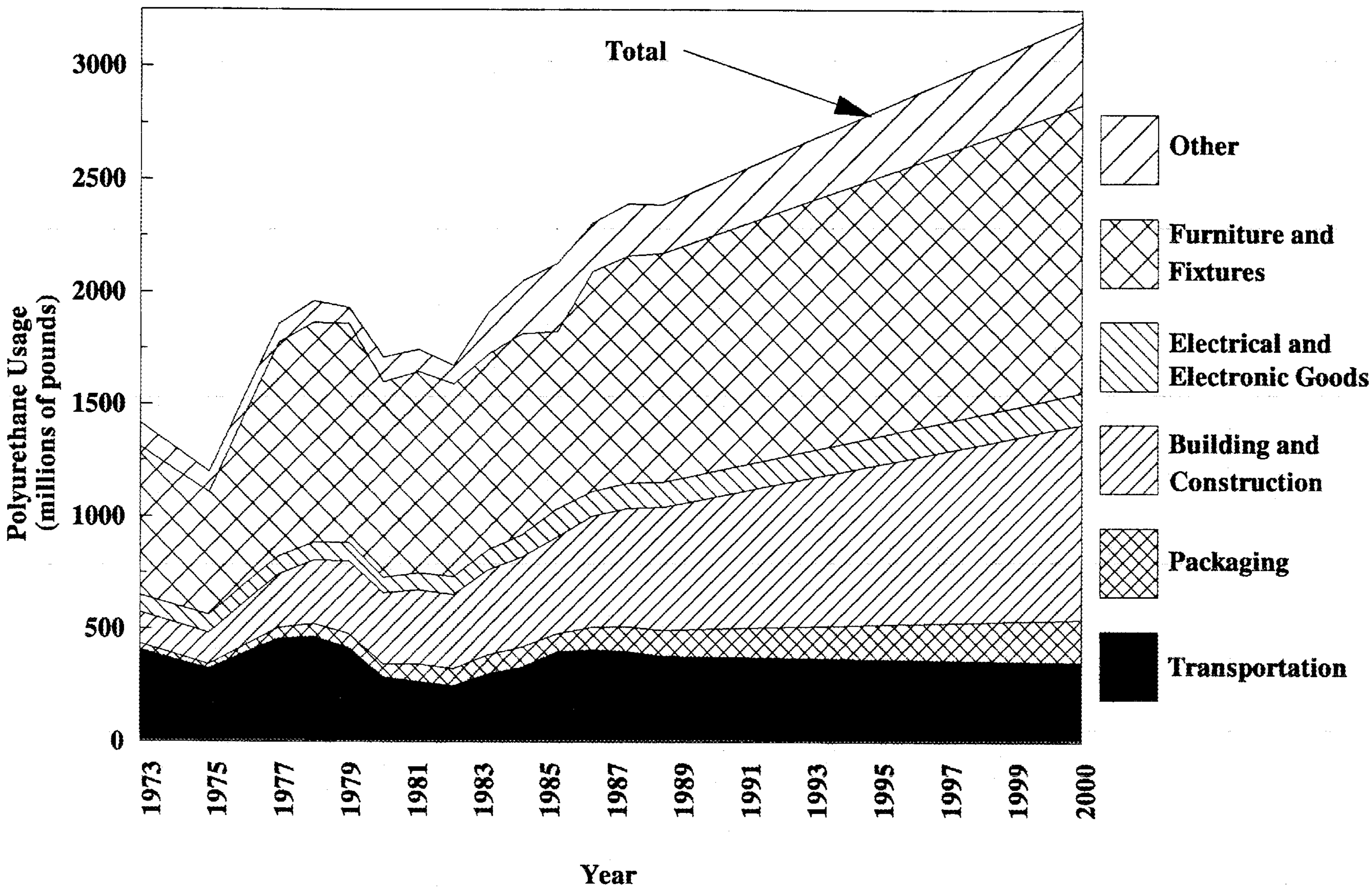
Note: Projected Values are from 1988 and onwards

TABLE 2.1. HISTORICAL AND PROJECTED USE OF PLASTICS IN SELECTED PRODUCT CATEGORIES IN PACKAGING

YEAR	CLOSURES	COATINGS	CONTAINERS & LIDS	FILM	TOTAL
1981	373	889	4214	3257	8733
1982	364	847	4159	3189	8559
1983	417	860	4580	3585	9442
1984	472	955	4965	3764	10156
1985	503	988	5355	4000	10846
1986	612	1035	5801	4004	11452
1987	676	1114	6433	4426	12649
1988*	701	1130	6595	4548	12974
1989	754	1172	6977	4746	13650
1990	808	1214	7360	4945	14326
1991	861	1256	7743	5143	15003
1992	914	1298	8126	5341	15679
1993	967	1340	8508	5540	16355
1994	1021	1382	8891	5738	17032
1995	1074	1424	9274	5936	17708
1996	1127	1466	9656	6134	18384
1997	1180	1509	10039	6333	19061
1998	1234	1551	10422	6531	19737
1999	1287	1593	10805	6729	20414
2000	1340	1635	11187	6928	21090

Note: *Starting year for projections

FIGURE 2.4. POLYURETHANE USAGE IN SELECTED MARKETS



projected to consume 0.9 billion pounds by 2000. Most of the projected increase in total polyurethane usage is in the building and construction sector.

2.2. PROJECTIONS OF MANUFACTURING NUISANCE PLASTICS

Projections of manufacturing nuisance plastics are given most recently in Curlee (1986). Those projections are, however, based on assumptions about the percentage of throughput that becomes a nuisance plastic from Leidner (1981). Leidner's work is, in turn, based on research published by Milgrom in 1971. The underlying assumptions on which the projections are based are therefore somewhat dated. Although manufacturing nuisance plastics have been estimated to compose only 8% to 9% of the total plastic waste potentially available for recycling, manufacturing waste is important because the segregated collection of manufacturing waste is easier to accomplish than is the case with post-consumer wastes.

This subsection addresses the question of what percentage of throughput becomes a nuisance plastic. That information is then used in combination with the projections of total resin production discussed in the previous subsection to formulate updated projections of manufacturing nuisance plastics. The update of the relevant percentages followed discussions with individuals familiar with the technological changes that have occurred with respect to plastics manufacturing equipment. Although this was not a formal survey of such individuals, the information gathered can be assumed to reflect a relevant range of estimates.

2.2.1. Methodology

A three step process was used. First, estimates of the percentage of total plastic throughput that has historically become a nuisance plastic at various stages of production -- i.e., resin producer; fabricator; converter; and packager, assembler, and distributor -- were updated. Second, the percentages derived from the first step were applied to the projections of total future U.S. resin production discussed in the previous subsection. This step gives projections of the total quantities of nuisance plastic to be produced by the different manufacturing processes or stages of production. Third, the estimates and projections derived from the second step were disaggregated by resin type according to the percentages of each resin produced in the U.S. in 1987 (as given in Facts and Figures of the U.S. Plastics Industry, 1988 edition).

2.2.2. Results

Figure 2.5 and Table 2.2 give estimates of the percentages of throughput that become nuisance plastics at different stages of production. The values in the first column of Table 2.2 indicate the percentages of resin content at different stages of production that would be affected. Note that five different sets of numbers are given, reflecting different opinions about technological changes that have occurred since Milgrom's 1971 publication. The second column in Table 2.2 reflects the numbers given in Leidner (1981) and subsequently in Curlee (1986). The third column reflects the conclusions of a follow-on assessment by Milgrom published in 1979. The fourth column assumes that Leidner's 1981 estimates are reduced by 50% and reflect the opinion of Albert Spaak, Technical Director of the Plastics Institute of America [Spaak (1988b)]. The fourth column assumes a 75% reduction in Leidner's 1981 numbers, but does not directly reflect the opinion of any particular expert. The final column reflects the opinion of Pearson (1988). Figure 2.5 presents this information in graphical form.

Table 2.3 gives estimates and projections of manufacturing nuisance plastics and disaggregates those estimates by stages of production. The numbers include the production of polyurethane. Figure 2.6 presents information about total nuisance plastics in graphical form. Note that while all the experts agree that technology has improved such that nuisance plastics are less today than in 1971, there is significant disagreement about the extent to which those wastes have been reduced.

FIGURE 2.5. PERCENTAGE OF THROUGHPUT THAT BECOMES A NUISANCE PLASTIC AT VARIOUS STAGES OF PRODUCTION

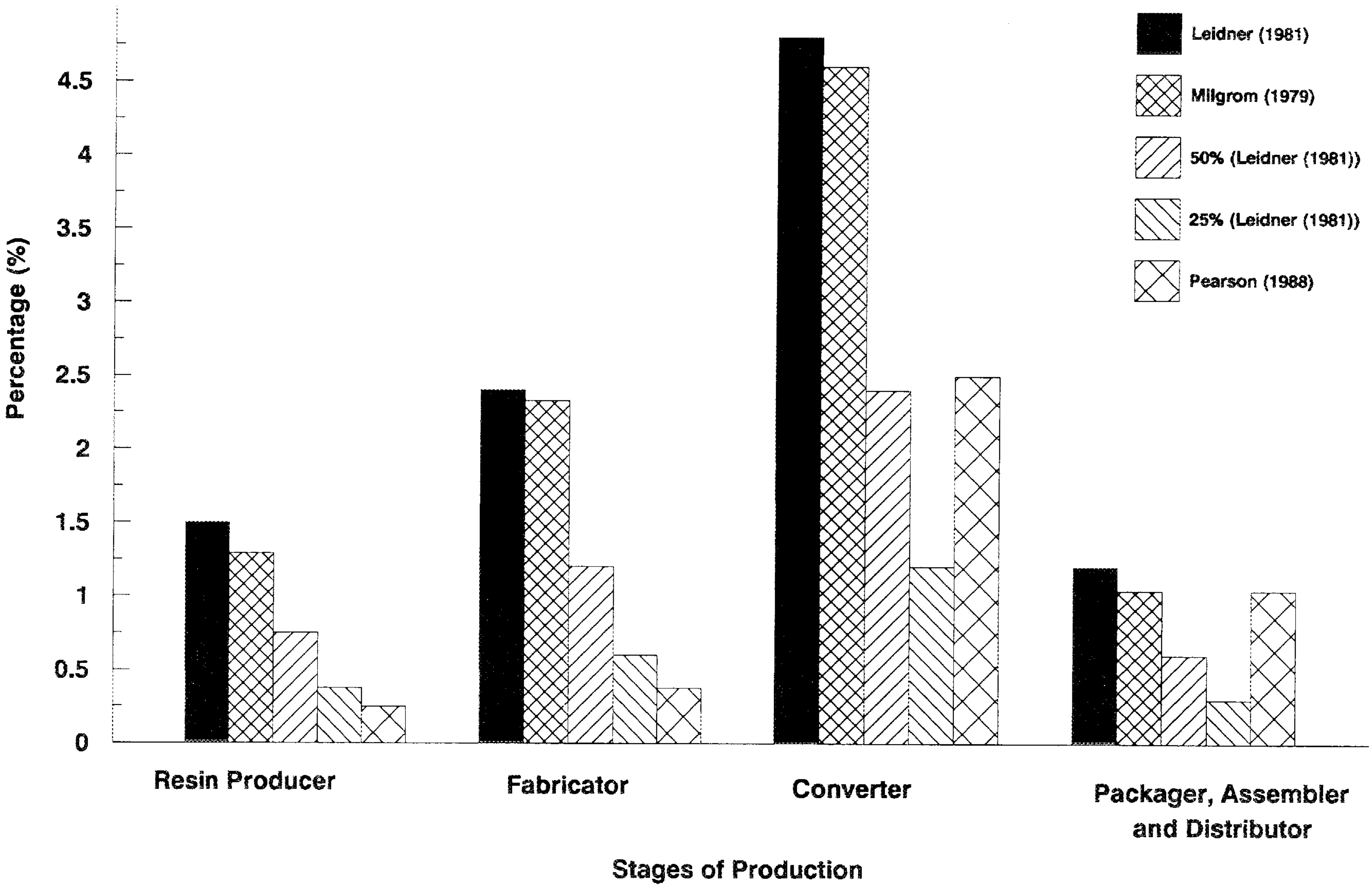


TABLE 2.2. PERCENTAGE OF THROUGHPUT THAT BECOMES A NUISANCE PLASTIC AT VARIOUS STAGES OF PRODUCTION

	Percentage of Commodity Resin Affected	Percentage of Throughput that Becomes a Nuisance Plastic				
		Leidner (1981)	Milgrom (1979)	50% Leidner(1981)	25% Leidner(1981)	Pearson (1988)
Resin Producer	100.0	1.5	1.29	0.75	0.375	0.250
Fabricator	84.2	2.4	2.33	1.20	0.600	0.375
Converter	40.1	4.8	4.60	2.40	1.200	2.500
Packager, Assembler and Distributor	68.0	1.2	1.04	0.60	0.300	1.040

TABLE 2.3. PROJECTIONS OF MANUFACTURING NUISANCE PLASTICS DISAGGREGATED BY STAGE OF PRODUCTION (IN MILLIONS OF POUNDS)

	Leidner (1981)	Milgrom (1979)	50% Leidner (1981)	25% Leidner (1981)	Pearson (1988)
1990 Estimates					
Resin Producer	793	682	396	198	132
Fabricator	1068	1037	534	267	167
Converter	1017	975	509	254	530
Packager, Assembler and Distributor	431	374	216	108	374
Total	3309	3067	1655	827	1203
1995 Estimates					
Resin Producer	936	805	468	234	156
Fabricator	1261	1224	630	315	197
Converter	1201	1151	600	300	625
Packager, Assembler and Distributor	509	441	255	127	441
Total	3906	3620	1953	976	1419
2000 Estimates					
Resin Producer	1079	928	539	270	180
Fabricator	1453	1411	727	363	227
Converter	1384	1326	692	346	721
Packager, Assembler and Distributor	587	509	293	147	509
Total	4503	4173	2251	1126	1636

FIGURE 2.6. PROJECTIONS OF MANUFACTURING NUISANCE PLASTICS

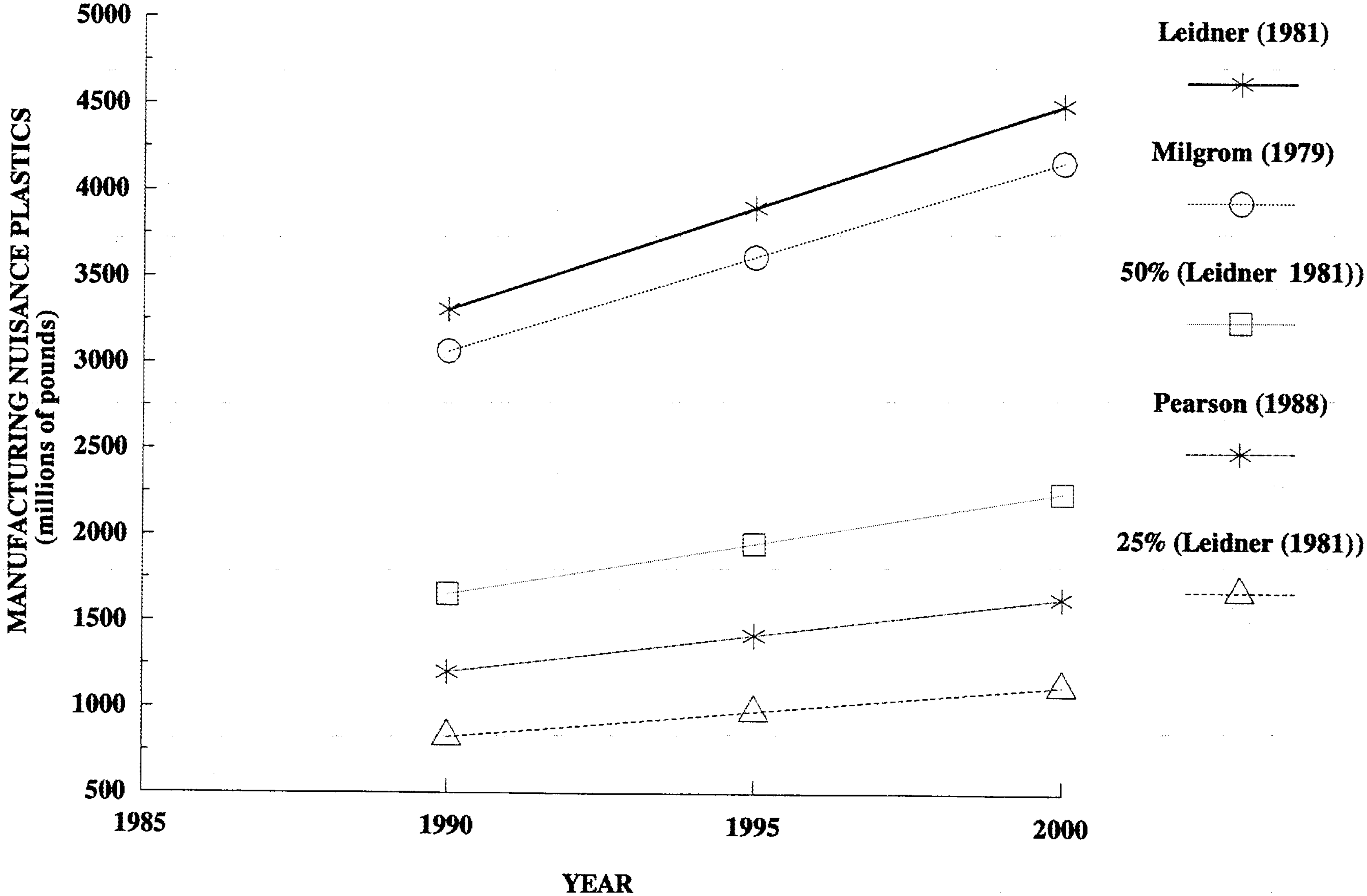


Table 2.4 gives projections of manufacturing nuisance plastics by resin type for the years 1990, 1995, and 2000, given the assumptions about waste generation rates made in Leidner's assessment. Table 2.5 provides similar information, given the "50% Leidner" case. The total quantities of nuisance plastics have been disaggregated according to the percentage composition of total 1987 plastic resins produced in the United States.

Table 2.6 gives information from another source on estimated manufacturing nuisance plastics. The estimates from a recent presentation by Albert Spaak (1988a) are disaggregated by a combination of resin types and products and are the result of a mini-survey conducted by the Plastics Institute of America (PIA). It is interesting to note that the findings of the survey place estimates and projections of nuisance plastics significantly higher than any of the cases considered above. The 1990 projected quantity of nuisance plastics at 5.89 billion pounds exceeds the 3.3 billion pounds projected for our highest case -- the Leidner (1981) assumptions.

2.3. PROJECTIONS OF POST-CONSUMER PLASTIC WASTES

Given that plastic wastes are difficult to separate from other similar materials in the municipal waste stream, it is important that information be available on the projected levels of post-consumer plastic waste not only in terms of quantity and resin type, but also in terms of the sources of that waste. The sources of waste will help in the identification of those wastes that are defined in this report to be divertable plastic wastes.

2.3.1. Methodology

Post-consumer wastes are estimated and projected for nine product categories by resin type for the years 1990, 1995, and 2000. Product categories include automobiles, other transportation applications, packaging, building and construction, electrical and electronic goods, furniture, consumer and institutional goods, industrial machinery, and adhesives and other applications. The

TABLE 2.4. MANUFACTURING NUISANCE PLASTICS DISAGGREGATED BY RESIN TYPE (IN MILLIONS OF POUNDS) (LEIDNER (1981))

	1987 Composition of U.S. Resins (%)	1990	1995	2000
Thermosets				
Epoxy	0.8%	26	30	35
Polyester	2.5%	81	96	110
Urea and Melamine	2.9%	95	112	129
Phenolics	5.1%	170	201	232
Other Thermosets	4.9%	162	191	221
Total Thermosets	16.1%	534	630	726
Thermoplastics				
LDPE	17.2%	570	673	775
HDPE	14.3%	475	560	646
Polypropylene	11.9%	395	466	537
ABS and SAN	2.3%	77	91	105
Polystyrene	8.6%	284	335	386
Nylon	0.9%	30	36	41
PVC	14.3%	473	558	644
Thermoplastic Polyesters	2.5%	83	98	113
Other Thermoplastics	7.9%	261	309	356
Total Thermoplastics	80.0%	2647	3125	3602
Polyurethane Foam	3.9%	552	651	751
Total	100.0%	3310	3907	4504

TABLE 2.5. MANUFACTURING NUISANCE PLASTICS BY RESIN TYPE (IN MILLIONS OF POUNDS) (50% LEIDNER (1981))

	1987 Composition of U.S. Resins (%)	1990	1995	2000
Thermosets				
Epoxy	0.8%	13	15	17
Polyester	2.5%	41	48	55
Urea and Melamine	2.9%	47	56	64
Phenolics	5.1%	85	101	116
Other Thermosets	4.9%	81	96	110
Total Thermosets	16.1%	267	315	363
Thermoplastics				
LDPE	17.2%	285	336	388
HDPE	14.3%	237	280	323
Polypropylene	11.9%	197	233	268
ABS and SAN	2.3%	39	46	53
Polystyrene	8.6%	142	167	193
Nylon	0.9%	15	18	20
PVC	14.3%	237	279	322
Thermoplastic Polyesters	2.5%	41	49	56
Other Thermoplastics	7.9%	131	154	170
Total Thermoplastics	80.0%	132.4	1562	1801
Polyurethane Foam	3.9%	65	76	88
Total	100.0%	1655	1954	2252

TABLE 2.6. MANUFACTURING NUISANCE PLASTIC ESTIMATES FROM SPAAK (1988a) (IN MILLIONS OF POUNDS PER YEAR)

Type	1988 Pounds Per Year
Wire insulation, PVC, HDPE and PE	1,500
Multilayer film, including coextruded film	500
Polyethylene coated paper	1,000
PVC coated fabrics	500
Polyethylene film	200
Rubber-backed poly-pro carpet aaste	4
Carpet waste, polyester, nylon and polypropylene	250
Diaper trim and rejects - plastic and paper	6
Acrylonitrile-PVC foam	2
Acrylics - mixture router shavings	2
Chopped polyethylene and polypropylene mixed	3
Plastics and rubber mixed	2
Polyethylene terephthalate	6
Flexible PVC regrind	12
Polyethylene regrind	1
Polypropylene regrind	3
Polystyrene regrind	1
NPE show conversation with various attendees, mixed plastic materials	90
Total	4,081

Total production 1988 - 54 billion pounds
Projected total production 1990 - 78 billion pounds
Therefore, Manufactured Nuisance Plastic Waste estimated in 1990 equals - 5.89 billion pounds.
BTU value at average 12 x 10^3 BTU's/pound = 7.068 x 10^{13} BTU's

specific methodology used to project wastes from each product category differed slightly depending on the availability of data. The general methodology was the same as used in Curlee (1986, Chapter 4 and Appendix B). Variations from that general methodology are described in the appendix of this report.

The general methodology involved two main steps. First, information was obtained on the average life spans of the products in the nine product categories. Second, information was obtained on the historical use of specific plastic resins in those product categories. Projections of future waste streams by product type and resin were subsequently made.

Table 2.7 gives information on average product life spans and is taken from Curlee (1986, page 80). Average product life spans range from less than one year for packaging to 25 years for building and construction materials. When the data permit, three year averages have been used to estimate the flow of plastics from any particular product category. For example, the 1995 projections of plastic waste from the furniture and fixtures category is given by averaging the quantities of plastic resins used in that category during the years 1984, 1985, and 1986.

Data on the historical use of plastic resins in specific product categories was obtained from various issues of the Society of the Plastics Industry's Facts and Figures of the U.S. Plastics Industry whenever possible. Other information on resin usage was obtained from the January issues of Modern Plastics, which give similar information but in a slightly different form. Polyurethane foams were considered separately from other resins. See the appendix to this report for additional information on data and methodology.

TABLE 2.7. ESTIMATED LIFE SPANS OF SELECTED PRODUCTS (IN YEARS)

Product Category	Estimated Life
Transportation	11
Packaging	<1
Building and construction	25
Electrical and electronics	15
Furniture and fixtures	10
Consumer and Institutional	5
Industrial machinery	15
Adhesives and Other	4

Source: Curlee (1986, page 80)

2.3.2. Results

2.3.2.1. Projections for 1990

Table 2.8 gives projected post-consumer plastic waste by product category and resin type. Figure 2.7 presents 1990 summary information. It is projected that total 1990 post-consumer wastes will total about 35.8 billion pounds. Thermoplastics will contribute 87.2%, followed by thermosets and polyurethane foams at 7.9% and 4.9%, respectively.

Note that the largest single source of waste is the packaging sector, which is projected to contribute 46.2% of the total. Further note that the vast majority (99.6%) of plastic packaging materials are made from thermoplastics, with LDPE and HDPE accounting for 68.8% of the total.

Following the adhesives and other category is the consumer and institutional goods category, which is projected to account for 11.2% of the total. Thermoplastics also dominate this category, accounting for 93.3% of the total.

Each of the remaining categories account for less than 8% of the total. The furniture and electrical and electronics sector account for about 7% each. Automobiles are expected to contribute 4.9% and other transportation applications about 1.4%.

2.3.2.2. Projections for 1995

Post-consumer plastic wastes are projected to increase in 1995 to 43.7 billion pounds, a 22% increase over the 1990 projected level. Thermoplastics are projected to contribute about 88.8% of the total, with thermosets and polyurethane foams accounting for 6.9% and 4.3%, respectively. Table 2.9 presents detailed information on wastes streams by product type and resin. Figure 2.8 presents summary information.

The packaging sector is projected to remain the largest contributor to the waste stream at 45.1% of the total. The adhesives and other category is again followed by the consumer and

TABLE 2.8. POST-CONSUMER PLASTIC WASTE (1990)

	Auto-mobile	%	Transportation Other	%	Packag-ing	%	Building and Construction	%	Electrical and Electronic	%	Furniture	%	Consumer and Institutional	%	Industrial Machinery	%	Adhesives and Others	%	Total	%
THERMOSETS																				
Epoxy	2.3	0.2%	----	----	6	0.0%	----	----	32	1.4%	----	----	----[b]	----	----	----	219	3.3%	260	0.7%
Polyester	143.4	9.9%	111.3	27.3%	6	0.0%	46	6.5%	263	11.5%	19	1.1%	75	1.9%	----	----	173	2.6%	837	2.3%
Urea and Melamine	----	----	----	----	33	0.2%	----	----	59	2.6%	66	3.8%	146	3.6%	26	6.9%	320	4.8%	650	1.8%
Phenolics	20.9	1.4%	15.5	3.8%	14	0.1%	91	12.8%	241	10.6%	275	15.8%	50	1.2%	58	15.5%	285	4.3%	1051	2.9%
Other Thermosets	----	----	----	----	----	----	7	1.0%	21	0.9%	----	----	----	----	----	----	----	----	28	0.1%
Total Thermosets	166.6	11.5%	126.8	31.1%	60	0.4%	144	20.3%	616	27.1%	361	20.8%	271	6.7%	84	22.4%	996	15.0%	2826	7.9%
THERMOPLASTICS																				
LDPE	56.8	3.9%	----	----	6647	40.4%	72[a]	10.1%	----	----	----	----	587	14.6%	----	----	1134	17.1%	8497	23.7%
HDPE	----	----	----	----	4666	28.4%	----	----	868[a]	38.1%	19[a]	1.1%	636	15.8%	97	26.0%	792	11.9%	7078	19.8%
Polypropylene	308.2	21.3%	94.9	23.3%	1564	9.5%	----	----	----	----	76	4.4%	779	19.3%	53	14.2%	1324	19.9%	4199	11.7%
ABS and SAN	327.1	22.7%	42.3	10.4%	30	0.2%	3	0.4%	----	----	38	2.2%	64	1.6%	----	----	526	7.9%	1031	2.9%
Polystyrene	1.9	0.1%	----	----	1533	9.3%	41	5.8%	----	----	474	27.3%	1367	33.9%	----	----	944	14.2%	4362	12.2%
PBT/PET	38.3	2.7%	----	----	1063	6.5%	----	----	16	0.7%	----	----	----[b]	----	----	----	----	----	1017	3.1%
Nylon	133.3	9.2%	16.4	4.0%	55	0.3%	----	----	59	2.6%	----	----	----[b]	----	25	6.6%	78	1.2%	367	1.0%
PVC	249.7	17.3%	81.1	19.9%	662	4.0%	330	46.5%	670	29.4%	731	42.1%	289	7.2%	18	4.8%	580	8.7%	3610	10.1%
Other Thermoplastics	162.1	11.2%	45.7	11.2%	154	0.9%	119[c]	16.8%	48	2.1%	38	2.2%	35	0.9%	97	26.0%	265	4.0%	965	2.7%
Total Thermoplastics	1277.5	88.5%	280.4	68.9%	16375	99.6%	565	79.6%	1662	72.9%	1376	79.2%	3757	93.3%	290	77.6%	5643	85.0%	31220	87.2%
Polyurethane foam	304.7	----	85.9	----	128	----	1[d]	0.1%	79	----	914	----	----	----	----	----	251	----	1764	4.9%
TOTAL	1748.8	100.0%	493.2	100.0%	16563	100.0%	710	100.0%	2358	100.0%	2651	100.0%	4028	100.0%	373	100.0%	6890	100.0%	35816	100.0%
PERCENT	4.9	----	1.4	----	46.2	----	2.0	----	6.6	----	7.4	----	11.2	----	1.0	----	19.2	----	100.0	----

[a] Data do not distinguish between LDPE and HDPE.
[b] Disaggregate information not available. Mostly insignificant quantity.
[c] Data do not distinguish between other thermosets and other thermoplastics.
[d] Data do not distinguish between polyurethane foam and other polyurethane uses.

Note: Low Density Polyethylene (LDPE); High Density Polyethylene (HDPE); Acrylonitrile-Butadiene-Styrene (ABS); Styrene-Acrylonitrile (SAN); Polyvinyl Chloride (PVC).

FIGURE 2.7. POST-CONSUMER PLASTIC WASTE (1990)

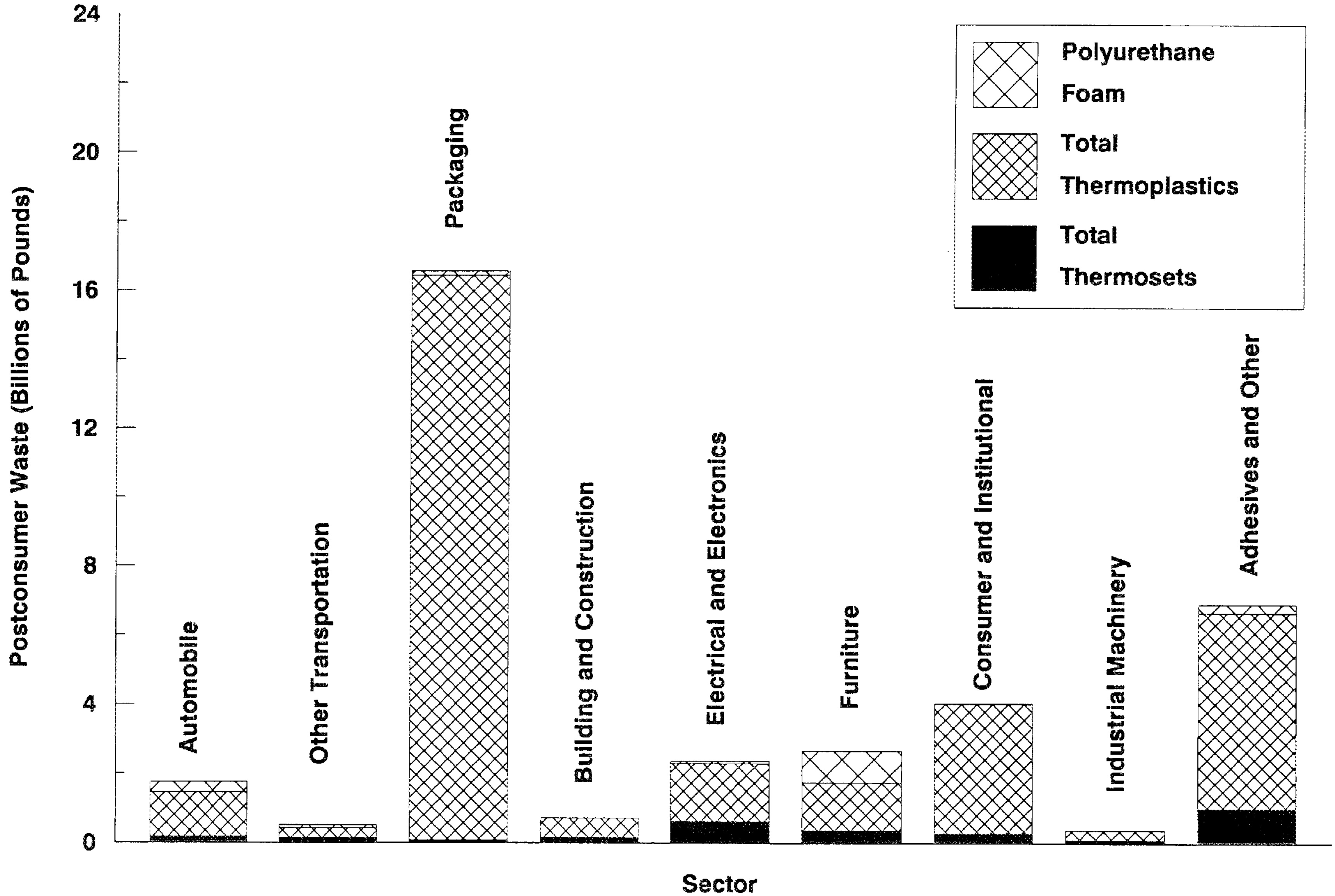


TABLE 2.9. POST-CONSUMER PLASTIC WASTE (1995)

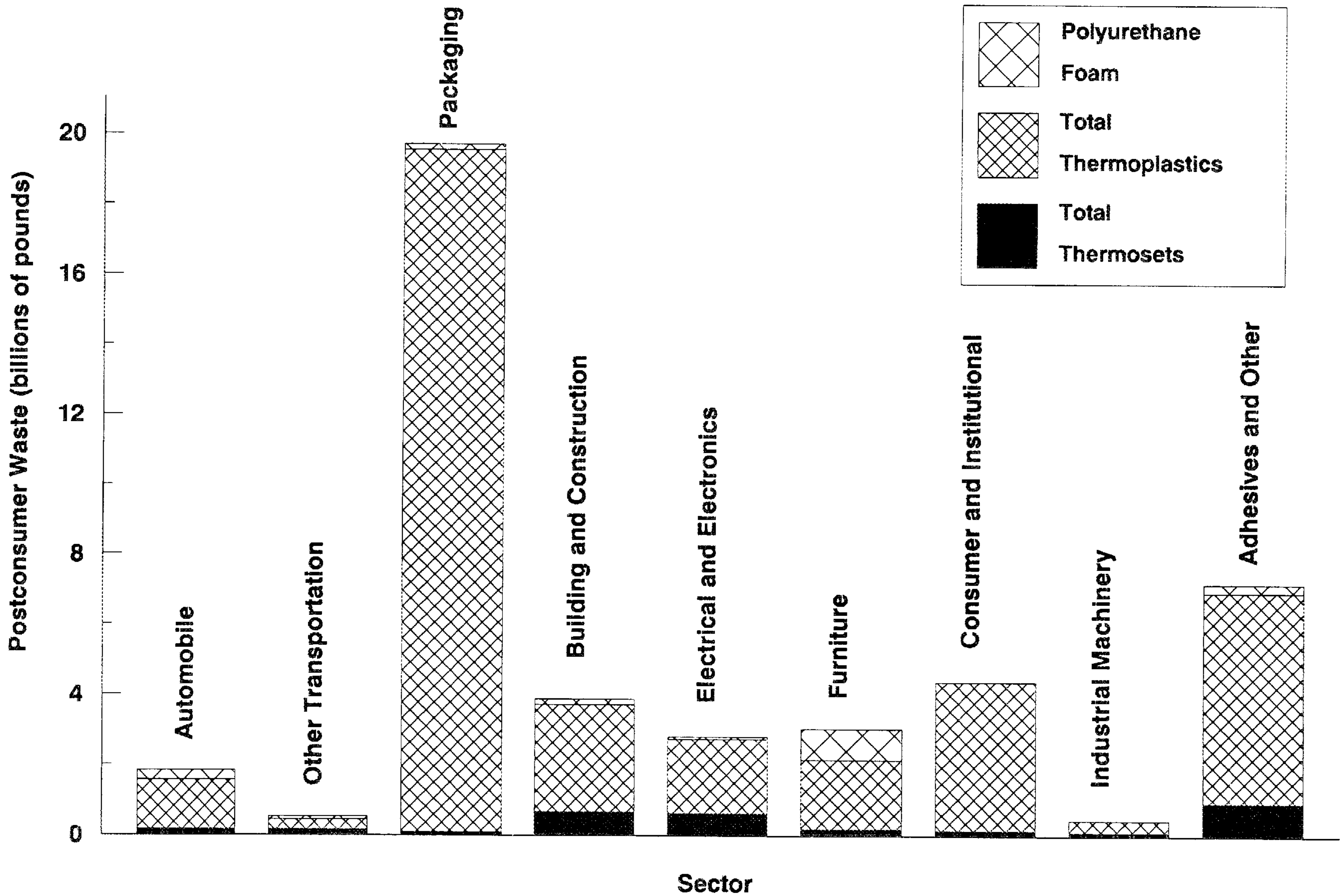
	Auto-mobile	%	Transportation Other	%	Packag-ing	%	Building and Construction	%	Electrical and Electronic	%	Furniture	%	Consumer and Institutional	%	Industrial Machinery	%	Adhesives and Others	%	Total	%
THERMOSETS																				
Epoxy	8.1	0.5%	----[b]	----	8	0.0%	----	----	41	1.5%	----[b]	----	----[b]	----	----	----	210	3.0%	267	0.6%
Polyester	123.3	7.9%	106.6	24.3%	8	0.0%	258	6.7%	255	9.4%	14	0.6%	91	2.1%	----	----	165	2.4%	1021	2.3%
Urea and Melamine	----	----	----[b]	----	40	0.2%	----	----	52	1.9%	54	2.5%	14	0.3%	30	6.9%	294	4.3%	484	1.1%
Phenolics	24.3	1.6%	41.5	9.4%	17	0.1%	228	5.9%	236	8.7%	108	5.0%	36	0.8%	67	15.5%	265	3.8%	1023	2.3%
Other Thermosets	----	----	----	----	----	----	173	4.5%	34	1.2%	----	----	----	----	----	----	----	----	207	0.5%
Total Thermosets	155.8	10.0%	148.1	33.7%	72	0.4%	659	17.0%	619	22.7%	175	8.2%	141	3.2%	97	22.4%	935	13.5%	3001	6.9%
THERMOPLASTICS																				
LDPE	88.7	5.7%	20.7[a]	4.7%	7900	40.4%	351[a]	9.1%	604	22.2%	46	2.2%	566	12.9%	----	----	967	14.0%	10543	24.1%
HDPE	----	----	----	----	5546	28.4%	----	----	187	6.9%	58	2.7%	831	19.0%	113	26.0%	741	10.7%	7476	17.1%
Polypropylene	358.9	23.0%	63.9	14.5%	1859	9.5%	----	----	19	0.7%	1401	65.5%	896	20.5%	62	14.2%	1165	16.8%	5825	13.3%
ABS and SAN	255.6	16.4%	73.6	16.7%	36	0.2%	195	5.0%	64	2.3%	5	0.2%	51	1.2%	----	----	1099	15.9%	1779	4.1%
Polystyrene	1.3	0.1%	----[b]	----	1822	9.3%	137	3.5%	394	14.5%	59	2.8%	1547	35.4%	----	----	568	8.2%	4528	10.4%
PBT/PET	66.9	4.3%	8.5	1.9%	1263	6.5%	----	----	34	1.2%	----	----	----[b]	----	----	----	----	----	1372	3.1%
Nylon	173.9	11.2%	42.7	9.7%	65	0.3%	----	----	49	1.8%	6	0.3%	33	0.8%	29	6.6%	51	0.7%	450	1.0%
PVC	233.4	15.0%	44.8	10.2%	787	4.0%	1900	49.1%	664	24.4%	388	18.1%	246	5.6%	21	4.8%	871	12.6%	5155	11.8%
Other Thermoplastics	224	14.4%	37.2	8.5%	183	0.9%	470[c]	12.2%	90	3.3%	----	----	58	1.3%	113	26.0%	524	7.6%	1699	3.9%
Total Thermoplastics	1402.7	90.0%	291.5	66.3%	19463	99.6%	3053	78.9%	2103	77.3%	1963	91.8%	4229	96.8%	337	77.6%	5986	86.5%	38828	88.8%
Polyurethane foam	268.1	----	75.6	----	159	----	156[d]	4.0%	76	----	888	----	----	----	----	----	253	----	1877	4.3%
TOTAL	1826.5	100.0%	515.2	100.0%	19694	100.0%	3868	100.0%	2798	100.0%	3027	100.0%	4370	100.0%	434	100.0%	7174	100.0%	43707	100.0%
PERCENT	4.2	----	1.2	----	45.1	----	8.9	----	6.4	----	6.9	----	10.0	----	1.0	----	16.4	----	100.0	----

a r ... uish between LDPE and HDPE.
... n not available. Mostly insignificant quantity.
... ween other thermosets and other thermoplastics.
... n polyurethane foam and other polyurethane uses.

...): High Density Polyethylene (HDPE); Acrylonitrile-Butadiene-Styrene (ABS); Styrene-Acrylonitrile (SAN); Polyvinyl Chloride (PVC).

GURE

2.8. POST-CONSUMER PLASTIC WASTE (1995)



institutional goods category at 10.0%. By far the largest growth category is building and construction, which is projected to increase from about 2% of the total in 1990 to almost 9% of the total in 1995. Only moderate changes are projected in the other product categories.

2.3.2.3. <u>Projections for 2000</u>

Table 2.10 and Figure 2.9 give projections of post-consumer wastes in 2000. Total waste is projected to increase to 48.7 billion pounds, an increase of 11.4% above the 1995 projected level. Thermoplastics are projected to account for 88.8% of the total, with thermosets and polyurethane foams accounting for 6.7% and 4.5% respectively.

No significant shift in the mix of waste according to product type is projected between 1995 and 2000. Packaging remains the largest source of waste at 46.9% of the total.

2.3.2.4. <u>Summary</u>

Figures 2.10, 2.11, and 2.12 summarize the findings concerning plastic waste projections. Figure 2.10 shows the projections for both manufacturing nuisance plastics and post-consumer plastics for 1990, 1995, and 2000. Note that the nuisance waste projections reflect the "50% Leidner" case. The total quantity of waste is expected to grow from the 1990 level of 37.5 billion pounds to 45.7 billion pounds in 1995 to 51.0 billion pounds in 2000. Manufacturing nuisance plastics are projected to remain at a relatively constant percentage of total plastic waste -- about 4.4%.

Figures 2.11 and 2.12 illustrate how the composition of waste by product category is projected to change. Packaging is expected to remain the largest single source of waste. The category with the largest projected percentage increase is the building and construction sector, increasing from 2.0% in 1990 to 8.0% in 2000.

TABLE 2.10. POST-CONSUMER PLASTIC WASTE (2000)

	Automobile	%	Transportation Other	%	Packaging	%	Building and Construction	%	Electrical and Electronic	%	Furniture	%	Consumer and Institutional	%	Industrial Machinery	%	Adhesives and Others	%	Total	%
THERMOSETS																				
Epoxy	20.4	1.2%	----[b]	----	9	0.0%	11	0.3%	77	2.9%	----[b]	----	----[b]	----	----	----	233	3.0%	350	0.7%
Polyester	183.6	11.1%	177.2	38.1%	9	0.0%	217	5.8%	65	2.4%	28	1.2%	102	2.1%	----[b]	----	184	2.4%	966	20%
Urea and Melamine	----	----	----[b]	----	46	0.2%	407	10.9%	37	1.4%	49	2.1%	16	0.3%	----[b]	----	327	4.3%	882	1.8%
Phenolics	30.0	1.8%	6.8	1.5%	19	0.1%	402	10.8%	136	5.1%	118	5.1%	41	0.8%	10	2.7%	295	3.8%	1058	2.2%
Other Thermosets	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Total Thermosets	234.0	14.2%	183.9	39.5%	83	0.4%	1037	27.8%	316	11.8%	195	8.4%	159	3.2%	10	2.7%	1038	13.5%	3256	6.7%
THERMOPLASTICS																				
LDPE	106.2	6.4%	24.4	5.2%	9154	40.4%	26	0.7%	430	16.1%	53	2.3%	637	12.9%	----[b]	----	1074	14.0%	11504	23.6%
HDPE	----	----	4.2	0.9%	6426	28.4%	398	10.7%	163	6.1%	----[b]	----	936	19.0%	205	54.7%	823	10.7%	8955	18.4%
Polypropylene	386.5	23.4%	118.5	25.4%	2154	9.5%	11	0.3%	291	10.9%	1625	69.9%	1009	20.5%	16	4.3%	1294	16.8%	6905	14.2%
ABS and SAN	208.8	12.6%	60.8	13.1%	42	0.2%	199	5.3%	257	9.6%	8	0.3%	57	1.2%	----[b]	----	1221	15.9%	2053	4.2%
Polystyrene	0.4	0.0%	----[b]	----	2111	9.3%	168	4.5%	329	12.3%	52	2.2%	1742	35.4%	----[b]	----	631	8.2%	5034	10.3%
PBT/PET	89.7	5.4%	13.5	2.9%	1463	6.5%	----	----	41	1.5%	----	----	----[b]	----	----	----	----	----	1607	3.3%
Nylon	174.1	10.5%	4.2	0.9%	76	0.3%	----	----	71	2.7%	13	0.6%	38	0.8%	47	12.4%	57	0.7%	480	1.0%
PVC	205.4	12.4%	56.1	12.1%	912	4.0%	1662	44.5%	511	19.1%	378	16.3%	277	5.6%	44	11.6%	967	12.6%	5013	10.3%
Other Thermoplastics	245.7	14.9%	----[b]	----	212	0.9%	234	6.3%	267	10.0%	----	----	66	1.3%	54	14.3%	582	7.6%	1660	3.4%
Total Thermoplastics	1416.7	85.8%	281.6	60.5%	22550	99.6%	2699	72.2%	2359	88.2%	2128	91.6%	4761	96.8%	365	97.3%	6649	86.5%	43211	88.8%
Polyurethane foam	295.9	----	83.5	----	191	----	140	----	111	----	1062	----	----	----	----	----	318	----	2202	4.5%
TOTAL	1946.6	100.0%	549.0	100.0%	22825	100.0%	3876	100.0%	2786	100.0%	3386	100.0%	4920	100.0%	375	100.0%	8005	100.0%	48669	100.0%
PERCENT	4.0	----	1.1	----	46.9	----	8.0	----	5.7	----	7.0	----	10.1	----	0.8	----	16.5	----	100.0	----

[a] Data do not distinguish between LDPE and HDPE.
[b] Disaggregate information not available. Mostly insignificant quantity.
[c] Data do not distinguish between other thermosets and other thermoplastics.
[d] Data do not distinguish between polyurethane foam and other polyurethane uses.

Note: Low Density Polyethylene (LDPE); High Density Polyethylene (HDPE); Acrylonitrile-Butadiene-Styrene (ABS); Styrene-Acrylonitrile (SAN); Polyvinyl Chloride (PVC).

FIGURE 2.9. POST-CONSUMER PLASTIC WASTE (2000)

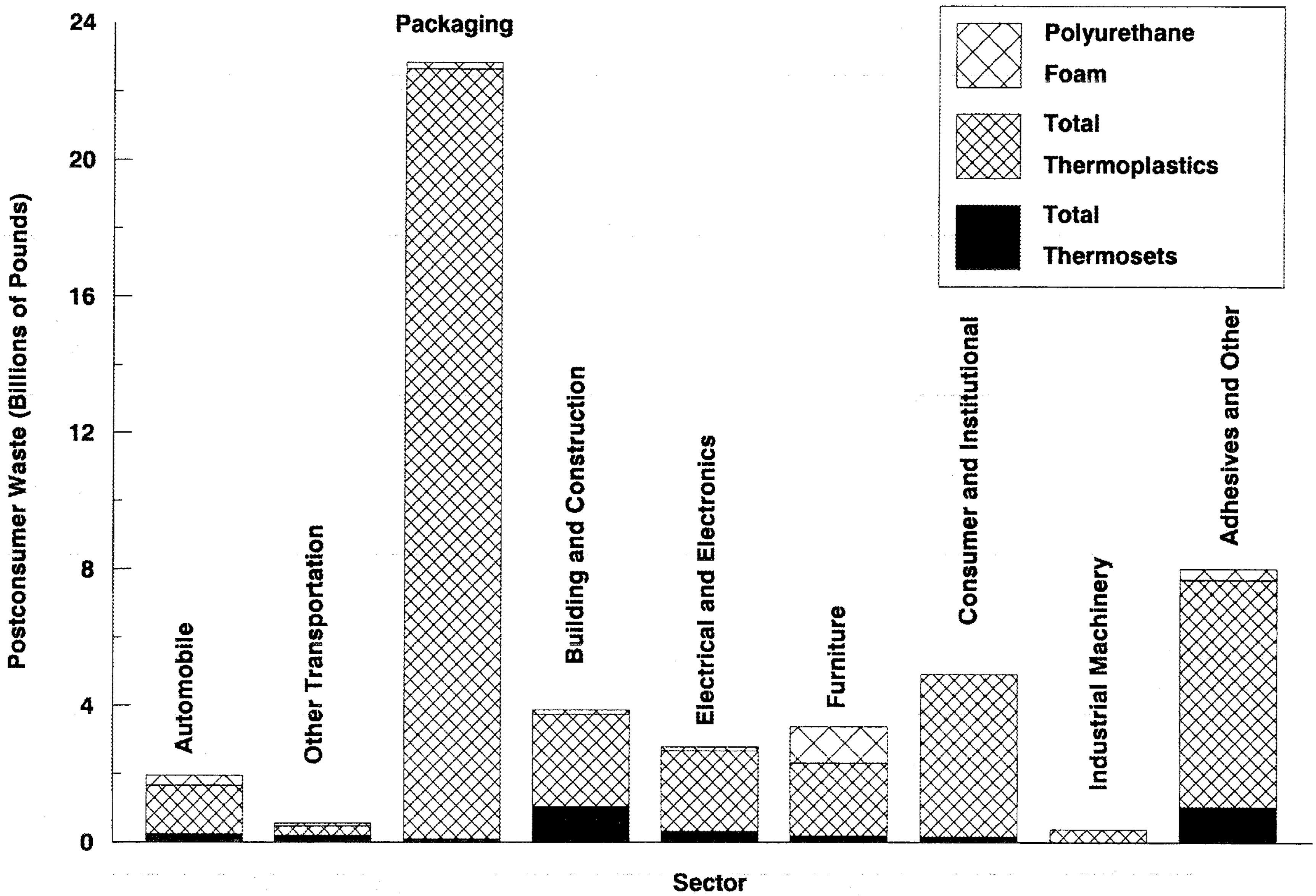


FIGURE 2.10. TOTAL PLASTIC WASTE PROJECTIONS: 1990, 1995, 2000

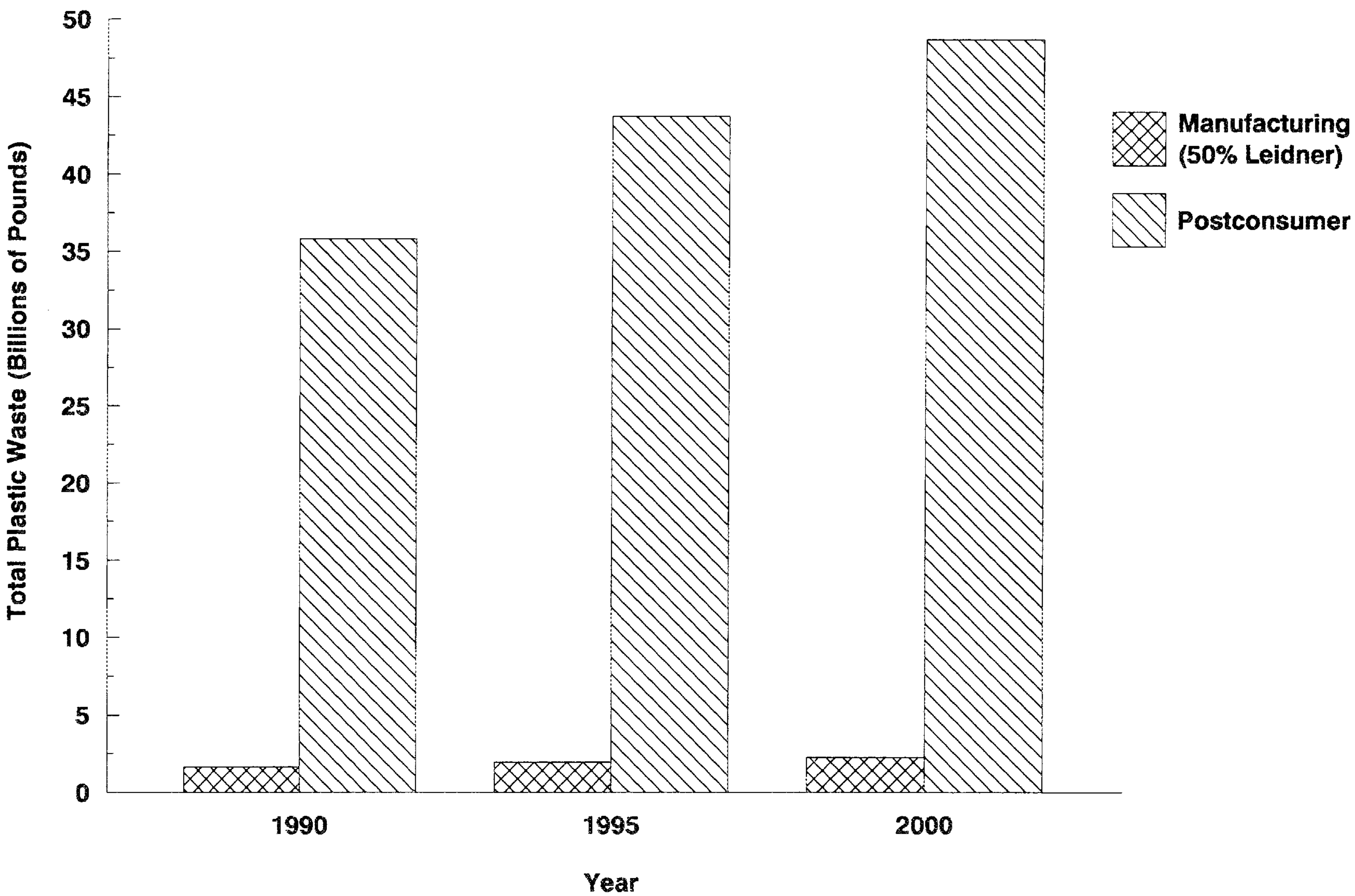


FIGURE 2.11. PROJECTED POST-CONSUMER PLASTICS BY PRODUCT CATEGORY

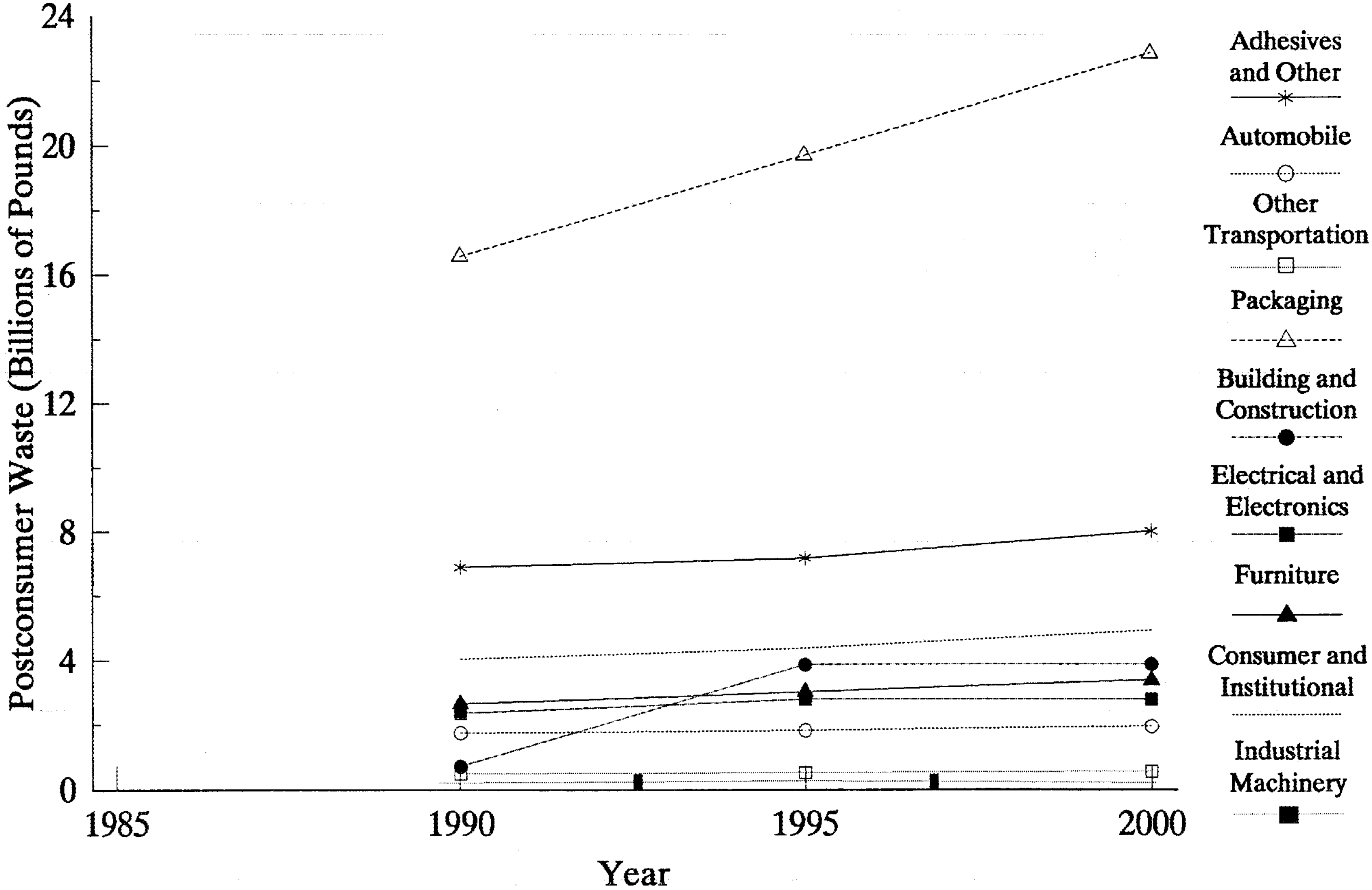
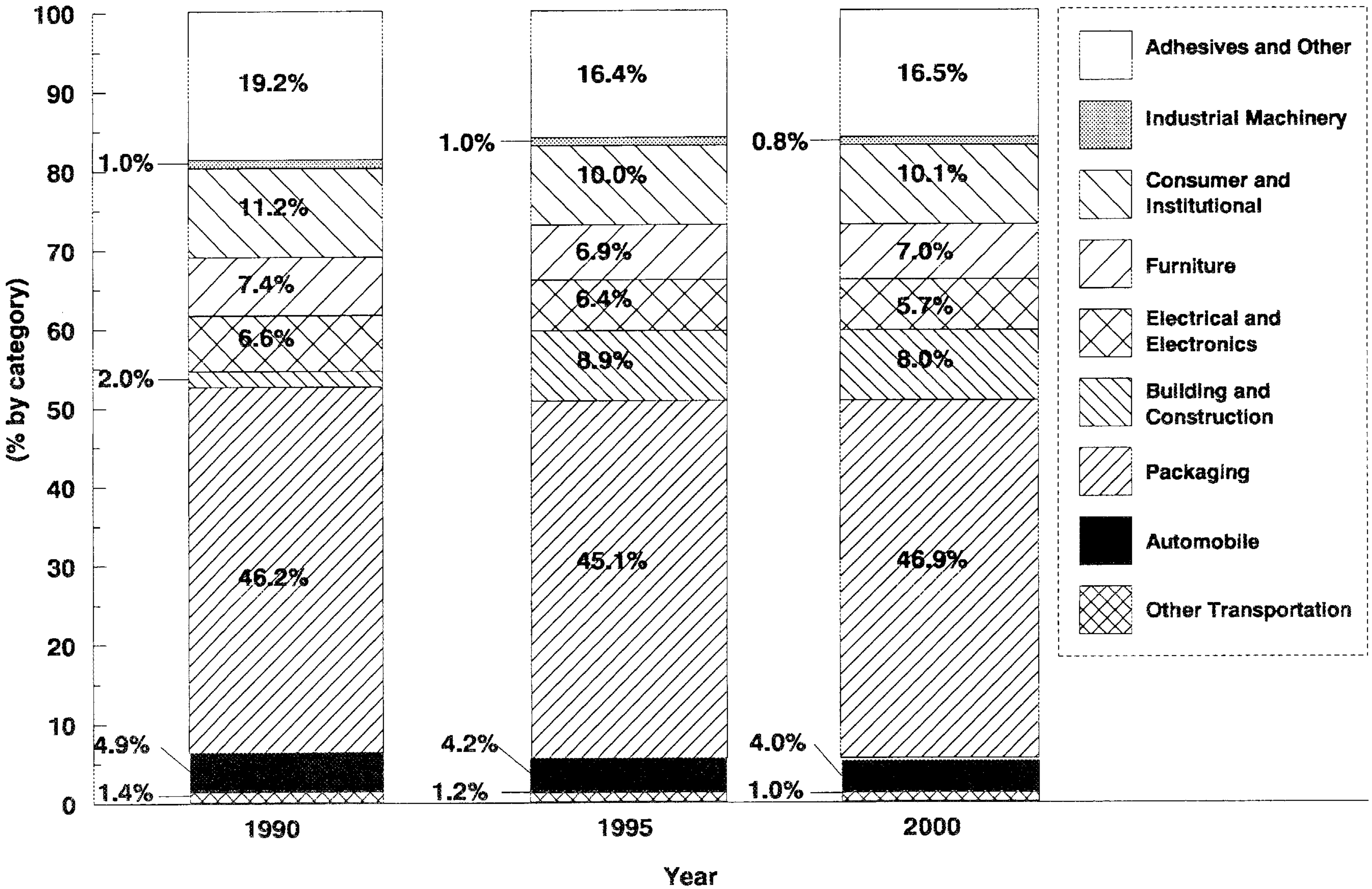


FIGURE 2.12. PROJECTED POST-CONSUMER PLASTICS BY PRODUCT CATEGORY (IN PERCENTAGES)



Given that packaging items have average life times of less than one year, the composition of the packaging sector by packaging type is projected to be the same as presented in Table 2.1 and Figure 2.3. The packaging sector in 1995 is projected to be made up of the following components: containers and lids, 52.4%; films, 33.5%; coatings, 8.0%; and closures, 6.1%. The composition of the packaging sector is important to the later discussion of the potential size and composition of DPW.

3. THE ENERGY CONTENT OF PLASTIC WASTES

Given that plastics are made for the most part from petroleum and natural gas, plastics recycling has been argued for on the basis of energy conservation. Quaternary recycling could directly retrieve the heat energy of the waste resins. Tertiary recycling could potentially retrieve pre-polymers that embody significant amounts of energy. Secondary recycling, if used to manufacture products that would otherwise be made from virgin resins, could reduce the overall demand for virgin resins and the energy embodied in those resins. This section presents estimates of the energy required to manufacture plastics, the energy that can be retrieved from plastics when burned, and the aggregate energy contained in manufacturing nuisance plastics and post-consumer plastics for the years 1990, 1995, and 2000.

3.1. THE ENERGY CONTENT OF PLASTICS

Gaines and Shen (1980) present estimates of the energy contained in various plastic resins. Four energy estimates are given: net heat of feed combustion, net processing energy, total energy input, and product heat of combustion. Gaines and Shen define the terms as follows: "Heat of combustion of feed is the sum of the heats of combustion of all feedstocks entering into a process sequence, starting with oil and gas. Net process energy is the total fuel required to complete all steps of a manufacturing process minus the heat of combustion of any by-product fuels not burned within that process sequence. Total energy input is the sum of the heat of combustion of the feed and the net process energy. It is the total energy embodied in the final product. Product heat of combustion is defined as the sum of the heats of combustion of all process products and nonfuel by-products. It is the energy that would be recovered if the final products were burned." (page 2).

Table 3.1 presents energy content information for the various resin types discussed in Section 2 of this report. Note that energy content estimates were not available from Gaines and Shen for all the resin types discussed in Section 2. For those resins not covered in the Gaines and

Shen report, information was obtained from Thiessen (1989). The specific assumptions made concerning these additional resins are listed in Table 3.1. Note that, with the exceptions of PVC and nylon, the energy contents of most resins do not vary significant.

3.2. THE AGGREGATE ENERGY CONTENT OF MANUFACTURING AND POST-CONSUMER PLASTICS

Tables 3.2 and 3.3 present estimates of the energy contents of manufacturing nuisance plastics and post-consumer plastic wastes for the years 1990, 1995, and 2000. Total energy inputs and product heat of combustion are given for each waste resin category and each year and are defined as given in the previous subsection. Total energy inputs for all manufacturing nuisance plastics are projected to be 61.6 X 10^{12} BTUs in 1990 and increase to 83.8 X 10^{12} BTUs in 2000. Total energy inputs for all post-consumer plastics in 1990 is projected to be about 1,317 X 10^{12} BTUs and increase to 1,779 X 10^{12} BTUs in 2000. If incineration is used to retrieve the heat energy of the waste, manufacturing nuisance plastics are projected to contain 26.8 X 10^{12} BTUs in 1990 and increase to 36.5 X 10^{12} BTUs in 2000. Post-consumer wastes are projected to contain 617 X 10^{12} BTUs in 1990 if incinerated. In 2000 the incineration heat value of post-consumer plastics is projected to increase to 843 X 10^{12} BTUs. For comparison purposes, note that the U.S. consumed a total of 73.82 quads of energy (1 quad = 1 X 10^{15} BTUs). In 1985 total energy consumption was disaggregated as follows: transportation, 20.01 quads; residential and commercial, 26.80 quads; and industrial, 27.01. Further note that the U.S. currently burns only about 2% of all solid waste in incinerators that allow for heat recovery. Waste incineration with heat recovery currently accounts for only 0.04% of the United States' primary energy supply.

TABLE 3.1. ENERGY CONTENTS OF PLASTIC WASTES

	Net Heat of Feed Combustion (Btu/lb)	Net Processing Energy (Btu/lb)	Total Energy Input (Btu/lb)	Product Heat of Combustion (Btu/lb)
Thermosets				
Epoxy	24,700	24,000	48,700	11,400
Polyester	24,700	24,000	48,700	11,400
Urea and Melamine[a]	24,700	24,000	48,700	11,400
Phenolics[a]	24,700	24,000	48,700	11,400
Other Thermosets[a]	24,700	24,000	48,700	11,400
Thermoplastics				
LDPE	28,100	10,400	38,500	20,000
HDPE	27,300	9,200	36,500	20,050
Polypropylene	28,000	6,200	34,200	20,000
ABS and SAN[b]	24,570	8,280	32,850	18,045
Polystyrene	23,600	10,700	34,300	17,800
PBT/PET	24,700	24,000	48,700	11,400
Nylon	27,700	62,700	90,400	13,200
PVC	12,600	13,000	25,600	7,700
Other Thermoplastics[c]	27,300	9,200	36,500	20,050
Polyurethane Foam[d]	21,840	7,360	29,200	16,040

[a]Assumed to approximately the same as polyester.
[b]Assumed to be 90% of the estimated values for HDPE.
[c]Assumed to be the same as HDPE.
[d]Assumed to be 80% of the estimated values for HDPE.

Source of information on resin other than those footnoted: Gaines and Shen (1980).
Source of information on resins with footnotes: Thiessen (1989).

TABLE 3.2. ENERGY CONTENT (IN BILLIONS OF BTUS) OF MANUFACTURING NUISANCE PLASTICS: 1990, 1995, 2000 (50% LEIDNER CASE)

	1990		1995		2000	
	(1)*	(2)**	(1)*	(2)**	(1)*	(2)**
Thermosets						
Epoxy	626	147	739	173	852	199
Polyester	1976	463	2332	546	2688	629
Urea and Melamine	2304	539	2719	637	3135	734
Phenolics	4147	971	4894	1146	5642	1321
Other Thermosets	3948	924	4660	1091	5372	1258
Total Thermosets	13001	3043	15345	3592	17689	4141
Thermoplastics						
LDPE	10968	5698	12946	6725	14923	7752
HDPE	8661	4758	10222	5615	11784	6473
Polypropylene	6747	3946	7963	4657	9180	5368
ABS and SAN	1268	697	1497	822	1726	948
Polystyrene	4866	2525	5743	2980	6621	3436
Nylon	1360	199	1606	234	1851	270
PVC	6056	1822	7148	2150	8240	2478
Thermoplastic Poly	2015	472	2378	557	2741	642
Other Thermoplastic	4771	2621	5631	3093	6492	3566
Total Thermoplastic	46713	22735	55135	26835	63557	30934
Polyurethane Foam	1884	1035	2224	1222	2564	1408
Total	61598	26814	72704	31648	83810	36483

*(1): Total Energy Input
**(2): Product Heat of Combustion

TABLE 3.3. ENERGY CONTENT (IN 10^{12} BTUS) OF POST-CONSUMER PLASTIC WASTES: 1990, 1995, 2000

	1990		1995		2000	
	(1)*	(2)**	(1)*	(2)**	(1)*	(2)**
Thermosets						
Epoxy	13	3	13	3	17	4
Polyester	41	10	50	12	47	11
Urea and Melamine	32	7	24	6	43	10
Phenolics	51	12	50	12	52	12
Other Thermosets	1	0	10	2	0	0
Total Thermosets	138	32	146	34	159	37
Thermoplastics						
LDPE	327	170	406	211	443	230
HDPE	258	142	273	150	327	180
Polypropylene	144	84	199	116	236	138
ABS and SAN	34	19	58	32	67	37
Polystyrene	150	78	155	81	173	90
PBT/PET	54	13	67	16	78	18
Nylon	33	5	41	6	43	6
PVC	92	28	132	40	128	39
Other Thermoplastics	35	19	62	34	61	33
Total Thermoplastics	1128	557	1393	685	1557	771
Polyurethane Foam	52	28	55	30	64	35
Total	1317	617	1594	750	1779	843

*(1): Total Energy Input
**(2): Product Heat of Combustion

4. THE COST OF RECYCLING VERSUS DISPOSAL

Curlee (1986) discusses the concept of economic costs as compared to accounting costs. Economic costs include an opportunity cost component, whereas accounting costs do not. A distinction is also made between private costs and social costs. Social costs and benefits include monetary and nonmonetary costs and benefits that accrue to individuals not directly involved in economic transactions. The costs of environmental degradation that may result from disposal or recycling activities are included in social costs and may be the determining factor in selecting the optimal technology to process plastics from a social perspective. The external costs associated with oil import disruptions -- which may be reduced by recycling plastics -- are also considered under social costs. Accounting costs do not consider external costs and benefits of these types and therefore are not recommended as a means for judging the optimal social response to waste disposal questions.

Although accounting costs pose problems, the assessment of accounting costs can be beneficial when viewed from the proper perspective. Curlee (1986, Chapter 5) presents various estimates of the accounting costs of recycling as well as disposing of plastic wastes. This section briefly reviews the conclusions of Curlee (1986, Chapter 5) and presents new information on the estimated costs of disposal and the estimated costs and revenues associated with recycling technologies not available at the time of that book's publication.

4.1. SUMMARY OF PREVIOUS ASSESSMENT

The assessment presented in Curlee (1986) included secondary, tertiary, and quaternary recycling technologies. Also included were landfill and incineration without heat recovery. Specific recycling technologies considered included a polyester bottle recycling technology developed by Goodyear, the Mitsubishi Reverzer (which converts plastic wastes to lumber-like products), a U.S.S.

Chemicals pyrolysis process, and an incineration process developed by Industronics Incorporated to retrieve the heat energy from polyester bottles.

Four main conclusions emerged from the study. First, the data available at that time were considered to be poor, suggesting that the data could not support definitive conclusions about the competitiveness of recycling with disposal. Second, given the caveat of the first conclusion, recycling of plastics as relatively uncontaminated wastes appeared to be competitive with disposal in many parts of the country where disposal costs were high. Third, the recycling of municipal waste, in which plastics are a relatively small part, is generally more costly than disposal. Finally, the available data did not suggest that any one type of recycling -- i.e., secondary, tertiary, or quaternary -- was superior from an economic perspective.

4.2. RECENT ESTIMATES OF THE COST OF DISPOSAL

The costs of disposal have increased enormously in recent years. In 1987 the national average cost of landfilling had increased to $20.36 per ton and waste-to-energy incineration had increased to $33.64 per ton in 1987 dollars. In 1986 the average cost of landfilling was $13.43 and the cost of waste-to-energy incineration was $30.42 in 1986 dollars. What may be more shocking is the range of landfilling costs across regions in 1987 -- ranging from a low of $3.15 per ton to $75.00 per ton. Nominal costs of landfilling by region were: West $10.01 (1986) $10.75 (1987); South $10.95 (1986) $12.27 (1987); Midwest $10.86 (1986) $12.71 (1987); and Northeast $20.59 (1986) $39.23 (1987).[3]

4.3. RECENT ESTIMATES OF THE COST OF RECYCLING

Three additional revenue/cost estimates have been identified. These include the ET/1 extruder, the Recyclingplas process, and a materials recovery process developed by Bezner Systems

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[3]This information was obtained from the March 1988 issue of Waste Age magazine, which conducts a yearly survey of disposal facilities around the country.

and operated in the U.S. by CR Inc. All estimates are given in 1988 dollars. The cost estimates are disaggregated into operating and capital costs. To avoid the problem of dealing with different rates of capital depreciation, capital costs are dealt with as though all capital is rented. In other words, it is assumed that capital investments must earn some real annual gross rate of return. While there is no general agreement on what this rate should be, the commonly used 15% rate is adopted as the base case. A low rate of 10% and a high rate of 20% are given as alternatives to assess the sensitivity of changing the capital cost component.

4.3.1. The ET/1 Extruder

The ET/1 Extruder process was developed in Belgium and has been used commercially in Europe for more than two years. The process has recently been adopted in the United States. Mid-Atlantic Plastic Systems, Incorporated, the U.S. agent for the ET/1 system, provided technical information about the system and cost and revenue information from which the cost/revenue estimates given in Table 4.1 were derived.

The process can accommodate a waste stream that contains various plastic resins and can tolerate as much as 50% non-thermoplastic contamination, although no more than 20% contamination is preferred. The ET/1 is based on a specially designed adiabatic extruder feeding a set of linear tubular molds housed in a water filled cooling bath. The resulting products of the process are claimed to be substitutes for similar products made from lumber or concrete.

Table 4.1 presents an assessment of the estimated costs and revenues associated with the ET/1. Note that it is assumed that input materials can be purchased at $0.06 per pound. Further

TABLE 4.1. COST/REVENUE ESTIMATES FOR THE ET/1 PROCESS (IN 1988 DOLLARS)

Capacity 2,304,000 pounds/year
Capital Cost $513,865

	Interest rate 10%	15%	20%
Interest on capital	$ 51,387	$ 77,080	$ 102,773
Production cost/year	346,586	346,586	346,586
General and administrative costs/year	113,386	113,386	113,386
Materials purchased @ $.06/pound	138,240	138,240	138,240
Total cost	$ 649,599	$ 675,292	$ 700,985
Total revenues			
@ $.30/pound	$ 691,200	$ 691,200	$ 691,200
@ $.50/pound	$1,152,000	$1,152,000	$1,152,000
Net revenue			
@ $.30/pound	$ 41,601	$ 15,908	$ -9,785
@ $.50/pound	$ 502,401	$ 476,708	$ 451,015
Net revenues per ton			
@ $.30/pound	$ 36.11	$ 13.81	$ -8.49
@ $.50/pound	$ 436.11	$ 413.81	$ 391.58

NOTE: Calculations are based on single ET/1 machine.

SOURCE: Data on cost and revenues from Maczko (1988).

note that two revenue assumptions are tested -- product sales at $0.30 per pound and at $0.50 per pound. At $0.50 the ET/1 is estimated to be quite profitable at all assumed rates of interest, with net revenues per ton ranging from about $392 to $436. Note that net costs are estimated in only one case -- a 20% interest rate in combination with a $0.30 price for the product sold. However, even in this worse case, the net cost is less than the $20.36 average cost of landfill in the United States.

4.3.2. The Recyclingplas Process

The Recyclingplas process was developed in West Germany and has been used commercially in Europe. The process was recently acquired by a new company in Atlanta, Georgia -- Innovative Plastic Products, Incorporated -- from which the base information presented in this subsection was obtained.

Like the ET/1, the Recyclingplas process can accommodate commingled plastics that contain at least 50% thermoplastics. The Recyclingplas process differs, however, from the ET/1 in that a significantly higher output rate is possible. The process also differs in that the products are extruded and compression molded. Multiple sizes of sheet and shapes are possible with the Recyclingplas process, whereas the ET/1 is more limited to plastic lumber.

Table 4.2 presents summary information about the estimated costs and revenues associated with the process. Note that input material costs were quoted at $0.10 per pound, as compared to $0.06 assumed for the ET/1. Also note that the assumed price at which the products can be sold is somewhat higher than in the case of the ET/1 -- $0.50 and $1.00 per pound. Given the assumptions made, the net revenues associated with the Recyclingplas technology are estimated to be higher than those associated with the ET/1. At $0.50 per pound, net revenue estimates range from $560 to $634 per ton. At $1.00 per pound, net revenue estimates range from $1,560 to

TABLE 4.2. COST/REVENUE ESTIMATES FOR THE RECYCLINGPLAS PROCESS (IN 1988 DOLLARS)

Capacity 14,000,000 pounds/year
Capital Cost $4,000,000

	Interest rate		
	10%	15%	20%
Interest on capital	$ 400,000	$ 600,000	$ 800,000
Mold cost*	60,000	120,000	180,000
Operating costs	700,000	700,000	700,000
Materials purchased @ $.10/pound	1,400,000	1,400,000	1,400,000
Total cost	$ 2,560,000	$ 2,820,000	$ 3,080,000
Revenues			
@ $.50/pound	$ 7,000,000	$ 7,000,000	$ 7,000,000
@ $1.00/pound	$14,000,000	$14,000,000	$14,000,000
Net revenues			
@ $.50/pound	$ 4,440,000	$ 4,180,000	$ 3,920,000
@ $1.00/pound	$11,440,000	$11,180,000	$10,920,000
Net revenues per ton			
@ $.50/pound	$ 634.28	$ 597.14	$ 560.00
@ $1.00/pound	$ 1,634,.28	$ 1,597.14	$ 1,560.00

*Mold life depends on the type of material being processed and can vary from three-four years for rough materials to about ten years for smooth, less-contaminated materials. In this calculation, mold cost is treated as a capital cost, as is the case with the assessment of the ET/1 technology.

SOURCE: Data on costs and revenues from Kelly (1988).

$1,634 per ton. Note that the capacity of each Recyclingplas unit is 14 million pounds per year, as compared to 2.3 million pounds per year for the ET/1 units.

4.3.3. The Bezner Systems Processs

CR Inc. is a company that currently recycles commingled municipal wastes in the New England area. Recently the company purchased and is the North American representative for a new sorting technology by Bezner Systems, a European company. The design is currently employed in 16 materials recovery facilities (MRFs) worldwide. Given that this technology is designed to separate PET and HDPE bottles from other curbside-collected municipal wastes, the technology could lead to significant quantities of relatively clean plastic waste that could be used in processes such as the ET/1 or Recyclingplas. CRInc. currently employs the ET/1 to recycle the plastics retrieved from their recycling operations. Other materials separated by the sorting technology include newspaper, glass bottles, aluminum cans, and tin cans. Note that the incoming waste is from curbside collection programs in which these recyclable materials are collected as a common commingled waste stream at the household level. The main benefit of this technology is that the recyclable materials can be collected as a common waste stream, rather than collected individually, as is currently done in some curbside collection programs.

Cost information was obtained from Torrieri (1988). That information was used to arrive at the cost/revenue estimates for the sorting technology presented in Table 4.3. Note that it is assumed that the incoming commingled waste is obtained at zero cost. Further note that the segregated plastic waste is assumed to be sold for $0.06 per pound, which is consistent with the assumed input price for plastics entering the ET/1 process given in Table 4.1. Other materials are sold according to the prices given in the table.

'ABLE 4.3. COST/REVENUE ESTIMATES FOR THE BEZNER SYSTEM SEPARATION PROCESS (IN 1988 DOLLARS)

Capacity* 40,000 tons/years
Capital Cost $3,000,000

	Interest rate		
	10%	15%	20%
Interest on capital	$ 300,000	$ 450,000	$ 600,000
Operating costs	1,000,000	1,000,000	1,000,000
Total costs	$ 1,300,000	$ 1,450,000	$ 1,600,000
Revenues**			
Newspaper @ $.015/pound	$ 456,000	$ 456,000	$ 456,000
Glass bottles @ $.02/pound	456,000	456,000	456,000
Aluminum cans @ $.50/pound	760,000	760,000	760,000
Plastic bottles @ $.06/pound	364,800	364,800	364,800
Tin cans @ $.01/pound	152,000	152,000	152,000
Total revenues	$ 2,188,800	$ 2,188,800	$ 2,188,800
Net revenues	$ 888,800	$ 738,800	$ 588,800
Net revenues per ton	$ 22.22	$ 18.47	$ 14.72

*Approximately 5% of the incoming curbside waste must be disposed of. Therefore, the 40,000 tons/year capacity implies that 38,000 ton/year is recyclable.

**The incoming curbside waste is assumed to have the following composition by weight: newspaper, 40%; glass bottles, 30%; aluminum cans, 2%; plastic bottles, 8%; tin cans, 20%.

Source of revenue estimates: Plastic Recycling Foundation, Annual Report 1988, under "Highlights of Activities."

Source of other information: Torrieri (1988).

Given the available information, the sorting process is estimated to result in net revenues of between about $15 and $22 per ton, depending on the assumed interest rate.

5. AN UPDATE OF RECENT INSTITUTIONAL CHANGES THAT MAY PROMOTE RECYCLING

Curlee (1986) concluded that plastics recycling is often hindered by institutional constraints that discourage the formation of required markets for waste materials and recycled products. Those same institutional constraints were also concluded to slow or prohibit the flow of information about available technologies, environmental impacts, economic viability, and regulatory issues. This section of the report summarizes recent developments in public-sector and private-sector institution building that may have significant positive implications for the future of plastics recycling.

Plastics recycling often requires the cooperation of plastic manufacturers, consumers, waste processors, and the public sector to overcome nontrivial barriers. And there are numerous arguments why each of these parties when acting individually has both incentives and disincentives to contribute to recycling efforts. If any one of the required parties faces a net disincentive to recycle, that party can, in effect, block a recycling effort that from a social perspective would result in positive net benefits. The formation of institutions through which cooperation and bargaining can occur is one means of "smoothing out" the incentives and disincentives among the various parties, such that the true social benefits of recycling can be realized.

The recent development of institutional structures that facilitate market formation and the flow of information is a major step towards encouraging plastics recycling. Several specific examples can be cited for both the public and private sectors.[4]

5.1 INDUSTRY SPONSORED GROUPS

Industry sponsored groups formed in recent years have greatly facilitated the flow of information about various aspects of recycling, provided financial support for the development of

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[4]Note that recent developments in the area of government legislation and regulation are discussed in Section 6 of this report.

new technologies and the preparation of reports on topics such as environmental effects and market assessments, and helped solidify industry's position on some controversial issues. For example, The Plastics Recycling Foundation (PRF), which is centered at Rutgers University and is funded by both industry and state government, has been instrumental in developing and publicizing technology to recycle PET bottles. More recently, PRF has entered the commingled, secondary-recycling field with their purchase of an ET-1 machine and initiation of a pilot program for curbside collection of plastic containers in two New Jersey municipalities. The containers, which are made from various resins, are being manufactured into lumber-like products using the ET-1 machinery. Another industry sponsored group, the National Association for Plastic Container Recovery based in Charlotte, North Carolina, has set a goal of recycling 50% of all PET Bottles by 1992. The group, which is sponsored by several large resin producers, will indirectly promote the use of PET for beverage bottles by facilitating post-consumer uses.

Industry sponsored organizations, such as the Society for the Plastics Industry (SPI), are providing detailed information about the opportunities for plastics recycling and about the firms currently involved in recycling activities. The SPI has also proposed that industry adopt a voluntary digital and letter code that would identify the resin contained in a product. The code, which may facilitate separation in some cases, would affect bottles exceeding 16 ounces and other containers exceeding 8 ounces.

The Council for Solid Waste Solutions, another recently formed industry-sponsored group, will sponsor technical research and public education to increase plastics recycling. The group, sponsored by several major resin producers, recently announced it will spend $8.5 million to conduct research on plastics recycling and disposal and to promote government relations. Among the R&D topics to be addressed are minimizing collection costs, plastics separation, emissions from plastics when incinerated, and methods to characterize degradability.

Actions by individual companies are also promoting technology and market development. For example, General Electric Plastics and Luria Brothers have recently announced plans to collect and recycle engineering resins based on polycarbonate, thermoplastic polyester, and other polymers from scrapped automobiles. These parts will be collected before automobiles enter an automobile shredder -- the typical approach to separating the metallic and non-metallic components in automobiles. Another example is the Solid Waste Management Solutions Group formed at Mobil Chemical Company. The stated objective of that new group is to develop and implement methods for recycling and disposing of plastic wastes.

5.2. PUBLIC SECTOR ACTIONS

At the public-sector level, the EPA, through its Solid Waste Task Force, has recently set a goal of recycling at least 25% of all municipal waste by 1992. Although EPA has no power to enforce the goal directly, the stated objective acts as moral persuasion for industry and local and state governments to increase all recycling activities. The task force has also called for federal actions to promote markets for secondary goods, which may include additional federal procurement of secondary goods (note that some procurement currently occurs under the Resource Conservation and Recovery Act). Two additional actions are also being considered: the development of a national recycling council to explore international markets, and research to investigate how states might use tax incentives and loans for industries using or processing secondary materials.

An EPA official has stated that the plastics area is one of two areas in which the federal government should take the lead in promoting recycling. EPA has also directly encouraged the plastics industry to promote recycling by product design and possibly by color coding different types of plastics. Recently, the EPA announced plans for the establishment of a national clearinghouse for information relevant to all forms of recycling. Actions at the state and local levels are also setting recycling goals and creating or promoting institutions that facilitate plastics recycling. Specific examples are given in the following section.

6. RECENT LEGISLATIVE AND REGULATORY ACTIONS

Local, state, and federal governments are passing legislation and implementing specific regulations that directly or indirectly affect plastics recycling. An assessment of these activities is important in assessing the viability of particular plastic recycling technologies and in evaluating the potential size of DPW. Curlee (1986) summarizes the activities prior to that book's publication. This section summarizes recent activities in this area.

Since 1986 legislative and regulatory activities have mushroomed at the local and state levels; and that movement is now reaching the federal level of government. Although a review of all the specific bills and regulations that affect plastics recycling is beyond the scope of this report, a review of some examples helps to identify the direction in which this movement is headed.

6.1. LOCAL AND STATE ACTIONS

Numerous actions have been taken at the local and state levels that, in general, promote recycling. For example, the National Solid Waste Management Association (NSWMA) reports that at lease six states currently require local jurisdictions to offer or provide recycling as an option to households. At least two of those states -- New Jersey and Rhode Island -- require some separation of waste materials at the source, meaning the household or business. Oregon was one of the first states to promote recycling. Its 1983 Opportunity to Recycle law requires that municipalities with populations over 4,000 must provide recycling drop-off centers and offer curbside collection of recyclables at least once per month. Household participation remains voluntary. Oregon also supports educational activities that appear to be successful. Although only 70 localities are covered by the law, more than 110 have established recycling programs. Many state laws set goals for recycling municipal solid waste -- usually about 25% of weight, but range between 15% to 50% -- and may have strong economic measures that take effect if the goals are not met.

A 1987 law passed in New Jersey labeled the "Mandatory Recycling Act" requires households to separate certain materials and gives municipalities until 1989 to achieve a recovery rate of 25%. The state government requires local governments to design their own programs and provides $8 million to those local governments in start-up aid. The program is funded by a tax on landfill use of $1.50 per ton and requires that a minimum of three materials be recycled -- with the specific materials to be selected by the local governments. While these actions have not in general been directed specifically at recycling plastics, they have indirectly encouraged plastics recycling by (1) fostering the formation of channels to collect recyclable materials and (2) providing moral suasion for consumers and plastic manufacturers to promote recycling.

Mandatory bottle deposits are probably the best known state measures that have directly promoted plastics recycling. At least 11 states currently have bottle deposits laws of some form. Typically, the deposits apply to beverage bottles of all types and are usually five cents per bottle.[5] These laws have been the key to the most publicized plastics-recycling success story -- i.e., PET beverage bottle recycling.

Several states offer incentives for firms involved in recycling activities. For example, Oregon offers income tax credits for the purchase of recycling equipment and facilities. New Jersey offers a 50% investment credit for recycling equipment. Indiana offers property tax exemptions for buildings, equipment, and land used for recycling operations. Wisconsin offers sales tax exemptions for equipment and facilities and some business property tax exemptions for some recycling equipment. North Carolina offers industrial and corporate tax credits and exemptions for recycling equipment and facilities. Other state actions include direct subsidies, grants, technical assistance, and low-interest loans.

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[5]Roth (1985) reports that bottle reclamation rates average 90% or better in states with bottle deposit laws.

In addition some states give preference to recycled goods through government procurement and other programs. For example, Oregon allows their state departments to pay up to 5% more for recycled products that contain either 50% industrial waste or 25% post-consumer waste, as compared to products made from virgin materials. Vermont has set goals for purchasing recycled goods -- 25% by 1990 and 40% by 1993. The procurement program in New York provides a 10% price preference and requires a recycled content of at least 40% to qualify for the preference. California's law provides a 5% price preference and requires recycled content to be 50%, including 10% post-consumer waste. The National Solid Waste Management Association (NSWMA) reports that at least 18 states have some type of procurement laws for recycled products. Keller (1988) reports that 19 states and four local governments have laws in place that favor recycled products, covering more than 60% of the total U.S. population. Further, at least 13 additional states have considered legislation in 1988 to establish or expand their procurement programs.

A recently passed law in Florida requires localities to reduce landfilling by 30% by 1993, mostly by increased recycling. Taxes and fees on a variety of products will be used to encourage recycling projects. The heart of the new legislation is, however, the provision that requires that a one cent charge be assessed on every type of retail container sold (i.e., plastic, glass, plastic-coated paper, aluminum, and other metals) that does not reach a 50% recycling rate by October 1, 1992. The fee will rise to two cents if the target is not met by October 1, 1995. California recently passed a beverage bottle law that has similar provisions.

While the focus of most states has been on recycling in general, some states are now focusing specifically on plastics recycling. For example, the state of Massachusetts recently issued a report calling for a sustained, aggressive effort to make plastics recycling work in that state. [See Brewer (1988).] Although other states have mandated curbside collection of separated wastes, Massachusetts is the first state to call for the separate collection of plastics. Glass, cans, and newspapers will also be collected. The plan calls for 45% of all rigid plastic containers to be recycled by the year 2000. To get the plan started, the state will help fund construction by 1990 of at least two production-sized plants, one for recycling polyolefins and one for recycling mixed plastics.

At the regional level, several Northeastern states have joined together to promote recycling. The June 1988 issue of Waste Age reports that "The Coalition of Northeastern Governors (CONEG) is advocating a coordinated, comprehensive solid waste management policy incorporating source reduction and recycling, refuse-to-energy, and landfilling." (page 8). The coalition will work to promote secondary markets; provide information to residents about risks, choices, and benefits; investigate which materials can be recycled; set standards for waste facilities; and establish regulatory schemes for incinerator ash.

Another important set of state and local actions has indirectly affected the overall viability of plastics recycling -- i.e., actions to reduce or prohibit the use of plastics in particular applications or to mandate that some plastics be degradable. A common argument used against degradables is that mixing degradables with non-degradables may severely constrain the types of recycling technologies that can be used.

Most of these actions have been directed at banning or limiting the use of plastic packaging and/or proposing packaging or product taxes. Measures are being considered in several states that would require some or all packaging to be biodegradable. Although several measures have passed, many more bills are currently pending.

The recently passed bans on selected plastic packaging in Suffolk County, New York and Berkeley, California are prime examples of local initiatives. These laws can be criticized for being somewhat arbitrary and for being inconsistent across retail markets. In the opinion of most experts, the benefits of the laws will be insignificant in terms of reducing either the size or toxicity of the municipal waste stream. These particular laws are, however, most important for the general message they send. Local governments in some cases view plastics as a major problem in the municipal waste stream -- either because of the quantity of waste contributed by plastics or because of perceived environmental problems. And in some cases, plastics have become a scapegoat for the severe problems some localities are currently experiencing in disposing of their municipal wastes.

Several states are proposing a tax, ranging from one to five cents per package, on materials used to package consumer products. For example, some legislators in Massachusetts have recently called for a packaging disposal tax of three cents per layer on non-food products retailed in that state. Others in that state are calling for bans on the use of certain plastics in packaging and for restricting all packaging to contain only one resin. The recently passed Florida waste bill requires as of January 1, 1990 that any plastic shopping bags used by retailers in that state must degrade within 120 days.

Several additional states are considering legislation that would require all or most packaging materials to be degradable. Some examples: A proposed Vermont law would establish a five cent per package tax on goods sold at the wholesale level if the wholesale dealer does not certify that at least half of the packaging sold in the state by that firm is manufactured from recycled materials. A Missouri bill would prohibit any manufacturer, retailer, or wholesaler from selling products transported in containers using any petroleum-based, non-biodegradable materials. A proposed California law would require all one-time plastic containers and packaging to be either recyclable or biodegradable. A recently passed Maine law prohibits the use of non-degradable individual food and beverage containers by food services at state or local municipal facilities or functions. Sales and use tax incentives for degradables are provided in Iowa.

Several states, including Washington and Oregon, have proposed to require all disposable diapers sold in their states to be biodegradable. And at least 16 states now ban non-biodegradable plastic yokes on six-pack beverage containers.

6.2. FEDERAL ACTIONS

Incentives at the federal level have been much less specific than at the state and local levels. In fact, previous to the passage of the Resource Conservation and Recovery Act in 1976, the federal government had little to do with plastics recycling or municipal waste management in general. Prior to 1976 the federal role was defined by the 1965 Solid Waste Disposal Act, which authorized federal involvement in R&D in solid waste management, and by the 1970 Resource Recovery Act, which strengthened the federal government's R&D activities.

RCRA's subtitle D addresses municipal waste by, for example, mandating regulations on landfills and incinerators, establishing procedures for states to develop solid waste management plans, and calling for procurement guidelines for recycled materials.[6] Yet, under RCRA the states retain primary responsibility of municipal waste management.

Another statute that has implications for state and local MSW management is the Clean Air Act, which in its reauthorized form may impose stricter standards on incinerator emissions. The Public Utility Regulatory Policies Act (PURPA), which requires utilities to purchase electric power from independent suppliers, such as electricity-producing incineration facilities, indirectly promotes incineration. Finally, the Energy Act of 1978 provided an investment tax credit for recycling equipment from 1978 to 1983. That particular incentive has been discontinued.

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[6]EPA recently established guidelines for federal procurement of recycled paper, re-refined oil, remanufactured tires, and building insulation made from recycled materials. Note that the standard for insulation may include some plastics. For example, McDonalds restaurants has recently initiated a program to recycle its polystyrene containers for non-food purposes -- one product being insulation. See Keller (1988) for additional information on recent federal procurement actions.

Action at the federal level to address the problem of municipal waste has quickened recently. For example, new legislation has been introduced in the U.S. Senate to reauthorize RCRA, which officially expired in September 1988. The Baucus Bill [Senator Max Baucus (D-MT)] calls for more federal involvement in MSW management and will probably be debated in the current session of Congress. Labeled "The Waste Minimization and Control Act," the bill sets ambitious goals, such as 25% recycling in four years, a 10% reduction in municipal solid waste within four years, waste minimization performance standards to be implemented within ten years, federal assistance to states to promote waste reduction and recycling opportunities, and federal procurement of recycled goods. Each state would be forced to develop a solid waste plan. The legislation would also establish a $7.00 per ton fee on new, unused materials to be utilized in packaging, including plastics.

Another example of proposed federal statutes is the Recyclable and Degradable Materials Act of 1988. If the provisions of this act should become law, they would mandate that within ten years all nondurable consumer goods made or sold in the U.S. be recyclable or composed of degradable materials. This legislation is an example of the recent movement against the use of conventional plastics in packaging.

Other federal actions have also been directed at degradable plastics.[7] For example, recent legislation introduced by Senator John Glenn (D-OH) would stimulate the market for biodegradables by forcing the federal government to give preference to buying degradable plastic products. In addition, Senator Sam Nunn (D-GA) supports degradables and amended the

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[7]At the request of Senator John Glenn, the General Accounting Office (GAO) published in September 1988 a report on degradable plastics. The GAO report found that the federal government and the private sector are only making limited efforts to develop standards for degradable plastics, which in the opinion of the authors has seriously hurt R&D efforts. The report says that "virtually no testing of degradable plastics has been done...." Testing remains necessary to resolve two basic technical uncertainties about the performance of degradable plastics in the environment: the rate of degradation and the safety of the end products. The report also states that several bills, including one by Senator Glenn, have been introduced in the U.S. Congress to promote or mandate the use of degradable plastics.

Department of Defense (DOD) authorization bill for 1989 to require DOD to study the feasibility of using biodegradable plastics made from corn. Recently enacted federal legislation requires that within two years any plastic beverage yokes be degradable, unless the EPA determines that the by-products of degradation pose a greater threat to the environment than non-degradable yokes.

The recently passed United States-Japan Fishery Agreement Approval Act of 1987 places restrictions on the dumping of plastics at sea and calls for two government studies -- one by EPA to study methods to reduce plastics pollution in the environment, with emphasis on recycling, degradability, and the development of incentives, and another by the Department of Commerce to study the effects of plastic materials on the marine environment and provide recommendations to prohibit, tax, or regulate all sources of plastic materials that enter the marine environment.

Forthcoming regulations concerning incinerator ash management and air emissions either from EPA or as mandated in a revised Clean Air Act could have implications for the acceptability of plastics in the waste stream, and thereby influence the viability of plastics recycling. In particular, regulations on dioxin emissions from incinerators may be forthcoming, which will bring additional emphasis to the hotly debated relationship between PVC and dioxins. Potential regulations concerning heavy metal emissions will also bring additional attention to plastics.

6.3. IMPLICATIONS FOR PLASTICS RECYCLING

The numerous government actions that impact on plastics recycling have in most cases promoted, but in other cases discouraged, additional recycling. Some measures directly mandate that recycling occur, others indirectly make the option of recycling more attractive, and yet others promote alternative responses to the "plastics problem" -- i.e., measures such as degradability and source reduction.

It is increasingly clear that all levels of government view plastics as a components of the waste stream that requires some type of public-sector attention. Unfortunately, the rules and regulations currently being imposed are in some cases inconsistent; and the public sector has not as yet established what the overall goal should be with respect to plastic wastes. This lack of consensus is a reflection of the great technological, environmental, and institutional uncertainties currently faced by public-sector decision makers. And until more credible information is available about the option of recycling as compared to the options of disposal, degradability, and bans on the use of plastics, it can be expected that government actions will continue to vary in terms of purpose and scope. Although additional recycling will likely result from public-sector incentives, the uncertainties associated with future government programs will make the adoption of recycling by private firms a risky venture.

7. THE POTENTIAL FOR DIVERTABLE PLASTIC WASTE

This section discusses the potential size and composition of divertable plastic waste (DPW) -- i.e., plastic wastes that could be diverted from the general municipal waste stream and be a candidate for recycling in a secondary or tertiary sense. The first step in this process is to develop a set of realistic scenarios, which are combinations of technical, economic, institutional, and regulatory conditions. In the second step, these scenarios are used in combination with plastic waste projections presented in Section 2 to assess the potential for DPW, given future technological, economic, institutional, and regulatory developments.

7.1. SCENARIO DEVELOPMENT

For the purposes of this section, five general scenarios are developed. The technical, economic, institutional, and regulatory assumptions underlying these scenarios range from very optimistic to very pessimistic in terms of the relative constraints on the supply of and demand for plastic wastes of different types. Note that at this point in time at least some information is available to argue for the validity of each scenario. Scenario 1 presents the most restrictive assumptions; scenario 5 presents the least restrictive assumptions.

7.1.1. Scenario 1

In scenario 1 it is assumed that technological and/or economic conditions are such that plastics recycling is viable only for those thermoplastic wastes that are available in a clean, single-resin form. It is also assumed that institutional and regulatory conditions are such that no curbside collection of plastic wastes occurs. Neither is there a national bottle deposit bill. In this scenario, plastics recycling faces severe supply-side and demand-side constraints.

7.1.2. Scenario 2

In scenario 2 it is assumed that technological and/or economic conditions dictate that clean, single-resin thermoplastic wastes must be obtained in order for recycling to be viable. It is assumed, however, that viable separation technologies exist that can separate a clean stream of two or three commingled resins into individual resin streams. The institutions or regulations that provide for curbside collection of PET and HDPE packaging are assumed to exist. All PET and HDPE containers and lids are labeled according to the resins used for manufacture. Other household plastics are assumed to be collected as part of the general municipal waste stream. In this scenario both supply-side and demand-side constraints are eased slightly.

7.1.3. Scenario 3

In scenario 3 it is assumed that technical and economic conditions are such that commingled thermoplastics can be recycled without further separation. The commingled plastics can either be cleaned and separated into individual resins or the mixture can be recycled without further cleaning and separation into products such as plastic lumber. Non-thermoplastic contamination of as much as 50% can be accommodated. Institutional and regulatory conditions are such that no curbside collection of segregated plastics exists. In addition, there are no viable technologies available to separate plastics from other materials in the general waste stream. As compared to Scenario 2, this scenario represents less severe demand-side constraints.

7.1.4. Scenario 4

It is assumed that any clean commingled plastics are applicable for recycling in scenario 4. Commingled wastes consisting of at least 50% thermoplastics can either be recycled in their contaminated form or further cleaned and separated to produce higher-valued products. Institutions and regulations are assumed to provide curbside collection of a segregated stream of household and commercial plastics. It is assumed that households and commercial operations do not separate individual resins. Any required separation and/or cleaning is done after collection. In this scenario, supply-side restrictions are eased as compared to Scenario 3.

7.1.5. Scenario 5

In this least restrictive scenario, it is assumed that technical and economic conditions exist such that any dirty, commingled plastic wastes are candidates for secondary or tertiary recycling. It is assumed that thermosets can be recycled either as fillers or processed by tertiary means. Technologies are assumed to exist that can technically and economically separate the majority of plastics from other materials in the municipal waste stream into a form acceptable for secondary or tertiary recycling. Plastics need not be collected as a segregated waste stream. In this scenario, improvements in the collection of solid wastes are not required to promote additional plastics recycling.

7.2. ESTIMATED QUANTITIES OF DPW

In this subsection, estimated quantities of DPW are given for each of the scenarios described above. The estimates given are for the year 2000 and are derived from information given in Section 2. Both manufacturing and post-consumer wastes are considered.

7.2.1. Scenario 1

The restrictive assumptions of Scenario 1 imply that few plastics will meet the requirements of DPW, in addition to those plastics already being diverted and recycled. In this scenario, no additional manufacturing waste will be a candidate for recycling. It can be assumed that any clean manufacturing waste containing only one resin is already being recycled in some form. Recall that about 75% of all manufacturing wastes is currently recycled.

The possibilities for DPW from the post-consumer waste stream are also very limited. DPW will be limited to plastics collected as part of state bottle deposit programs and single-resin plastics that are delivered to a collection center by households. Without significant changes in institutions and regulations, the quantities of plastics delivered to collection centers by households are likely to be very small. The potential for DPW in this scenario is therefore no greater than the quantity of post-consumer plastics currently being recycled in this country -- about 1% of all post-consumer plastics.

7.2.2. Scenario 2

It is unlikely that easing the restrictions on plastics recycling as depicted in Scenario 2 will significantly increase the percentage of manufacturing waste that can be classified as DPW. Most clean plastic wastes containing two or three thermoplastics are currently being recycled. Neither will the easing of the restrictions contribute to the recycling of post-consumer wastes, with the exception of PET and HDPE packaging.

The marginal contribution of easing supply-side and demand-side restrictions as given in Scenario 2 will therefore be limited to PET and HDPE packaging -- in particular the container portion of the packaging sector. (Note that other packaging applications, such as films and coatings, will not be retrievable under the assumptions of this scenario.) A recent study by Robert A. Bennett (1989) estimated that about 130 million pounds of PET were recycled in 1987. About 58 million pounds of HDPE were recycled. Modern Plastics estimates that in 1987 a total of 3,331 million pounds of HDPE was used in the manufacture of containers. A total of 900 million pounds of PET was consumed in the production of containers. Therefore, the marginal contribution of collecting and recycling all post-consumer HDPE and PET containers would be 3,273 million pounds of HDPE and 770 million pounds of PET -- or a total of 4,043 million pounds given 1987 data. Modern Plastics estimates that total resin usage for containers in 1987 was 6,433 million pounds. A total of about 63% of all containers could therefore be recycled, given the conditions of Scenario 2. The total usage of plastics for all packaging was estimated at 12,649 million pounds in 1987.

It is estimated in Section 2 of this report that a total of 11,187 million pounds of plastic waste will come from plastic containers in the year 2000. Total plastic waste from all packaging is projected to total 21,090 million pounds in 2000. If we assume that the marginal contribution of recycling HDPE and PET containers in 2000 is in percentage terms the same as for 1987, the marginal contribution of easing recycling restrictions as given in Scenario 2 is equal to 7,031 million pounds of additional plastic waste available for recycling. The projected total quantity of plastics entering the post-consumer waste stream in 2000 is 48,669 million pounds. Therefore, a marginal improvement in the quantity of plastics available for recycling of 7,031 million pounds would be equivalent to 14% of all post-consumer plastics.

7.2.3. Scenario 3

Scenario 3 presents a situation in which commingled wastes are acceptable for recycling if at least 50% of the waste stream is composed of thermoplastics. There is, however, no curbside collection program to provide post-consumer waste as a segregated waste stream. Neither is there a viable separation system that can separate plastics from other materials in the municipal waste stream. Under these conditions, the availability of waste from the post-consumer waste stream will not change from the current situation.

The demand-side improvements represented in this scenario do, however, make it more likely that some or all manufacturing nuisance plastics will become divertable plastic wastes. The exact percentage of current manufacturing nuisance plastics that would be affected cannot be estimated because detailed information about the contamination levels of different parts of that waste stream is not currently available.

Significant additions to DPW are obtained if it is assumed that all of the thermoplastic portion of manufacturing nuisance plastics becomes recyclable as a result of technical and/or economic improvements. The thermoplastic portion of the manufacturing nuisance waste stream is estimated to total 1,801 million pounds in 2000 if the assumptions adopted in Table 2.5 are adopted. The estimates for 2000 increase to 3,602 million pounds if more pessimistic assumptions -- those represented in Table 2.4 -- are adopted.

7.2.4. Scenario 4

In Scenario 4 the demand-side constraints are the same as in Scenario 3; however, the potential for supplying the required waste stream is increased tremendously by the addition of curbside collection of all household and commercial items that are made predominantly from plastics. The potential for DPW in this scenario is therefore all the manufacturing nuisance plastics discussed in the above assessment of Scenario 3, as well as any household and commercial wastes that could be collected as part of a curbside collection program.

It is anticipated that a curbside collection program will target the collection of packaging and consumer and institutional goods. It is assumed that virtually all packaging items, with the exception of coatings, could be collected by a curbside recycling program. In addition, the vast majority of consumer and institutional goods could be collected if a 50% contamination level is acceptable.

By the year 2000 it is projected that the use of plastics for closures, films, and containers will total 19,455 million pounds. Consumer and institutional goods will total 4,920 million pounds. Combined, the two product sectors could contribute 24,375 million pounds to secondary and tertiary recycling streams. Given that post-consumer plastics are projected to total 48,669 million pounds in 2000, recycling all consumer and institutional goods and all packaging, with the exception of coatings, could reduce the quantities of post-consumer plastics going to landfills and/or incinerators by 50% of its weight. (Note that while thermosets may not be recyclable in this scenario, it is likely that thermosets would be collected with thermoplastics in a curbside collection program. Thermosets would be considered a contaminant in this case. In the case of packaging, thermosets are projected to represent only 0.4% of the total waste stream. In the case of consumer and institutional goods, thermosets are projected to represent 3.2%.)

7.2.5. Scenario 5

Scenario 5 allows for the technical and economic feasibility of recycling dirty commingled plastics. Collection is not particularly important in this scenario, because it is assumed that either separation technologies exist that can economically separate plastics from other waste materials or processes exist that can recycle the commingled waste stream in either a secondary or (more likely) tertiary sense.

In this scenario, all manufacturing nuisance plastics can be classified as DPW. These less restrictive assumptions also open several large post-consumer product sectors to DPW consideration. In particular, plastics from automobiles and other transportation applications may qualify as DPW. Automobiles are usually recycled for their metallic content by shredding the vehicles into fist-size pieces and separating the metallic from the non-metallic pieces. The non-metallic residue contains most of the plastics, which can account for 10% to 20% of the residue's total weight. Plastic wastes from the automobile sector are projected to total 1,947 million pounds in 2000. Wastes from other transportation applications are projected to contribute another 549 million pounds. The two sectors combined are projected to account for 5.1 percent of all post-consumer plastics in 2000.

The less restrictive assumptions may also increase the potential for recycling plastics from the building and construction sector, electrical and electronic goods, furniture, and industrial machinery. These product categories are projected to contribute the following percentages to the post-consumer plastics wastes stream in 2000: building and construction, 8.0%; electrical and electronic goods, 5.7%; furniture, 7.0 %; and industrial machinery, 0.8%.

The potential for recycling plastics from these sectors under the conditions of Scenario 5 are not clear because of insufficient information on the usual methods used to recycle or dispose of wastes from these product categories. Industrial machinery and electrical and electronic goods are sometimes recycled for their metallic contents. The remaining residue may contain significant percentages of plastics. The use of plastics in the building and construction sector is growing at a rate exceeded only by the packaging sector. New methods for collecting plastics from the building and construction sector may make those plastic wastes candidates for DPW classification.

The only product classifications that would not appear to be candidates for DPW classification in Scenario 5 are adhesives and coatings. In 1987, adhesives and coatings accounted for only 1,797 million pounds or 3.6% of all plastics consumed in that year.

7.3. SUMMARY

Table 7.1 summarizes the demand-side and supply-side constraints assumed in the five scenarios. In addition, the table summarizes the potential marginal impacts that altering the supply-side and demand-side limitations to plastics recycling may have on the availability of DPW.

The most likely scenario for the coming decade depends for the most part on legislation and regulation at the state and federal levels. Scenario 1, which represents no easing of demand-side or supply-side restrictions, is not probable, given the current level of interest in plastics recycling. Neither is Scenario 5, which represents the development of an economically viable technology that can separate and recycle plastics, given that plastics are collected as part of a single solid waste stream. In the authors' subjective judgement, Scenario 4 is most probable during the coming decade. Commingled plastics containing at least 50% thermoplastics can be recycled currently into products that compete with lumber and concrete. Other more sophisticated technologies are under development that could produce higher valued products. The main uncertainty on the supply-side with respect to Scenario 4 is the economic viability of these existing and proposed processes. Significant uncertainties exist about the economic viability of plastic

TABLE 7.1. SCENARIO SUMMARY AND MARGINAL IMPACTS ON DPW

SCENARIO	DEMAND SIDE CONSTRAINTS	SUPPLY SIDE CONSTRAINTS	MARGINAL CONTRIBUTION TO DPW
1	Technological and/or economic conditions limit recycling to clean, single-resin waste. No viable separation technologies.	No curbside collection of plastics.	Zero. Quantities of DPW from manufacturing and post-consumer sectors remain at current levels.
2	Technological and/or economic conditions limit recycling to clear, single-resin waste. Viable separation technologies exist to separate two or three commingled resins from a clean waste stream.	Curbside collection of PET and HDPE packaging containers.	No marginal impacts on manufacturing wastes. Assuming all PET and HDPE conditioners are recycled: PET, 770 million pounds (year 2000) HDPE, 3,273 million pounds (year 2000). Equivalent to 14% of all post-consumer plastics.
3	Technological and/or economic conditions limit recycling to waste streams containing a minimum of 50% thermoplastics. No viable technology exists to remove plastics from the general waste stream.	No curbside collection of plastics.	No marginal impacts on post-consumer wastes. Most manufacturing nuisance plastics added to DPW. Depending on assumptions, marginal DPW additions range from 1,971 million pounds to 3,943 million pounds in 2000.
4	Same as Scenario 3.	Curbside collection of all items made predominantly from plastics.	Marginal impacts on manufacturing waste are same as in Scenario 3. Margin impacts on post-consumer waste equal to 24,375 million pounds in 2000, or the equivalent of 50% of all post-consumer plastic wastes.
5	Dirty, commingled plastic wastes are acceptable for recycling. Thermosets can be used as fillers or processed in a tertiary sense. Viable technologies exist to separate plastics from other materials in the general waste stream.	No curbside collection required.	Marginal impacts on manufacturing waste are same as in Scenario 3. Most post-consumer plastics become candidates for DPW, with exceptions of adhesives and coatings--which account for only 3.6% of all post-consumer plastics.

lumber and proposed tertiary processes both in terms of costs of operations and future product prices. [See Curlee (1989) for more details].

The availability of plastic waste from curbside collection programs is becoming less uncertain as the cost of disposal and incineration escalate and the institutions are put into place to facilitate such collection. The average cost of landfill in the U.S. has increased in nominal terms from $13.43 per ton in 1986 to $26.92 per ton in 1988. Certain parts of the country, especially the Northeast, have experienced drastic increases in the cost of landfill in recent years. In 1988 the average cost of landfill in the Northeast region was $45.48 per ton, as compared to $20.59 per ton in 1986. (Disposal cost estimates are from various issues of Waste Age magazine, which conducts a yearly survey of disposal costs.) A recent article in the February issue of Waste Age estimated that a curbside recycling program in an average U.S. municipality is economically feasible if the cost of disposal is greater than $20 per ton. Plastics were included in the analysis.

It is likely that the combination of economic, political, and institutional incentives will combine to increase significantly the curbside collection of commingled plastics within the next decade. If Scenario 4 is representative of the future, virtually all thermoplastic nuisance plastics and about 50% of all post-consumer plastics can be added to the classification of divertable plastic wastes.

8. PLASTICS RECYCLING FROM THE CURRENT INDUSTRY'S PERSPECTIVE

The Society of the Plastics Industry (SPI) publishes an annual listing of all the firms in the United States currently involved in one or more segments of the plastics recycling industry [Society of the Plastics Industry (1988)]. That listing was obtained, and individuals at selected firms were contacted by phone to informally assess the current industry's perspective of the technical, economic, institutional, and regulatory incentives and barriers currently facing their industry. Note that this process did not involve any questionnaire nor did it involve a formal interview format. The findings of the semi-structured interview format which was used cannot therefore be employed in any formal analytical way to assess the status or opinions of the current industry. However, given the rapidly changing nature and composition of the plastics recycling industry and the rapidly changing technical, economic, institutional, and regulatory environment in which that industry must operate, the authors are of the opinion that information gathered through informal conversations with industry representatives can be both informative and revealing.

According to the SPI data, 22 firms are currently involved in the manufacture of end products from plastic wastes. An additional 43 firms are involved in one or more of the other phases of recycling, i.e., equipment manufacture, brokering, processing, and third-party pickup. Figures 8.1, 8.2, and 8.3 show the geographical dispersion of the firms in the various phases of recycling. When the 22 firms involved in end-product manufacture are disaggregated by type of resin processed, 13 firms are primarily involved with PET, 15 with HDPE, and 10 with other resin types. Only firms involved in end-product manufacture were selected for our informal, semi-structured phone conversations. One additional firm involved in end-product manufacture was identified from a recent publication, bringing the total number of firms in that phase of recycling to 23. Of the 23 firms, representatives of 20 of the firms were contacted by phone.

FIGURE 8.1. GEOGRAPHICAL DISTRIBUTION OF FIRMS IN BROKERING AND THIRD-PARTY PICK-UP

Source of data: PLASTIC BOTTLE RECYCLING DIRECTORY AND REFERENCE GUIDE, 1988, The Society of the Plastics Industry, Inc., Washington, D.C.

FIGURE 8.2. GEOGRAPHICAL DISTRIBUTION OF FIRMS IN EQUIPMENT MANUFACTURE

Source of data: PLASTIC BOTTLE RECYCLING DIRECTORY AND REFERENCE GUIDE, 1988, The Society of the Plastics Industry, Inc., Washington, D.C.

FIGURE 8.3. GEOGRAPHICAL DISTRIBUTION OF FIRMS IN PROCESSING AND END-PRODUCT MANUFACTURE

Source of data: PLASTIC BOTTLE RECYCLING DIRECTORY AND REFERENCE GUIDE, 1988, The Society of the Plastics Industry, Inc., Washington, D.C.

Table 8.1 presents summary information about the firms contacted. Two firms employed tertiary processes in the recycling of PET bottles, while the remaining 18 firms used some type of secondary process. The source of the firms' waste material varied widely, from 100% manufacturing waste to 100% post-consumer waste. Eight of the firms contacted are involved in the manufacture of products that can substitute for products made from wood. In terms of capacity, a wide variation was found, with about half of the respondents in the 1 million to 10 million pounds per year range. Although no statistically defensible conclusions can be drawn from the informal phone conversations, some informal observations are worthy of discussion. In particular, the suggested relationships between perceptions about the industry's strengths and weaknesses and the type of recycling process used and type of waste processed are interesting.

First, firms primarily involved in the recycling of PET beverage bottles do not generally cite lack of demand for their products as a problem of concern. The exception is with firms involved in the tertiary recycling of bottles, in which case the products being produced are not very competitive with the same products produced from virgin materials. PET recycling firms do often cite problems with obtaining sufficient quantities of waste for processing. In some cases, the firms advocate stronger incentives for consumers to provide a larger stream of segregated PET bottles.

Second, firms involved in the recycling of commingled post-consumer plastics -- usually into products that substitute for wood -- typically cite the reverse problems. In other words, these firms often cite problems with marketing their products, but seldom cite problems with obtaining sufficient quantities of plastic materials. In some cases, the firms suggest that supply of waste is no problem.

Third, firms primarily involved in recycling manufacturing waste cite problems with marketing their products most often. The availability of waste materials is not usually mentioned as a severe problem.

TABLE 8.1. SUMMARY INFORMATION ABOUT FIRMS MANUFACTURING END-PRODUCTS FROM RECYCLED PLASTICS

	Number of Firms
Type of Recycling Operation:	
Secondary	18
Tertiary	2
Source of Firm's Plastic Waste:	
100% Post-consumer	5
100% Manufacturing	3
>50% Post-consumer	6
50%-50% Split	2
>50% Manufacturing	4
Type of Product Produced:	
Wood substitutes	8
Pipes	3
PET derived products	5
Other	2
Capacity:	
1 Million pound/year or less	5
Between 1 million and 10 million pounds/year	9
Greater than 10 million pounds/year	4
Not disclosed	2

Several other general observations are worth noting. It may be surprising that at least 8 firms are involved in the production of lumber substitutes. What may be more surprising, however, is that several of these firms use proprietary processes. Although the technologies currently available from Europe to recycle relatively contaminated commingled plastics are receiving a lot of attention in the press, there are other proprietary technologies available in the U.S. that perform much the same function.

Several firms recycling commingled wastes into lumber-like products cited the advantages that larger scale operations would offer. It is interesting to note that recent entries in this area plan relatively large scale operations.

Biodegradable plastics were not favored by those firms currently processing commingled plastics. Individuals mentioned that biodegradables mixed with conventional plastics could severely degrade the physical properties of their products. One individual commented that "Biodegradables are the worst."

An interesting observation was made by one individual about a potential environmental benefit of recycling commingled plastics. In processing PET, HDPE, and PVC containers, some cleaning is usually required. The residual contents of the containers are to some extent removed and collected and therefore diverted from the general municipal waste stream. The individual suggested that the collected wastes could subsequently be processed in a sound environmental way. As a side note, the EPA has estimated that about 0.5% of municipal waste entering landfills could be classified as toxic waste. The degree to which the residual contents of plastic containers contribute to this percentage is unknown, at least to the knowledge of the authors.

In some instances, individuals provided information on the price paid for incoming waste materials and the price charged for recycled products. Costs per pound of incoming wastes were as follows: HDPE, \$.06 to \$.25 for baled and slightly higher (2 to 5 cents) for regrind; PET bottles, \$0.04 to \$0.12; and commingled, \$0.00 to \$0.20. The selling price of the products produced obviously depends on the particular product. Prices per pound for products ranged as follows: HDPE, \$0.40 to \$1.20; PET, \$0.35 to \$0.50; and commingled, \$0.30 to \$2.00.

9. CONCLUSIONS

This report addresses numerous issues related to plastics recycling in the industrial sector: manufacturing and post-consumer plastic waste projections, the estimated energy content of plastic wastes, the costs of available recycling processes, institutional changes that promote additional recycling, legislative and regulatory trends, the potential quantities of plastics that could be diverted from the municipal waste stream and recycled in the industrial sector, and the perspectives of current firms in the plastics recycling business. This work updates and extends the findings presented in Curlee (1986).

The production and use of plastics are expected to increase at a rapid rate during the coming decade, increasing from an estimated 56 billion pounds in 1987 to almost 72 billion pounds in 2000. Post-consumer wastes are projected to increase from 35.8 billion pounds in 1990 to 48.7 billion pounds in 2000. Plastic packaging is expected to account for about 46% of all post-consumer plastics during the coming decade and remain the by-far largest single contributor to the waste stream. The product category with the largest projected percentage increase is, however, the building and construction sector, which is projected to increase from 2.0% of the total in 1990 to 8.0% in 2000.

Information on the percentage of manufacturing throughput that becomes a manufacturing nuisance plastic was obtained from several industry experts. While there is significant variance between the high and low estimates provided by the experts, estimates of the throughput that becomes a nuisance plastic are generally lower than those used in Leidner (1981) and Curlee (1986). Manufacturing nuisance plastics are projected to account for about 4% of total plastic wastes. These manufacturing wastes, which are currently landfilled or incinerated, may represent a unique opportunity for recycling because they can often be collected independently of other waste materials. Expensive and technically difficult separation processes can thus be avoided.

The energy content of plastic wastes depends on whether one means embodied energy or retrievable energy. Embodied energy refers to the energy required to manufacture plastics. Retrievable energy refers to the energy that could be obtained from burning the plastics. Estimates presented in Section 3 of this report indicate that the total energy inputs required to manufacture the resins that are projected to appear in the solid waste stream in 1990 will exceed 1,378 X 10^{12} BTUs. If all manufacturing nuisance plastics and post-consumer plastics are incinerated, the product heat of combustion from those plastics is projected to be about 644 X 10^{12} BTUs in 1990. The estimate for total energy inputs is equivalent to about 1.8% of what total U.S. energy consumption was in 1985. The estimate for product heat of combustion is equivalent to about 0.8% of the 1985 estimate for total energy consumption. While small as a percent of total U.S. energy consumption, the energy quantities available from plastics are nonetheless large in absolute terms.

Recent estimates of the costs of recycling plastic wastes reconfirm the conclusions presented in Curlee (1986). As was the case in 1986, the cost and revenue data are not sufficiently detailed or validated to draw definitive conclusions. Given the caveats, both the ET/1 and the Recyclingplas secondary processes appear to be economically viable if the appropriate materials are available. It is interesting to note, however, that informal discussions with representatives of the current recycling industry indicate that secondary recyclers are experiencing some difficulty in marketing their products. Although the costs of secondary technologies appear favorable, no good information is available to suggest the potential size of the market for the lumber-like materials being produced. Neither is there information about how the prices of lumber substitutes may decrease as the production of those products increases.

The lack of information about potential secondary markets is one of the most severe handicaps faced by government and private-sector decision makers. If, on the one hand, lumber-like materials have a large potential market, regulators may select to divert plastics away from the municipal waste stream in a form that will be appropriate to these technologies. In that case, alternative technologies, such as tertiary processes may be de-emphasized. On the other hand, if the potential market for these lumber-like materials is small, the development of alternative recycling technologies becomes more important. It may also be the case that regulations that influence the type of waste available for recycling outside of the municipal waste stream should be designed to cater to the specific technologies that have the greatest technical and economic potential.

Significant changes have occurred recently in terms of the institutional structures and regulations that impact on plastics recycling. In the majority of cases, these changes promote additional recycling. For example, mandatory moves to curbside collection of plastics and subsidies for the development and use of new recycling technologies have made plastics recycling more economically attractive. In some cases, however, the institutional and regulatory trends have questionable implications for plastics recycling and are reflective of the continuing uncertainty about plastics in general. For example, recent bans on plastic products and required adoption of biodegradable plastics may hinder some future recycling operations.

Section 7 presents several scenarios in which specific technical, economic, institutional, and regulatory conditions are assumed. Given the most probable scenario, the quantity of plastics available for recycling will grow tremendously. If curbside collection of segregated household plastics becomes the norm and if economically viable technologies are available to recycle commingled plastics containing 50% contaminants, most manufacturing nuisance plastics will become recyclable. In addition, about 50% of the post-consumer plastic waste stream -- i.e., about 24 million pounds in 2000 -- will be a candidate for some kind of recycling.

This assessment suggests that there are significant opportunities for the industrial sector to recycle plastic wastes during the coming decade. Most technical, economic, institutional, and regulatory trends point toward more possibilities and greater incentives for additional recycling activities. There are, however, potential barriers. Technologies that can accommodate dirty commingled plastics require further development, especially tertiary technologies that could produce high-valued pre-polymers. Separation technologies also require further development if some of the larger waste streams are to be recycled in a secondary or tertiary sense. Market constraints may limit significantly the potential for secondary products, especially those products that compete with wood or concrete. Finally, regulatory programs, which will impact on the collection of plastics and the economic viability of recycling operations, are currently being developed at the federal, state, and local levels. Unfortunately, the specifics of these regulations are highly uncertain at this time. The appropriate regulatory structure will depend in part on the outcomes of additional work to further develop technological and economic options for plastics recycling.

APPENDIX
PLASTIC WASTE PROJECTIONS: METHODOLOGY AND ASSUMPTIONS

A.1. INTRODUCTION

This appendix discusses the methodology and assumptions that underlie the plastic waste projections presented in Section 3 of this report. The methodology is similar to that used in Curlee (1986). Please see Appendix B of that book for a further description of the methodology.

A.2. HISTORICAL AND PROJECTED U.S. RESIN PRODUCTION AND USE

All projections were developed using time series analyses. In the interest of studying the historical relationships between resin production and use and the level of production in certain product categories, the regressions included appropriate industrial production index as an independent variable. Included in this appendix are projections of future values of these production indexes, which are derived using simple time series analyses. Note that the inclusion of these production indices in the regression equations does not alter the projections of resin production and use, since future values of the indices are based solely on time. Ordinary least squares was used for all regressions.

Data on the production and use of plastics were obtained from either the SPI's Facts and Figures of the U.S. Plastics Industry or Modern Plastics. Production indices were obtained from the Survey of Current Business.

Table A.1 defines the variables used in this appendix. Table A.2 gives summary information on the regression results for the projection of the production indices used in subsequent projections of resin usage. Table A.3 gives summary information on regression results to project the use of resins in various product categories. Table A.4 presents regression results for the use of polyurethanes in selected product categories.

Table A.5 presents projected values for the relevant production indices. Detailed numerical results from the projection of the use of resins in product categories are given in Table A.6. Projections of the use of polyurethanes are given in Table A.7.

Table A.8 presents summary information from regressions to project the use of resins in selected packaging categories. Table 3.1 in the text gives the actual projections for the different packaging sectors.

A.3. POST-CONSUMER PLASTIC WASTE PROJECTIONS

Data on the historical use of plastic resins in specific product categories was obtained from various issues of SPI's Facts and Figures of the U.S. Plastics Industry, wherever possible. Other source information was obtained from the January issues of Modern Plastics. The average product life spans were assumed to be the same as given in Curlee (1986, Table 4.3).

A.3.1. Transportation

The three-year average method was used to estimate the use of plastics in the transportation sector. Estimates of the use of plastics in 1990 were made using data from 1978, 1979, and 1980; for 1995 using data from 1983, 1984, and 1985; and for 2000 using projections for 1988, 1989, and 1990. The total use of plastics in the sector was disaggregated between automobiles and other transportation categories in the ratio of 78% to 22%, respectively. This ratio corresponds to the use of plastics in these two categories of the transportation sector in 1987 (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition).

Projections for 1990:

The use of plastics in the automobile sector was disaggregated according to the usage of particular resins in the production of automobiles in 1982 (Source: Automotive Plastics Report - 1987, Market Search Inc., Toledo, Ohio 43615, 1987). Data from 1982 was used as proxy data

TABLE A.1. DEFINITION OF VARIABLES

Variable Name	Definition of Variable
RESPRO	Total resin production
RESPAK[a]	Total resins used in packaging
RESC&I[a]	Total resins used in consumer and institutional goods
RESTRA[a]	Total resins used in the transportation sector
RESE&E[a]	Total resins used in the electrical and electronics sector
RESBUI[a]	Total resins used in the building and construction sector
RESFUR[a]	Total resins used in furniture and fixtures
RESIND[a]	Total resins used in industrial equipment
RESADH[a]	Total resins used in adhesives
RESEXP[a]	Total resins exported
RESOTH[a]	Total resins used in goods not included in other product categories
PFTRAN	Polyurethane used in the transportation sector
PFPACK	Polyurethane used in packaging
PFBUIL	Polyurethane used in building and construction
PFELEC	Polyurethane used in electrical and electronic goods
PFFUR	Polyurethane used in furniture and fixtures
PFOTH	Polyurethane used in products not included in other product categories
PITOT	Production index for all goods
PIMAN	Production index for all manufacturing goods
PINON	Production index for all nondurable goods
PIDUR	Production index for all durable goods
PIC&I	Production index for consumer goods
PIINDU	Production index for industrial equipment
PIFUR	Production index for furniture and fixtures
PITRAN	Production index for transportation equipment
PICONS	Production index for construction supplies
PIELEC	Production index for electrical machinery
CLOSUR	Total resins used in closures for packaging
COATNG	Total resins used in coatings for packaging
CONTNR	Total resins used in containers and lid for packaging
FILM	Total resins used in films for packaging

Note: [a]Excludes the use of polyurethane

TABLE A.2. SUMMARY OF REGRESSION RESULTS: PRODUCTION INDEXES COEFFICIENT

DEPENDENT VARIABLE	R-SQUARED	TIME INTERVAL	CONSTANT	T-STAT	TIME	T-STAT
PITOT	0.85	1973-1987	-5345.89	-8.58	2.75	8.75
PIMAN	0.85	"	-6006.32	-8.34	3.09	8.50
PINON	0.92	"	-6406.77	-11.97	3.29	12.17
PIDUR	0.78	"	-5713.41	-6.59	2.94	6.71
PIC&I	0.89	"	-5307.60	-10.28	2.73	10.48
PIINDU	0.84	"	-7832.91	-8.06	4.01	8.18
PIFUR	0.82	"	-8239.09	-7.49	4.22	7.59
PITRAN	0.55	"	-4642.47	-3.87	2.40	3.96
PICONS	0.52	"	-4244.45	-3.64	2.20	3.73
PIELEC	0.93	"	-13932.97	-12.76	7.10	12.88

TABLE A.3. SUMMARY OF REGRESSION RESULTS: RESIN USE IN SELECTED PRODUCT CATEGORIES

DEPENDENT VARIABLE	R-SQUARED	TIME INTERVAL	CONSTANT (T-STAT)	T-STAT (T-STAT)	PRODUCTION INDEX	COEFFICIENT (T-STAT)
RESPRO	0.98	1974-1987	-629821.09	306.04	PITOT	581.72
			(-1.22)	(1.16)		(6.99)
RESPAK	0.98	"	-750516.08	379.83	PIMAN	77.67
			(-4.98)	(4.92)		(3.61)
RESC&I	0.84	"	35010.84	-18.35	PIC&I	46.97
			(.34)	(-0.34)		(2.69)
RESTRA	0.71	"	53556.84	-27.16	PITRAN	19.68
			(1.68)	(-1.67)		(4.33)
RESE&E	0.66	"	175624.62	-89.25	PIDUR	34.10
			(3.16)	(-3.13)		(4.32)
RESBUI	0.97	"	-762416.09	385.72	PICONS	56.32
			(-9.02)	(8.93)		(4.42)
RESFUR	0.83	"	54231.64	-27.46	PIFUR	17.25
			(1.13)	(-1.12)		(3.59)
RESIND	0.64	"	67366.51	-34.23	PIINDU	6.78
			(4.47)	(-4.44)		(4.04)
RESADH	0.59	"	387316.47	-196.91	PIMAN	44.25
			(3.85)	(-3.82)		(3.08)
RESOTH	0.94	"	-162853.36	81.28	PITOT	48.10
			(-1.80)	(1.75)		(3.30)
RESEXP	0.90	"	-490391.03	249.40	PIMAN	-2.89
			(-3.88)	(3.85)		(-0.16)

TABLE A.4. SUMMARY OF REGRESSION RESULTS: THE USE OF POLYURETHANE IN SELECTED PRODUCT CATEGORIES

DEPENDENT VARIABLE	R-SQUARED	TIME INTERVAL	CONSTANT	T-STAT	TIME	T-STAT	PRODUCTION INDEX	COEFFICIENT	T-STAT
PFTRAN	0.79	1973-1985	33798.41	5.40	-17.21	-5.39	PITRAN	6.19	5.53
PFPACK	0.92	"	-10173.34	-4.38	5.15	4.33	PIMAN	0.37	1.00
PFBUIL	0.98	"	-45357.05	-16.57	22.97	16.44	PICONS	1.84	3.42
PFELEC	0.46	"	-1998.82	-0.70	1.03	1.47	PIDUR	0.48	1.07
PFFUR	0.32	"	-25788.90	-0.74	13.34	0.75	PIFUR	1.92	0.45
PFOTH	0.51	"	-10968.13	-0.66	5.46	0.64	PITOT	2.71	0.93

TABLE A.5. HISTORICAL AND PROJECTED VALUES FOR SELECTED PRODUCTION INDEXES

	PITOT	PIMAN	PINON	PIDUR	PIC&I	PIINDU	PIFUR	PITRAN	PICONS	PIELEC
1973	94.4	94	90.8	96.3	91.2	92.4	100.5	99.1	102.3	90.7
1974	93	92.6	90.2	94.3	88.4	96.5	93.5	90.1	95.8	89.8
1975	84.8	83.4	84.5	82.6	84.9	86.1	80	81	82.3	77.2
1976	92.6	91.9	93.1	91.1	93.3	89.3	89.4	92.2	92	86.8
1977	100	100	100	100	100	100	100	100	100	100
1978	106.5	107.1	105.5	108.2	104.3	112.2	109.1	106.3	106.9	112.9
1979	110.7	111.5	108.2	113.9	103.9	124.7	111.7	108.3	108.7	125.7
1980	108.6	108.2	107	109.1	102.7	125.1	108.9	96.9	100.6	130.3
1981	111	110.5	109.7	111.1	104.1	127.6	109.9	95.1	98.6	134.1
1982	103.1	102.2	105.5	99.9	101.4	113.6	104.5	87.6	88.3	128.4
1983	109.2	110.2	113.7	107.7	109.3	115.4	118.2	99.2	100.6	143.8
1984	121.4	123.4	122.3	124.2	118	134.2	134.3	112.2	114	170.5
1985	123.7	126.4	124.6	127.6	119.8	140.2	138	122.8	119.2	168.4
1986	125.1	129.1	130.1	128.4	124	139.4	143.8	127.5	126.4	165.7
1987	129.8	134.7	136.8	133.1	127.8	144.5	152.8	129.2	131.5	172.3
1988*	121.1	136.6	133.7	131.3	119.6	139.0	150.27	128.73	129.15	181.83
1989	123.9	139.7	137.0	134.3	122.4	143.0	154.49	131.13	131.35	188.93
1990	126.6	142.8	140.3	137.2	125.1	147.0	158.71	133.53	133.55	196.03
1991	129.4	145.9	143.6	140.1	127.8	151.0	162.93	135.93	135.75	203.13
1992	132.1	149.0	146.9	143.1	130.6	155.0	167.15	138.33	137.95	210.23
1993	134.9	152.1	150.2	146.0	133.3	159.0	171.37	140.73	140.15	217.33
1994	137.6	155.1	153.5	149.0	136.0	163.0	175.59	143.13	142.35	224.43
1995	140.4	158.2	156.8	151.9	138.7	167.0	179.81	145.53	144.55	231.53
1996	143.1	161.3	160.1	154.8	141.5	171.0	184.03	147.93	146.75	238.63
1997	145.9	164.4	163.4	157.8	144.2	175.1	188.25	150.33	148.95	245.73
1998	148.6	167.5	166.6	160.7	146.9	179.1	192.47	152.73	151.15	252.83
1999	151.4	170.6	169.9	163.7	149.7	183.1	196.69	155.13	153.35	259.93
2000	154.1	173.7	173.2	166.6	152.4	187.1	200.91	157.53	155.55	267.03

Note: *Starting year for projections

TABLE A.6. HISTORICAL AND PROJECTED PRODUCTION AND USE OF PLASTICS (IN MILLIONS OF POUNDS)

	RESPRO	RESPAK	RESC&I	RESTRA	RESE&E	RESBUI	RESFUR	RESIND	RESOTH	RESADH	RESEXP
1974	29274	6720	3168	1725	2524	4327	1791	488	2215	2150	1585
1975	22828	5579	2875	1248	1787	3736	1360	313	1771	1942	1351
1976	29196	7342	2801	1808	2524	4555	1617	319	2160	2330	2168
1977	33948	7899	3242	1911	2756	6008	1391	472	2728	2566	2142
1978	37605	9044	3592	2015	2952	6965	1686	380	2939	2902	2588
1979	41577	10334	3753	1934	3043	7573	1894	517	3443	2794	3432
1980	37347	10003	3553	1605	2453	6424	1646	391	3054	2387	3670
1981	39867	10465	3670	1573	2670	7259	1670	393	3259	2572	3425
1982	36607	10497	3269	1392	2275	7154	1556	241	3232	1584	3909
1983	42777	11813	3816	1896	2514	8552	2007	318	3636	1800	4150
1984	46336	12398	3986	2109	2757	9691	2117	400	4080	1993	3796
1985	47946	12774	3975	1989	2659	10038	2107	364	5122	2142	4170
1986	50849	13267	4123	1988	2609	10085	2191	361	4555	1638	4206
1987	55751	15234	5063	2029	2779	11285	2235	332	4665	1797	4593
1988*	49039	15196	4151	2096	2673	11669	2233	259	4557	1904	5021
1989	50944	15816	4260	2116	2684	12179	2279	252	4770	1844	5262
1990	52850	16435	4370	2136	2695	12688	2324	245	4984	1784	5502
1991	54756	17055	4480	2156	2706	13198	2369	238	5197	1723	5743
1992	56662	17675	4590	2176	2717	13707	2415	231	5411	1663	5983
1993	58567	18295	4700	2197	2728	14217	2460	224	5624	1603	6224
1994	60473	18915	4810	2217	2739	14727	2505	217	5838	1543	6464
1995	62379	19534	4920	2237	2750	15236	2551	210	6052	1483	6705
1996	64285	20154	5030	2257	2761	15746	2596	203	6265	1423	6945
1997	66190	20774	5139	2277	2772	16256	2641	196	6479	1362	7186
1998	68096	21394	5249	2297	2783	16765	2687	189	6692	1302	7426
1999	70002	22014	5359	2317	2794	17275	2732	182	6906	1242	7667
2000	71908	22634	5469	2337	2805	17784	2777	175	7119	1182	7907

Note: *Starting year for projections

TABLE A.7. HISTORICAL AND PROJECTED USE OF POLYURETHANE IN SELECTED PRODUCT CATEGORIES (IN MILLION OF POUNDS)

	PFTRAN	PFPACK	PFBUIL	PFELEC	PFFUR	PFOTH
1973	410	25	140	75	660	107
1974	367	21.5	140	77.5	602.5	99
1975	324	18	140	80	545	91
1976	390.5	33.5	188	80.5	748	87
1977	457	49	236	81	951	83
1978	466	57	283	79	980	96
1979	418	62	322	84	973	71
1980	288	57	315	69	872	111
1981	268	77	328	76	898	97
1982	248	77	328	80	859	82
1983	301	85	379	87	872	185
1984	330	90	400	100	895	235
1985	400	80	430	125	790	305
1986*	409	102	494	108	980	214
1987	402	110	526	112	1011	233
1988	382	115	545	112	1020	215
1989	379	122	572	114	1041	227
1990	377	128	599	117	1062	240
1991	375	134	626	119	1084	253
1992	372	141	653	122	1105	266
1993	370	147	680	124	1127	279
1994	368	153	707	126	1148	292
1995	365	159	734	129	1170	305
1996	363	166	761	131	1191	318
1997	361	172	788	134	1213	331
1998	358	178	815	136	1234	344
1999	356	185	842	139	1255	357
2000	354	191	869	141	1277	370

Note: *Starting year for projections

TABLE A.8. SUMMARY OF REGRESSION RESULTS: PLASTICS USE IN PACKAGING

Dependent Variable	R-Squared	Time Interval	Constant	T-Stat	Time	T-Stat
CLOSUR	0.94	1981-1987	-105159.86	-8.50	53.25	8.54
COATNG	0.86	1981-1987	-82585.14	-5.45	42.11	5.51
CONTNR	0.96	1981-1987	-754232.71	-10.43	382.71	10.50
FILM	0.94	1981-1987	-389652.43	-8.90	198.29	8.98
TOTAL	0.96	1981-1987	-1331630.10	-10.54	676.36	10.62

for the year 1979, for which no information was available. For the "Other" category, disaggregation was done according to the usage of particular resins in the transportation sector in 1979 (Source: Modern Plastics, January 1980).

Projections for 1995

The use of plastics in the automobile sector was disaggregated according to the usage of particular resins in the production of automobiles in 1987 (Source: Automotive Plastics Report - 1987, Market Search Inc., Toledo, Ohio 43615, 1987). Data from 1987 was used as a proxy for the year 1984, for which no information was available. For the "Other" category, disaggregation was done according to the usage of particular resins in the transportation sector in 1984 (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition).

Projections for 2000:

The use of plastics in the automobile sector was disaggregated according to the projected usage of particular resins in the production of automobiles in 1992 (Source: Automotive Plastics Report - 1987, Market Search Inc., Toledo, Ohio 43615, 1987). Projected data for 1992 was used as the proxy year for 1989, for which no information was available. For the "Other" category, disaggregation was done according to the usage of particular resins in the transportation sector in 1987 (Source: Modern Plastics, January 1988).

A.3.2. Packaging

The quantities of plastics entering the waste stream from the packaging sector are equal to the quantities used in that sector in any given year. Recall that the life of packaging is typically less than one year. The totals were disaggregated according to the use of resins in packaging in 1987 (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition).

A.3.3. Building and Construction

The disaggregation by resin type for this product category for 1990 and 1995 was based on information about the use of specific resins in building and construction for the time periods 1960-62 and 1972-74, respectively. This information was obtained from the SPI's 1977 edition of Facts and Figures of the U.S. Plastics Industry. For the year 2000, the use of specific resins in building and construction in 1975 was used for disaggregation by resin types (Modern Plastics, January 1976).

A.3.4. Electrical and Electronic Goods

The three-year average method was used for projections for this sector. For example, data on resin consumption in 1984, 1985, and 1986 were averaged to project plastic wastes for 2000. The projections were disaggregated by resin type according to the use of particular resins in the sector in those particular years. Information was obtained from the January 1976 and January 1981 issues of Modern Plastics and used as proxies for information from the years 1975 and 1980 to disaggregate the projections for 1990 and 1995 by resin type. The projections for 2000 were disaggregated by resin type according to the usage of particular resins in 1985 in that sector (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition).

A.3.5. Furniture

The three-year average method was used for resin consumption data in this sector for the years 1990, 1995, and 2000. Estimated wastes for 1990 were disaggregated into specific resins according to the usage of resins in furniture manufacturing in 1980 (Source: Modern Plastics, January 1980). Disaggregation of projections for 1995 and 2000 by resin type was done according to information available for years 1985 and 1987, respectively (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition). Data from 1987 was used as a proxy for data from 1990, for which no information is available.

A.3.6. Consumer and Institutional Goods

Disaggregation by resin type for 1990, 1995, and 2000 required information about the composition of resins used in this sector in 1985, 1990, and 1995. For 1990 and 1995, 1987 information was used to accomplish the disaggregation by resin type (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition). Information on the use of particular resins in that sector in 1985 was obtained from the same source.

A.3.7. Industrial Machinery

Disaggregation by resin type for the years 1990 and 1995 is the same as is described in Curlee (1986, Appendix B). The disaggregation by resin type for 2000 is done according to the use of resins in this product category in 1985 (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition).

A.3.8. Adhesives and Other Goods

Disaggregation by resin type for the years 1990, 1995, and 2000 required information about the resins used in the product category in 1986, 1991, and 1996. For disaggregation of 1995 and 2000 projections, 1987 information was used (Source: Facts and Figures of the U.S. Plastics Industry, 1988 Edition). Information for 1986, required for 1990 projection, was obtained from the same source.

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