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EPA

Characterization of Products Containing Lead and Cadmium in Municipal Solid Waste in the United States, 1970 to 2000

Final Report

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Final Report

Prepared for
United States
Environmental Protection Agency
Municipal Solid Waste Program
by Franklin Associates, Ltd.
Prairie Village, Kansas

PREFACE

This report was prepared for the Environmental Protection Agency by Franklin Associates, Ltd. Marjorie A. Franklin was project manager and principal author of the report. Staff support was provided by Jacob E. Beachey, Kristine L. Cavosie, Suzanne C. Metzler, Janet M. Nelson, John P. Neuhaus, Veronica R. Sellers, Robert C. Taylor, and Katherine L. Totten.

EPA's project manager was Gerry Dorian; later Janette Hansen became project manager. The work was performed under subcontract to NUS Corporation, EPA Contract No. 68-01-7310, Work Assignment 65. Gary Galida was the NUS project manager.

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Table		Page
2-12	Consumption of Lead in "All Other" Glass in MSW, 1967 to 1997	68
2-13	Discards of Lead in Glass and Ceramics in MSW, 1970 to 2000	69
2-14	Form of Lead Consumed in Storage Batteries, 1986	71
2-15	Weight Analysis of Typical SLI Batteries	71
2-16	Lead Consumption in U. S. Automotive Battery Shipments, 1966 to 1986	73
2-17	Lead Consumption in U. S. Motorcycle Shipments, 1966 to 1986	75
2-18	Summary of Lead Consumption by U. S. Battery Shipments, 1966 to 1986	76
2-19	Lead in Automotive SLI Batteries, 1966 to 1996	79
2-20	Lead in Motorcycle Batteries, 1966 to 1997	80
2-21	Discards of Lead in SLI Lead-Acid Batteries, 1970 to 2000	81
2-22	Lead Consumption in Portable Sealed Lead-Acid Batteries, 1966 to 1996	84
2-23	Discards of Lead in Portable Sealed Lead-Acid Batteries, 1970 to 2000	85
2-24	Light Bulbs Assumed to Contain Solder and to be Discarded into MSW	87
2-25	Lead Oxide (PbO) Levels in Light Bulbs	88
2-26	Discards of Lead in Light Bulbs, 1970 to 2000	89
2-27	Estimate of Deinked Papers Removed from MSW by Paper Recycling, 1970 to 2000	97
2-28	Discards of Lead in Printing Inks in MSW, 1970 to 2000	98
2-29	Consumption of Lead in Pigments, 1970 to 2000	103
2-30	Consumption of Lead in Pigments, 1970 to 2000	104
2-31	Consumption of PVC Resin by End Use, 1960 to 1986	108
2-32	Estimates of Lead Used in Stabilizers in PVC, 1960 to 1986	109
2-33	Import/Export Adjustment Ratios for Plastic Products, 1962 to 1986	110
2-34	Discards of Lead in Stabilizers in PVC Plastics Products, 1970 to 2000	111
2-35	Typical Ranges of Composition of Lead Chromate Pigments	112
2-36	Consumption of Resins by End Use, 1960 to 1986	113
2-37	Estimates of Lead Used in Pigments in Plastics, 1960 to 1986	116
2-38	Discards of Lead in Pigments in Plastic Products, 1970 to 2000	117

EXECUTIVE SUMMARY

As disposal of municipal solid waste (MSW) has become an issue of increasing importance in the United States, combustion of wastes has been recognized as one of several alternative management approaches. A concern associated with municipal waste combustion, however, is that heavy metals (lead and cadmium in particular) have been found in analytical tests of the ash from these facilities. This report characterizes the sources of lead and cadmium in products disposed in MSW over the time period 1970 to 1986, with projections to the year 2000.

LEAD IN MUNICIPAL SOLID WASTE

Lead is widespread in the municipal waste stream; it is in both the combustible and noncombustible portions of MSW. Discards of lead in MSW are overwhelmingly greater than discards of cadmium (Figure 1).

Lead-acid batteries (primarily batteries for automobiles) rank first, by a wide margin, of the products containing lead that enter the waste stream. Trends in quantities of lead discarded in products in MSW (ranked by tonnage discarded in 1986) are shown in Table 1. The last two columns on the table indicate whether the total tonnage of lead in a product is generally increasing or decreasing, and whether the percentage of total MSW lead contained in a product is increasing or decreasing.

Changing trends in discards of lead are illustrated in Figure 2. Lead discards in batteries are shown to be growing steadily, as are discards in consumer electronics. Discards of leaded solder in cans and lead in pigments, however, virtually "disappear" from the graphic between 1970 and 1986. Lead discards in other products are shown to be relatively small.

Findings about the individual products in MSW that contain lead are:

* <u>Lead-acid Batteries</u> contributed 65 percent of the lead in MSW in 1986; this percentage has ranged between 50 and 85 percent during the 1970 to 1986 period studied. The tonnages in Table 1 represent discards after recycling, but of all the products considered, only lead-acid batteries are recycled to a significant extent. Recycling rates, which have ranged from 52 to 80 percent, have a major effect on the tonnage of lead-acid batteries discarded.

* <u>Consumer Electronics</u> (television sets, radios, and video cassette recorders) accounted for 27 percent of lead discards in MSW in 1986. They contribute lead from soldered circuit boards, leaded glass in television sets, and plated steel chassis. Leaded glass accounts for most of the lead in these products.

* <u>Glass and Ceramics</u>, as reported here, include lead in products such as glass containers, tableware and cookware, and other items such as

Figure 1. Relative discards of lead and cadmium in MSW, 1986.

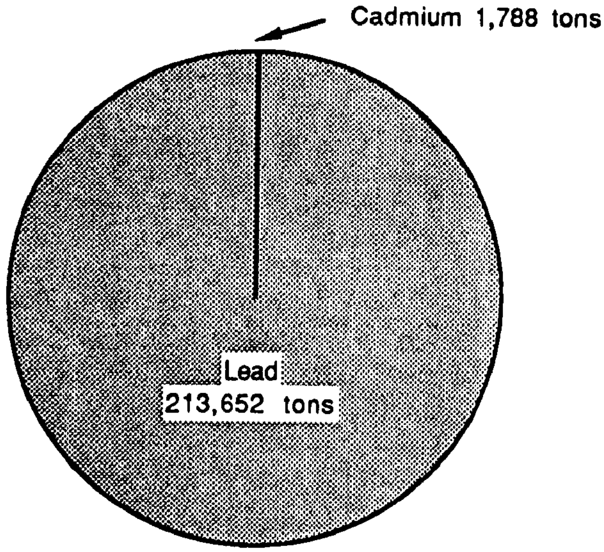
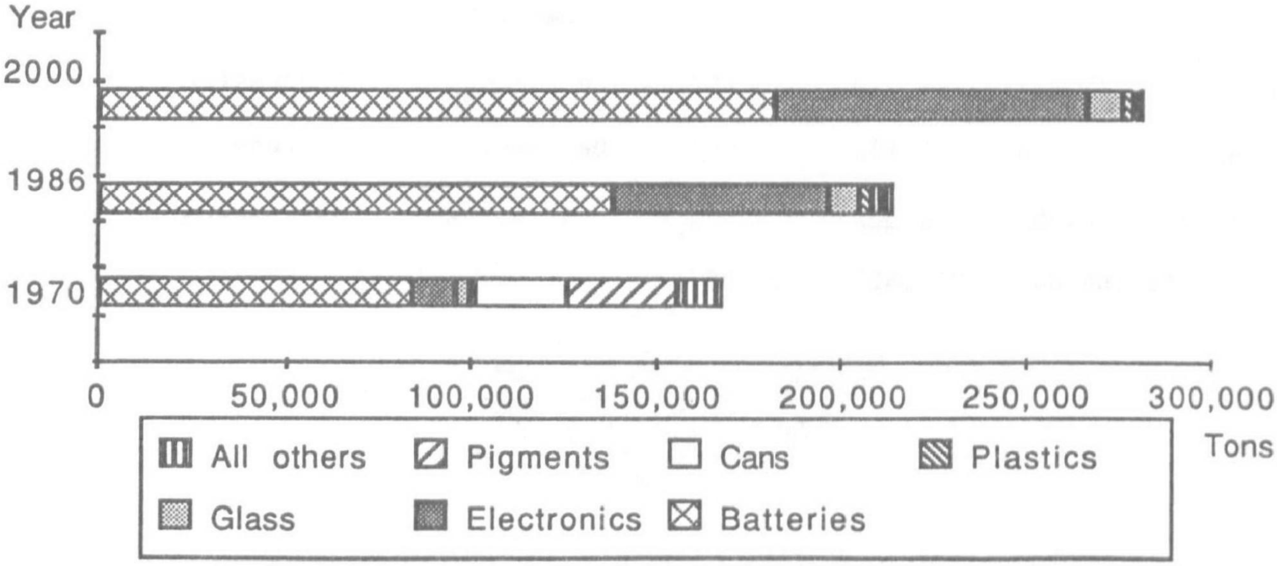


Table 1

LEAD IN PRODUCTS DISCARDED IN MSW, 1970 TO 2000
(In short tons)

Products	1970	1986	2000	Tonnage	Percentage
Lead-acid batteries	83,825	138,043	181,546	Increasing	Variable
Consumer electronics	12,233	58,536	85,032	Increasing	Increasing
Glass and ceramics	3,465	7,956	8,910	Increasing	Increasing; stable after 1986
Plastics	1,613	3,577	3,228	Increasing; decreasing after 1986	Fairly stable
Soldered cans	24,117	2,052	787	Decreasing	Decreasing
Pigments	27,020	1,131	682	Decreasing	Decreasing
All others	12,567	2,537	1,701	Decreasing	Decreasing
Totals	164,840	213,652	281,887		

Figure 2. Lead in discards of products in MSW, 1970, 1986, anc 2000.



optical glass. These contributed 4 percent of lead discards in 1986. (Leaded glass in light bulbs is included in the "All Other" category in Table 1.)

* Plastics use lead in two ways: As a heat stabilizer (primarily in polyvinyl chloride resins) and as a component of pigments in many resins. This category, which includes products such as nonfood packaging, clothing and footwear, housewares, records, furniture, appliances, and other miscellaneous products, accounted for about 2 percent of lead discards in 1986. Plastics in consumer electronics products are counted under that category.

* Soldered Cans have experienced a large decline in usage since 1970, when they contributed 14 percent of the lead in MSW. Leaded solder is currently used in steel food cans, general purpose cans (like aerosols), and shipping containers.

* Pigments containing lead compounds have declined greatly since 1970, dropping from 18 percent of total lead discards to less than one percent. This category includes pigments used in paints, printing inks, textile dyes, etc. Pigments used in plastics, glass and ceramics, and rubber products are accounted for in those categories.

* All Others include brass and bronze products, light bulbs (which contain lead in solder and in glass), rubber products, used oil, collapsible tubes, and lead foil wine bottle wrappers. Collapsible tubes contributed over 5 percent of total lead discards in 1970, but their use has declined dramatically since then. None of the other items has exceeded one percent of the total since 1970.

CADMIUM IN MUNICIPAL SOLID WASTE

Like lead, cadmium is widespread in products discarded into MSW, although it occurs in much smaller quantities overall. Since 1980, nickel-cadmium household batteries have been the Number 1 contributor of cadmium in MSW.

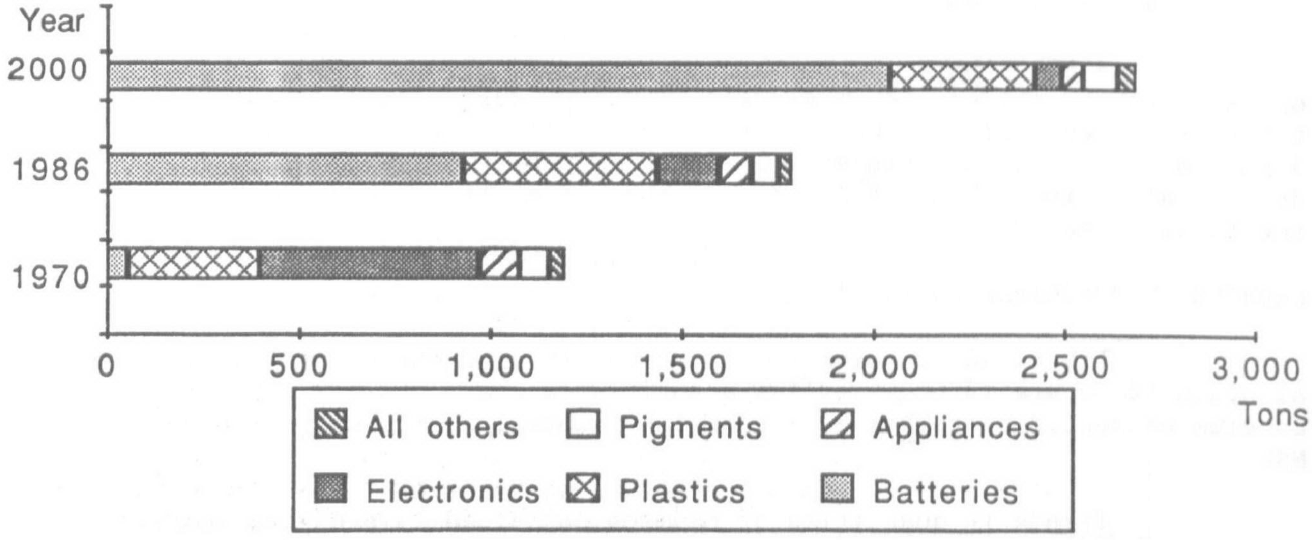
Trends in quantities of cadmium discarded in products in MSW (ranked by tonnage discarded in 1986) are shown in Table 2.

Trends in discards of cadmium in products in MSW are illustrated in Figure 3. Discards of cadmium in household batteries were small in 1970, but then increased dramatically. Cadmium discards in plastics are relatively stable. Discards of cadmium in consumer electronics are shown to decrease over time, while the other categories are relatively small.

Findings about cadmium discards in individual products in MSW are:

* Household Batteries (rechargeable nickel-cadmium batteries) have accounted for more than half of cadmium discards in the U.S. since 1980. This growth is projected to continue unless they are replaced by another type of battery.

Figure 3. Cadmium in discards of products in MSW, 1970, 1986, and 2000.



* Plastics continue to be an important source of cadmium in MSW, contributing 28 percent of discards in 1986. Cadmium is used in stabilizers in polyvinyl chloride resins and in pigments in a wide variety of plastic resins. Cadmium is found in nonfood packaging, footwear, housewares, records, furniture, and other plastic products.

Table 2

CADMIUM IN PRODUCTS DISCARDED IN MSW, 1970 TO 2000
(In short tons)

Products	1970	1986	2000	Tonnage	Percentage
Household batteries	53	930	2,035	Increasing	Increasing
Plastics	342	502	380	Variable	Variable; decreasing after 1986
Consumer electronics	571	161	67	Decreasing	Decreasing
Appliances	107	88	57	Decreasing	Decreasing
Pigments	79	70	93	Variable	Variable
Glass and ceramics	32	29	37	Variable	Variable
All others	12	8	11	Variable	Variable
Totals	1,196	1,788	2,684		

* Consumer Electronics (television sets and radios) formerly had cadmium-plated steel chassis in many cases. These chassis have been replaced by circuit boards, so cadmium discards in consumer electronics are declining as the older units are replaced. They contributed 9 percent of the total in 1986.

* Appliances (dishwashers and washing machines) formerly had cadmium-plated parts to resist corrosion. This source of cadmium is declining as cadmium-plated parts are replaced by plastics, which are themselves another source of cadmium discards in appliances. Cadmium discards from appliances accounted for about 5 percent of total in 1986.

* Pigments used in printing inks, textile dyes, and paints may contain cadmium compounds, although this is not a large source of cadmium in MSW (about 4 percent of total).

* Glass and Ceramics may contain cadmium as a pigment, as a glaze, or as a phosphor. This is a relatively small source of cadmium in MSW.

* All other sources of cadmium include rubber products, used oil, and electric blankets and heating pads. These contribute very small amounts of cadmium to MSW.

LEAD AND CADMIUM IN COMBUSTIBLE AND NONCOMBUSTIBLE PRODUCTS

Removal of the noncombustible products containing lead and cadmium before municipal solid waste is incinerated has been suggested as a way to manage the heavy metal content of incinerator ash. Using data developed in this study, the lead and cadmium content of the combustible and noncombustible fractions of MSW was examined.

Almost 98 percent of the lead in MSW is found in noncombustible products, mostly in lead-acid batteries (Figure 4). If all the noncombustible products containing lead were removed, most of the remaining lead would be in plastics (71 percent) and other pigments (24 percent).

Noncombustible products also contribute the majority (64 percent) of cadmium in MSW, with nickel-cadmium batteries being the primary source (Figure 5). If all of the noncombustible products containing cadmium were removed, plastics would contribute most of the remainder (88 percent), with other pigments accounting for 11 percent.

POTENTIAL EFFECTS OF RECYCLING

Recycling of lead-acid batteries to recover lead has a very significant influence on the amount of lead discarded. A previous study for EPA estimated the recycling rate of these batteries to be 80 percent in 1986; if there were no recycling of batteries, up to 700,000 additional tons of lead would have been discarded. The battery recycling rate has been as low as 52 percent in the early 1980s. The rate is affected by several factors, including the price of lead and regulatory requirements.

No other recycling of lead or cadmium was identified, although small amounts of nickel-cadmium batteries may be exported for recycling. There are, however, several products that are recovered for recycling in which lead or cadmium is an incidental constituent. The lead or cadmium is thus removed from the waste stream entering an incinerator by the recycling process. The recycled products identified are: paper products that are deinked for recycling purposes, soldered cans, rubber tires, appliances, glass containers, and plastics.

LIMITATIONS OF THIS REPORT

While this report contains useful data on discards of lead and cadmium in municipal solid waste, there are some limitations in its application to the issue of lead and cadmium in municipal waste combustor ash. These limitations are:

Figure 4. Relative discards of lead in combustible and noncombustible products, 1986.

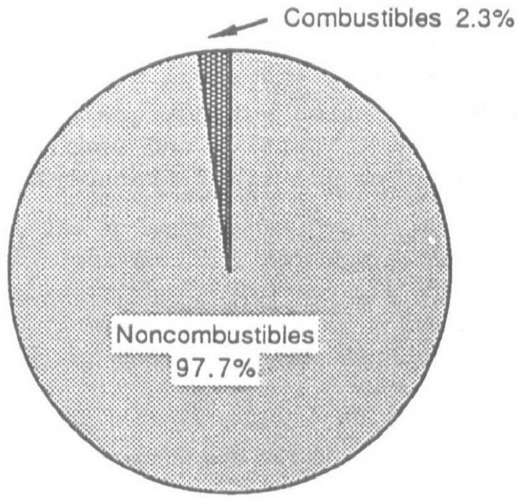
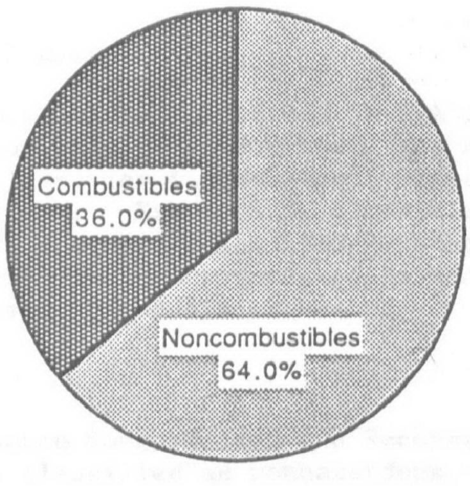


Figure 5. Relative discards of cadmium in combustible and noncombustible products, 1986.



* This characterization identifies the sources of lead and cadmium in MSW; it does not tell us whether these are the major sources of leachable lead and cadmium in MWC ash.

* The MSW characterization presented here may not correlate well with the waste input at any particular MWC facility.

* The identified compounds of lead and cadmium may recombine with other materials in the combustion chamber to form new compounds; this issue is beyond the scope of this study.

* In addition to MSW, other nonhazardous wastes contain lead and cadmium; these wastes may in some instances be incinerated along with MSW. These wastes, which were identified but not characterized in this study, include: municipal sludge, construction and demolition wastes, industrial and military wastes, and automotive and other transportation equipment wastes.

Chapter 1

LEAD AND CADMIUM IN MUNICIPAL SOLID WASTE: OVERVIEW AND SUMMARY

In the past few years, environmentally-sound disposal of municipal solid waste (MSW) has become a major issue for the United States, especially at the local and state levels. As more and more landfills are closed and new landfills become increasingly difficult to site, communities are seeking methods of disposal. Recovery and recycling of materials and combustion (incineration) of MSW are two important alternatives that are being considered and implemented.

Municipal waste combustion (MWC) is attractive to many communities because combustion reduces the volume of waste by up to 90 percent and the weight of waste by up to 80 percent. In addition, sales of recovered energy products (e.g., steam or electricity) help to offset the costs of disposal. Combustion of municipal solid waste does present some problems, however, and one of these is the disposal of the ash remaining after the combustion process is complete.

Analytical tests have detected heavy metals (lead and cadmium in particular) in the ash remaining after municipal waste combustion (1). This report addresses one of many unanswered questions about MWC ash: What are the sources of lead and cadmium in municipal solid waste?

OVERVIEW OF THIS REPORT

This report characterizes lead and cadmium in products disposed in municipal solid waste over the time period 1970 to 1986, with projections of disposal to the year 2000. A summary of the findings is included in this chapter, with more detailed discussions on lead in Chapter 2, and cadmium in Chapter 3.

Wastes Included in This Report

Municipal solid waste is defined in EPA's Subtitle D* reports (2) as wastes coming from household, institutional, and commercial sources. Examples of institutional sources include hospitals (except for infectious wastes), schools, and prisons. Examples of commercial sources include retail stores, office buildings, and warehouses. Some wastes from industrial sources are also included, for example: corrugated boxes and other packaging, cafeteria and washroom wastes, and office wastes.

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* Subtitle D of the Resource Conservation and Recovery Act (RCRA) regulates those wastes generally classified as nonhazardous, while Subtitle C deals with hazardous wastes.

Wastes Not Included in this Report

A number of wastes* regulated under Subtitle D are not characterized in this study, including:

- Municipal sludge
- Industrial nonhazardous process waste
- Small quantity generator waste
- Construction and demolition waste.

While these wastes are not characterized for lead and cadmium content in this report, they may contain those metals and if incinerated along with MSW, they could contribute to lead and cadmium in the ash.

METHODOLOGY

The general methodology for this study is called the materials flow methodology; it is based on a methodology for estimating municipal solid waste that was developed at EPA in the mid-1970s (3) and that has been used periodically for EPA reports ever since. The materials flow methodology applies to the United States as a whole; it is not tailored to any specific locality. Data series on production of the products and materials in the waste stream are used as a basis. Adjustments are then made for imports and exports of the products, for diversions away from the waste stream, for the lifetimes of the products, and for materials recovery.

Application of the methodology to discards of lead and cadmium required some additional steps. Numerous assumptions were required to determine end uses of products (like lead-containing solder) that would enter the municipal waste stream rather than others, such as demolition wastes. Also, lead and cadmium occur in many intermediate products, such as pigments, that enter the waste stream as part of another product. All assumptions were documented. The methodology is summarized in Figure 1-1, and a more detailed description is included in Appendix A of this report.

RELATIVE DISCARDS OF LEAD AND CADMIUM

Both lead and cadmium have been detected in analyses of ash from municipal waste combustors (MWC). Discards of lead in products classified as MSW are, however, very much greater than discards of cadmium.** As Figure 1-2 demonstrates, nearly 100 times more lead than cadmium was discarded in 1986; this relationship has been relatively constant since 1970.

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* See Reference 2 for definitions and discussion of these wastes.

** Later in this chapter, relative discards of lead and cadmium in the combustible and noncombustible fractions of MSW are discussed.

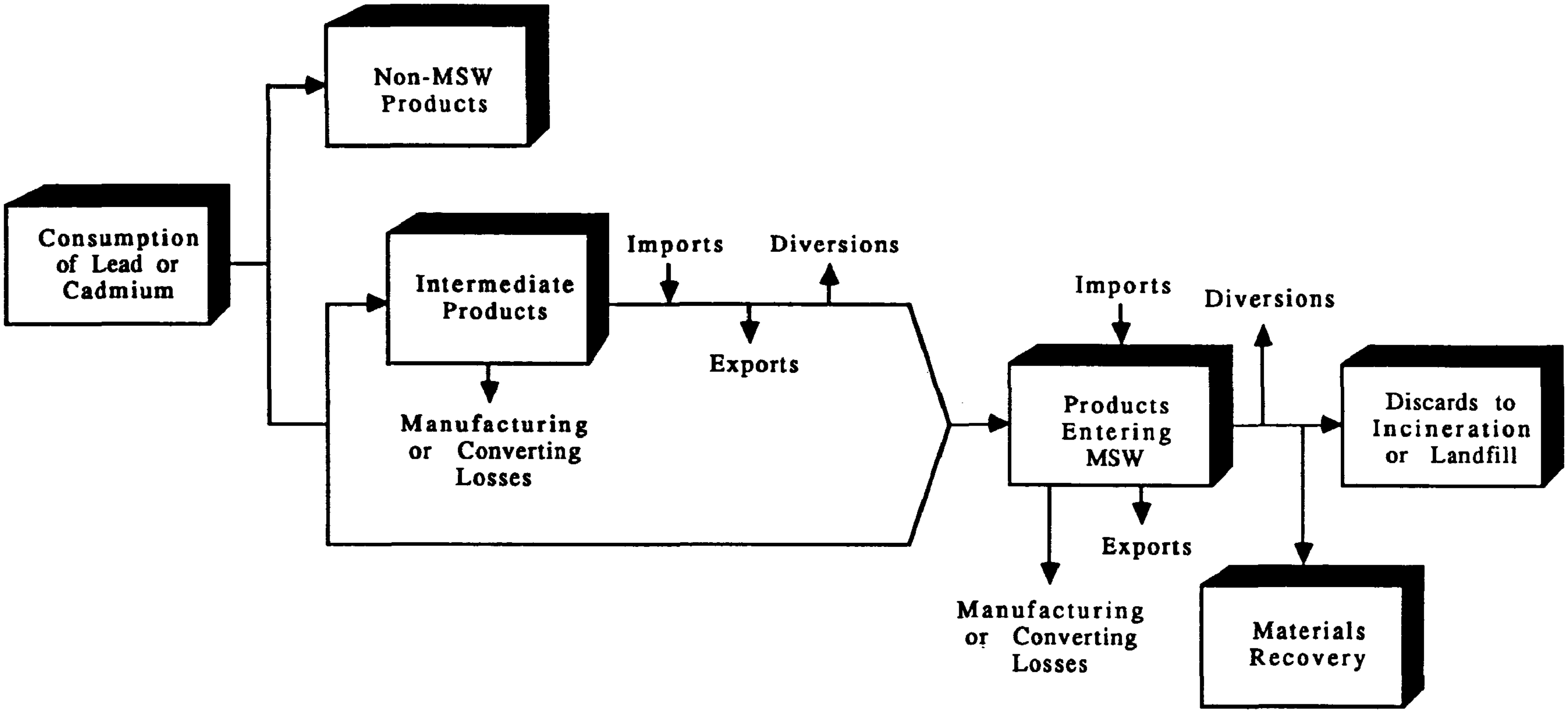
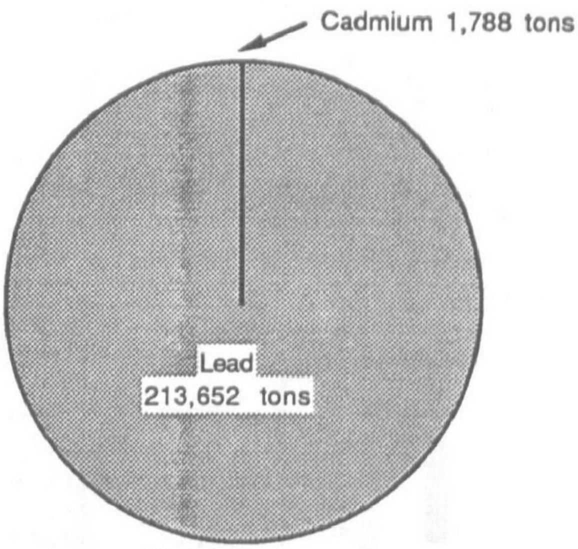


Figure 1-1. Materials flow methodology for estimating lead and cadmium in MSW discards.

Figure 1-2. Relative discards of lead and cadmium in MSW, 1986.



TRENDS IN DISCARDS* OF LEAD AND CADMIUM

Lead in MSW

Discards of lead in products in MSW from 1970 to 2000 are summarized in Tables 1-1 and 1-2. Some perspective on the discards of various products can be gained from Tables 1-3 and 1-4 and Figure 1-3. The products are discussed below in order of their relative rankings in 1986 (Table 1-3). (Each of these products is discussed in more detail in Chapter 2.)

Lead-Acid Batteries. By any measure, lead discarded in lead-acid storage batteries overwhelms all other sources. These batteries, which primarily provide starting, lighting, and ignition (SLI) for automotive products, rank Number 1 in discards for all years from 1970 to 2000 (Table 1-4 and Figure 1-3).

Table 1-2 demonstrates the high percentage of lead discarded in these batteries. They were 50 percent of the total lead discards in 1970, 76 percent in 1980, and 65 percent in 1986, a percentage that is projected to remain about constant to 2000. The figures show that discards of lead from batteries peaked in 1982 at about 409,000 tons. Several factors contributed to this: sales and imports of automotive vehicles were high in 1978 (there is a four-year lag between battery purchases and discards); the estimated pounds of lead per battery peaked at that time; and recycling of lead from batteries was declining. (Recycling is discussed in more detail later in this chapter.)

An estimated 138,000 tons of lead in batteries were discarded in 1986. These discards are projected to increase gradually to about 182,000 tons in 2000 under stable conditions (Table 1-1 and Figure 1-3).

Consumer Electronics. This category of products includes primarily television sets, radios, and more recently, video cassette recorders (VCRs). Consumer electronics were the Number 4 contributor of lead in MSW in 1970, but by 1975 they were Number 2, a position they continue to hold (Table 1-4). The sources of lead in these electronics products include soldered circuit boards, leaded glass in television sets, and plated steel chassis. Discards of lead in consumer electronics amounted to about 12,000 tons in 1970, or 7 percent of total lead discards. By 1986, this has grown to 58,500 tons, or 27 percent of total. By 2000, discards of lead in consumer electronics is projected to be 85,000 tons, or 30 percent of total. (See Figure 1-3.)

Solder containing lead is commonly used in circuit boards in consumer electronic products. This has been an increasing source of lead discards, but the amount discarded is projected to decline in the future (Table 1-1). This reflects a general decline in the use of lead in solder in

* "Discards" in this section refers to discards after recycling; in other words, the products shown in these tables and figures would be incinerated unless otherwise disposed.

Table 1-1

DISCARDS* OF LEAD IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1970 TO 2000
(In short tons)

	1970	1975	1980	1985	1986	1990	1995	2000
BRASS AND BRONZE PRODUCTS	410	474	404	267	321	310	181	207
CANS AND OTHER SHIPPING CONTAINERS								
Solder in food cans	11,995	10,291	6,882	1,898	1,139	642	594	443
Solder in beverage cans	9,227	7,260	1,077	0	0	0	0	0
Solder general cans	2,307	1,911	1,257	911	778	439	406	303
Solder in shipping containers	588	660	459	198	135	52	46	41
Subtotal - cans and shipping containers	24,117	20,122	9,675	3,007	2,052	1,133	1,046	787
CONSUMER ELECTRONICS								
Circuit boards	1,417	1,759	3,441	5,883	6,092	3,568	2,714	990
Plastics	0	0	0	0	0	46	26	42
TV picture tubes	10,430	17,935	17,690	40,818	52,165	48,230	76,280	84,000
TV and radio chassis	386	499	683	310	279	0	0	0
Subtotal - consumer electron.	12,233	20,193	31,814	47,011	58,536	51,844	79,020	85,032
GLASS AND CERAMIC PRODUCTS**	3,465	4,122	5,396	6,911	7,956	8,415	8,663	8,910
LEAD-ACID STORAGE BATTERIES								
Starting-lighting-ignition	83,823	206,420	205,641	221,913	137,996	167,236	172,639	181,445
Portable	2	7	18	41	47	71	91	101
Subtotal - lead-acid batteries	83,825	206,427	205,659	221,954	138,043	167,307	172,730	181,546
LIGHT BULBS								
Glass	491	507	623	706	709	727	787	847
Solder	156	161	197	224	225	230	249	268
Subtotal - light bulbs	647	668	820	930	934	957	1,036	1,115
PIGMENTS+								
Printing inks	19,192	13,819	8,222	1,414	265	220	179	140
All other products	7,828	3,198	1,642	954	866	718	630	542
Subtotal - pigments	27,020	17,017	9,864	2,368	1,131	938	809	682
PLASTICS++								
Nonfood packaging	775	689	968	916	934	1,007	1,003	1,003
Clothing	116	182	67	31	29	30	30	30
Footwear	152	342	264	372	324	290	290	290
Miscellaneous nondurables	56	89	371	377	391	390	390	390
Subtotal - nondurables	1,099	1,302	1,670	1,696	1,678	1,717	1,713	1,713
Housewares	80	227	189	166	177	137	145	145
Toys	130	354	222	183	219	176	183	183
Records	97	166	304	209	242	215	95	120
Luggage	3	4	8	4	5	7	5	6
Furniture	84	155	426	368	416	362	160	177
Appliances	88	74	113	98	92	148	139	153
Miscellaneous durables	32	61	80	742	748	758	731	731
Subtotal - durables	514	1,041	1,342	1,770	1,899	1,803	1,458	1,515
Subtotal - plastics	1,613	2,343	3,012	3,466	3,577	3,520	3,171	3,228
RUBBER PRODUCTS								
Tires and rubber products	36	38	70	42	48	55	57	59
All other rubber products	16	15	33	18	21	24	24	24
Subtotal - rubber products	52	53	103	60	69	79	81	83
USED OIL	1,557	1,230	810	314	192	61	48	36
MISCELLANEOUS PRODUCTS								
Collapsible tubes	9,310	2,860	1,477	607	639	240	220	200
Foil wine wrappers	591	356	383	243	202	100	80	60
Subtotal - misc. products	9,901	3,216	1,860	850	841	340	300	260
GRAND TOTAL	164,840	275,865	269,417	287,138	213,652	234,904	267,086	281,887

* Discards after recycling.
** Except for glass in light bulbs and television sets.
\+ Except for pigments in glass, plastics, and rubber.
++ Except for plastics in consumer electronics.

Table 1-2

DISCARDS* OF LEAD IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1970 TO 2000
(In percent of total lead discards)

Products	1970	1975	1980	1985	1986	1990	1995	2000
BRASS AND BRONZE PRODUCTS	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.1
CANS AND OTHER SHIPPING CONTAINERS								
Solder in food cans	7.3	3.7	2.5	0.7	0.5	0.3	0.2	0.2
Solder in beverage cans	5.6	2.6	0.4	0.0	0.0	0.0	0.0	0.0
Solder in general cans	1.4	0.7	0.5	0.3	0.4	0.2	0.2	0.1
Solder in shipping containers	0.3	0.2	0.2	0.1	0.1	0.0	0.0	0.0
Subtotal - cans and shipping containers	14.6	7.3	3.6	1.1	1.0	0.5	0.4	0.3
CONSUMER ELECTRONICS								
Circuit boards	0.9	0.6	1.3	2.1	2.9	1.5	1.0	0.4
Plastics	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TV picture tubes	6.3	6.5	10.3	14.2	24.4	20.5	28.6	29.8
TV and radio chassis	0.2	0.2	0.3	0.1	0.1	0.0	0.0	0.0
Subtotal - consumer electronics	7.4	7.3	11.8	16.4	27.4	22.1	29.6	30.2
GLASS AND CERAMIC PRODUCTS**	2.1	1.5	2.0	2.4	3.7	3.6	3.2	3.2
LEAD-ACID STORAGE BATTERIES								
Starting-lighting-ignition	50.8	74.8	76.3	77.3	64.6	71.2	64.6	64.4
Portable	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Subtotal - lead-acid batteries	50.9	74.8	76.3	77.3	64.6	71.2	64.7	64.4
LIGHT BULBS								
Glass	0.3	0.2	0.2	0.2	0.3	0.3	0.3	0.3
Solder	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Subtotal - light bulbs	0.4	0.2	0.3	0.3	0.4	0.4	0.4	0.4
PIGMENTS+								
Printing inks	11.6	5.0	3.1	0.5	0.1	0.1	0.1	0.1
All other products	4.8	1.2	0.6	0.3	0.4	0.3	0.3	0.2
Subtotal - pigments	16.4	6.2	3.7	0.8	0.5	0.4	0.3	0.3
PLASTICS++								
Nonfood packaging	0.5	0.3	0.4	0.3	0.4	0.4	0.4	0.4
Clothing	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Footwear	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Miscellaneous nondurables	0.0	0.0	0.1	0.1	0.2	0.2	0.1	0.1
Subtotal - nondurables	0.7	0.5	0.6	0.6	0.8	0.7	0.6	0.6
Housewares	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Toys	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Records	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0
Luggage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Furniture	0.0	0.1	0.2	0.1	0.2	0.2	0.1	0.1
Appliances	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Miscellaneous durables	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.3
Subtotal - durables	0.3	0.4	0.5	0.6	0.9	0.8	0.5	0.5
Subtotal - plastics	1.0	0.9	1.1	1.2	1.7	1.5	1.2	1.1
RUBBER PRODUCTS								
Tires and tire products	0.02	0.01	0.03	0.01	0.02	0.02	0.02	0.02
All other rubber products	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Subtotal - rubber products	0.03	0.02	0.04	0.02	0.03	0.03	0.03	0.03
USED OIL	0.9	0.4	0.3	0.1	0.1	0.03	0.02	0.01
MISCELLANEOUS PRODUCTS								
Collapsible tubes	5.6	1.0	0.6	0.2	0.3	0.1	0.1	0.1
Foil wine wrappers	0.4	0.1	0.1	0.1	0.1	0.0	0.0	0.0
Subtotal - misc. products	6.0	1.2	0.7	0.3	0.4	0.1	0.1	0.1
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Discards after recycling.
** Except for glass in light bulbs and television sets.
\+ Except for pigments in glass, plastics, and rubber.
++ Except for plastics in consumer electronics.

Table 1-3

DISCARDS* OF LEAD IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1986
RANKED IN ORDER OF WEIGHT OF LEAD
(In short tons and percent of total)

Products	Short Tons	Percent
LEAD-ACID STORAGE BATTERIES		
Starting-lighting-ignition	137,996	64.6
Portable	47	0.0
Subtotal - lead batteries	138,043	64.6
CONSUMER ELECTRONICS		
Circuit boards	6,092	2.9
TV picture tubes	52,165	24.4
TV and radio chassis	279	0.1
Subtotal-consumer electronics	58,536	27.4
GLASS AND CERAMIC PRODUCTS**	7,956	3.7
PLASTICS+		
Nonfood packaging	934	0.4
Clothing	29	0.0
Footwear	324	0.2
Miscellaneous nondurables	391	0.2
Subtotal-nondurables	1,678	0.8
Housewares	177	0.1
Toys	219	0.1
Records	242	0.1
Luggage	5	0.0
Furniture	416	0.2
Appliances	92	0.0
Miscellaneous durables	748	0.3
Subtotal-durables	1,899	0.9
Subtotal-plastics	3,577	1.7
CANS AND OTHER SHIPPING CONTAINERS		
Solder in food cans	1,139	0.5
Solder in general cans	778	0.4
Solder in shipping containers	135	0.1
Subtotal-cans and shipping containers	2,052	1.0
PIGMENTS++		
Printing inks	265	0.1
All other products	866	0.4
Subtotal -pigments	1,131	0.5
LIGHT BULBS		
Glass	709	0.3
Solder	225	0.1
Subtotal-light bulbs	934	0.4
COLLAPSIBLE TUBES	639	0.3
BRASS AND BRONZE PRODUCTS	321	0.2
FOIL WINE WRAPPERS	202	0.1
USED OIL	192	0.1
RUBBER PRODUCTS		
Tires and tire products	48	0.02
All other rubber products	21	0.01
Subtotal-rubber products	69	0.03
GRAND TOTAL	213,653	100.0

* Discards after recycling.
** Except for glass in light bulbs and television sets.
\+ Except for plastics in consumer electronics.
++ Except for pigments in glass, plastics, and rubber

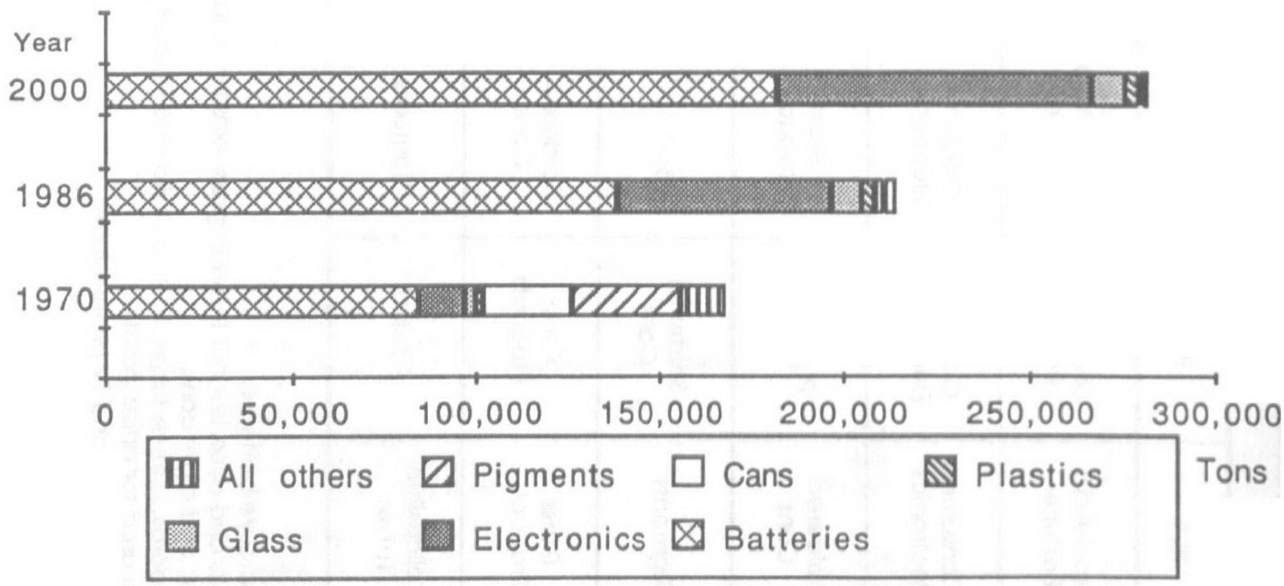
Table 1-4

SOURCES OF LEAD IN MSW, RANKED BY TONNAGE, 1970 TO 2000

RANK / YEAR	1970	1975	1980	1986	1990	1995	2000
No. 1	Lead-Acid Batteries	Lead-Acid Batteries	Lead-Acid Batteries	Lead-Acid Batteries	Lead-Acid Batteries	Lead-Acid Batteries	Lead-Acid Batteries
No. 2	Pigments	Consumer Electronics	Consumer Electronics	Consumer Electronics	Consumer Electronics	Consumer Electronics	Consumer Electronics
No. 3	Soldered Cans	Soldered Cans	Pigments	Glass Products	Glass Products	Glass Products	Glass Products
No. 4	Consumer Electronics	Pigments	Soldered Cans	Plastics	Plastics	Plastics	Plastics
No. 5	Collapsible Tubes	Glass Products	Glass Products	Soldered Cans	Soldered Cans	Soldered Cans	Light Bulbs
No. 6	Glass Products	Collapsible Tubes	Plastics	Pigments	Pigments	Light Bulbs	Soldered Cans

Lead-Acid Batteries are primarily automotive batteries.
Pigments include pigments in paints, inks and dyes, but not those in glass, plastics, and rubber.
Soldered Cans include food, beverage, and other cans.
Consumer Electronics include circuit boards, picture tubes, TV and radio chassis, and plastics.
Collapsible Tubes are tubes of the type used for artists' paints.
Glass Products include all uses except light bulbs and TV picture tubes.

Figure 1-3. Lead in discards of products in MSW, 1970, 1986, and 2000.



electronic components as reported by the Bureau of Mines, and reflects changes in the manufacturing processes. Discards of lead from solder in consumer electronics were about 1,400 tons in 1970 (less than one percent of the total), and were about 76,000 tons in 1986 (about 3 percent of total). These discards of lead are projected to decline to less than 1,000 tons and less than one percent of total discards by 2000.

Leaded glass in television picture tubes is the major source of lead in consumer electronic products. (According to the Bureau of Mines, 75 percent of lead used in glass is used in picture tubes.) Lead in the glass provides shielding from X-rays and otherwise enhances the qualities of the glass. This source of lead in MSW has increased steadily since 1970, and is projected to continue to do so (Table 1-1). Discards of lead from glass in TVs were about 10,000 tons in 1970 (6 percent of total), and were about 52,000 tons in 1986, or 24 percent of total lead. These discards are projected to be 84,000 tons, or 30 percent of total, in 2000 if present trends continue.

Finally, many steel chassis in television sets and radios were coated with terne metal (a lead and tin alloy) up until 1980. This has never been a major source of lead in MSW (less than one percent), and is projected to disappear as old television sets are phased out.

It is of interest to note that in 1986, lead-acid batteries and lead in consumer electronics together accounted for 92 percent of lead discards in MSW.

Glass and Ceramic Products. It was possible to quantify lead in glass in television picture tubes and light bulbs separately (Chapter 2). Lead discards in the remaining products in MSW were quantified in total, but it was not possible to determine separate end uses of the lead. This category of discarded products includes glass containers for food, beverages, and miscellaneous products such as cosmetics; glass and ceramic tableware and cookware; mirrors; optical glasses; electronic products; enamels for appliances and other uses; and miscellaneous decorative and other uses.

The major uses of leaded glass are in television picture tubes and light bulbs, as described elsewhere. Other uses of leaded glass include tableware and bifocal lenses in reading glasses.

Lead is a component in glazes and enamels used on glass containers, tableware, and cookware. Enamels used in silk screening designs on glass typically contain 40 to 50 percent lead monoxide. Lead is also used as a colorant in some of these designs.

These discards ranked Number 3 in 1986 at almost 8,000 tons and almost 4 percent of total lead discards. In 1970 lead use in these glass products ranked Number 6 at 3,500 tons and 2 percent of total. This use is projected to grow to 9,000 tons in 2000, or 3 percent of the total.

Plastics.* Discards of lead in plastic products did not rank in the top six sources in 1970, but in 1986 plastics ranked fourth, and this is projected to continue (Table 1-4). Lead is used in two ways in plastics: as a component in compounds designed to act as heat stabilizers, primarily in polyvinyl resins, and as a component in pigments used in a variety of plastic resins.

Discards of lead in plastic products has been growing, but this source contributes a small portion of the total (Figure 1-3). In 1970 lead in plastic discards contributed 1,600 tons, about one percent of the total. In 1986 lead in plastics comprised about 3,500 tons, less than 2 percent of total. Projections to 2000 show about 3,200 tons of lead in plastics being discarded, slightly more than one percent of total. The projected decline is attributed to regulations on lead in certain products, such as toys and furniture.

Discards of lead in products made of plastics ranked as follows in 1986: nonfood packaging (highest tonnage), miscellaneous durables, furniture, miscellaneous nondurables, footwear, records, toys, housewares, appliances, and others.

Soldered Cans. In 1970, lead in solder in cans and shipping containers represented the Number 3 discard into MSW, but by 1986 this was the Number 5 source of discards (Table 1-4). The use of leaded solder in steel food cans has declined dramatically, and soldered steel beverage cans have virtually disappeared. Use of leaded solder in general purpose cans, such as aerosols, and in shipping containers has also declined. Figure 1-3 illustrates this decline.

Discards of lead in soldered cans were 24,000 tons, or over 14 percent of total discards, in 1970. In 1986, only 2,000 tons of lead were discarded in soldered cans, representing less than one percent of total. These discards are projected to be about 800 tons, much less than one percent of total, in 2000.

Pigments. Discards of pigments in plastics, glass, and rubber are discussed in other sections. The remaining pigments--those used in paints, printing inks, textile dyes, and miscellaneous uses--are included in this section. These pigments ranked second in discards of lead into MSW in 1970, but they are ranked Number 6 in 1986 (Table 1-4). As illustrated in Figure 1-3, use of lead in pigments has been in decline, in large part due to concerns about toxicity.

Discards of lead in printing inks, once an important source of lead, have declined dramatically, from 19,000 tons in 1970 to less than 300 tons in 1986. Use of lead in many kinds of paint has been regulated, also leading to a decline in consumption.

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* Plastics in consumer electronics are counted in that category.

Total discards of lead in these pigments was 30,000 tons in 1970, or 16 percent of total lead discards. This had declined to about 1,200 tons in 1986--less than one percent of total. The decline is projected to continue, to about 700 tons in 2000, much less than one percent of the total.

Light Bulbs. Light bulbs are not a large source of lead in MSW, but are of interest because they contain two sources of lead: solder and leaded glass. While not ranked in the top six sources of lead in MSW in 1986, light bulbs are projected to be the Number 5 source in 2000 (Table 1-4).

In 1970 lead discarded into MSW from light bulbs was estimated to be about 600 tons, less than one percent of the total. By 1986 these discards were over 900 tons; by 2000, over 1,000 tons. The percentage of total is not projected to be over one percent in any case.

Collapsible Tubes. Collapsible tubes made of lead are used for products such as artists' paints. These tubes represented the Number 5 source of lead in MSW in 1970 (Table 1-4), at over 9,000 tons and over 5 percent of total discards. By 1986, however, collapsible tubes contributed only about 600 tons, less than one percent of the total. The decline is projected to continue, to only 200 tons in 2000.

Brass and Bronze Products. Lead is a component of some brass and bronze products, although most of these applications are not discarded into MSW. Brass and bronze items that may be discarded into MSW include locks, keys, and miscellaneous products such as clock and watch parts, musical instruments, etc.

Discards of lead in brass and bronze products are a very small part of total lead discards, estimated to be less than 500 tons per year since 1970 and declining.

Foil Wine Wrappers. Lead foil wine wrappers are used to cover the corks on some wine bottles, although aluminum foil is replacing lead in many instances. Discards of lead from this source are estimated to have declined from about 600 tons in 1970 to about 200 tons in 1986, with a continued decline to about 60 tons in 2000.

Used Oil. Gasoline additives were formerly an important use of lead before the phase-out due to regulatory action began. Some of the lead from the additives enters used automotive oil, as does some lead from other sources such as engine wear. It was estimated that about 1,500 tons of lead in used oil entered MSW in 1970, almost one percent of total discards. By 1986 this had decreased to less than 200 tons, and by 2000, lead in used oil is projected to be only 36 tons.

Rubber Products. Most of the lead consumed by the rubber industry is used in products like lead-sheathed hose that do not enter MSW. It was estimated that 100 tons or less of lead enters MSW in rubber products each year. About 50 tons of lead in rubber were discarded in 1970; about 70 tons in 1986; and a projected 80 tons in 2000.

Cadmium in MSW

Discards of cadmium in products in MSW from 1970 to 2000 are summarized in Tables 1-5 and 1-6. Tables 1-7 and 1-8 show how products discarded into MSW rank in their contributions of cadmium. A perspective on the changing importance of the various sources of cadmium is shown in Figure 1-4. Products containing cadmium in MSW are discussed below in order of the relative rankings in 1986 (Table 1-7). (More details on these products are contained in Chapter 3.)

Household Batteries. Household batteries (primarily rechargeable nickel-cadmium batteries) have been the Number 1 source of cadmium in MSW since 1980 (Table 1-8). Their growth has been rapid--they were the Number 5 source of cadmium in 1970. Nickel-cadmium (Ni-Cd) batteries have become very popular for uses such as portable hand tools, small appliances such as vacuum cleaners and mixers, portable television sets, cameras, etc.

In 1970 discards of cadmium in household batteries were estimated at 53 tons, or 4 percent of total cadmium discards. By 1986 this number was 930 tons, or 52 percent of the total. If this growth continues as projected, discards in 2000 will be over 2,000 tons, or 76 percent of total (Figure 1-4).

Plastics. Plastics have ranked second only to household batteries as a source of cadmium in MSW since 1980 (Table 1-8). Like lead, cadmium is used as a stabilizer in polyvinyl chloride resin and as a pigment in a variety of resins.

Discards of cadmium in plastics were 342 tons in 1970, or almost 29 percent of the total cadmium discards. Cadmium in plastics peaked at 595 tons in 1978 (38 percent of total discards), then generally declined to 502 tons in 1986 (28 percent of total discards). Projected discards are 384 tons in 2000, or 14 percent of total (Figure 1-4). The decline is generally attributed to concern over toxicity and regulations on the use of cadmium in products like toys and furniture.

In 1986, plastic products containing cadmium in discards ranked as follows: nonfood packaging (highest tonnage), miscellaneous durables, miscellaneous nondurables, furniture, toys, records, footwear, and others.

It is of interest to note that household batteries and plastics combined accounted for 80 percent of cadmium discards into MSW in 1986.

Consumer Electronics. Discards of cadmium-plated chassis in radios and television sets gave consumer electronics the Number 3 ranking in cadmium discards in 1986. This is a declining source of cadmium discards, however, ranking Number 1 in 1970 and Number 4 in 2000 (Table 1-8 and Figure 1-3). Cadmium was formerly used to plate the chassis or steel sheet that holds electronic parts of the radio or TV together. By 1980 this technology has been replaced by printed circuit boards, so this source of cadmium is declining as older equipment is replaced.

Table 1-5

DISCARDS* OF CADMIUM IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1970 to 2000
(In short tons)

Products	1970	1975	1980	1985	1986	1990	1995	2000
APPLIANCES								
Cadmium plating	47	39	32	25	24	19	12	9
Plastics	60	52	77	54	64	38	46	48
Subtotal - appliances	107	91	109	79	88	57	58	57
CONSUMER ELECTRONICS								
Cadmium plating	571	330	176	158	161	101	67	20
Plastics	0	0	0	0	0	36	41	47
Subtotal - consumer electronics	571	330	176	158	161	137	108	67
GLASS AND CERAMIC PRODUCTS	32	27	23	25	29	32	34	37
HOUSEHOLD BATTERIES								
Nickel-cadmium batteries	51	209	996	996	927	1,305	1,709	2,032
Dry cell casings	2	2	2	3	3	3	3	3
Subtotal-household batteries	53	211	998	999	930	1,308	1,712	2,035
PIGMENTS**	79	65	56	59	70	78	85	93
PLASTICS+								
Nonfood packaging	209	133	128	139	166	150	150	150
Clothing	15	36	8	2	2	2	2	2
Footwear	19	70	31	27	21	21	21	21
Miscellaneous nondurables	11	13	37	43	51	46	46	46
Subtotal-nondurables	254	252	204	211	240	219	219	219
Housewares	19	56	33	21	31	20	22	22
Toys	34	109	53	32	44	34	33	33
Records	12	21	65	22	29	12	7	8
Luggage	5	6	9	5	9	7	6	7
Furniture	10	18	77	35	46	23	11	13
Miscellaneous durables	8	21	15	73	103	78	82	82
Subtotal-durables	88	231	252	188	262	174	161	165
Subtotal-plastics	342	483	456	399	502	393	380	384
RUBBER PRODUCTS++	10	13	8	6	6	8	9	9
USED OIL	1	1	1	1	1	1	1	1
MISCELLANEOUS PRODUCTS								
Electric blankets and heating pads	1	1	1	1	1	1	1	1
GRAND TOTAL	1,196	1,222	1,828	1,727	1,788	2,015	2,388	2,684

* Discards after recycling.
** Except for pigments in glass, plastics, and rubber.
\+ Except for plastics in appliances and consumer electronics.
++ Assumed to be all nontire products.

Table 1-6

DISCARDS* OF CADMIUM IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1970 TO 2000
(In percent of total cadmium discards)

	1970	1975	1980	1985	1986	1990	1995	2000
APPLIANCES								
Cadmium plating	3.9	3.2	1.8	1.4	1.3	0.9	0.3	0.3
Plastics	5.0	4.3	4.2	3.1	3.6	1.9	1.8	1.8
Subtotal-appliances	8.9	7.4	6.0	4.6	4.9	2.8	2.1	2.1
CONSUMER ELECTRONICS								
Cadmium plating	47.7	27.0	9.6	9.1	9.0	5.0	0.7	0.7
Plastics	0.0	0.0	0.0	0.0	0.0	1.8	1.8	1.8
Subtotal-consumer electronics	47.7	27.0	9.6	9.1	9.0	6.8	2.5	2.5
GLASS AND CERAMIC PRODUCTS	2.7	2.2	1.3	1.4	1.6	1.6	1.4	1.4
HOUSEHOLD BATTERIES								
Nickel-cadmium batteries	4.3	17.1	54.5	57.7	51.8	64.8	75.7	75.7
Dry cell casings	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1
Subtotal-household batteries	4.4	17.3	54.6	57.8	52.0	64.9	75.8	75.8
PIGMENTS**	6.6	5.3	3.1	3.4	3.9	3.9	3.5	3.5
PLASTICS+								
Nonfood packaging	17.5	10.9	7.0	8.0	9.3	7.4	5.6	5.6
Clothing	1.3	2.9	0.4	0.1	0.1	0.1	0.1	0.1
Footwear	1.6	5.7	1.7	1.6	1.2	1.0	0.8	0.8
Miscellaneous nondurables	0.9	1.1	2.0	2.5	2.9	2.3	1.7	1.7
Subtotal-nondurables	21.2	20.6	11.2	12.2	13.4	10.9	8.2	8.2
Housewares	1.6	4.6	1.8	1.2	1.7	1.0	0.8	0.8
Toys	2.8	8.9	2.9	1.9	2.5	1.7	1.2	1.2
Records	1.0	1.7	3.6	1.3	1.6	0.6	0.3	0.3
Luggage	0.4	0.5	0.5	0.3	0.5	0.3	0.3	0.3
Furniture	0.8	1.5	4.2	2.0	2.6	1.1	0.5	0.5
Miscellaneous durables	0.7	1.7	0.8	4.2	5.8	3.9	3.1	3.1
Subtotal-durables	7.4	18.9	13.8	10.9	14.7	8.6	6.1	6.1
Subtotal-plastics	28.6	39.5	24.9	23.1	28.1	19.5	14.3	14.3
RUBBER PRODUCTS++	0.8	1.1	0.4	0.3	0.3	0.4	0.3	0.3
USED OIL	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
MISCELLANEOUS PRODUCTS								
Electric blankets and heating pads	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0
GRAND TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* Discards after recycling.
** Except for pigments in glass, plastics and rubber.
\+ Except for plastics in appliances and consumer electronics.
++ Assumed to be all non-tire products.

Table 1-7

DISCARDS* OF CADMIUM IN PRODUCTS IN THE MUNICIPAL WASTE STREAM, 1986
RANKED IN ORDER OF WEIGHT OF CADMIUM
(in short tons and percent of total)

Products	Short Tons	Percent
HOUSEHOLD BATTERIES		
Nickel-cadmium batteries	927	51.8
Drycell casings	3	0.2
Subtotal-household batteries	930	52.0
PLASTICS**		
Nonfood packaging	166	9.3
Clothing	2	0.1
Footwear	21	1.2
Miscellaneous nondurables	51	2.9
Subtotal-nondurables	240	13.4
Housewares	31	1.7
Toys	44	2.5
Records	29	1.6
Luggage	9	0.5
Furniture	46	2.6
Miscellaneous durables	103	5.8
Subtotal-durables	262	14.7
Subtotal-plastics	502	28.1
CONSUMER ELECTRONICS		
Cadmium plating	161	9.0
APPLIANCES		
Cadmium plating	24	1.3
Plastics	64	3.6
Subtotal-appliances	88	4.9
PIGMENTS+	70	3.9
GLASS AND CERAMIC PRODUCTS	29	1.6
RUBBER PRODUCTS++	6	0.3
USED OIL	1	0.1
MISCELLANEOUS PRODUCTS		
Electric blankets and heating pads	1	0.1
GRAND TOTAL	1,788	100.0

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* Discards after recycling.
** Except for plastics in appliances.
+ Except for pigments in glass, plastics, and rubber.
++ Assumed to be all non-tire products.

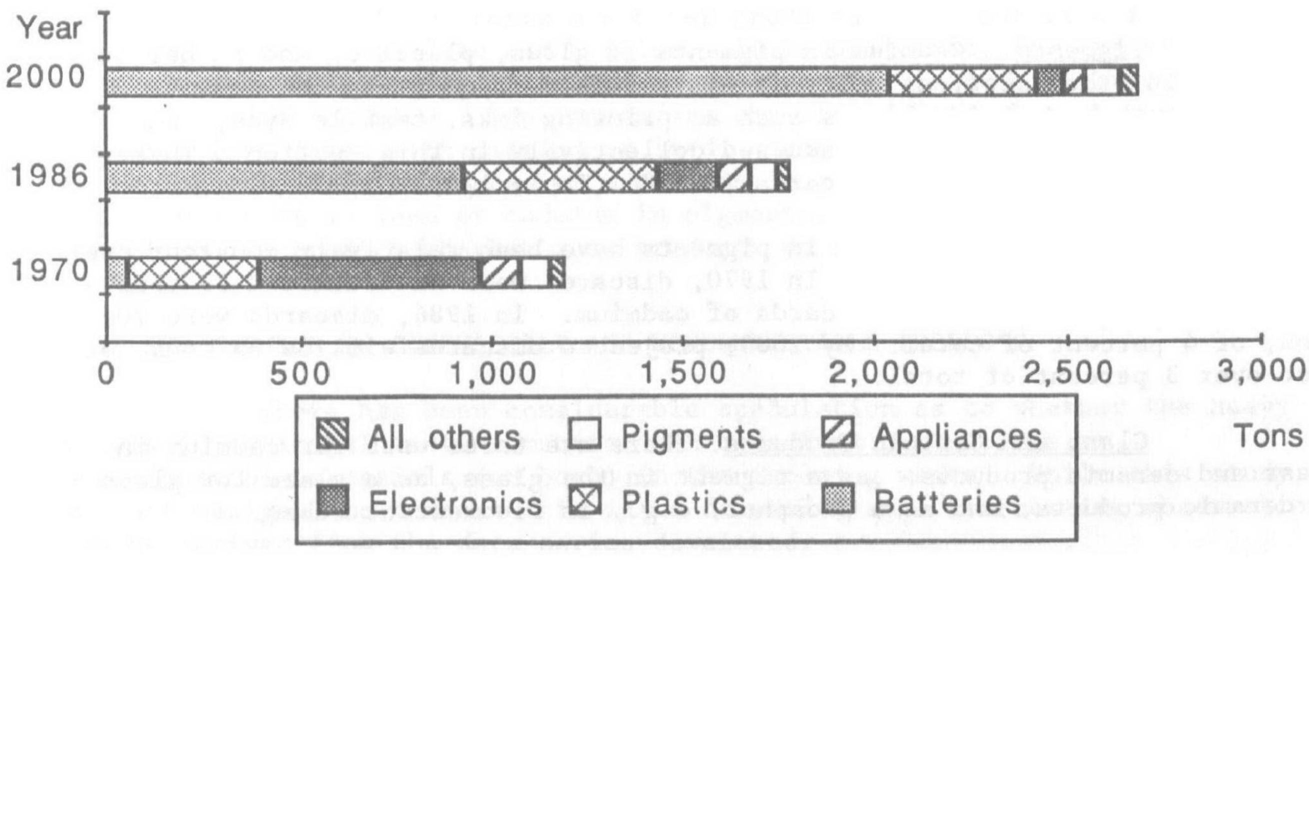
Table 1-8

SOURCES OF CADMIUM IN MSW, RANKED BY TONNAGE, 1970 TO 2000

RANK / YEAR	1970	1975	1980	1986	1990	1995	2000
No. 1	Consumer Electronics	Plastics	Household Batteries	Household Batteries	Household Batteries	Household Batteries	Household Batteries
No. 2	Plastics	Consumer Electronics	Plastics	Plastics	Plastics	Plastics	Plastics
No. 3	Appliances	Household Batteries	Consumer Electronics	Consumer Electronics	Consumer Electronics	Consumer Electronics	Pigments
No. 4	Pigments	Appliances	Appliances	Appliances	Pigments	Pigments	Consumer Electronics
No. 5	Household Batteries	Pigments	Pigments	Pigments	Appliances	Appliances	Appliances

Consumer Electronics primarily includes cadmium plating on televisions and radios, plus some plastics in later years.
Plastics include all plastic uses except for appliances and consumer electronics.
Appliances primarily include cadmium plating in dishwashers and washing machines and plastics.
Pigments includes pigments in paints, inks, and dyes, but not those in glass, plastics and rubber.
Household Batteries are primarily rechargeable nickel-cadmium household batteries.

Figure 1-4. Cadmium in discards of products in MSW, 1970, 1986 and 2000.



In 1970, cadmium discards in consumer electronics were estimated at 571 tons, or 48 percent of total discards. By 1986, these discards were 161 tons, or 9 percent of total; projected 2000 discards are 67 tons, or 2.5 percent of total.

Appliances. There are two potential sources of cadmium in discarded appliances: cadmium plating and plastics. Appliances ranked Number 4 in cadmium discards in 1986, but are projected to drop to Number 5 by 1990 (Table 1-8).

Cadmium was formerly used to plate nuts, bolts, and screws in dishwashers and washing machines because of cadmium's corrosion-resistant properties. As more appliance parts are made of plastic, however, the use of cadmium plating has been phased out.

Appliances contributed an estimated 107 tons of cadmium to MSW in 1970, or 9 percent of the total. By 1986, these discards had declined to 88 tons, 5 percent of total. A continued decline is projected, to 57 tons, or 2 percent, in 2000.

Pigments. Cadmium in pigments in glass, plastics, and rubber is discussed in other sections. It was not possible to quantify the amounts of cadmium in other individual uses such as printing inks, textile dyes, and paints; these categories are discussed collectively in this section. These pigments ranked Number 5 in discards in 1986 (Table 1-8).

Discards of cadmium in pigments have been relatively constant over the study period (Figure 1-4). In 1970, discards were an estimated 79 tons, or about 7 percent of total discards of cadmium. In 1986, discards were 70 tons, or 4 percent of total. By 2000, projected discards will be 93 tons, or just over 3 percent of total.

Glass and Ceramic Products. There are three uses for cadmium in glass and ceramic products: as a pigment in the glass, as a glaze for glass or ceramic products, and as a phosphor, e.g., in fluorescent tubes.

Glass and ceramic products account for a relatively minor portion of cadmium discards in MSW. In 1970, 32 tons, or less than 3 percent of total, were discarded. In 1986, 29 tons, or less than 2 percent of total, were discarded. In 2000, it is estimated that 37 tons, or less than 2 percent of total, will be discarded.

Rubber Products. Small amounts of cadmium are used in non-tire rubber products such as hose and hot water bottles. This is a very minor source of cadmium in MSW. An estimated 10 tons of cadmium were discarded in rubber products in 1970, less than one percent of the total. In 1986, an estimated 6 tons were discarded, again less than one percent. In 2000, discards of 9 tons of cadmium in rubber products are projected, less than one percent of the total.

Used Oil. Studies have shown that small amounts of cadmium are detected in used automotive oil. It was therefore estimated that one ton of cadmium per year is discarded into MSW with used oil. This may overstate these discards.

Miscellaneous Uses. Cadmium is used in very minor amounts in the controls of electric blankets and heating pads. It was estimated that one ton of cadmium is discarded in these products each year. This may overstate these discards.

PRODUCTS CONTAINING BOTH LEAD AND CADMIUM

Throughout this report, estimates of lead and cadmium discards in products have been made separately. There are a number of products, however, that may often contain both metals in varying amounts. Table 1-9 presents a listing of these products in 1986. Those quantified include consumer electronics, glass and ceramic products, plastics, pigments, rubber products, and used oil.

In addition, there are other products not quantified in Table 1-9 that may contain both lead and cadmium. It is projected, for example, that some consumer electronics discarded after 1986 will include plastics that may contain lead or cadmium. Appliances are not listed here, but they may contain pigments formulated with cadmium or lead. Many products, especially packaging, are made of composite materials, e.g., paper, plastic, and foil, that could contain lead or cadmium in pigments. It is very difficult, therefore, to predict whether some products do or do not contain lead and/or cadmium.

LEAD AND CADMIUM IN COMBUSTIBLE AND NONCOMBUSTIBLE PRODUCTS

There has been considerable speculation as to whether the heavy metals in municipal waste combustor ash come from combustible or noncombustible materials (or both) in the incoming waste. While this study was not designed to address this issue directly, some interesting observations can be derived from the data series developed.

Lead in Combustible and Noncombustible Products

The relative tonnages of lead in combustible and noncombustible products in MSW are shown in Figure 1-5. The noncombustible products overwhelmingly predominate at almost 98 percent of the total weight of lead. The reasons for this are illustrated in Figure 1-6: lead-acid batteries and consumer electronics, two relatively heavy products, contribute most of the lead in MSW. Glass products and all other sources, e.g., light bulbs and soldered cans, account for the rest of the lead.

Sources of lead in combustible products in MSW are illustrated in Figure 1-7. If all of the noncombustible products were removed from the incoming waste at an incinerator (by deposits, preprocessing, or other management methods), most of the remaining lead (71 percent) would be

Table 1-9

PRODUCTS CONTAINING BOTH LEAD AND CADMIUM, 1986
(In short tons)

Products	Lead	Cadmium
CONSUMER ELECTRONICS		
Circuit boards	6,092	-
TV picture tubes	52,165	-
TV and radio chassis	279	-
Cadmium plating	-	24
Subtotal - consumer electronics	58,536	24
GLASS AND CERAMIC PRODUCTS	7,956	29
PLASTICS		
Nondurables	1,678	240
Durables	1,899	262
Subtotal - plastics	3,577	502
PIGMENTS	1,131	70
RUBBER PRODUCTS		
Tires	48	-
Non-tire products	21	6
Subtotal - rubber products	69	6
USED OIL	192	1

Figure 1-5. Relative discards of lead in combustible and noncombustible products, 1986.

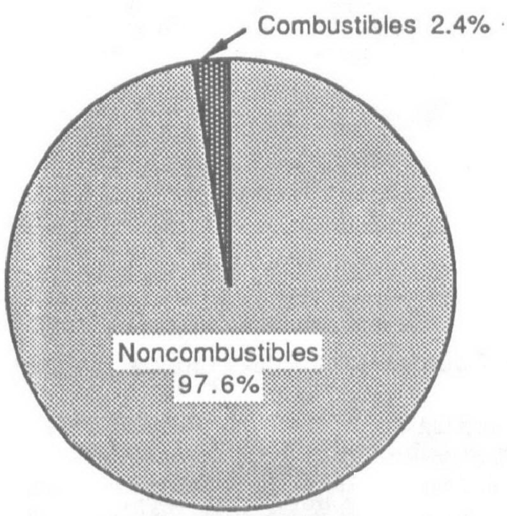


Figure 1-6. Sources of lead in noncombustible products, 1986

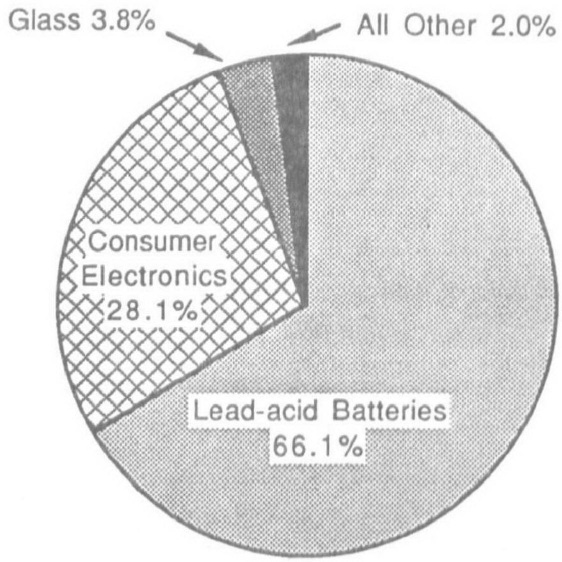
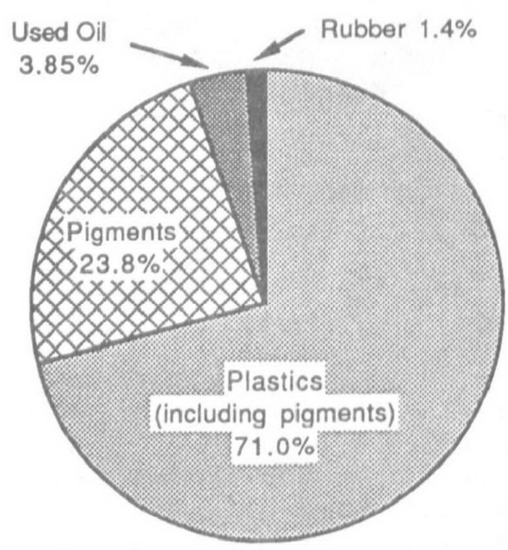


Figure 1-7. Sources of lead in combustible products, 1986.



contained in plastic products. Other pigments in painted products or products such as printed paper and dyed textiles would account for most of the rest (24 percent). Other small contributors of lead include used oil and rubber products.

Cadmium in Combustible and Noncombustible Products

Noncombustible products also contribute the majority of cadmium in MSW (64 percent), but not in such overwhelming amounts as is the case for lead (Figure 1-8). The primary source of cadmium in noncombustible products is household (nickel-cadmium) batteries (81 percent). Figure 1-9 also illustrates that consumer electronics contribute the second highest amount of cadmium in noncombustible products (14 percent). The remainder is contributed by appliances and other products (e.g., electric blankets and heating pads).

If all the cadmium in noncombustible sources were removed from MSW entering an incinerator, the cadmium in plastics would provide most of the remainder (88 percent). This is illustrated in Figure 1-10. Pigments in painted products, printed paper, and dyed textiles would contribute most of the remainder of the cadmium (11 percent). Very small amounts would come from rubber products and used oil in MSW.

Lead and Cadmium in Combustible and Noncombustible Products

The data reported above can be combined in another way to show the relative discards of lead and cadmium in combustible and noncombustible products.

Combined discards of lead and cadmium in noncombustible products come overwhelmingly from the lead in products (Figure 1-11). For both metals the primary source in this instance is batteries.

For combined discards of lead and cadmium in combustible products, lead still predominates, but not by such an overwhelming margin (Figure 1-12). Lead contributes almost 89 percent of these discards; cadmium, 11 percent. For both lead and cadmium, plastic products contribute the highest tonnage in combustible products, while pigments in other products are the second largest contributor.

THE POTENTIAL EFFECTS OF RECYCLING

Lead-acid Batteries

Recycling has been suggested as a way to reduce the amounts of lead and cadmium entering municipal waste combustors. Only one of the lead or cadmium-containing products currently identified is recycled in significant amounts: lead-acid SLI batteries. This one product is extremely significant. As noted earlier, lead-acid batteries contributed 65 percent of the lead discards in MSW in 1986--138,000 tons. If these batteries were not recovered for recycling at significant rates (80 percent in 1986), up to 700,000

Figure 1-8. Relative discards of cadmium in combustible and noncombustible products, 1986.

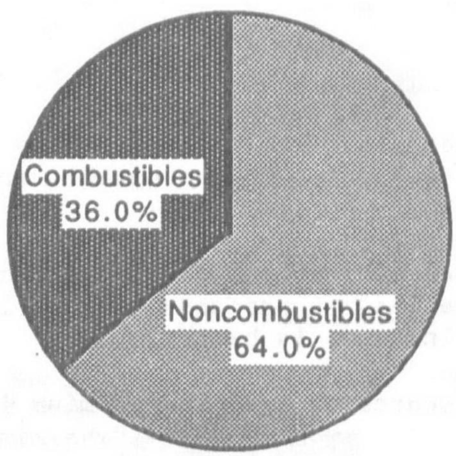


Figure 1-9. Sources of cadmium in noncombustible products, 1986.

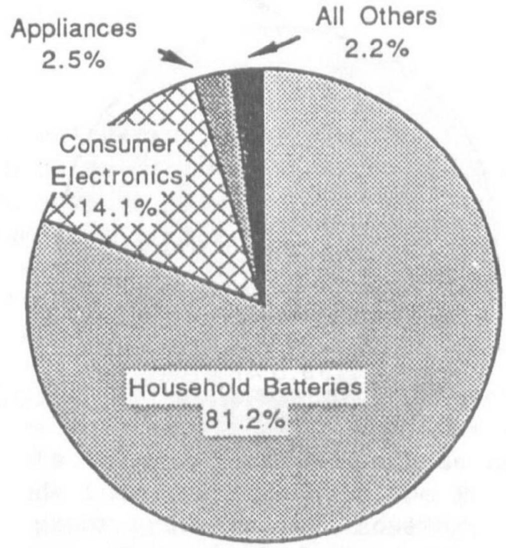


Figure 1-10. Sources of cadmium in combustible products, 1986.

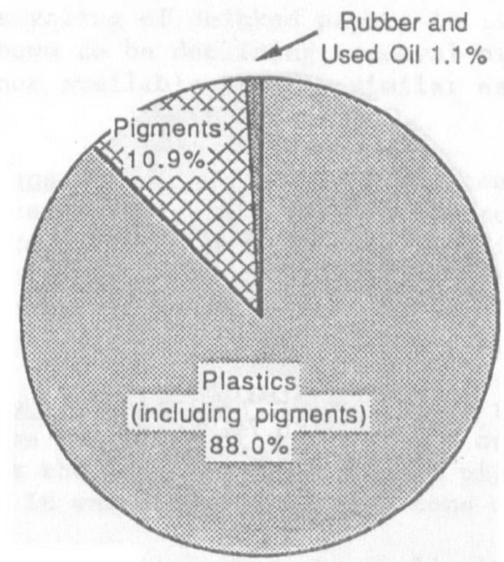


Figure 1-11. Relative discards of lead and cadmium in noncombustible products in MSW, 1986.

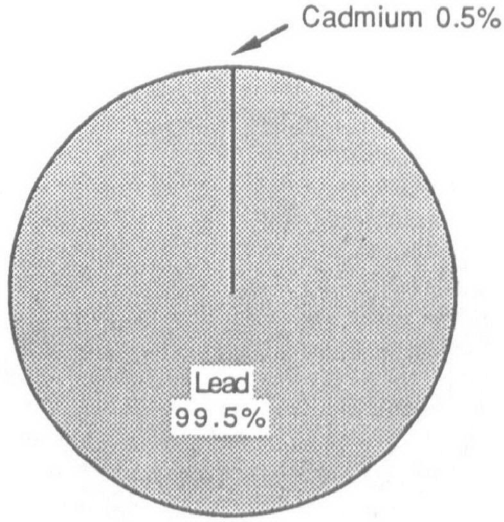
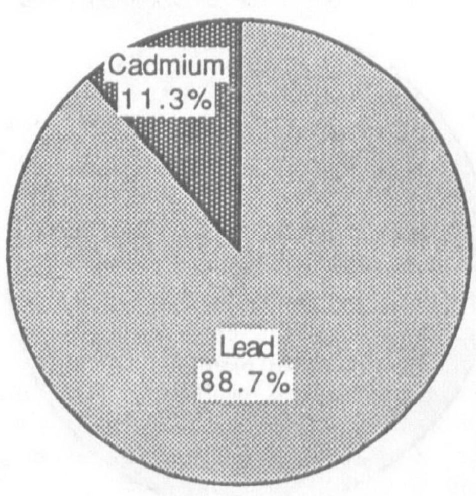


Figure 1-12. Relative discards of lead and cadmium in combustible products in MSW, 1986.



additional tons of lead from lead-acid batteries would have been discarded in 1986.

Historic discards and recycling of lead-acid batteries are illustrated in Figure 1-13. Recycling rates dropped as low as 52 percent in the early 1980s (apparently due to low prices for lead and increased regulations), and the figure illustrates that net quantities of batteries to be disposed increased at that time. Recycling obviously plays an important role in management of these batteries.

Other Products

No other recycling of lead or cadmium in products in MSW was identified, although there may be some small exports of nickel-cadmium batteries for recycling abroad. Some recycling of products in MSW that removes lead and cadmium from disposal in a landfill or incinerator as a by-product rather than as a goal of the recycling activity was identified.* These activities are discussed briefly in this section. (More information can be found in Chapters 2 and 3.)

Paper Products. A number of paper products are recovered for recycling, including some that are printed with inks that could contain lead or cadmium in the pigments. In many cases, such as newspapers made into boxboard or magazines made into roofing felt, the inks tend to remain in the recycled product. Some paper products are, however, deinked before being recycled into new products. These include recovered newspapers that are deinked before being made into new newsprint, and high grade recovered papers like computer printout that are deinked before being made into a product like paper towels.

It was estimated that up to 49 tons of lead in printing inks could have been removed by recycling of deinked papers in 1986. Since use of lead in printing inks was shown to be declining, removal of lead would also be declining. Data were not available to make similar estimates for cadmium in printing inks.

Solder in Cans. The lead in soldered steel cans is removed from the municipal waste stream when the cans are recovered for recycling, though the lead itself is not recycled, but would become an industrial waste. It was estimated that 85 tons of lead were removed through recovery and recycling of steel cans in 1986. Since the use of leaded solder in steel cans is declining, removal of lead in this manner is also declining.

Rubber Products. Although rubber is not recovered for recycling in large quantities, some recycling of rubber tires does occur. This has the potential to remove from the waste stream any lead pigments or other chemicals present in the rubber. It was estimated that 3 tons of lead were removed from

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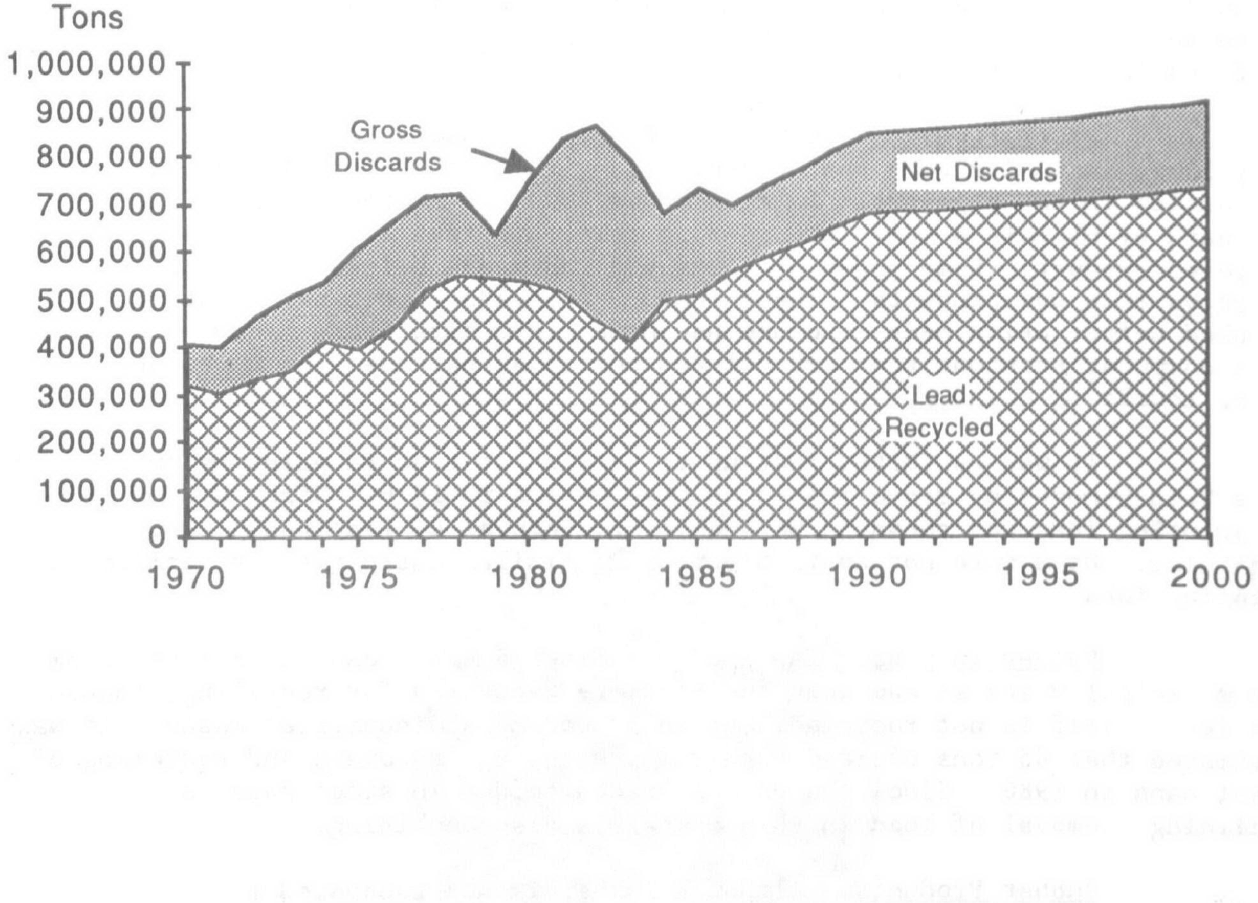
* Lead or cadmium in these recycled products would either be incorporated into the new products or would become industrial waste, e.g., sludges from deinking papers.

Figure 1-13. Discards of lead in SLI lead-acid batteries, 1970 to 2000.



the waste stream in this manner in 1986. Since all cadmium in rubber was assumed to be in non-tire products, no recovery of cadmium was estimated.

Appliances. There is cadmium plating in older model dishwashers and washing machines. If the ferrous metal in these appliances is recovered for recycling, the cadmium is removed from the waste stream as well. It was estimated that 2 tons of cadmium were removed in this way in 1986. This is a declining source of cadmium in the waste stream.

Glass Products. Although it was not possible to quantify, there are silk-screened designs that may contain lead and/or cadmium on many glass containers. Many glass containers are recycled, so some lead and cadmium is removed from the waste stream in this manner.

Plastics. Recycling of plastics in the United States has been minimal; it was estimated to be one percent in 1986. Further, most of the plastic products recycled under existing programs have been polyethylene terephthalate (PET) beverage bottles or high-density polyethylene (HDPE) milk jugs. Since lead and cadmium are not approved for use in food-contact packaging, the metals would not be affected by this recycling. There is an increasing amount of recycling of other plastic products, however, so some lead and cadmium may be removed from the waste stream in this manner, now or in the future.

Summary. Although precise estimates are not possible, probably not more than one to 2 percent of lead in MSW (exclusive of lead in batteries) is currently removed by recycling activities. The amount of cadmium affected by recycling is even smaller.

LIMITATIONS OF THIS REPORT

While this report contains useful data on discards of lead and cadmium in municipal solid waste, there are a number of limitations in its application to the issue of lead and cadmium in municipal waste combustor ash. Some of these limitations are discussed in this section.

Correlation of Characterization Data with Leachable Metals in Ash

The purpose of this report was to characterize the sources of lead and cadmium in municipal solid waste. It is beyond the scope of this study to identify the sources of leachable lead and cadmium in municipal waste combustor ash.

Correlation of Characterization Data with Individual Samples of Ash

This report contains data characterizing the lead and cadmium content of products defined as constituents of municipal solid waste. This characterization may not correlate well with the input into any particular combustion facility at the time ash samples were taken.

Management practices vary widely at municipal waste combustor (MWC) facilities depending on many factors. If the waste was pre-processed before combustion, then many of the noncombustible materials that may contain lead or cadmium were probably removed. Facility management also varies as to whether large items such as appliances and furniture are excluded, and these items are likely sources of heavy metals. If a facility has a small capacity and small quantities of waste are handled at any given time, then the opportunity to remove large noncombustible products is more frequent.

There are also differences among facilities as to the mixtures of residential and commercial wastes handled, with some facilities processing almost exclusively one or the other.

Effects of the Combustion Process on Ash Characteristics

This report characterized lead and cadmium in products that may enter an incinerator. Whether the metals leave the incinerator in the same form that they enter is unknown. For example, lead monoxide (PbO) is a very common compound used in many products--glass, batteries, pigments, etc. The melting point of lead monoxide is 1,630 degrees Fahrenheit, well within the range of most municipal waste combustors. It is not known whether the PbO would recombine with other elements in the MWC to form new lead compounds, but it seems highly likely.

Lead and Cadmium in Other Wastes

This study was specifically designed to characterize lead and cadmium in municipal solid waste. There are instances, however, when incinerators that burn primarily MSW may receive and burn other wastes that may contain these metals. While it was not possible in this report to quantify the amounts of those wastes, nor to characterize them in terms of lead and cadmium content, some data were gathered in the course of this study that indicate where lead and cadmium may occur in some other wastes (Table 1-10). This partial listing illustrates the problems involved in identifying the sources of lead and cadmium in the ash from municipal waste combustors.

Table 1-10

WASTES OTHER THAN MSW THAT MAY CONTAIN LEAD AND CADMIUM

Nonhazardous Wastes	Possible Sources of Lead and Cadmium
Municipal sludge	Lead pipes, lead solder
Construction and demolition wastes	Siding Wall and ceiling tile Structural steel Polyvinyl chloride (PVC) pipe Wire and cable coverings Gutters and downspouts Conduit Wallcoverings Plumbing fittings and hardware Pipes and solder Light fixtures Neon tubing Some window glass Enameled building panels Flooring materials Paint (especially older houses) Caulking
Industrial and military wastes	Conveyor belts Industrial and military batteries Industrial and military electronics Communications equipment Electrical machinery Storage tanks
Automotive and other transportation wastes	Hosing Automotive finishes Upholstery and trim Auto tops Mufflers

Chapter 1

REFERENCES

1. U.S. EPA, Office of Solid Waste. Characterization of Municipal Waste Combustor Ashes and Leachates from Municipal Solid Waste Landfills, Monofills and Co-disposal Sites. November 1987.

2. U.S. EPA, Office of Solid Waste. Subtitle D Study, Phase I Report. (EPA/530-SW-86-054). October 1986.

3. Smith, F. L., Jr. A Solid Waste Estimation Procedure: Material Flows Approach. U.S. EPA, Office of Solid Waste. (SW-147). May 1975.

Chapter 2

LEAD IN MUNICIPAL SOLID WASTE

BACKGROUND*

The metal lead has been used since ancient times; it may have been the first metal to be smelted by early man. Lead pipes used by ancient Romans are still in use today, and pottery glazed with lead oxide dates back to the bronze age.

Lead is a bluish-white metal with a bright luster. It is soft, malleable, and ductile. It is a poor conductor of electricity and is very resistant to corrosion. Lead ores commonly occur with zinc, copper, and pyrite ores. Galena (lead sulfide) accounts for more than 90 percent of primary lead production at present. There is also a large secondary lead industry that recycles lead from batteries and other lead scrap.

COMPOUNDS OF LEAD*

Lead is used in many compounds. Some of the more common are briefly described here.

Lead Monoxide (PbO) commonly called litharge, is the most widely used inorganic lead chemical. It is used in storage battery plates, ceramics and glasses, paint, rubber, and other products. It is also used in the production of other lead chemicals such as lead orthoplumbate.

Lead Dioxide (PbO_2) is used as an oxidizing agent in the manufacture of chemicals and dyes and as a curing agent for sulfide polymers. It is the active material of the positive plate in electric storage batteries.

Lead Orthoplumbate (Pb_3O_4) is commonly called red lead. It is a brilliant red pigment, and is used as an inhibitor in surface coatings to prevent corrosion of metals. It is used in storage batteries, leaded glass, lubricants, and rubber. It is also used for making lead dioxide.

Lead Sulfide (PbS) or galena is a common lead mineral. Lead sulfide has semiconducting properties. It is also used for mirror coatings, and it is a component of blue lead pigments.

Lead Metaborate ($PbO \cdot B_2O_3 \cdot H_2O$) is used in glazes, enamels, and glasses.

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* These sections are based on References 1 through 7.

Basic Lead Carbonate ($2PbCO_3 \cdot Pb(OH)_2$) is commonly called white lead. It is the most important basic salt of lead. It is a white pigment and is used in surface coatings, greases, and plastic stabilizers.

Lead Silicates. The most common silicate of lead is lead metasilicate ($PbSiO_3$). The silicates are used in ceramics, glasses, paints, rubber, and as stabilizers in plastics.

Basic Lead Sulfates ($XPbO \cdot PbSO_4$) are used as white or blue pigments in paints and as stabilizers for plastics. It is also used as a filler in rubbers and in inks.

Lead Chromate ($PbCrO_4$) is an important pigment and is often formulated in combination with other lead compounds or with inorganic salts of other metals to make a range of colors, including chrome green, chrome yellow, and molybdate chrome orange. Chrome yellows contain lead sulfate; chrome greens contain iron cyanides; and molybdenum chrome oranges contain molybdate and often lead sulfate. These pigments are used in paints, coatings, inks, and leather goods.

Basic Lead Chromate ($PbCrO_4 \cdot PbO$) is used in pigments commonly called chrome oranges.

Lead Chloride ($PbCl_2$) can be prepared by the reaction of lead monoxide or basic lead carbonate with hydrochloric acid. Most of its uses are industrial rather than in products that would commonly enter municipal solid waste.

Lead chloride is used as a catalyst, as a cathode for seawater batteries, as a flame retardant in polycarbonates, as a flux for the galvanizing of steel, as a photochemical-sensitizing agent for metal patterns on printed circuit boards, and for other uses.

Lead Salts are formed of lead and organic acids. Several lead salts of higher fatty acids (C_{10} and over; commonly called lead soaps) have important uses as paint driers, stabilizers for plastics, additives to lubricating oil, and additives in rubber.

Tetraethyl Lead and Tetramethyl Lead were widely used as gasoline additives before the phaseout of lead additives began.

ALLOCATION OF PRODUCTS CONTAINING LEAD TO MSW

The basic source of information on lead consumption in the United States is the Minerals Yearbook published annually by the Bureau of Mines (8). The categories reported by the Bureau of Mines are shown in Table 2-1. This table has been arranged to show which categories of products have been assumed to be at least partially disposed of in municipal solid waste, and which have been assumed to be otherwise disposed, e.g., as industrial, construction, demolition, or automotive waste.

Table 2-1

PRODUCTS CONTAINING LEAD

Products Assumed to Partially or Totally Enter MSW When Disposed	Products Assumed to Not Enter MSW When Disposed
Brass and bronze	Ammunition
Casting metals	Casting metals
Electrical machinery and equipment	Motor vehicles and equipment
	Other transportation and equipment
	Nuclear radiation shielding
Solder	Solder
Metal cans and containers	Building construction
Electronic components and accessories	Motor vehicles and equipment
Other electrical machinery	
Storage batteries	Bearing metals
Other metal products	Cable covering
Paints	Caulking (building construction)
Glass and ceramics	Pipes, traps, and other extruded products
Other pigments and chemicals	Sheet lead
Gasoline additives	Terne metal (automotive)
Miscellaneous uses	Type metal

Source: Bureau of Mines (Reference 8). Allocations to municipal solid waste disposal by Franklin Associates, Ltd.

The product categories as defined by the Bureau of Mines that are assumed not to be discarded into MSW are discussed briefly in the following section. Each category assumed to be discarded into MSW is discussed in detail in later sections.

PRODUCTS ASSUMED NOT TO BE DISCARDED INTO MSW

Ammunition

Ammunition, by the nature of its use, was assumed not to be discarded into MSW except under unusual circumstances.

Bearing Metals

Bearing metals using lead have been steadily declining. This decline is attributed to the replacement of babbitt metals, which are lead and tin-based, by copper and aluminum alloys, which contain much less lead. The main market for the bearings is in the crankshafts of motor vehicles, especially for heavy machinery. The other markets for leaded bearings are industrial uses such as piston compressors, fractional horsepower motors, and hydraulic gear pumps. The ball and roller bearings used in consumer goods do not contain lead (9, 10). Since leaded bearings are used only in automotive and industrial uses, which are not classified as MSW, it was assumed that no leaded bearings are disposed of in MSW.

Cable Covering

Cable coverings (sheathing) made of lead are used for telephone cables, power cables, etc. It was assumed that these cables would be disposed of in demolition or industrial waste landfills; about 25 percent are recycled. The use of lead sheathing has declined because of replacement of lead sheathings in telephone and low-to-medium power cables by paper-insulated, polyethylene-covered cables (11, 12). The lead sheathing that is still used is primarily for underground and submarine applications.

Caulking

The Bureau of Mines category of "caulking lead: building construction" is assumed to be discarded as construction or demolition waste.

Casting Metals

The Bureau of Mines reports four categories of casting metals containing lead. The category "electrical machinery and equipment" includes some lead use in terne-coating for radio and television chassis; this is described in a later section.

The other three categories of casting metals containing lead are "motor vehicles and equipment," "other transportation and equipment," and "nuclear radiation shielding." Automobiles and other transportation equipment are not classified as municipal solid waste, and nuclear radiation shielding would not be disposed of as MSW, so these latter three categories are assumed not to enter MSW.

Pipes, Traps, and Other Extruded Products

As reported by the Bureau of Mines, over 90 percent of the lead in this category is consumed for building construction. Waste from this category would thus be classified as construction or demolition waste. The remainder of the lead consumed in this category goes to storage tanks, process vessels, pipes, etc., for industrial use where corrosion protection is needed. Thus it was assumed that none of this category goes to MSW.

Sheet Lead

Sheet lead is used in building construction, storage tanks and process vessels for the chemical industry, and nuclear radiation shielding (8). It is used in building construction as a roof sealant and as a noise insulator. It was assumed that none of these uses would result in disposal into MSW.

Solder

The Bureau of Mines reports lead in five uses of solder. Three categories--"metal cans and shipping containers," "electronic components and accessories," and "other electrical machinery and equipment"--include products that enter MSW; these are discussed in detail in later sections. The other two categories are "building construction" and "motor vehicles and equipment." Products from these categories are assumed not to enter MSW.

Terne Metal: Motor Vehicles and Equipment

Terne metal is steel coated with a lead-tin alloy. This category as reported by the Bureau of Mines is assumed not to be discarded into MSW. Because of its corrosion resistance, terne metal is used in automobiles for fuel tanks, air cleaners, and radiator and heater assemblies. Some terne metal is discarded into MSW; this is discussed later in the section "Casting Metals."

Type Metal

Type metal was formerly commonly used in typesetting printed matter, but typesetting with molten lead has been almost entirely replaced with other printing methods (letterpress) and this use of lead has nearly disappeared. The lead type is reformed after each use, so none would have been discarded into MSW in any event (13).

BRASS AND BRONZE PRODUCTS

Brass and bronze are used in a variety of products because both have good mechanical properties, corrosion resistance, and excellent ease of forming.

Brass is mainly an alloy of copper and zinc with small additions of various other metals. It is either cast into its final product, or it can be cast into billets and then rolled, extruded, forged, or otherwise processed. There are many types of brass; some examples are red-gold brass, which is 75 to 85 percent copper; yellow brass, which is 60 to 70 percent copper; and naval brass, which contains approximately 2 percent tin. Brass is used in a variety of products, including architectural grillwork, bullet jackets, imitation gold jewelry, plumbing fixtures, valves, decorative objects, and marine hardware. Leaded brass is only used in plumbing fittings and hardware. It is defined as leaded brass because it contains over 2 percent lead.

Bronze used to be an alloy of copper and tin, but the term is now used to describe a variety of copper alloy materials. Bronze is mainly copper, which can be alloyed with many metals to produce aluminum bronze, manganese bronze, silicon bronze, tin bronze, and others. Bronze is used where special properties are needed, such as acoustical properties in bells and color properties in decoration. Leaded bronze can have as much as 30 percent lead and is used only in pressure valves and fittings. Lead is not used in plating applications for either brass or bronze (14).

An estimated 98 percent of leaded brass and bronze is used in building and plumbing hardware (14), which would become demolition waste when discarded. A high percentage of this hardware would be recycled rather than disposed because of its scrap value. The remaining 2 percent of leaded brass and bronze is used in a variety of products, mainly locks and lock sets (Table 2-2). It was assumed that these products will be discarded into MSW, although some undoubtedly become demolition waste.

Table 2-2

PRODUCTS CONTAINING LEADED BRASS AND BRONZE DISCARDED INTO MSW

Locks, lock sets, and lock hardware
Keys and key blanks
Miscellaneous products
  Clock and watch parts
  Musical instruments
  Ornamental products

Source: Copper Development Association (Reference 14).

Estimates of discards of lead in products containing lead and brass and bronze into MSW were made using the following adjustments and assumptions:

1. Domestic consumption was adjusted for imports and exports of alloy rod, bar, and basic shapes, which is used for the majority of leaded brass and bronze products. (Net imports are greater.)

2. Manufacturing losses were assumed to be zero, since the high value of the metal makes it feasible to recover and recycle (15).

3. It was assumed that there is no recovery for recycling of these materials after they become consumer products, since they are so dispersed.

4. A 10-year lifetime before discard was assumed for these products. Discards of lead in brass and bronze products are shown in Table 2-3 and Figure 2-1.

CANS AND OTHER SHIPPING CONTAINERS

Lead is used in solder for the seams of steel cans and containers. This use is in decline, however, as more steel cans have been made without seams and as steel cans have been displaced by containers made of other materials, such as aluminum or plastic. Steel cans are used for packaging food and other products such as paint and aerosols. In the past, large quantities of soldered steel cans were used for beverages, but this use began to be phased out in the late 1970s, and use of 3-piece (soldered seam) cans for beverages was negligible in 1986 (19). Lead solder use in steel shipping containers (barrels and drums) was also estimated.

Estimates of lead in solder for steel cans were made using statistics from the Bureau of Mines, the American Iron and Steel Institute, the Department of Commerce, and the Can Manufacturers Institute (8, 17, 18, 19). The following adjustments and assumptions were made:

1. The effect of imports and exports of empty steel cans was less than one percent and thus was not adjusted for. For steel shipping containers, net exports were of some significance, and appropriate adjustments were made. Imports and exports of steel cans containing products were also considered. For beverages, imports and exports were nearly equal and thus were not adjusted for. Data were not available to permit adjustments for nonfood and beverage steel cans. Adjustments were made, however, for foreign trade of canned food products. It was assumed that the conversion of canning equipment from solder to nonsoldered steel cans was somewhat slower abroad than domestically.

2. A 2 percent fabrication loss was assumed for steel cans.

3. Estimates of recycling of steel cans were taken from the previous MSW characterization study for EPA (20).

4. It was assumed that steel cans are discarded in the same year that they are manufactured (20). It was assumed that steel shipping containers have a three-year life cycle.

5. It was assumed that all steel cans that are not recycled are discarded into MSW, but that only 20 percent of steel shipping containers are discarded into MSW (20).

6. Projections were made assuming a continued decline in discards of steel cans and shipping containers.

Results of these estimates are shown in Table 2-4 and Figure 2-2.

CONSUMER ELECTRONICS

The printed circuit boards used in comsumer electronics--television, radios, and video cassette recorders (VCRs)--contribute lead in solder to the municipal waste stream. In addition, television sets contain leaded glass. Estimates of the contribution of lead from these products is included in this section.

Table 2-3

DISCARDS OF LEAD IN LEADED BRASS AND BRONZE INTO MSW, 1970 TO 2000
(In short tons)

Year	Domestic Lead Consumption 1/	Adjustment for Imports/ Exports 2/	Gross Discards of Lead 3/	Discards Other Than MSW 4/	Discards of Lead Into MSW 5/
1970	20,485	-	20,485	20,075	410
1971	20,114	-	20,114	19,712	402
1972	20,607	-	20,607	20,195	412
1973	21,943	-	21,943	21,504	439
1974	23,328	-	23,328	22,861	467
1975	23,699	-	23,699	23,225	474
1976	25,447	-	25,447	24,938	509
1977	20,467	-	20,467	20,058	409
1978	21,021	-	21,021	20,601	420
1979	21,512	-	21,512	21,082	430
1980	20,044	165	20,209	19,805	404
1981	18,927	285	19,212	18,828	384
1982	19,805	135	19,940	19,541	399
1983	22,735	15	22,750	22,295	455
1984	22,240	-210	22,030	21,589	441
1985	13,404	-60	13,344	13,077	267
1986	15,660	405	16,065	15,744	321
1990	15,411	75	15,486	15,176	310
1995	8,623	420	9,043	8,862	181
2000	9,549	795	10,344	10,137	207

1/ Bureau of Mines (Reference 8). Projections to 2000 by Franklin Associates, Ltd. A 10-year product life was assumed, so discards are consumption of 10 years earlier.
2/ Based on Reference 16. Not available before 1970.
3/ Domestic consumption + import/export adjustment.
4/ Assumed to be 98 percent of gross discards based on Reference 14.
5/ By difference.

Figure 2-1. Discards of lead in brass and bronze into MSW, 1970 to 2000.

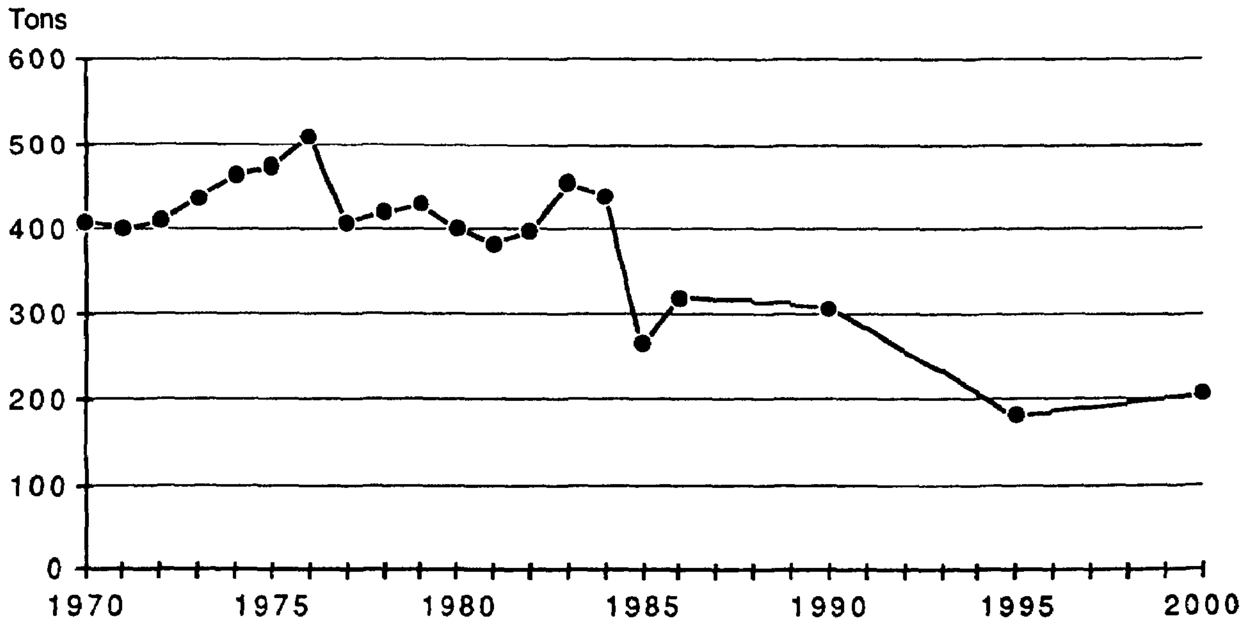


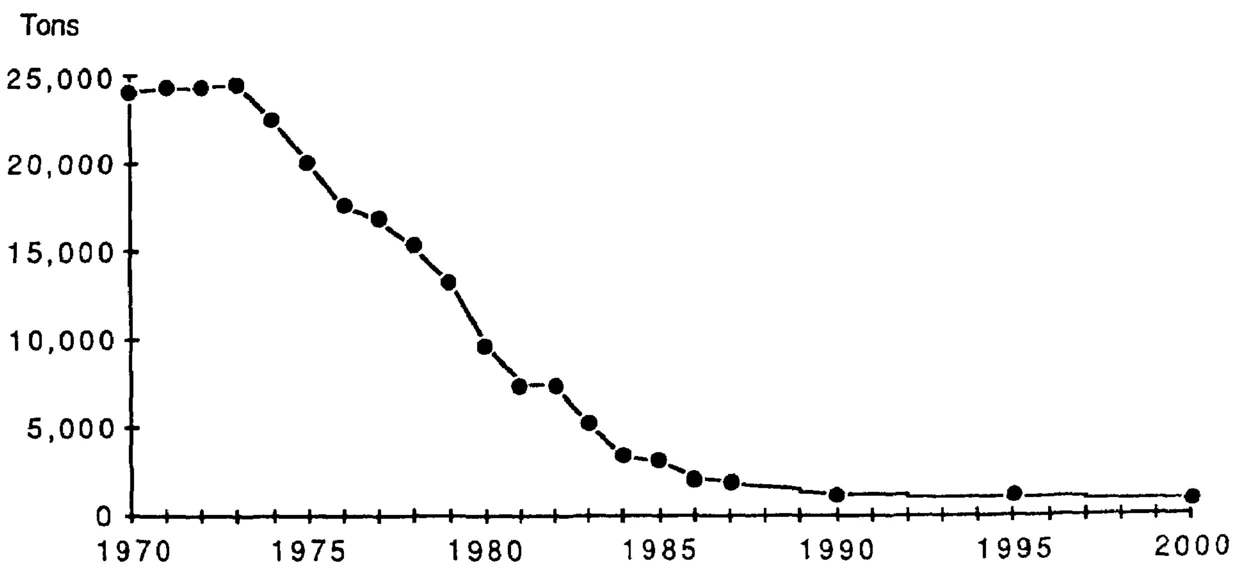
Table 2-4

DISCARDS OF LEAD IN SOLDER IN STEEL CANS AND SHIPPING CONTAINERS, 1970 TO 2000
(In short tons)

	Gross Discards 1/								
Year	Food Cans	Beverage Cans	Other Cans	Subtotal	Shipping Containers	Total Gross Discards	Percent Recovery 2/	Recovery	Net Discards 3/
1970	12,240	9,415	2,354	24,009	600	24,609	2	492	24,117
1971	12,354	9,506	2,376	24,236	600	24,836	2	497	24,339
1972	12,454	9,511	2,378	24,343	600	24,943	2	499	24,444
1973	12,525	9,542	2,385	24,452	609	25,061	2	501	24,560
1974	11,472	8,723	2,181	22,376	587	22,963	2	459	22,504
1975	10,609	7,485	1,970	20,064	680	20,744	3	622	20,122
1976	9,284	6,349	1,888	17,521	701	18,222	3	547	17,675
1977	9,455	5,644	1,826	16,925	691	17,616	4	705	16,911
1978	9,462	4,543	1,514	15,519	478	15,997	4	640	15,357
1979	8,889	3,029	1,581	13,499	545	14,044	5	702	13,342
1980	7,244	1,134	1,323	9,701	483	10,184	5	509	9,675
1981	5,766	280	1,259	7,305	484	7,789	5	389	7,400
1982	5,925	70	1,327	7,322	482	7,804	5	390	7,414
1983	3,849	0	1,202	5,051	319	5,370	4	215	5,155
1984	2,345	0	888	3,233	265	3,498	4	140	3,358
1985	1,977	0	949	2,926	206	3,132	4	125	3,007
1986	1,186	0	810	1,996	141	2,137	4	85	2,052
1990				1,150	55	1,205	6	72	1,133
1995				1,075	50	1,125	7	79	1,046
2000				820	45	865	9	78	787

1/ Based on data from the Bureau of Mines, the American Iron and Steel Institute, the Department of Commerce, and the Can Manufacturers Institute (References 8, 17, 18, 19).
2/ Recycling rates from Characterization of Municipal Solid Waste (Update 1988) (Reference 20).
3/ Net discards = gross discards - recovery for recycling.

Figure 2-2. Net discards of lead in solder in steel cans and containers, 1970 to 2000.



Lead in Printed Circuit Boards

The Bureau of Mines reports annual consumption of lead in solder for electronic components and accessories (8). It was assumed that all of this solder is used in printed circuit boards. The major markets for printed circuit boards are computers, communications, and government/military uses. Consumer products accounted for 11.7 percent of the printed circuit board market in 1986 (21)

It was determined that printed circuit boards in computers--the major market--generally do not enter MSW, because the boards removed for repairs are returned to the manufacturers for recovery of components such as memory chips (22). The circuit boards are thus assumed to become industrial waste rather than MSW. Other end uses such as communications were also assumed to enter industrial rather than municipal waste.

Lead in solder in printed circuit boards for televisions, radios, and VCRs was estimated using the following adjustments and assumptions:

1. The solder used in electronics is 63 percent by weight tin and 37 percent by weight lead (7).

2. An adjustment was made for imports and exports of these products, assuming that the imported products have the same amount of solder per item as the domestically-produced products (23, 24).

3. Manufacturing losses were assumed to be zero because of the soldering techniques used.

4. It was assumed that there is no recycling of these products.

5. The lifetime of these products was assumed to be eight years (25).

6. Projections were made based on a declining trend in lead in solder used in consumer electronics.

Consumption of lead in solder in consumer electronics is shown in Table 2-5.

Lead in Glass in Television Sets

Leaded glass is used in many television components including the screen, funnel, and neck. Additionally, leaded glass solder is used to join the various glass components. The typical lead composition of glass parts in television sets is shown in Table 2-6.

Estimates of lead in glass in television sets were made using the following adjustments and assumptions:

Table 2-5

LEAD CONSUMED IN SOLDER IN CONSUMER ELECTRONICS, 1962 TO 1992
(In short tons)

Year	Lead Consumed in Solder in Domestic Electronics 1/	Lead Consumed in Solder in Domestic Consumer Electronics 2/	Adjustment for Imports/ Exports 3/	Adjusted Lead Consumed in Solder in Consumer Electronics 4/
1962	4,554	533	884	1,417
1963	4,785	560	901	1,461
1964	5,017	587	895	1,482
1965	5,248	614	784	1,398
1966	5,480	641	783	1,424
1967	5,712	668	1,091	1,759
1968	5,943	695	1,290	1,985
1969	6,175	722	1,873	2,595
1970	6,644	777	2,152	2,929
1971	6,757	791	2,487	3,278
1972	7,500	878	2,681	3,559
1973	7,650	895	2,203	3,098
1974	7,177	840	3,144	3,984
1975	6,516	762	3,132	3,894
1976	7,630	893	3,857	4,750
1977	8,860	1,037	4,847	5,884
1978	9,575	1,120	4,972	6,092
1979	11,402	1,334	4,377	5,711
1980	9,074	1,062	3,399	4,461
1981	6,179	723	2,497	3,220
1982	6,577	770	2,799	3,569
1983	6,254	732	2,744	3,476
1984	5,909	691	3,232	3,923
1985	4,615	540	2,079	2,619
1986	4,776	559	2,237	2,796
1987	4,394	514	2,200	2,714
1992	2,501	293	698	991

1/ Bureau of Mines (Reference 8).
2/ Estimated to be 11.7 percent of solder used in electronics. Institute of Printed Circuits (Reference 21).
3/ Department of Commerce (Reference 23). Projections by Franklin Associates, Ltd.
4/ Domestic consumption + import/export adjustment.

1. It was assumed that lead in glass used domestically in television sets is 75 percent of consumption of lead in glass and ceramics (8).

2. An adjustment was made for imports and exports of television sets using Department of Commerce data (23). The lead content of imported television sets was assumed to be the same as that of domestically-produced sets.

Table 2-6

LEAD OXIDE (PbO) LEVELS IN TELEVISION COMPONENTS

Component	Lead Oxide (percent)
Face place or panel	2 to 2.25
Funnel	22.5 to 23
Neck	28.4 to 31
Glass solder	60 to 90

Source: References 2, 45, and 46.

3. Manufacturing losses were assumed to be minimal (one percent).

4. It was assumed that there is no recycling of glass in television sets.

5. The lifetime of television sets was assumed to be eight years (25).

Consumption of lead in glass in television sets is shown in Table 2-7.

Total Lead in Consumer Electronics

The combined lead in solder in printed circuit boards and in glass in television sets is shown in Table 2-8 and Figure 2-3. While discards of solder in consumer electronics are declining, lead in glass is continuing to grow.

GLASS AND CERAMIC PRODUCTS

Lead is used in several ways in a wide variety of glass products. It was possible to quantify lead use in two products that enter MSW: television picture tubes and light bulbs. Use of lead in other glass and ceramic products that enter MSW was quantified by difference and the products are listed and described.

Table 2-7

LEAD CONSUMED IN GLASS IN TELEVISION SETS, 1962 TO 1992
(In short tons)

Year	Domestic Consumption of Lead in Glass in TV Sets 1/	Manufacturing Losses @ 1% 2/	Net Domestic Consumption of Lead in Glass in TV Sets 3/	Adjustment Factor for Exports/Imports of TV Sets 4/	Adjusted Consumption of Lead in Glass in TV Sets 5/
1962	10,000	100	9,900	1.05	10,395
1963	11,000	110	10,890	1.04	11,326
1964	12,000	120	11,880	1.05	12,474
1965	13,000	130	12,870	1.10	14,157
1966	14,000	140	13,860	1.13	15,662
1967	15,000	150	14,850	1.21	17,969
1968	16,000	160	15,840	1.25	19,800
1969	17,000	170	16,830	1.44	24,235
1970	18,434	184	18,250	1.53	27,922
1971	18,278	183	18,095	1.60	28,952
1972	17,414	174	17,240	1.61	27,756
1973	26,946	269	26,677	1.57	41,882
1974	34,949	349	34,600	1.61	55,705
1975	25,456	255	25,201	1.52	38,306
1976	24,225	242	23,983	1.77	42,449
1977	22,455	225	22,230	1.84	40,904
1978	28,222	282	27,940	1.87	52,247
1979	40,310	403	39,907	1.70	67,842
1980	37,501	375	37,126	1.63	60,515
1981	36,656	367	36,289	1.67	60,603
1982	28,544	285	28,259	1.71	48,322
1983	32,797	328	32,469	1.85	60,068
1984	38,114	381	37,733	2.06	77,730
1985	36,497	365	36,132	2.11	76,239
1986	33,715	337	33,378	2.21	73,765
1987	33,500	335	33,165	2.30	76,280
1992	30,000	300	29,700	2.75	81,675

1/ 1970-1986: Estimated to be 75 percent of total consumption (Reference 8).
2/ Manufacturing losses are assumed to be small because glass is recycled in the manufacturing process.
3/ Net consumption = domestic consumption - converting losses.
4/ Derived from information in Reference 23. 1987 and 1992 estimated by Franklin Associates.
5/ Net consumption x adjustment factor.

Table 2-8

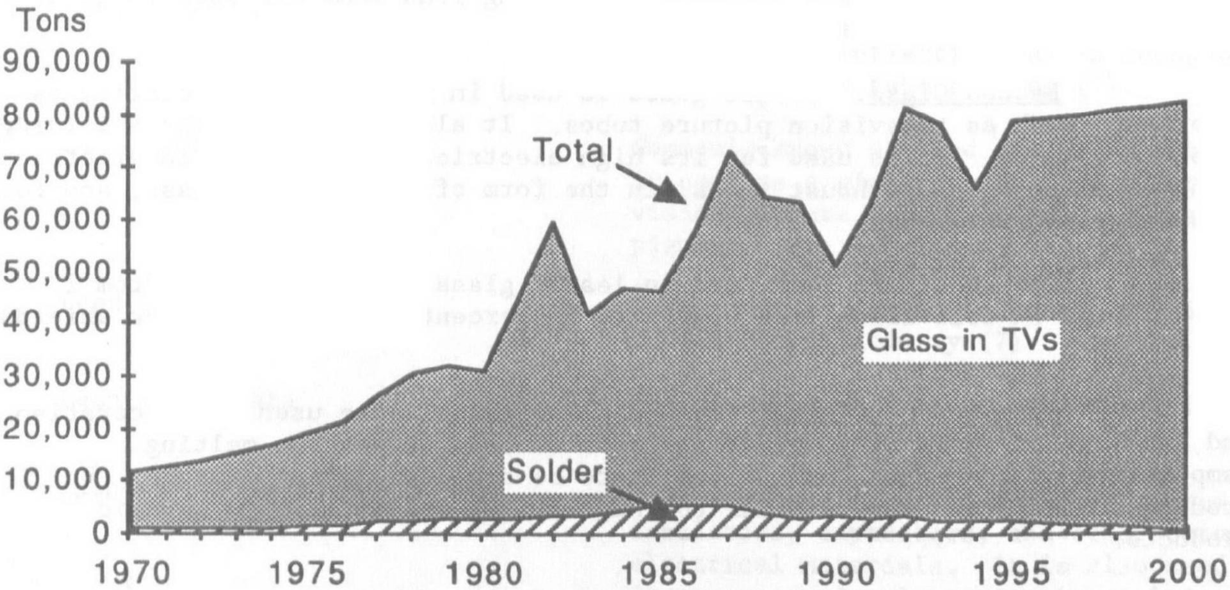
DISCARDS OF LEAD IN CONSUMER ELECTRONICS, 1970 TO 2000
(In short tons)

Year	Discards of Lead in Solder in Consumer Electronics 1/	Discards of Lead in Glass in Television Sets 2/	Total Discards of Lead in Consumer Electronics
1970	1,417	10,395	11,812
1971	1,461	11,326	12,787
1972	1,482	12,474	13,956
1973	1,398	14,157	15,555
1974	1,424	15,662	17,086
1975	1,759	17,969	19,728
1976	1,985	19,800	21,785
1977	2,595	24,235	26,830
1978	2,929	27,922	30,851
1979	3,277	28,952	32,229
1980	3,441	27,756	31,197
1981	3,098	41,882	44,980
1982	3,984	55,705	59,689
1983	3,894	38,306	42,200
1984	4,750	42,449	47,199
1985	5,883	40,904	46,787
1986	6,092	52,247	58,339
1990	3,568	48,322	51,890
1995	2,714	76,280	78,994
2000	990	81,675	82,665

1/ From Table 2-5. Assumes an eight-year lifetime for products (Reference 25).

2/ From Table 2-7. Assumes an eight-year lifetime for products (Reference 25).

Figure 2-3. Discards of lead in consumer electronics, 1970 to 2000.



Glass is a hard, brittle, usually transparent material that is formed by melting crystalline materials at high temperatures and then cooling them to a rigid condition. Silica is the primary constituent of most glasses. Most glass products are manufactured by blowing, molding, forming, or rolling molten glass.

Ceramics are made by heating clay minerals or clay mixed with other substances such as silica. The clay mixture can be formed into virtually any shape.

Use of Lead in Glass and Ceramics

Lead monoxide (PbO) is the most commonly used form of lead in glass and ceramics. Lead compounds used in glass and ceramics are summarized in Table 2-9.

The intermediate products containing lead that are used in glass and ceramic end products are discussed below.

Leaded Glass. Leaded glass is used in products where clarity is important, such as television picture tubes. It also provides x-ray shielding in picture tubes. It is used for its high electrical resistivity in electric light bulb flares and exhaust tubes, in the form of woven fiber glass, and for crystal glassware.

The amount of lead used in leaded glass products varies from 2 percent lead in television face plates to 82 percent lead in radiation shields (26).

Enamels and Glazes. Leaded glass enamels are used for decoration and labeling of, primarily, glass and metal. Lead lowers the melting temperature of the enamel and allows it to be applied without damaging the product. Glazes are very similar to enamels, but are applied to ceramic products.

Enamels typically contain 40 to 50 percent lead oxide and are applied to glass or metal (27). Glazes can contain 50 to 60 percent lead oxide and are applied to ceramics. Not all enamels or glazes contain lead; lead use in glazes for tableware has dropped significantly due to health concerns.

Solders and Sealers. Solders and sealers made of leaded glass are used to join glasses of differing compositions, in metal to glass joints, when an entire unit (such as capacitors) needs to be encapsulated within a solder-type seal, and when electrical resistivity characteristics are advantageous. Both glass solders and glass sealers have numerous applications within the electronics industry.

Solders and sealers typically have lead levels of 70 to 80 percent (28). These levels allow the soldering or sealing process to take place at relatively low temperatures, thus avoiding product damage.

Table 2-9

CHEMICAL FORM AND FUNCTION OF LEAD IN GLASS AND CERAMICS

Chemical	Function
Lead monoxide	Lead is added in the form of lead monoxide (PbO) to enamels, glazes, and glass. It can impart many desirable properties to these products. Lead monoxide is the most common source of lead in glass and ceramics.
Lead fluoride	Lead fluoride is used in glass coatings for infrared reflection and in phosphors for television tube screens (7).
Lead tetroxide	Commonly known as lead red, lead tetroxide is used as a glass sealant for color television picture tubes, and as a glass pigment.
Lead sulfide	Lead sulfide is used in mirror coatings to limit reflectivity (7).
Lead metaborate	The primary use of lead metaborate is in glazes and enamels (7).
Lead titanate	Lead titanate is a component of ceramic insulators, capacitors, and other ceramic electrical materials. It is also used in some ceramic glazes and low-melting glass sealants (7).
Lead silicates	Lead monoxide and silicate are combined to form lead silicates. See lead monoxide.
Lead pigments	Numerous lead compounds are used as colorants for glass, enamels, and glazes. They include: lead tetroxide (red lead), lead antimonate, basic lead carbonate (white lead) (7), basic lead chromate, and lead uranate (26).

PZT/PZLT. Lead-based ceramics are reported to be "critically important" to the electronics industry (2). They are piezoelectric materials and are used to convert mechanical to electrical energy. These ceramics contain 60 to 64 percent lead (65 to 69 percent lead oxide).

Glass-Bonded Mica. Glass-bonded mica is a mixture of powdered lead glasses and powdered mica, which is formed using heat and pressure. Glass-bonded mica fills the properties gap between ceramics and plastics, and is known as the "ceramoplastic." Of the applications for the ceramoplastic, only a few would be likely to find their way into the MSW stream, e.g., microwave components. Thus, the contribution of lead by glass-bonded mica to MSW is probably quite low.

Glass Products Containing Lead that Enter MSW

According to the Bureau of Mines, 75 percent of lead used in glass and ceramics goes to television sets (primarily picture tubes). These are discussed in the Consumer Electronics section of this report. Lead used in glass in light bulbs (electric lamps) is also quantified in a separate section. Other uses are discussed in this section and summarized in Table 2-10.

Table 2-10

GLASS OR CERAMIC PRODUCTS CONTAINING LEAD THAT MAY ENTER MSW

Products	Lead Form	Lead Amount
Glass containers	PbO and pigments	40-50 percent in silk-screened labels
Crystal glassware	PbO	24-25 percent
Other glassware	PbO	40-50 percent in decorations
Ceramic tableware	PbO	11-61 percent in some glazes
Appliances	PbO	Unknown amount in enamel
Enameled cookware	PbO	35-42 percent in enamel
Ophthalmic bifocal segment	PbO	51 percent
Mirrors	PbS	Unknown
Igniters - gas appliances	PZT	
Igniters - cigarette lighters	PZT	
Transducers - remote controls	PZT	
Electrical filters - radios, stereos	PZT	
Ceramic bimorph (VCR head controller)	PZT	
Phonograph pickup	PZT	
Microwave components	Glass-bonded mica (PbO)	

Glass Containers. Glass containers are typically made of soda-lime glass. Lead in glass containers can come from two sources:

- glass colored with lead-containing pigments (see section on pigments)
- glass which has been decorated or labeled with silk screening or decals.

Silk screened containers are limited primarily to beverage containers and toiletries. Only a very small percentage of other containers are silk screened (29).

The enamels used in silk screening glass contain 40 to 50 percent lead monoxide. The lead content allows firing onto the surface at lower temperatures without damage to the container.

Glassware. Lead in glassware comes from two sources: lead monoxide and pigments. The lead monoxide may be a primary component of the glass itself as in crystal, where the lead monoxide content is typically 24 to 25 percent (27), or it may be screen printed on the surface as decoration. Screen-printed decorations contain 40 to 50 percent lead monoxide.

Tableware. Ceramic and whiteware glazes may contain lead monoxide. The use of lead monoxide in glazes for tableware has reportedly decreased in recent years, but how much it is currently used has not been documented. Reported levels of lead monoxide in glazes range from 11 percent to 61 percent (2). Also, decorated tableware may have lead monoxide in the screen-printed or decaled designs.

Electronic Components. Electronic components are an area of increasing use of leaded glass and ceramics. Leaded glass is often used as a solder or sealer. Lead is also a component of many so-called high-tech ceramics, such as PZT and PZLT. They are piezoelectric materials and are used to convert mechanical to electrical energy.

Glass-bonded mica may also be used in electronic components.

Enameled Products. Appliances are a major area of enamel use. Enamels are applied in two layers, the ground-coat and cover-coat. The ground-coat, which is formulated to promote a metal to enamel seal, typically contains no lead. Some of the cover-coats contain lead monoxide, but this is limited to clear cover-coat enamels (30). The level of use of this type of enamel is not known.

Cookware is often enameled because of its heat resistance, ease of cleaning, permanent color, and corrosion resistance. Typical enamel compositions for aluminum cookware contain 35 to 42.5 percent lead monoxide (2).

Products Containing Lead That Do Not Enter MSW

Many glass and ceramic products containing lead do not enter the municipal waste stream. Some of these include architectural uses such as porcelain-enameled aluminum building panels, windows glazed with lead compounds for light reflectance and color properties, and lead-glazed wall and floor tiles.

Industrial uses for these products include liquid level sensors, strain gauges, many applications of circuit boards, fiber optic applications, and radiation shielding.

Lead Discarded in Glass and Ceramics

Lead discarded in glass in television sets and light bulbs is quantified in other sections. All other discards of lead in glass and ceramics in MSW were estimated using the following assumptions:

1. Imports and exports could not be quantified because the amounts of lead in specific products were not known.

2. Manufacturing losses were assumed to be one percent. Glass scrap can be recycled in-plant easily and economically.

3. Removal of lead in glass and ceramic products by recycling could not be estimated because the amounts of lead in specific products were not known. Some glass containers that have silk-screened designs containing lead undoubtedly are recycled.

4. The lifetime of these products was assumed to be three years.

5. Projections were based on a conservative growth rate.

These estimates are shown in Tables 2-11, 2-12, and 2-13, and Figure 2-4.

LEAD-ACID STORAGE BATTERIES

According to the Bureau of Mines (8), manufacture of lead-acid storage batteries consumed 76 percent of the lead used domestically in the United States. Storage batteries are used in a wide range of applications. The most familiar are starting, lighting, and ignition (SLI) applications (e.g., automobile batteries); "traction" appliances (e.g., for powering electric golf carts, fork lifts, wheel chairs, etc.); and stationary batteries used for emergency and standby power. Small lead-acid batteries are also used to power portable equipment, such as toys, tools, lighting, and photographic equipment, etc. About 80 percent of all lead-acid storage batteries are used as SLI batteries for cars, trucks, buses, motorcycles, etc.

Table 2-11

DOMESTIC CONSUMPTION OF LEAD IN GLASS AND CERAMICS, 1970 TO 1986
(In short tons)

Year	Domestic Consumption in Glass and Ceramics 1/	Domestic Consumption in TV Sets 2/	Domestic Consumption in Light Bulbs 3/	All Other Domestic Consumption 4/	Portion of "All Other" Entering MSW 5/
1970	24,578	18,434	462	5,683	4,262
1971	24,371	18,278	473	5,620	4,215
1972	23,219	17,414	506	5,299	3,974
1973	35,928	26,946	487	8,495	6,371
1974	46,598	34,949	421	11,229	8,421
1975	33,941	25,456	405	8,080	6,060
1976	32,300	24,225	432	7,643	5,732
1977	29,940	22,455	435	7,050	5,288
1978	37,629	28,222	439	8,968	6,726
1979	53,746	40,310	456	12,981	9,735
1980	50,001	37,501	437	12,063	9,047
1981	48,875	36,656	424	11,795	8,846
1982	38,058	28,544	414	9,101	6,825
1983	43,729	32,797	434	10,498	7,874
1984	50,819	38,114	461	12,244	9,183
1985	48,662	36,497	423	11,743	8,807
1986	44,953	33,715	422	10,816	8,112

1/ Bureau of Mines (Reference 8).
2/ Assumed to be 75 percent of domestic consumption based on information from the Bureau of Mines (Reference 8).
3/ See section on light bulbs.
4/ By difference.
5/ Assumed to be 75 percent of "All Other." Includes crystal glassware, glass containers, decorative tableware, ceramics, enameled cookware, and some electronics.

Table 2-12

CONSUMPTION OF LEAD IN "ALL OTHER" GLASS IN MSW, 1967 TO 1997
(In short tons)

Year	Consumption of Lead in "All Other Glass" Entering MSW 1/	Converting Losses @ 1% 2/	Net Consumption of Lead in "All Other Glass" 3/
1967	3,400	34	3,666
1968	3,700	37	3,663
1969	4,000	40	3,960
1970	4,262	43	4,219
1971	4,215	42	4,173
1972	3,974	40	3,934
1973	6,371	64	6,307
1974	8,421	84	8,337
1975	6,060	61	5,999
1976	5,732	57	5,675
1977	5,288	53	5,235
1978	6,726	67	6,659
1979	9,735	97	9,638
1980	9,047	90	8,957
1981	8,846	88	8,758
1982	6,825	68	6,757
1983	7,874	79	7,795
1984	9,183	92	9,091
1985	8,807	88	8,719
1986	8,112	81	8,031
1987	8,500	85	8,415
1992	8,750	88	8,663
1997	9,000	90	8,910

1/ From Table 2-11. 1967 to 1969 and projections by Franklin Associates, Ltd.
2/ Converting losses are assumed to be small because scrap glass is recycled in the manufacturing process.
3/ Consumption - converting losses. Includes crystal glassware, glass containers, decorative tableware, ceramics, enameled cookware, and some electronics.

Table 2-13

DISCARDS OF LEAD IN GLASS AND CERAMICS IN MSW, 1970 TO 2000
(In short tons)

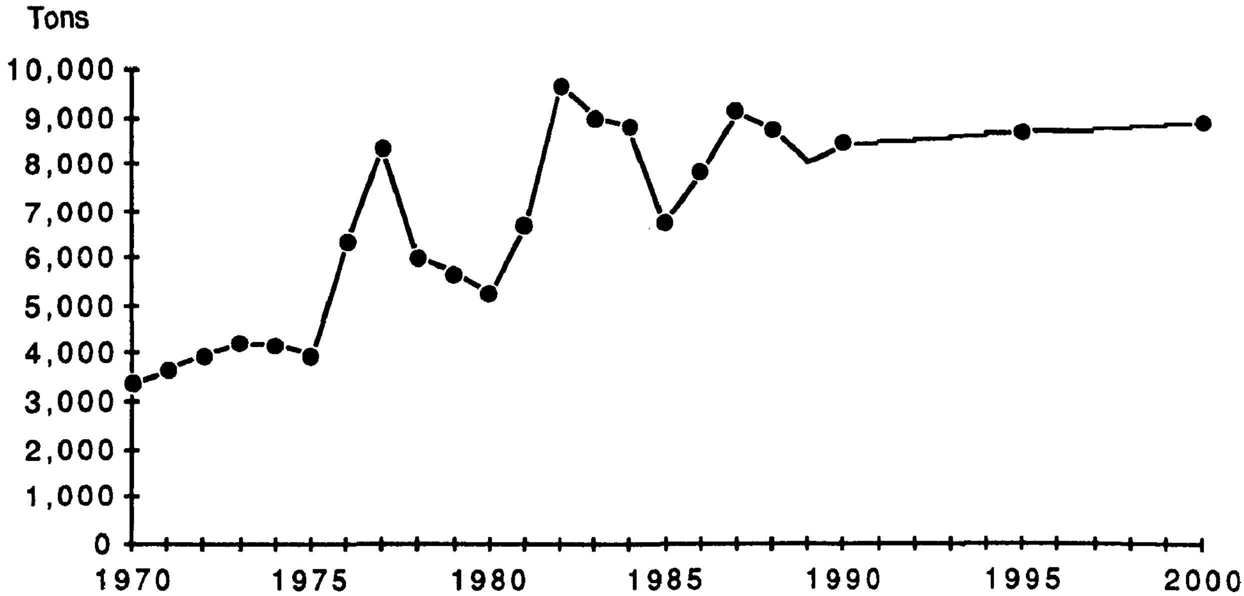
Year	Lead in Television Sets 1/	Lead in Light Bulbs 2/	Lead in "All Other" Glass and Ceramics 3/	Total Lead in Glass and Ceramics
1970	10,395	491	3,366	14,252
1971	11,326	510	3,663	15,499
1972	12,474	532	3,960	16,966
1973	14,157	576	4,219	18,952
1974	15,662	565	4,173	20,400
1975	17,969	506	3,934	22,409
1976	19,800	512	6,307	26,619
1977	24,235	586	8,337	33,158
1978	27,922	611	5,999	34,532
1979	28,952	623	5,675	35,250
1980	27,756	635	5,235	33,626
1981	41,882	600	6,659	49,141
1982	55,705	607	9,638	65,950
1983	38,306	610	8,957	47,873
1984	42,449	706	8,758	51,913
1985	40,904	709	6,757	48,370
1986	52,247	672	7,795	60,714
1990	48,322	727	8,415	57,464
1995	76,280	787	8,663	85,730
2000	81,675	847	8,910	91,432

1/ See section on television sets (Table 2-7). Assumes an 8-year life for television sets (Reference 25).

2/ See section on light bulbs (Table 2-26). Assumes a one-year life for light bulbs.

3/ From Table 2-12. Assumes a 3-year life for "all other" glass and ceramics in MSW. Projections by Franklin Associates.

Figure 2-4. Discards of lead in "all other" glass and ceramics in MSW, 1970 to 2000.



Composition of Lead-Acid Storage Batteries

Approximately one-half of the lead-acid storage battery's weight is lead or lead components. Lead (metal) and lead dioxide are used in roughly equal quantities. The form and quantities of lead consumed in the United States in the production of storage batteries are shown in Table 2-14.

The components of SLI lead-acid batteries are shown in Table 2-15. Batteries for other applications have analogous components. The averge weight of SLI batteries is 36 pounds, one-half of which is lead.

Table 2-14

FORM OF LEAD CONSUMED IN STORAGE BATTERIES
(1986)

	Total Lead (short tons)
Soft lead	567,545
Lead in antimonial lead	292,995
Lead in alloys	80,615
Total	941,155

Source: Bureau of Mines (Reference 8).

Table 2-15

WEIGHT ANALYSIS OF TYPICAL SLI BATTERIES

	Percent
Active materials	36.0
Electrolyte	27.5
Grids	21.5
Container, lid, vent plugs, separators	10.3
Top lead	4.7
Total	100.0

Source: Handbook of Batteries and Fuel Cells (Reference 31).

The lead-acid battery uses lead dioxide as the active material of the positive electrode and metallic lead, in a highly porous structure, as the negative active material. The preparation of the active material consists of a series of mixing and curing operations using leady oxide (PbO + Pb), sulfuric acid, and water. The electrolyte is a sulfuric acid and water solution, about 1.28 specific gravity or 37 percent acid by weight in the solution, about 1.28 specific gravity or 37 percent acid by weight in the fully-charged condition. As the cell discharges, both electrodes are converted to lead sulfate; the process reverses as the battery is charged.

Lead is used to make the grid on which the active materials are placed as well as the active materials. Pure lead is generally too soft to use as a grid material, so it is hardened by the addition of antimony metal. Other elements are often added to grid alloys as grain refiners or to improve workability. Cadmium was used in the Seventies to enhance processability, but is not being used in significant quantities now because of its toxicity and difficulty in removal during lead recovery (recycling) operations.

For preparation of the lead dioxide, lead is oxidized and then converted to a plastic dough-like material so it can be pasted onto the grid structure.

A simple lead-acid cell consists of one negative electrode, one positive electrode, and one separator in between. Separators, typically rubber, cellulose, or sintered PVC, are used to electrically insulate each plate from its nearest counterelectrode neighbors. They are porous to allow acid transport into or out of the plates. A variety of tank materials have been used for lead-acid storage batteries, but the most common are PVC, polyethylene, or polypropylene.

Portable lead-acid batteries usually include spirally-wound plates in a cylindrical metal container in sizes ranging from D cells to 12-ounce cans and from six ounces to 3-1/2 pounds (32). These batteries are operationally like the car batteries, but instead of the liquid sulfuric acid, they contain a minimum amount of electrolyte, which is absorbed in the separator material or in a gel. They are often termed sealed lead-acid (SLA) batteries.

Lead Consumption in Batteries

There are four major categories of lead-acid batteries for which data are available:

1. Automotive SLI batteries
2. Motorcycle SLI batteries
3. Portable sealed lead-acid (SLA) batteries
4. Industrial batteries.

Automotive SLI Batteries. The Battery Council International maintains annual statistics for automotive batteries, including those for passenger cars, trucks and buses, special tractors, marine, general utility, golf cart, and miscellaneous uses. The data do not include batteries for motorcycles, aircraft, and military uses.

The typical useful lifetime of these batteries is three to four years (33). Failing batteries are not normally repaired, but are recycled or discarded.

Table 2-16

LEAD CONSUMPTION IN U.S. AUTOMOTIVE BATTERY SHIPMENTS, 1966 TO 1986 1/

Year	Replacement Batteries (millions)	Original Equipment (millions)	Export (millions)	Total (millions)	Lead per Battery (pounds) 2/	Total Lead Consumed (short tons)
1966	31.1	10.3	0.2	41.6	20.1	418,080
1967	31.0	9.0	0.2	40.2	20.4	410,040
1968	33.8	10.7	0.5	45.0	20.9	470,250
1969	35.5	10.1	0.8	46.4	22.0	510,400
1970	37.9	8.2	0.8	46.9	23.0	539,350
1971	39.1	10.6	0.9	50.6	23.7	599,610
1972	43.2	11.3	1.0	55.5	24.0	666,000
1973	43.5	12.6	1.0	57.1	24.9	710,895
1974	44.4	10.1	1.1	55.6	25.8	717,240
1975	42.6	9.0	1.3	52.9	24.5	648,020
1976	49.2	13.4	1.5	64.1	23.6	756,380
1977	54.6	14.7	1.4	70.7	23.9	844,865
1978	56.4	15.2	1.6	73.2	23.7	867,420
1979	53.7	14.4	1.2	69.3	22.6	783,090
1980	50.1	10.0	1.6	61.7	21.7	669,445
1981	53.6	10.0	1.9	65.5	22.2	727,050
1982	54.2	8.4	2.0	64.6	21.5	694,450
1983	56.1	10.8	2.1	69.0	21.1	727,950
1984	59.3	12.8	2.6	74.7	20.6	769,410
1985	58.7	13.5	2.2	74.4	20.6	766,320
1986	60.3	13.3	2.1	75.7	20.0	757,000

1/ Battery Council International (Reference 36). Includes passenger car (12 volt and 6 volt), heavy duty (12 volt and 6 volt), special tractor, marine, general utility, golf car, and miscellaneous.

2/ Through 1981 (Reference 33). After 1981, data are from Bureau of Mines (Reference 8).

Estimates of lead consumption in automotive batteries are shown in Table 2-16. Millions of batteries used for original equipment vehicles, for replacement of failed batteries, and for export were summed. These numbers were then multiplied by an average weight of lead per battery to obtain total lead consumption.

Motorcycle SLI Batteries. This category includes batteries for motorcycles, scooters, and all terrain vehicles (ATVs). Lead consumption for these batteries was estimated based on information from the Motorcycle Industry Council and Department of Commerce statistics (34)(35) (Table 2-17). Again, replacement batteries and original equipment batteries were summed, then multiplied by an average weight of lead per battery.

Portable SLA Batteries. Sealed lead-acid storage batteries have a number of consumer uses--providing power for toys, VCRs, portable radios and TVs, flashlights, portable tools and appliances, electric-start lawn mowers, emergency lighting, and alarm systems. They also have a number of nonconsumer uses, including power for telecommunications, medical instrumentation, and backup lighting and alarm systems. These batteries were developed in the early 1970s; their uses are often the same as those of nickel-cadmium batteries (discussed in Chapter 3).

Industrial Batteries. The Lead Industries Association maintains data on lead consumed in industrial batteries. Industrial batteries are defined as those used for the following applications:

1. Motive power for in-plant industrial trucks, underground mining equipment, airline ground support equipment, on-road electric vehicles, and other special purposes. Golf cart batteries are excluded from this category.

2. Stationary batteries for telephone switching equipment, remote telecommunications, standby and emergency power, alarms systems, computers that require an uninterruptible power supply, etc.

3. Other applications such as renewable energy storage (solar), railroad car lighting and diesel locomotive starting batteries, and other commercial-industrial applications.

Total Lead Consumed in Batteries. Consumption of lead in the four categories of storage batteries is summed in Table 2-18. Since this is such an important category of lead consumption, the totals were checked against the annual lead consumption figures published by the Bureau of Mines (8). The agreement is generally quite close; differences can probably be explained by annual variations in the way the data from the various sources are reported.

Table 2-17

LEAD CONSUMPTION IN U.S. MOTORCYCLE SHIPMENTS, 1966 TO 1986 1/

Year	Replacement Batteries (thousands)	Original Equipment (thousands)	Total (thousands)	Lead per Battery (pounds) 2/	Total Lead Consumed (short tons)
1966	584	30	614	8.9	2,732
1967	651	30	681	9.0	3,064
1968	696	30	726	9.2	3,340
1969	772	40	812	9.7	3,938
1970	941	35	976	10.2	4,978
1971	1,115	25	1,140	10.5	5,985
1972	1,253	35	1,288	10.6	6,826
1973	1,457	45	1,502	11.0	8,261
1974	1,655	40	1,695	11.4	9,662
1975	1,655	40	1,695	10.8	9,153
1976	1,644	80	1,724	10.4	8,965
1977	1,644	110	1,754	10.6	9,296
1978	1,623	80	1,703	10.5	8,941
1979	1,807	120	1,927	10.0	9,635
1980	1,898	130	2,028	9.6	9,734
1981	1,944	125	2,069	9.8	10,138
1982	1,918	100	2,018	9.5	9,586
1983	1,862	100	1,962	9.3	9,123
1984	1,827	155	1,982	8.8	8,721
1985	1,815	130	1,945	8.8	8,558
1986	1,786	105	1,891	8.4	7,942

1/ Motorcycle Industry Council, Inc. and Statistical Abstract (References 34 and 35). Includes motorcycles, scooters, and all terrain vehicles (ATVs).

2/ Franklin Associates, Ltd. estimate of 8 pounds in 1987 from catalog shipping weights. Variation assumed to parallel automotive battery weights.

Table 2-18

SUMMARY OF LEAD CONSUMPTION IN U.S. BATTERY SHIPMENTS, 1966 TO 1986

Year	Automotive (short tons) 1/	Motorcycle (short tons) 2/	Industrial (short tons) 3/	Portable (short tons) 4/	Total Lead (short tons)	Bureau of Mines Total Lead Consumption (short tons) 5/	Percent Accounted For
1966	418,080	2,732	-	1.0	420,813	-	-
1967	410,040	3,064	52,100	1.3	465,206	-	-
1968	470,250	3,340	58,400	1.7	531,991	-	-
1969	510,400	3,938	57,400	2.0	571,740	-	-
1970	539,350	4,978	63,600	2.5	607,930	593,453	102.4
1971	599,610	5,985	68,100	3.1	673,698	679,803	99.1
1972	666,000	6,826	64,400	3.8	737,230	726,592	101.5
1973	710,895	8,261	80,800	4.7	779,961	769,447	104.0
1974	717,240	9,662	80,900	5.8	807,807	851,881	94.8
1975	648,025	9,153	75,400	7.0	732,585	699,414	104.7
1976	756,380	8,965	77,800	8.5	843,153	822,404	102.5
1977	844,865	9,296	90,900	10.2	945,071	945,876	99.9
1978	867,420	8,941	93,400	12.1	969,773	969,224	100.1
1979	783,090	9,635	101,900	14.3	894,639	897,638	99.7
1980	669,445	9,734	83,600	16.7	762,796	711,377	107.2
1981	727,050	10,138	85,600	19.2	822,307	848,939	96.9
1982	694,450	9,586	75,100	22.0	799,157	776,375	100.4
1983	727,950	9,123	91,700	24.7	828,798	889,445	93.2
1984	769,410	8,123	113,000	27.5	891,158	954,096	93.4
1985	766,320	8,558	160,700	30.3	935,608	926,968	100.9
1986	757,000	7,942	184,500	32.9	949,475	941,155	100.9

1/ From Table 2-16.
2/ From Table 2-17.
3/ Battery Council International for 1967 through 1982 (Reference 36). After 1982, data are from Bureau of Mines (Reference 8).
4/ Estimate by Franklin Associates, Ltd., based on total sales dollars (Reference 31).
5/ Bureau of Mines (Reference 8).

Discards of Lead from Storage Batteries

A flow diagram for SLI storage batteries is shown in Figure 2-5. Recycling is an important factor in determining lead-acid storage battery discards. The Bureau of Mines tracks the total lead recovered from lead-acid batteries. The total lead recycled each year consists of lead recovered for reuse plus scrap battery lead exported plus any increase in battery lead scrap inventory at the smelters. The recycle rate for automotive and motorcycle SL batteries is obtained by first subtracting the industrial lead recovered (about 9 percent of total) (37) from the total battery lead recycled and dividing by the gross discards. The remainder is presumed to be discarded into municipal solid waste.

Since 1970, the recycle rate has varied from a high of 85 percent to a low of 52 percent. Other researchers (References 33 and 38) have calculated the recycle rate using a somewhat different approach for estimating gross discards, but similar recycle rates result. In the Sixties, when the price of secondary lead was high and regulations on the secondary smelters were minimal, the recycle rate was reported to be as high as 97 percent (33). In the Seventies and early Eighties, a number of secondary smelters went out of business because of the low price of lead, changes in the materials used for battery manufacture (e.g., polypropylene cases), and the high cost of complying with environmental regulations. Of 60 operational secondary smelters in 1982, only 23 remained in 1987 (39, 40). In spite of the small number of secondary smelters remaining, the recycle rate appears to be significantly higher in 1986 than in 1982.

Discards for each type of battery are summarized below.

SLI Battery Lead. Discards of lead in automotive and motorcycle SLI batteries were estimated using the following adjustments and assumptions:

1. Adjustments were made for imports and exports using Department of Commerce data (41).

2. Manufacturing losses were assumed to be 5 percent based on information in a recent study for EPA (33).

3. Recycling of lead in batteries was taken from a recent study for EPA (33). Recovery of lead from industrial batteries was assumed to be 9 percent; industrial batteries are assumed to not be discarded into MSW (37).

4. The lifetime of automotive batteries was assumed to be four years (33); for motorcycle batteries, three years (34).

5. Projections of discards were based on past trends.

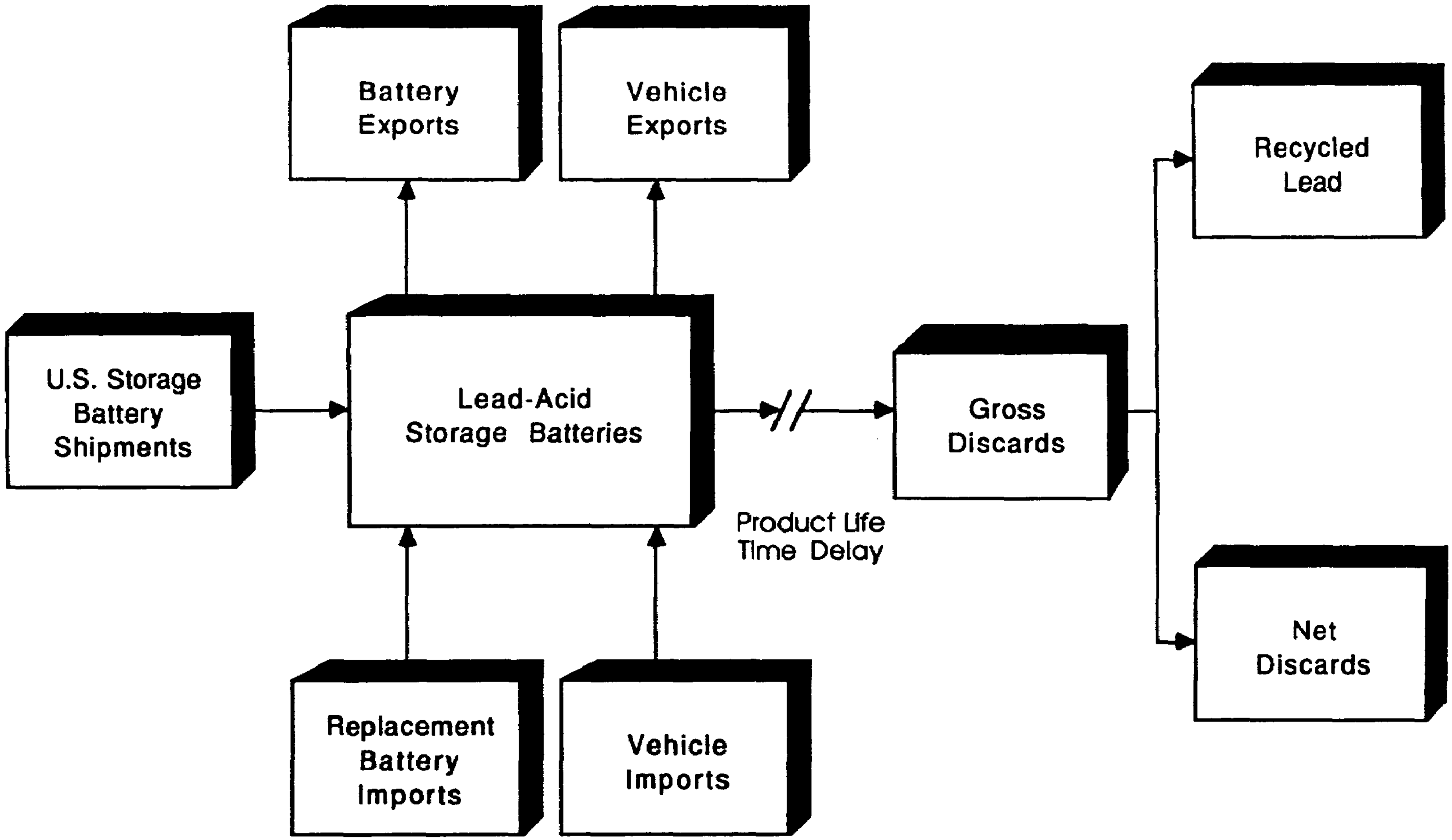


Figure 2-5. Methodology flow diagram for SLI Storage Batteries

Table 2-19

LEAD IN AUTOMOTIVE SLI BATTERIES, 1966 TO 1996
(In short tons)

Year	Domestic Lead Consumption in Auto Batteries 1/	Manufacturing Losses 2/	Domestic Consumption	Total Imports 3/	Total Exports 3/	Gross Lead Available for Discard in Auto Batteries 4/
1966	418,080	20,904	397,176	12,364	4,554	404,986
1967	410,040	20,502	389,538	16,144	4,864	400,817
1968	470,250	23,512	446,738	20,222	8,200	458,760
1969	510,400	25,520	484,880	25,164	12,028	498,016
1970	539,350	26,968	512,382	30,367	12,848	529,902
1971	599,610	29,980	569,630	38,611	16,335	591,906
1972	666,000	33,300	632,700	38,659	17,738	653,620
1973	710,895	35,545	675,350	42,483	19,835	697,999
1974	717,240	35,862	681,378	49,279	22,623	708,034
1975	648,025	32,401	615,624	36,861	25,125	627,359
1976	756,380	37,819	718,561	40,760	26,500	732,820
1977	844,865	42,243	802,622	49,178	25,679	826,120
1978	867,420	43,371	842,049	58,337	28,200	854,186
1979	783,090	39,154	743,936	58,488	23,746	778,677
1980	669,445	33,472	635,973	57,306	24,769	668,509
1981	727,050	36,352	690,698	54,709	27,565	717,841
1982	694,450	34,722	659,728	52,902	25,562	687,067
1983	727,950	36,398	691,552	83,628	27,923	747,258
1984	769,410	38,470	730,940	110,661	33,024	808,576
1985	766,320	38,316	728,004	138,671	30,206	836,469
1986	757,000	37,850	719,150	145,295	28,291	836,154
1987	-	-	-	-	-	791,838
1988	-	-	-	-	-	817,177
1989	-	-	-	-	-	835,154
1990	-	-	-	-	-	845,176
1991	-	-	-	-	-	862,925
1992	-	-	-	-	-	871,554
1993	-	-	-	-	-	880,270
1994	-	-	-	-	-	889,072
1995	-	-	-	-	-	897,963
1996	-	-	-	-	-	906,943

1/ Battery Council International (Reference 36). Includes original equipment and replacement batteries for cars, trucks, tractors, marine, general utility, golf car, and miscellaneous. Excludes industrial batteries, aircraft, military, motorcycles, scooters, and ATVs.

2/ Five percent of consumption (Reference 33).

3/ Estimated based on Department of Commerce data (Reference 41).

4/ Projections from 1986 to 1991 are based on U.S. Industrial Outlook projections for car and truck sales, including imports (Reference 39). One percent growth rate estimated by Franklin Associates, Ltd. after 1991.

Table 2-20

LEAD IN MOTORCYCLE BATTERIES, 1966 TO 1997
(In short tons)

Year	Domestic Lead Consumption in Motorcycle Batteries 1/	Manu-facturing Losses 2/	Net Domestic Con-sumption	Total Imports 3/	Total Exports 3/	Gross Lead Available for Discard in Motorcycle Batteries 4/
1966	2,732	137	2,595	879	0	3,475
1967	3,064	153	2,911	1,325	0	4,236
1968	3,340	167	3,173	1,800	0	4,973
1969	3,938	197	3,741	3,013	0	6,754
1970	4,978	249	4,729	5,361	0	10,091
1971	5,985	299	5,686	7,771	0	13,456
1972	6,826	341	6,485	8,616	10	15,091
1973	8,261	413	7,848	6,462	12	14,298
1974	9,662	483	9,179	8,593	9	17,762
1975	9,153	458	8,695	5,016	13	13,699
1976	8,926	448	8,517	3,383	33	11,868
1977	9,296	465	8,831	4,504	57	13,279
1978	8,941	447	8,494	4,871	38	13,327
1979	9,635	482	9,153	4,500	91	13,562
1980	9,734	487	9,247	5,390	116	14,521
1981	10,138	507	9,631	5,194	121	14,704
1982	9,586	479	9,107	5,633	82	14,657
1983	9,123	456	8,667	4,952	76	13,542
1984	8,721	436	8,285	5,424	87	13,622
1985	8,558	428	8,130	7,050	70	15,110
1986	7,942	397	7,545	5,302	65	12,782
1987	-	-	-	-	-	12,910
1988	-	-	-	-	-	13,039
1989	-	-	-	-	-	13,169
1990	-	-	-	-	-	13,301
1991	-	-	-	-	-	13,434
1992	-	-	-	-	-	13,568
1993	-	-	-	-	-	13,704
1994	-	-	-	-	-	13,841
1995	-	-	-	-	-	13,979
1996	-	-	-	-	-	14,119
1997	-	-	-	-	-	14,260

1/ Motorcycle Industry Council, Inc. and Statistical Abstract (References 34 and 35). Includes original equipment and replacement batteries for motorcylces, scooters, and all terrain vehicles (ATVs).
2/ Five percent of consumption (Reference 33).
3/ Estimated based on Department of Commerce data (Reference 41).
4/ Projections by Franklin Associates, Ltd.

Table 2-21

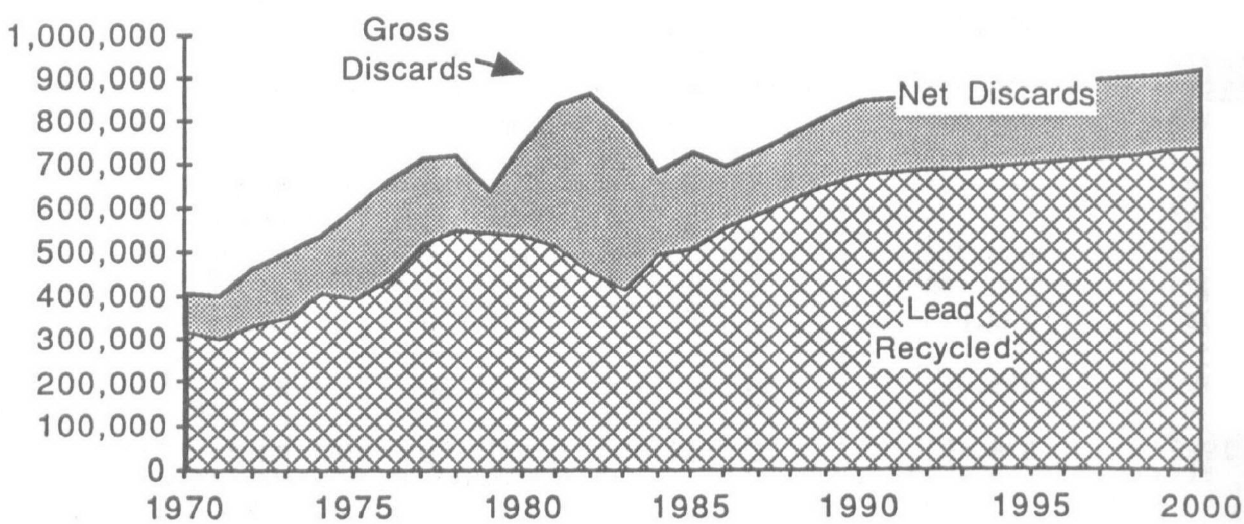
DISCARDS OF LEAD IN SLI LEAD-ACID BATTERIES, 1970 TO 2000
(In short tons)

Year	Gross Discards of Lead in SLI Batteries 1/	Recycled Lead in SLI Batteries 2/	Net Discards of Lead in SLI Batteries	Percent Recycled
1970	409,222	325,399	83,823	79.5
1971	405,791	306,109	99,682	75.4
1972	465,514	335,209	130,305	72.0
1973	508,106	353,067	155,039	69.5
1974	543,358	414,685	128,673	76.3
1975	606,996	400,576	206,420	66.0
1976	667,918	443,566	224,352	66.4
1977	715,761	521,829	193,932	72.9
1978	721,732	553,796	167,936	76.7
1979	639,227	545,969	93,258	85.4
1980	746,099	540,458	205,641	72.4
1981	839,447	519,404	320,043	61.9
1982	867,749	458,557	409,192	52.8
1983	793,198	415,126	378,072	52.3
1984	683,213	500,334	182,879	73.2
1985	732,498	510,585	221,913	69.7
1986	700,610	562,614	137,996	80.3
1990	849,063	681,827	167,236	80.3
1995	876,493	703,854	172,639	80.3
2000	921,203	739,758	181,445	80.3

1/ From Tables 2-19 and 2-20. Assumes a four-year life for automotive batteries and three years for motorcycle batteries (References 33 and 34).

2/ From Reference 33. Assumes that 9 percent of lead recovered from battery scrap is from industrial batteries (Reference 37).

Figure 2-6. Discards of lead in SLI lead-acid batteries, 1970 tc 2000.



Gross discards of lead in automotive and motorcycle batteries are summarized in Tables 2-19 and 2-20. Gross discards for the two types of batteries are combined and recycled battery lead is deducted to obtain net discards into MSW (Table 2-21 and Figure 2-6).

Portable Lead-Acid Batteries. Only a limited number of companies manufacture portable lead-acid batteries, and quantitative data were difficult to obtain. Best estimates were made using the following adjustments and assumptions:

1. Consumption of lead was estimated based on dollar sales from the Handbook of Batteries and Fuel Cells (31) and a weight of lead per battery number from an industry representative (32).

2. Manufacturing losses were assumed to be 5 percent.

3. Recycling of these batteries was assumed to be negligible.

4. The lifetime of these batteries was assumed to be four years.

5. Growth of production of these batteries has been rapid, but it is projected to level off in a few years.

6. It was assumed that 25 percent of these batteries would not be discarded in municipal solid waste. This accounts for those used for medical and industrial instrumentation.

The results of these estimates are shown in Tables 2-22 and 2-23 and Figure 2-7. It is estimated that these batteries have grown from a contribution of two tons of lead in MSW in 1970 to 47 tons in 1986. Growth is expected to continue to about 101 tons in 2000.

LIGHT BULBS

The industry classified as "Electrical Machinery and Equipment" is the Standard Industrial Classification (SIC) system includes light bulbs (called electric lamps in the SIC classification). Light bulbs typically contain both lead and solder in leaded glass.

Lead in Solder in Light Bulbs

Solder is used at the base of many light bulbs to hold the assembly together. The solder can be seen upon inspection of the bulb.

Table 2-22

LEAD CONSUMPTION IN PORTABLE SEALED LEAD-ACID BATTERIES, 1966 TO 1996
(In short tons)

Year	Domestic Lead Consumption in Portable Batteries 1/	Manu-facturing Losses 2/	Adjustment for Imports/ Exports 3/	Net Consumption of Lead in Portable Batteries 4/
1966	1	0.1	2	3
1967	1	0.1	3	4
1968	2	0.1	3	5
1969	2	0.1	4	6
1970	3	0.1	5	7
1971	3	0.2	6	9
1972	4	0.2	7	11
1973	5	0.2	9	13
1974	6	0.3	11	17
1975	7	0.4	13	20
1976	9	0.4	16	24
1977	10	0.5	19	29
1978	12	0.6	23	34
1979	14	0.7	27	41
1980	17	0.8	32	48
1981	19	1.0	37	55
1982	22	1.1	42	63
1983	25	1.2	47	70
1984	28	1.4	47	73
1985	30	1.5	58	86
1986	33	1.6	63	94
1991	43	2.1	81	121
1996	47	2.4	90	135

1/ Estimated by Franklin Associates based on dollar values (Reference 31).
2/ Estimated to be 5 percent of consumption.
3/ Estimated based on information from an industry representative (Reference 32). Exports are negligible.
4/ Net consumption = domestic consumption - manufacturing losses + net imports.

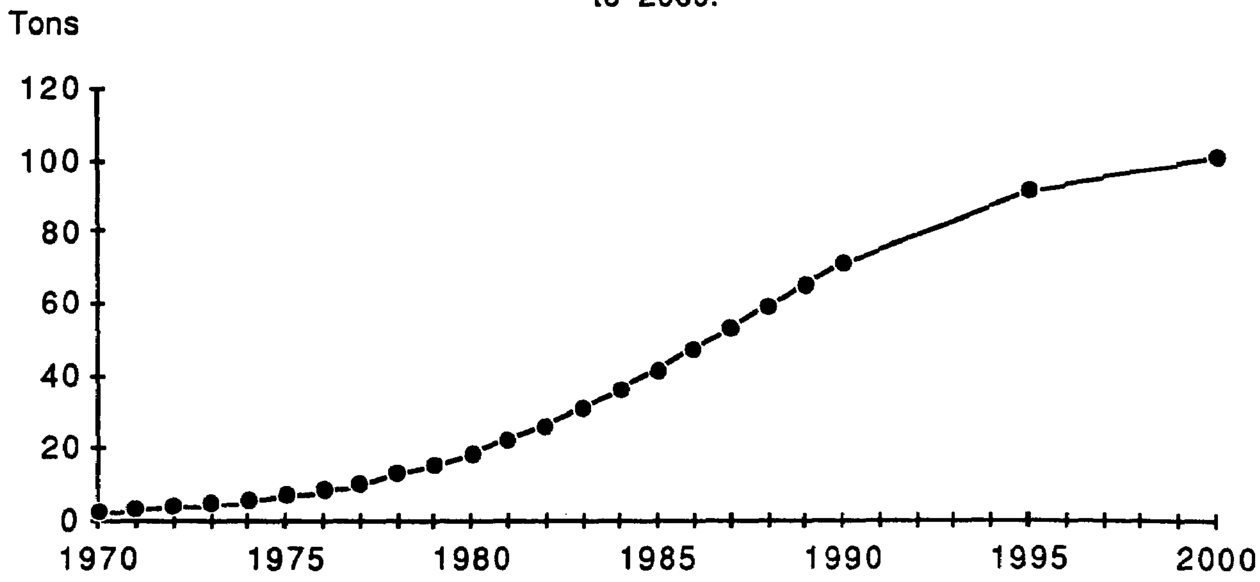
Table 2-23

DISCARDS OF LEAD IN PORTABLE SEALED LEAD-ACID BATTERIES, 1970 TO 2000
(In short tons)

Year	Discards of Lead in Portable Batteries 1/	Discards Other Than MSW 2/	Net Discards of Lead Into MSW 3/
1970	3	1	2
1971	4	1	3
1972	5	1	4
1973	6	2	5
1974	7	2	5
1975	9	2	7
1976	11	3	8
1977	13	3	10
1978	17	4	13
1979	20	5	15
1980	24	6	18
1981	29	7	22
1982	34	9	26
1983	41	10	31
1984	48	12	36
1985	55	14	41
1986	63	16	47
1990	94	24	71
1995	121	30	91
2000	135	34	101

1/ From Table 2-22. Assumes a four-year life.
2/ Assumes that 25 percent not discarded in MSW to account for those used in medical and industrial instrumentation.
3/ Net discards = total discards - discards other than MSW.

Figure 2-7. Discards of lead in portable lead-acid batteries, 1970 to 2000.



The Bureau of Mines (8) reports lead consumption by the total SIC category Electrical Machinery and Equipment, but in no further detail. Lead consumption in light bulbs was estimated by obtaining the units of light bulbs produced, estimating how many of these would be discarded into MSW, and multiplying the estimated quantity of lead in solder per light bulb. The latter estimate was made by experimental means.

Different kinds of light bulbs included in the SIC classification were categorized into bulbs assumed to enter MSW and those assumed not to enter MSW. (The latter include automotive and industrial bulbs, for example.) Bulbs that enter MSW were further categorized into those that contain lead in older and those that do not. Bulbs that do not contain lead in solder include flash cubes and other flash lamps, some projection lamps, and miniature Christmas tree bulbs.

Using Department of Commerce statistics, units of the kinds of bulbs shown in Table 2-24 were tabulated.

Table 2-24

LIGHT BULBS ASSUMED TO CONTAIN SOLDER AND TO BE DISCARDED INTO MSW

15 to 150 watts, white lamps	15 to 150 watts, all other
Lamps above 150 watts	Three-way lamps
Reflector: par type	Reflector: R type
Tungsten halogen	Decorative under 150 watts
All other special types	Flashlight
Christmas tree lamps*	Sun lamp bulbs

* Does not include miniature bulbs, which do not contain leaded solder.

Source: Department of Commerce Standard Industrial Classification Manual (Reference 42). Allocations by Franklin Associates, Ltd.

Additional adjustments and assumptions included:

1. Adjustments for imports were made for each type of lamp. Export adjustments were included in the Department of Commerce (43) figures used.

2. The amount of solder in 16 lamps of nine different types was determined experimentally. The solder in each lamp was removed by melting and weighed. The mean amount of solder in each lamp was 0.1585 grams. Both the experiment and discussions with industry representatives confirmed that the amount of solder in each type of lamp is approximately the same (44).

3. The amount of lead in the solder was assumed to be 50 percent of the total weight (44).

4. It was assumed that there is no recycling of light bulbs.

5. Bulbs were assumed to have a one-year life before discard (44).

Lead in Glass in Light Bulbs

Light bulbs contain leaded glass in the flare and exhaust tube, both of which are part of the mount that is at the base of the bulb. (These glass parts can be seen inside a transparent bulb.) Leaded glass is used at the base of light bulbs because the glass needs to be highly insulating so that the bulbs can operate at low temperatures.

Lead monoxide content in light bulbs ranges from 20 to 30 percent (Table 2-25). The best estimate is that there are 0.25 grams of lead in the glass in an average bulb (44). The same methodology was used as that outlined above, except that the weight of lead in the glass was not obtained experimentally.

Table 2-25

LEAD OXIDE LEVELS IN LIGHT BULBS

Component	Lead Oxide (percent)
Unspecified	20 to 30
Tubes	20 to 29
Flares	20 (incandescent or fluorescent) 6 (halogen)

Source: References 45 and 46.

Total Lead in Light Bulbs

Lead in glass and solder in light bulbs that would be discarded in MSW is summarized in Table 2-26 and Figure 2-8. The lead in solder has been increasing very slowly, while lead in glass has been on a more rapidly increasing trend.

PIGMENTS

Pigments are intermediate products that become constituents in a wide variety of end products, including inks, paints, dyes, and colorants for glass and plastics. Because pigments become so widely dispersed, it was not possible to quantify every end use to which they might be applied. In this

Table 2-26

DISCARDS OF LEAD IN LIGHT BULBS, 1970 TO 2000

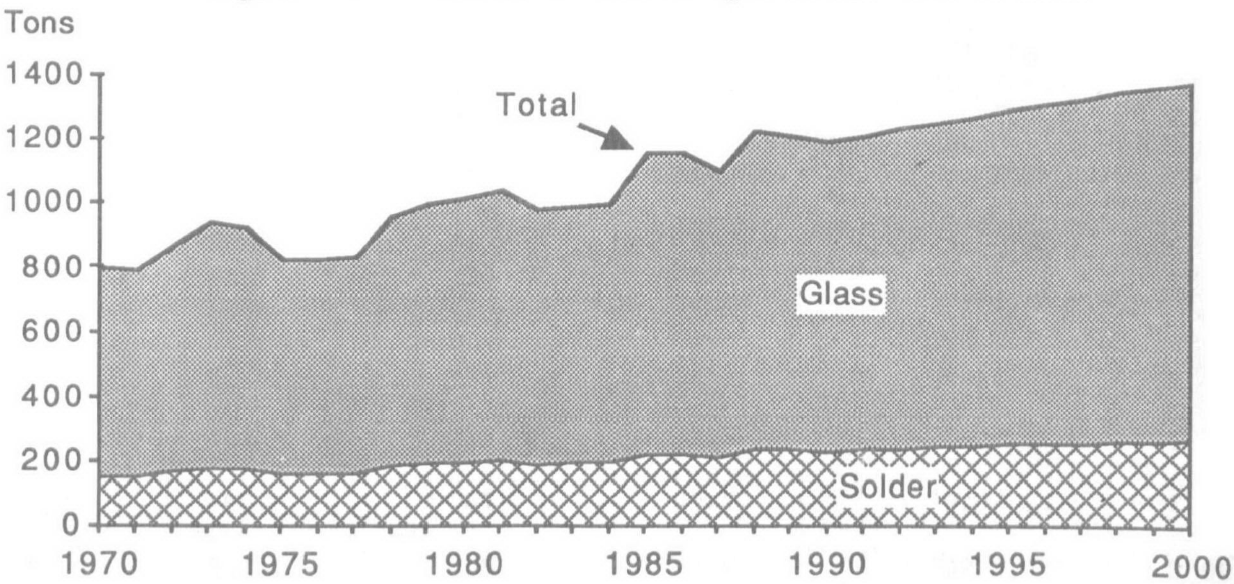
Year	Light Bulb Consumption 1/ (thousand units)	Lead in in Solder Light Bulbs 2/ (short tons)	Lead in Glass in Light Bulbs 3/ (short tons)	Total Lead in Light Bulbs (short tons)
1970	1,782,498	156	491	647
1971	1,748,498	153	482	635
1972	1,930,407	169	532	701
1973	2,089,385	183	576	758
1974	2,051,291	179	565	744
1975	1,840,991	161	507	668
1976	1,837,121	160	506	667
1977	1,857,306	162	512	674
1978	2,127,018	186	586	772
1979	2,215,646	194	611	804
1980	2,260,592	197	623	820
1981	2,304,932	201	635	837
1982	2,176,621	190	600	790
1983	2,204,020	193	607	800
1984	2,213,537	193	610	803
1985	2,562,037	224	706	930
1986	2,571,385	225	709	933
1990	2,638,045	230	727	957
1995	2,855,494	249	787	1,036
2000	3,072,943	268	847	1,115

1/ Consumption one year prior to discard (Reference 44). Includes adjustment for exports and imports. Department of Commerce data (Reference 46).

2/ Weight of solder in each bulb estimated at 0.1585 grams. Lead in solder assumed to be 50 percent of weight (Reference 44).

3/ Weight of lead in glass in each bulb estimated at 0.25 grams (Reference 44).

Figure 2-8. Discards of lead in light bulbs, 1970 to 2000



section, lead compounds that are used in pigments are discussed, followed by a discussion of end uses for pigments. Finally, quantities of lead in pigments in MSW are estimated.

Lead Pigment Compounds*

Pigments can be colored, colorless, black, white, or metallic. Generally, they are of small particle size and remain insoluble in the medium or binder in which they are dispersed. Properties and characteristics that are factors in pigment selection include hue, tint, tinctorial strength, brightness, texture, dispersibility, opacity, oil absorption, lightfastness, weatherability, and chemical, heat, moisture, bleed, and migration resistance. Some of the more common lead pigments are discussed below.

Basic Lead Silico Sulfate ($PbSO_4 \cdot SiO_2$). Basic lead silico sulfate is a pigment with a core of silica and a coating of mixed lead salts. It was the first of such pigments developed for the paint industry. Its greatest utilization has been in multi-pigment house paints, both water-base and solvent-base.

Dibasic Lead Phosphite ($2PbOPbHPO_3 \cdot 1/2H_2O$). Dibasic lead phosphite was first used as a stabilizer for plastics, but its ability to eliminate bleed-through of cedar and redwood stains in emulsion primers has broadened its use. It is still used by plastics and pigment industries. In the plastics industry, it acts as an effective stabilizer for polyvinyl chloride resins or other resins having a chlorine content. In the pigment industry, it acts as an anti-corrosive agent in metal protective coatings and as an anti-staining agent in latex coatings over cedar and redwood.

Basic Lead Silicate ($PbSO_4 \cdot PbO$). Basic lead silicate pigments were first promoted as a stabilizer for vinyl chloride plastics for use in polyvinyl chloride wire coating. Basic lead silicates tend to produce durable paint films, and are helpful in water-base primers for wood by reducing and controlling cedar and redwood staining. The high lead content is also helpful in resisting corrosion on metal surfaces. The mild reactivity of basic lead silicate helps to stabilize linseed oil films. This pigment is still used as an effective stabilizer for polyvinyl chloride plastic compounds.

Chrome Green Pigments ($PbCrO_4 \cdot xPbSO_4 \cdot yFeNH_4Fe(CN)_6$). Chrome green pigment used to be the most widely used green pigment. Today its market has been challenged by phthalocyanine green because of the potential toxicity of lead content in chrome green pigments. Chrome green has been used in the manufacture of paints, printing inks, linoleum, paper goods, and plastics.

White Hiding Lead Pigments ($2PbCO_3 \cdot Pb(OH)_2$). This pigment is generally called lead carbonate. Legislation has prohibited the use of lead ingredients above promulgated limits for use on interior surfaces or exterior paints that are accessible to children.

* This section is based on References 47 and 48.

These regulations have made way for titanium dioxide and zinc pigments to take command of the white pigment market. Although the use of basic lead carbonates has been reduced, it has not been eliminated, and because of its cost and multitude of applications, the products that it has been applied to are numerous.

Molybdate Orange Pigment ($PbCrO_4$,$PbSO_4$,$PbMoO_4$). Molybdate orange pigment is a solid solution of lead chromate, lead molybdate, and lead sulfate. Molybdate orange is principally valued for its hiding power and its tinting strength. Printing inks and color graphics have used this pigment extensively because of the ease of use and rapid processing capabilities, as well as its eye-catching qualities when used in advertisements, magazine covers, and printed layouts. Molybdate orange pigments are also used in floor coverings, pigmented leather, paper, plastics, and coated fabrics.

Calcium Plumbate ($2CaO+PbO_2$). Calcium plumbate was first used as a method of preparation for glass manufacture. Calcium plumbate became a viable paint pigment as the need for reduced lead in pigments surfaced. Its major use is in the manufacture of primers for steel and galvanized steel.

Lead Chromate Pigments ($3 \cdot 2PbCrO4 \cdot 1PbSO_4$,$PbCrO_4$,$2 \cdot 5PbCrO_4 \cdot 1PbSO_4$). Chrome yellow and chrome orange are considered to be two of the most versatile pigments, and thus have a wide spectrum of end uses. Major end uses include: automotive finishes, agricultural machinery, architectural finishes, and coatings for interior and exterior use. Traffic paints consume large amounts of medium chrome yellow for highway stripes and road markings, as well as curb markings and crosswalks. Other areas where lead chromate pigments are used include colorants in vinyl, rubber, and paper.

Red Lead (Pb_3O_4). Most red lead is manufactured from lead oxides (litharge) or leady oxides. Red lead is designated by grades, principally, 85, 95, 97, and 98 percent red lead. Most pigments that are used today are the 97 to 98 percent red lead composition. This reflects the true minimum lead content. Red lead is one of the oldest pigments, and has been used extensively for the protection of many iron and steel products.

Basic Lead Silico Chromate ($PbSiO_3 \cdot 3PbO$,$PbCrO_4 \cdot PbO$). The orange-colored metal pigments are basic lead silico chromate. They are unique in the fact that they contain a core of silica and are coated with active basic lead salts. Basic lead silico chromate was first marketed in 1955. Since then it has had a broad application in metal protective paints (shop coats, maintenance paints, and body and finish coats for structural steel). A second type of basic lead silico chromate was marketed in 1969 for its use in the electro-deposition of water-base coatings for the automotive industry. Their use has been increased because of the capability to be tinted to a variety of colors.

Phloxine ($C_{20}H_6Br_4O_5Pb$). Phloxine has a market in publication printing because of its excellent transparency and brilliance. A form of phloxine in mineral oil is being used in some newspaper printing, replacing lithols that were previously used. Phloxine is still used in some rotogravure inks.

End Uses of Pigments

In addition to pigmentation, lead pigments can be used as driers, activators, vulcanizers, etc., to impart a physical change or properties to a product. More discussion on end uses is included below.

Paints. Leaded house paints such as basic lead carbonate (white lead), basic lead sulfate, leaded zinc oxide, and lead silicates, were common up until 40 or 50 years ago. During the 1930s, more economical pigments such as titanium dioxide began to replace white lead pigments for interior application.

By 1955, the American National Standards Institute established voluntary standards limiting the lead content in paints intended for children's toys, furniture, and interior surfaces to a maximum of one percent lead. In 1971, the Lead-Based Paint Poisoning Prevention Act prohibited the use of paints containing more than one percent lead by weight in the nonvolatile portion of liquid paints or in the dried film on all interior and exterior surfaces accessible to children in residential structures. In 1972, the Food and Drug Administration (FDA) ordered a reduction of the lead content in paints used in and around households to 0.5 percent by January 1, 1973 and 0.06 percent two years later. Further legislation in 1976 limited lead in paint to 0.06 percent and also required the Department of Housing and Urban Development to prohibit lead-based paint in residential structures built or rehabilitated with federal assistance. Also, the Department of Health, Education and Welfare banned lead paints from cooking and eating utensils and the Consumer Products Safety Commission prohibited lead paints on toys and furniture. As a result of all these events, the white lead content of paint dropped dramatically (Figure 2-9).

Red lead and other corrosion-inhibiting pigments are also important lead pigments, but they are used primarily for coating structural steel and iron, and thus are not generally discarded into MSW. Consumption of red lead has also decreased dramatically (Figure 2-10).

Printing Inks. Printing inks consist of a dissolved dye or pigment in a vehicle to produce a fluid or paste that can be transferred to paper, film, foil, or metal, then dried. Literally thousands of commercial printing inks have been developed to meet needs of printers such as rates of feed, drying time, opacity, brilliance, and the nature of the medium to be printed. The type of ink used varies with the type of printing used. The four major types of printing are:

- Raised type (typographic, letterpress, flexographic)
- Planar surface (planographic, lithographic)
- Recessed or engraved (intaglio, rotogravure)
- Stencil (wire, silk screen).

Carbon black is the most widely-used substance for pigmenting inks, but organic pigments, including those using lead compounds, account for a considerable amount. Lead compounds often used in printing inks include

Figure 2-9. White lead content of paint produced, 1970 to 1985.

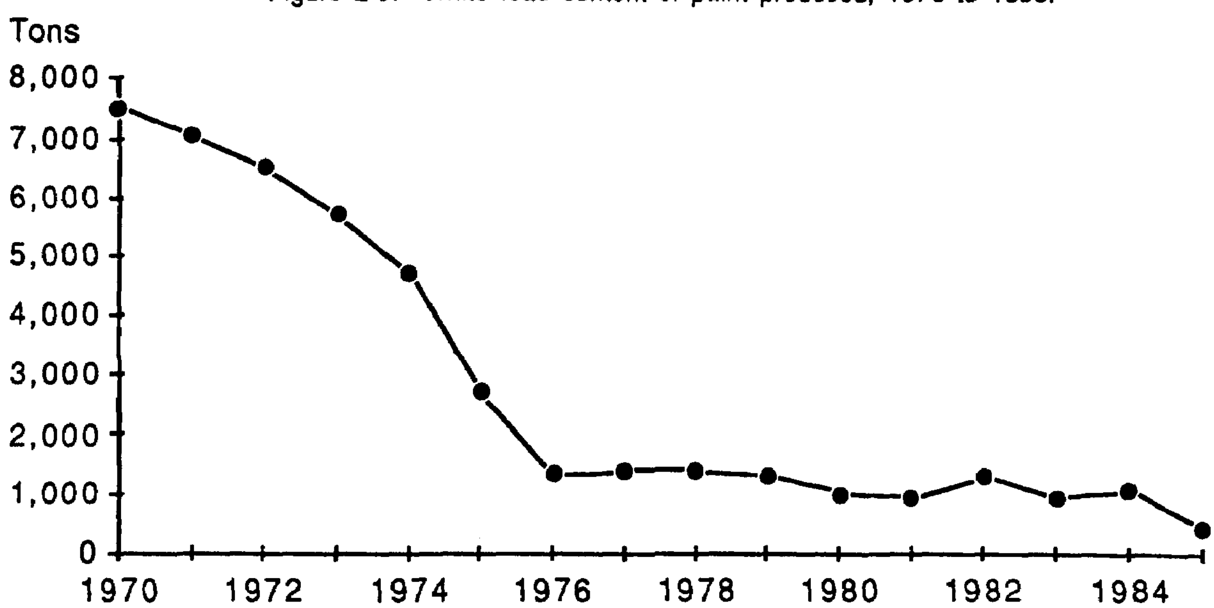
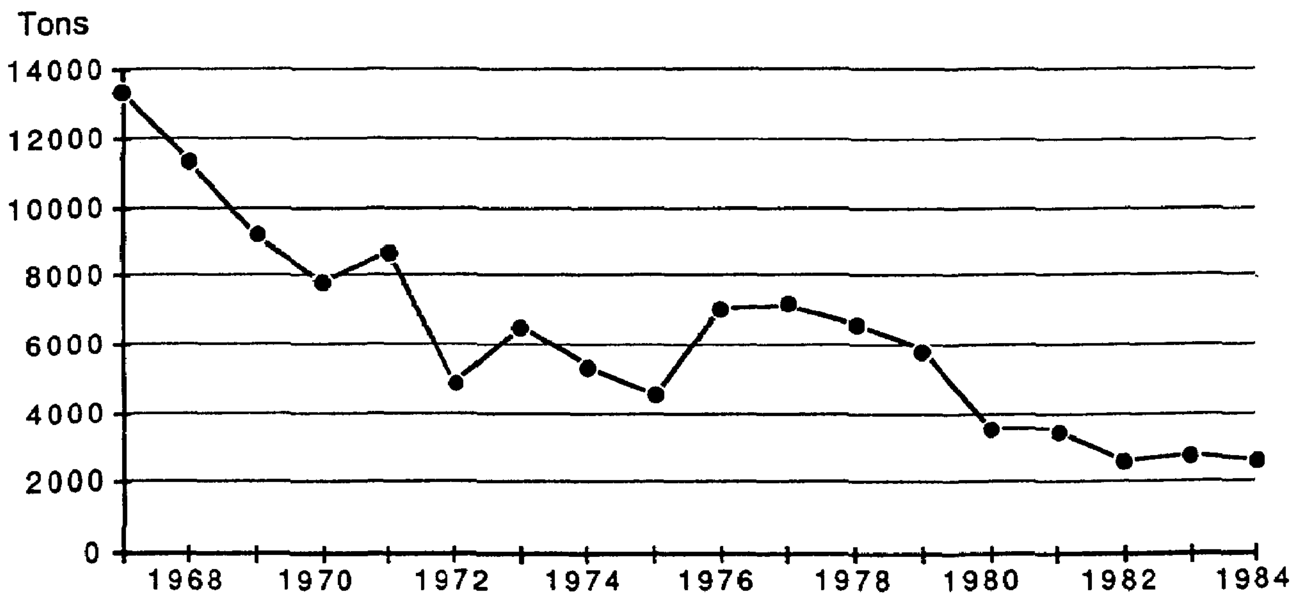


Figure 2-10. Consumption of red lead pigments in the U.S., 1967 to 1984.



phloxine red, chrome yellow (varying formulations of lead chromate depending on the shade desired), lead chromate, and lead sulfochromate.

Discards of lead in printing inks in products entering MSW were estimated using data on consumption of lead in printing inks from the Department of Commerce (51). The following adjustments and assumptions were used:

1. Imports and exports of these products were not available, but they are believed to be insignificant.

2. Manufacturing losses were estimated to be 5 percent (52).

3. An adjustment was made for recycling of paper, which removes some of the ink from the waste stream (Table 2-27). Only recycling of paper that is deinked (some newspapers and some office-type papers such as computer printout) was used in the adjustment. The ink that is removed from these recycled papers is not recycled, of course, but it becomes an industrial waste rather than MSW. Ink that is recycled on paper that is not deinked (e.g., newspapers made into boxboard) was considered to enter the municipal solid waste stream at some point.

4. Lead in ink was assumed to enter MSW in the same year that it is consumed.

5. Projections were made based on past trends, which show a decreasing use of lead in printing ink.

The results of these estimates as shown in Table 2-28 and Figure 2-11 indicate that the use of lead in printing inks has declined rapidly.

Textiles. Inorganic salts, including lead compounds, are useful to the textile dyeing industry. Titanium dioxide, however is the most widely-used inorganic pigment for these purposes. Dyes in the yellow, orange, and green colors are most likely to contain lead compounds. Use of lead in these dyes is discussed below.

Yellow textile pigments may contain chrome yellows, which are essentially lead chromate with varying amounts of lead sulfate. This pigment is not in common use in textile dyeing, however.

Chrome orange pigments are basic lead chromates; they are not currently used in textile dyeing. Molybdate orange pigments (coprecipitate mixtures of lead chromate, lead molybdate, and sulfate) do have some limited use in textile printing.

Table 2-27

ESTIMATE OF DEINKED PAPERS REMOVED FROM MSW BY PAPER RECYCLING, 1970 TO 2000
(In thousand tons and percent)

Year	Total Waste Paper Recycled 1/	Newspapers Recycled 1/	Deinked Newspapers Recycled 2/	Deinked News as a Percent of Newspapers Recycled	High-Grade Deinking Paper Recycled 1/	Total Deinked Papers Recycled 3/	Deinked Papers as a Percent of Total Waste Paper Recycled
1970	12,562	2,445	371	15.2	851	1,222	9.7
1971	12,899	2,405	393	16.3	891	1,284	10.0
1972	11,369	2,557	421	16.5	852	1,273	11.2
1973	15,189	2,903	483	16.6	946	1,429	9.4
1974	15,689	2,854	406	14.2	892	1,298	8.3
1975	13,072	2,416	463	19.2	803	1,266	9.7
1976	15,419	2,821	522	18.5	934	1,456	9.4
1977	16,348	3,081	544	17.7	944	1,488	9.1
1978	16,791	2,862	532	18.6	1,158	1,690	10.1
1979	18,025	3,162	679	21.5	1,250	1,929	10.7
1980	17,971	3,279	852	26.0	1,318	2,170	12.1
1981	17,659	3,276	894	27.3	1,346	2,240	12.7
1982	16,975	3,402	1,066	31.3	1,358	2,424	14.3
1983	18,596	3,436	1,036	30.2	1,547	2,583	13.9
1984	20,309	3,719	1,258	33.8	1,663	2,921	14.4
1985	20,049	3,772	1,312	34.8	1,664	2,976	14.8
1986	21,598	4,050	1,364	33.7	1,819	3,183	14.7
1990	24,048	4,500	1,594	35.4	2,000	3,594	14.9
1995	27,386	4,900	1,800	36.7	2,300	4,100	15.0
2000	30,709	5,400	2,000	37.0	2,600	4,600	15.0

1/ 1970-1977: Franklin Associates, Ltd. (Reference 54).
1978-1986: American Paper Institute (Reference 55).
1990-2000: Estimated by Franklin Associates, Ltd..
2/ 1970-1980: Franklin Associates, Ltd. (Reference 53).
1981-1990: American Paper Institute (Reference 56).
1995-2000: Estimated by Franklin Associates, Ltd..
3/ Deinked newspapers recycled + high grade deinking papers recycled.

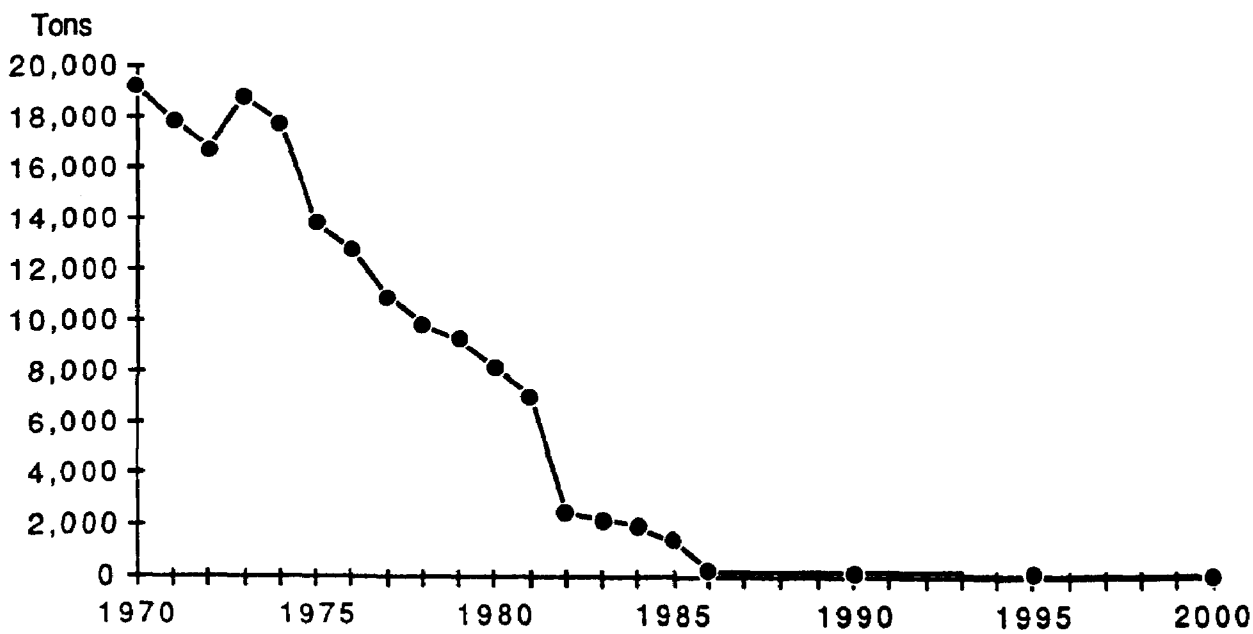
Table 2-28

DISCARDS OF LEAD IN PRINTING INKS IN MSW, 1970 TO 2000
(In short tons)

Year	Consumption of Lead in Printing Ink 1/	Manufacturing Losses 2/	Removed by Recycling of Paper 3/	Net Discards
1970	22,500	1,125	2,183	19,192
1971	21,000	1,050	2,100	17,850
1972	19,946	997	2,234	16,715
1973	21,929	1,096	2,061	18,772
1974	20,497	1,025	1,701	17,771
1975	16,200	810	1,571	13,819
1976	14,987	749	1,409	12,829
1977	12,563	628	1,488	10,447
1978	11,571	579	1,169	9,823
1979	11,020	551	1,179	9,290
1980	9,918	496	1,200	8,222
1981	8,595	430	1,092	7,073
1982	3,086	154	441	2,491
1983	2,755	138	383	2,234
1984	2,424	121	349	1,954
1985	1,763	88	261	1,414
1986	331	17	49	265
1990	275	14	41	220
1995	225	11	34	180
2000	175	9	26	140

1/ Department of Commerce (Reference 51). 1970-1971 and projections by Franklin Associates.
2/ Assumed to be 5 percent (Reference 52).
3/ From Table 2-27. Previously in percentage form.

Figure 2-11. Discards of lead in printing inks in MSW, 1970 to 2000.



Chrome green can be developed using lead chromate for the pigment base, but it is generally not used in textile printing (47).

It was not possible to quantify the amounts of lead pigments used in textile dyeing.

Plastics. Use of plastic products in the United States is growing, and use of pigments in the products is thus growing also. Lead pigments are not extensively used in plastics manufacture, but chrome green, chrome yellow, and chrome orange pigments are used. Molybdate orange is also used. More information in use of pigments in plastics is included elsewhere in this report.

Artists' Paints. Oil colors contain large amounts of pigment, ranging from 30 percent for toners to as high as 75 to 80 percent with dense pigments such as white leads. Because of toxicity concerns, labeling of paints containing toxic substances is required under the Pure Food and Drug Act.

Basic carbonate white lead, called flake white by artists, is the most important lead pigment in oil paints. Although flake white is the traditional white pigment used, it has been largely displaced now by titanium and zinc white pigments.

Another lead pigment with minor use is Naples yellow (lead antimoniate). Lead chromate yellows and greens are no longer listed by most paint manufacturers (47).

Industrial Crayons. The wood product industries use "lumber crayons" that are sometimes called kiel markers. These crayons can be tinted with inorganic pigments such as lead chromate for orange, green, and yellow markers.

Elastomers. Pigments in elastomers (rubber products) have four uses:

- as an inert filler
- as a reinforcing filler
- as an acceleration activator
- as a colorant.

Pigments may be used in elastomers for color identification of two similar objects, to improve aesthetic appeal, or to match two parts of different composition with the same color. Examples of these uses include coloring white walls on tires, the backing on carpeting, sporting goods such as basketballs, rubber bands, rubber-based floor tile, housewares, and clothing and footwear (47).

Lead compounds used as activators and vulcanizers in rubber include litharge (lead oxide), lead peroxide, and lead stearate. Molybdate oranges and chrome yellows may use lead compounds to pigment rubber products.

More information on lead use in rubber is included in another section of this report.

Adhesives. Adhesives are used in many industries, including paper, wood, furniture, shoes, textiles, film and foil, and other. The adhesives may be colored for identification or for aesthetic purposes.

Inorganic pigments such as chrome yellow, chrome green, and molybdate orange may be used for pigmenting adhesives. The pigments generally constitute about 10 percent by weight of the product (47).

Data to quantify use of lead pigments in adhesives were not found.

Traffic Paints. Yellow traffic paints applied to highways, signs, and guard railings are a major user of lead-based chrome yellow pigments. The pigment constitutes 25 percent of the total weight of the paint (47). It has been estimated that nearly 40 million pounds of lead in paints is applied to the nation's highways (53).

Since these paints are not used in products that would enter MSW, they were not included in the estimates made here.

Metal Coil Coatings. Coil coating refers to the continuous application of a protective and/or decorative and/or functional finish on metal strips. The process originated with the Venetian blind industry. Inorganic pigments that may be used for coil coatings include chrome yellow and molybdate orange.

Most coil coated strip is used in the building and construction trades, in commercial equipment, and in the traffic and transportation industries, and thus they would not typically enter MSW. A few coil coated consumer goods, such as tool and tackle boxes, garden tools, games and toys, and clocks, were estimated to be disposed of in MSW.

Machinery and Automotive Finishes. Paints used for machinery and automotive finishes represent another important use that is not discarded into MSW. Lead chromate yellows are often used in finishes for farm equipment, trucks, and other machinery. Molybdate lead chromates are also used. Use of these pigments was not included in the amounts estimated to go to MSW.

Structural Steel Coatings. Red lead paints are used for corrosion protection of structural steel in items such as bridges, support beams, and other construction products. Basic lead silicochromate has also been used for this purpose, and monobasic lead chromate was used in the past, although it has been discontinued. These uses were assumed not to go to MSW.

Marine Coatings. Anti-corrosive coatings are also needed for marine applications such as ship bottoms, buoys, and offshore towers. Red lead has been used extensively for this purpose, but zinc dust has largely replaced red lead. Basic lead silicochromate is also being used for corrosion protection. All marine uses were assumed not to go to MSW.

Discards of Pigments

Discards of lead in pigments in MSW were estimated using as the basic source consumption of lead reported by the Bureau of Mines (8). The categories reported by the Bureau of Mines as "Paints" and "Other Pigments and Chemicals" were included. The category reported as "Glass and Ceramics" is used in the Glass and Ceramics section of this report. Other adjustments and assumptions were as follows:

1. An adjustment was made for imports and exports of lead in pigments using Department of Commerce data (57). In this instance exports are larger than imports. Data were not available to determine pigments in products imported and exported, such as textiles or paper products.

2. Manufacturing losses were estimated to be two percent based on industrial sources (58).

3. It was assumed that there is no recycling of these products except for the removal of some printing ink as described earlier.

4. It was assumed that lead in pigments in the "all other" category is disposed the same year that the lead is consumed. While this would not be true for pigmented products entering demolition or automotive waste, for example, it is a reasonable approximation for the types of products that enter MSW.

5. Projections were made using past trends. Only lead pigments used in non-MSW applications were projected to increase substantially. Most applications assumed to enter MSW, such as printing inks, are declining.

The results of these estimates are summarized in Tables 2-29 and 2-30 and Figure 2-12. Overall the use of lead in pigments has declined steadily since 1976.

PLASTIC PRODUCTS

Lead has two uses in the manufacture of plastics: as a heat stabilizer and as an ingredient in pigments. Discards of lead into MSW from these uses were estimated separately, then totaled.

Table 2-29

CONSUMPTION OF LEAD IN PIGMENTS, 1970 TO 2000
(In short tons)

Year	Domestic Consumption of Lead in Pigments 1/	Manufacturing Losses 2/	Adjustment for Imports/ Exports 3/	Net Consumption of Lead in Pigments 4/
1970	74,158	1,483	1,163	71,512
1971	56,887	1,138	892	54,857
1972	65,995	1,320	970	63,705
1973	72,838	1,457	1,214	70,167
1974	69,615	1,392	1,439	66,784
1975	45,131	903	490	43,738
1976	73,291	1,466	1,077	70,748
1977	70,042	1,401	892	67,749
1978	63,688	1,274	748	61,666
1979	46,331	927	681	44,723
1980	36,451	729	535	35,187
1981	39,491	790	619	38,082
1982	29,034	581	312	28,141
1983	31,992	640	316	31,036
1984	33,847	677	464	32,706
1985	31,544	631	435	30,478
1986	31,686	634	437	30,615
1990	33,630	673	440	32,517
1995	35,696	714	442	34,540
2000	37,517	750	445	36,322

1/ Bureau of Mines (Reference 8). Includes categories reported as "Paints" and "Other Pigments and Chemicals." Lead consumption reported as "Glass and Ceramics" is included in that section of this report. 1970-1978 estimated by Franklin Associates, Ltd. based on Bureau of Mines figures.

2/ Estimated to be 2 percent based on industry sources (Reference 58).

3/ Derived from Department of Commerce data (Reference 57). Exports exceed imports. Does not include pigments in imported/exported products.

4/ Domestic consumption - manufacturing losses - net exports.

Table 2-30

CONSUMPTION OF LEAD IN PIGMENTS BY END USE, 1970 TO 2000
(In short tons)

Year	Net Consumption of Lead in Pigments 1/	Consumption of Lead in Pigments Other Than MSW 2/	Consumption of Lead in Pigments Into MSW 3/	Consumption of Lead as a Pigment in Rubber 4/	Consumption of Lead as a Pigment in Plastics 5/	Consumption of Lead as a Pigment in Inks 6/	All Other Consumption of Lead in Pigments in MSW 7/
1970	71,512	38,128	33,384	103	2,953	22,500	7,828
1971	54,858	25,980	28,878	102	2,924	21,000	4,852
1972	63,706	34,615	29,091	102	2,895	19,946	6,148
1973	70,168	38,288	31,880	95	2,867	21,929	6,989
1974	66,784	37,369	29,415	102	2,838	20,497	5,978
1975	43,739	21,436	22,303	96	2,809	16,200	3,198
1976	70,749	46,141	24,608	147	2,780	14,987	6,694
1977	67,750	45,998	21,752	169	2,752	12,563	6,268
1978	61,667	41,747	19,920	196	2,723	11,571	5,430
1979	44,724	27,610	17,114	75	3,042	11,020	2,977
1980	35,187	21,168	14,019	78	2,381	9,918	1,642
1981	38,083	25,037	13,046	105	2,712	8,595	1,634
1982	28,142	21,159	6,983	97	2,249	3,086	1,551
1983	31,037	24,036	7,001	107	2,574	2,755	1,565
1984	32,707	26,221	6,486	118	2,673	2,424	1,271
1985	30,479	25,006	5,473	131	2,625	1,763	954
1986	30,616	26,725	3,891	127	2,567	331	866
1990	32,518	28,790	3,728	135	2,600	275	718
1995	34,541	30,951	3,590	135	2,600	225	630
2000	36,322	32,870	3,452	135	2,600	175	542

1/ From Table 2-29.

2/ Estimated by Franklin Associates, Ltd. based on Department of Commerce and other references (References 7, 47, 59, 60, and 61). Includes traffic paints, coil coatings, machinery and automobile finishes, structural steel paints, and marine finishes.

3/ By difference.

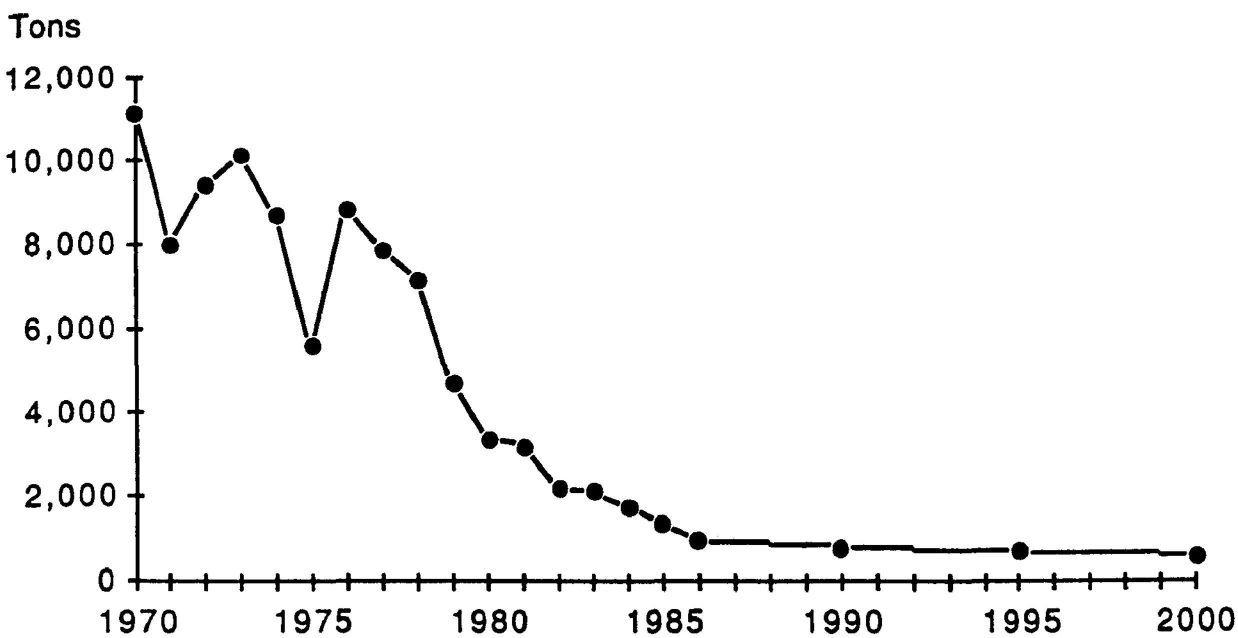
4/ See Table 2-41 in the Rubber section.

5/ See Table 2-37 in the Plastics section.

6/ See Table 2-28 in this section.

7/ By difference. Includes lead in pigments in textiles, adhesives, artists' paints, some coil coatings, and miscellaneous. Discards assumed to be the same as consumption.

Figure 2-12. Discards of lead in pigments, 1970 to 2000



Heat Stabilizers

Heat stabilizers are used extensively in polyvinyl chloride (PVC) resins to protect the polymer from thermal degradation during processing and to help retain the physical properties and color of the finished product. In fact, development of effective heat stabilizers has contributed to the growth of PVC use in a wide variety of applications. Lead stabilizers are used mainly in opaque, rigid, and flexible formulations of extrusion, injection, and compression molded products.

Barium, cadmium, and lead compounds are used as heat stabilizers, with lead ranking third in usage. The principal compounds of lead used as heat stabilizers include tribasic lead sulfate, basic lead sulfate silicate, basic lead carbonate, and basic lead phthalate (62).

Applications of Heat Stabilizers. Consumer products that are likely to be made of PVC containing lead stabilizers include: appliance housings, sporting and recreational items, toys (previous to 1978), footwear, handbags, luggage, credit/bank cards, floppy disk jackets, furniture (previous to 1978), shower curtains, window shades, blinds and awnings, and garden hose. Use of lead stabilizers has become more limited than in the past due to the toxicity of the metal.

Other products apt to be made of PVC are assumed not to enter MSW: wire and cable coverings, building and construction applications (siding, pipe, conduit, gutters, etc.), and transportation applications (auto upholstery, auto tops, etc.).

Estimates of Discards. The basic source of data on use of lead as a heat stabilizer in plastics was a Special Report on Chemicals and Additives published by Modern Plastics (63). Allocation of plastic resin use to products in MSW followed the same methodology as that used for previous MSW characterization studies (20)(64). Adjustments and assumptions were made as follows:

1. It was assumed that all lead in heat stabilizers is used in polyvinyl chloride (65). Data on polyvinyl chloride resin consumption by product category was taken from Modern Plastics (66).

2. It was assumed that 80 percent of the amount of lead stabilizer use reported is lead metal (67).

3. It was assumed that no lead stabilizers are used in food packaging, since lead is not approved for that use.

4. It was assumed that lead in heat stabilizers is distributed evenly throughout the remaining PVC uses. The end uses assumed to be discarded into MSW are: nonfood packaging, clothing, footwear,

miscellaneous nondurables (disposable bags and wrap, and home-use trash bags), housewares, toys, records, luggage, consumer electronics, furniture, appliances, and miscellaneous durables (shower curtains, handbags, flooring, lighting, blinds, and window shades). Heat stabilizers are also used in PVC resins destined for other end uses, e.g., PVC pipe, that are not discarded into MSW.

5. Each category of PVC end use was adjusted for imports and exports using Department of Commerce data (39). It was assumed that use of lead heat stabilizers in these products is in the same proportion as domestic use.

6. Manufacturing losses were assumed to be one percent (20)(64).

7. It was assumed that there is no recycling of these PVC products.

8. The lifetimes of these products were assumed to be as follows:
   - Packaging and miscellaneous nondurables: Less than one year
   - Clothing and footwear: 2 years
   - Housewares, toys, and miscellaneous durables: 5 years
   - Records, luggage, consumer electronics, furniture, and appliances: 10 years.

   These are the same lifetimes as those used in the previous MSW characterization studies (20)(64).

9. Projections were based on past trends.

The results of these estimates are shown in Tables 2-31 through 2-34. Consumption of PVC resin by end use destined to be discarded into MSW is shown in Table 2-31. Estimates of lead use in heat stabilizers per ton of nonfood PVC resin are shown in Table 2-32. Adjustment ratios for imports/exports of certain products are shown in Table 2-33. These ratios show that imports are greater than domestic consumption for products such as footwear, luggage, and consumer electronics.

Finally, discards of lead in stabilizers used in plastic products made of PVC resin are shown in Table 2-34.

Pigments

The two most widely-used lead-based pigments used in plastics are lead chromates and molybdate oranges. The plastics industry has been cited as the third largest consumer of lead chromate pigments (48). Molybdate oranges

Table 2-31

CONSUMPTION OF PVC RESIN BY END USE, 1960 TO 1986 1/
(In thousand short tons)

	Nondurables				Durables						
Year	Nonfood Packaging	Clothing	Footwear	Miscellaneous Nondurables	Housewares	Toys	Records	Furniture	Appliances	Miscellaneous Durables	Total
1960	-	-	-	-	-	-	28	20	20	-	68
1961	-	-	-	-	-	-	30	24	15	-	69
1962	-	-	-	-	-	-	30	28	14	-	72
1963	-	-	-	-	-	-	38	32	14	-	84
1964	-	-	-	-	-	-	40	27	14	-	81
1965	-	-	-	-	9	30	48	37	17	6	147
1966	-	-	-	-	11	33	48	44	16	6	158
1967	-	-	-	-	12	39	50	51	15	6	173
1968	-	34	37	-	14	43	61	58	15	6	268
1969	-	32	45	-	17	48	58	77	18	7	302
1970	83	36	47	5	17	53	70	75	19	8	413
1971	86	36	48	6	19	58	66	91	21	8	439
1972	102	46	50	8	24	64	75	108	22	10	509
1973	110	48	69	12	24	77	73	120	22	12	567
1974	118	38	53	14	28	67	77	118	23	12	548
1975	111	33	54	12	22	52	64	91	23	15	477
1976	128	36	55	36	24	49	75	104	22	15	544
1977	142	25	55	47	26	47	88	114	23	64	631
1978	155	25	56	67	28	41	106	116	32	127	753
1979	191	8	49	55	25	40	80	108	43	165	764
1980	171	6	42	57	23	33	57	82	35	168	674
1981	181	7	44	63	23	40	52	77	40	163	690
1982	189	6	37	62	21	33	56	47	32	171	654
1983	217	8	42	78	23	37	40	34	45	183	707
1984	258	8	37	78	26	35	35	43	46	171	737
1985	203	10	34	83	24	29	34	38	43	192	690
1986	221	9	33	94	26	31	22	41	54	209	740

1/ From Reference 66.

Table 2-32

ESTIMATES OF LEAD USED IN STABILIZERS IN PVC, 1960 TO 1986
(In short tons)

Year	Lead Stabilizers Used in Plastics 1/	Lead in Lead Stabilizers 2/	PVC Resin Used in in Nonfood Applications 3/	Use of Lead in Stabilizers per Ton of Resin 4/
1960	-	-	-	0.003249
1961	-	-	-	0.003249
1962	-	-	-	0.003249
1963	-	-	-	0.003249
1964	-	-	-	0.003249
1965	-	-	-	0.003249
1966	-	-	-	0.003249
1967	-	-	-	0.003249
1968	-	-	-	0.003249
1969	-	-	-	0.003249
1970	7,150	5,720	1,421,000	0.004025
1971	7,431	5,945	1,561,000	0.003808
1972	7,712	6,170	1,734,000	0.003558
1973	7,993	6,394	1,906,000	0.003355
1974	8,274	6,619	2,072,000	0.003195
1975	8,555	6,844	2,227,000	0.003073
1976	8,835	7,068	2,320,000	0.003047
1977	9,116	7,293	2,231,000	0.003269
1978	6,800	5,440	2,488,000	0.002186
1979	11,140	8,912	2,590,000	0.003441
1980	10,968	8,774	2,420,000	0.003626
1981	11,519	9,215	2,526,000	0.003648
1982	10,362	8,290	2,385,000	0.003476
1983	10,800	8,640	2,488,000	0.003473
1984	10,800	8,640	3,128,000	0.002762
1985	10,650	8,520	3,151,000	0.002704
1986	10,826	8,661	3,357,000	0.002580

1/ 1978-1985 from Reference 63. Previous years and 1986 estimated by Franklin Associates, Ltd.

2/ Estimated to be 80 percent of weight of stabilizer based on Reference 67.

3/ From Reference 64.

4/ 1960-1969 is the average of 1970-1986.

Table 2-33

IMPORT/EXPORT ADJUSTMENT RATIOS FOR PLASTIC PRODUCTS, 1962 TO 1986 1/

Year	Clothing	Footwear	Toys	Luggage	Consumer Electronics
1962	-	-	-	1.07	-
1963	-	-	-	1.06	-
1964	-	-	-	1.06	-
1965	-	-	-	1.06	-
1966	-	-	1.05	1.12	-
1967	-	-	1.06	1.12	-
1968	-	1.24	1.07	1.11	-
1969	-	1.30	1.08	1.10	-
1970	1.05	1.35	1.11	1.15	-
1971	1.05	1.39	1.09	1.14	-
1972	1.06	1.30	1.08	1.23	-
1973	1.06	1.47	1.10	1.23	-
1974	1.05	1.48	1.10	1.19	-
1975	1.06	1.57	1.00	1.21	-
1976	1.08	1.67	1.12	1.29	-
1977	1.08	1.94	1.14	1.38	1.64
1978	1.12	2.06	1.16	1.50	1.66
1979	1.12	2.02	1.17	1.43	1.58
1980	1.17	1.95	1.18	1.38	1.54
1981	1.14	2.04	1.17	1.44	1.81
1982	1.16	2.24	1.22	1.54	1.85
1983	1.13	2.58	1.21	1.57	1.98
1984	1.25	3.18	1.36	1.92	2.31
1985	1.30	2.64	1.58	1.82	2.59
1986	1.33	2.73	1.67	2.09	2.67

1/ Ratios for the adjustment of domestic consumption to reflect domestic consumption determined by category, from Reference 39.

Table 2-34

DISCARDS OF LEAD IN STABILIZERS IN PVC PLASTICS PRODUCTS, 1970 TO 2000 1/
(In short tons)

Year	Nondurables				Durables						Total
	Packaging	Clothing	Footwear	Miscellaneous Nondurables	Housewares	Toys	Records	Furniture	Appliances	Miscellaneous Durables	
1970	331	109	142	20	29	96	91	64	64	19	966
1971	324	103	181	23	35	111	97	77	48	19	1,019
1972	359	151	243	28	39	133	97	90	45	19	1,204
1973	365	143	241	40	45	148	123	103	45	19	1,273
1974	373	172	220	44	55	167	130	87	45	23	1,315
1975	338	169	323	37	68	234	156	119	55	32	1,530
1976	386	126	238	109	72	238	156	142	51	30	1,548
1977	458	106	248	153	85	243	161	164	48	35	1,702
1978	336	117	266	146	80	281	196	187	48	40	1,697
1979	650	89	332	188	89	233	187	248	58	38	2,110
1980	614	61	241	206	67	158	279	299	76	46	2,047
1981	652	29	320	227	72	166	249	343	79	45	2,183
1982	649	23	281	212	86	175	264	380	77	207	2,355
1983	746	27	312	269	60	102	242	399	73	274	2,504
1984	706	22	277	212	86	158	244	373	73	563	2,714
1985	542	30	357	222	83	140	195	277	70	601	2,517
1986	564	27	309	239	84	168	226	314	66	589	2,586
1990	641	29	278	231	63	123	206	293	127	514	2,503
1995	641	29	278	231	70	136	91	102	114	546	2,237
2000	641	29	278	231	70	136	114	120	129	546	2,294

1/ Consumption of PVC resin (Table 2-31) adjusted for lead per ton (Table 2-32), one percent manufacturing losses, exports/imports (Table 2-33), and life of products.

also find a wide range of applications in plastics. Consumption of molybdate orange by the plastics industry accounts for 25 percent of the total usage (48). Use of these pigments peaked in the early and mid-Seventies, however, and usage has been declining due to concerns over possible health hazards and restrictive legislation.

Lead chromate pigments impart hues ranging from greenish or light yellows to deep oranges and primrose. These pigments may also be mixed with blue pigments to produce chrome greens or phthalochrome greens.

Molybdate orange is a mixture of lead chromate, lead molybdate, and lead sulfate. Colors can range varying from reddish yellows to red-shade oranges depending on the mixture of compounds. Some typical ranges of composition are shown in Table 2-35.

Table 2-35

TYPICAL RANGES OF COMPOSITION OF LEAD CHROMATE PIGMENTS 1/

	Medium (Percent)	Lemon (Percent)	Primrose (Percent)	Molybdate Orange (Percent)
$PbCrO_4$	90 to 94	62	65 to 71	69 to 80
$PbSO_4$	0 to 6	20 to 38	23 to 30	9 to 15
$PbMoO_4$	0	0	0	3 to 7
PbO	0	0	0	0
Other	4 to 6	1 to 6	3 to 8	3 to 13

1/ Adapted from the Pigment Handbook (Reference 48).

Estimates of Discards. The methodology for estimating discards of lead-containing pigments in plastics was similar to that for heat stabilizers, except that pigments are widely used in all resins, rather than being restricted to PVC. Plastic resin use was allocated to products assumed to be discarded into MSW, again using data from Modern Plastics (63) (Table 2-36).

Effective early in 1978, the Consumers Safety Commission issued a ban on lead in toys and other articles intended for use by children, and on furniture articles for household use. The use of lead-containing additives in food-contact products has never been allowed by the Food and Drug Administration. One of the categories included in the products allocated to disposal in MSW is "Toys." This category contains sporting and recreational items, and was therefore considered to contain lead pigments in spite of the ban on lead in children's items. Likewise, there is a "Furniture" category included in MSW discards. This category includes furniture for other uses than in households. In addition, there is assumed to be a 10-year time lag before furniture is discarded. Therefore, discards of furniture containing lead pigments are still included in the estimates.

Table 2-36

CONSUMPTION OF RESINS BY END USE, 1960 TO 1986 1/
(In thousand short tons)

Year	Nonfood Packaging	Clothing	Footwear	Miscellaneous Nondurables: Total Misc. Nondurables	Food Contact Misc. Nondurables	Total Nonfood Misc. Nondurables 2/
1960	–	–	–	–	–	–
1961	–	–	–	–	–	–
1962	–	–	–	–	–	–
1963	–	–	–	–	–	–
1964	–	–	–	–	–	–
1965	–	–	–	–	–	–
1966	–	–	–	–	–	–
1967	–	–	–	–	–	–
1968	–	34	46	–	–	–
1969	–	32	56	–	–	–
1970	1,226	36	58	143	43	100
1971	1,270	36	59	186	56	130
1972	1,507	46	61	231	71	161
1973	1,618	48	54	344	105	239
1974	1,730	38	64	391	119	272
1975	1,606	33	66	347	106	242
1976	1,853	36	67	1,026	312	714
1977	2,058	25	67	1,358	413	945
1978	2,209	25	68	1,551	509	1,043
1979	2,573	8	61	1,708	597	1,111
1980	2,295	6	52	1,664	590	1,074
1981	2,336	7	54	1,636	587	1,049
1982	2,288	6	43	1,596	574	1,022
1983	2,468	8	48	1,826	650	1,176
1984	2,737	8	40	1,941	686	1,255
1985	2,886	10	37	1,881	688	1,193
1986	3,056	9	36	1,996	740	1,256

(continued)

Table 2-36 (continued)

Year	Durables: Housewares	Toys 3/	Records	Luggage	Consumer Electronics 4/	Furniture	Appliances 5/	Misc. Durables 6/
1960	-	-	28	14	-	95	112	-
1961	-	-	30	15	-	113	84	-
1962	-	-	30	15	-	132	78	-
1963	-	-	38	16	-	153	81	-
1964	-	-	40	16	-	176	80	-
1965	245	161	48	16	-	173	93	62
1966	282	189	48	17	-	208	87	63
1967	314	208	50	17	-	241	84	65
1968	373	243	61	18	-	273	84	68
1969	447	369	58	20	-	360	97	77
1970	441	297	70	20	-	352	103	80
1971	478	326	66	14	-	423	114	82
1972	602	363	75	17	-	501	118	104
1973	623	437	73	22	-	554	121	126
1974	707	381	77	21	-	543	124	123
1975	558	292	64	14	-	418	125	156
1976	625	277 7/	75	17	-	478	121	163
1977	662	262	88	13	186	519	125	685
1978	564	267	106	18	176	519	129	857
1979	631	268	80	21	95	538	133	1,008
1980	537	237	57	32	194	449	137	912
1981	559	261	52	34	215	461	149	945
1982	499	211	56	26	201	364	160	872
1983	548	240	40	28	212	377	172	1,047
1984	565	251	38	26	124	441	183	1,202
1985	575	260	34	22	78	447	195	1,881
1986	597	277	22	21	89	460	206	1,966

1/ Based on Reference 2.
2/ Includes disposables, home-use bags and wrap, and home-use trash bags.
3/ Includes sporting and recreational equipment.
4/ Includes radios, stereos, telephones, etc.
5/ Includes plastic destined for discard from room air conditioners, dishwashers, dryers, freezers, microwave ovens, ranges, refrigerators, washers, and water heaters.
6/ Includes shower curtains, handbags, flooring, lighting, window shades, and blinds.
7/ Estimated by Franklin Associates, Ltd.

Lead in lead-containing pigments was assumed to be 60 percent of the pigment weight used, and the amount of lead in pigments per ton of nonfood resin used was calculated (Table 2-37). Adjustments for manufacturing losses and imports/exports were made in the same manner as that for estimating lead use in stabilizers.

Finally, the adjusted estimates of discards of lead in pigments in plastic products were tabulated (Table 2-38).

Total Lead in Plastics

Total discards of lead in products in municipal solid waste were obtained by adding the contributions of heat stabilizers and pigments (Table 2-39). The relative contributions of heat stabilizers and pigments are shown in Figure 2-13, and the products contributing to lead in plastics are shown in Figure 2-14.

RUBBER PRODUCTS

Lead (or cadmium) compounds may be added to elastomers (rubber products) for a number of purpose: as pigments, fillers, activators, vulcanizers, curing activators, and plasticizers. Lead may also be used as a metal as part of the product, for lead-sheathed hosing, for example.

Pigments may be used in elastomers for color identification of two similar objects, to improve aesthetic appeal, or to match two parts of different composition with the same color. Examples of these uses include coloring white walls on tires, the backing on carpeting, sporting goods such as basketballs, rubber bands, rubber-based floor tile, housewares, and clothing and footwear (47).

Lead compounds used as activators and vulcanizers in rubber include litharge (lead oxide), lead peroxide, and lead stearate. Molybdate oranges and chrome yellows may use lead compounds in pigment rubber products. Accelerator activators may employ inorganic compounds such as lead oxide, red oxide, and white lead (68). Lead dimethyl dithicarbamate is used in the base compound for V-belt compositions. Table 2-40 lists some of the products manufactured by the rubber industry that may contain lead and/or cadmium.

A breakdown of pigment use between tires and other rubber products was made using information from the Department of Commerce and a previous study for EPA (Table 2-41).

The Department of Commerce reports annual use of lead in the rubber industry (Table 2-42) (51). Information from a study for EPA (68) indicates, however, that most of this lead use is for manufacture of lead-sheathed hosing and for making molds for the manufacturing process. Therefore, lead in products that reach MSW is assumed to come from the lead in pigments for rubber as estimated in the section on Pigments.

Other adjustments and assumptions used in making estimates of lead discarded in rubber products are as follows:

Table 2-37

ESTIMATES OF LEAD USED IN PIGMENTS IN PLASTICS, 1960 TO 1986
(In short tons)

Year	Chrome Yellow	Molybdate Orange	Total	Lead in Lead Pigments 2/	Total Resin Used in Nonfood Applications 3/	Use of Lead in Pigments per Ton of Resin 4/
1960	-	-	-	-	-	0.00020
1961	-	-	-	-	-	0.00020
1962	-	-	-	-	-	0.00020
1963	-	-	-	-	-	0.00020
1964	-	-	-	-	-	0.00020
1965	-	-	-	-	-	0.00020
1966	-	-	-	-	-	0.00020
1967	-	-	-	-	-	0.00020
1968	-	-	-	-	-	0.00020
1969	-	-	-	-	-	0.00020
1970	2,942	1,979	4,921	2,953	8,460,000	0.00035
1971	2,912	1,962	4,874	2,924	9,400,000	0.00031
1972	2,881	1,944	4,825	2,895	10,340,000	0.00028
1973	2,851	1,927	4,778	2,867	11,280,000	0.00025
1974	2,821	1,909	4,730	2,838	12,220,000	0.00023
1975	2,790	1,891	4,681	2,809	13,160,000	0.00021
1976	2,760	1,874	4,634	2,780	13,712,720	0.00020
1977	2,630	1,856	4,486	2,692	13,246,480	0.00020
1978	2,699	1,839	4,538	2,723	15,156,560	0.00018
1979	3,086	1,984	5,070	3,042	16,795,920	0.00018
1980	2,315	1,653	3,968	2,381	16,803,440	0.00014
1981	2,646	1,874	4,520	2,712	17,523,480	0.00015
1982	2,205	1,543	3,748	2,249	16,913,420	0.00013
1983	2,530	1,760	4,290	2,574	19,376,220	0.00013
1984	2,640	1,815	4,455	2,673	20,920,640	0.00013
1985	2,625	1,750	4,375	2,625	21,885,080	0.00012
1985	2,529	1,748	4,277	2,566	22,936,940	0.00011

1/ 1979-1985 from Reference 63. Previous years and 1986 estimated by Franklin Associates, Ltd.
2/ Estimated to be 60 percent of weight of pigments based on Reference 67.
3/ From Reference 64.
4/ By division. 1960-1969 is the average of 1970-1986.

Table 2-38

DISCARDS OF LEAD IN PIGMENTS IN PLASTIC PRODUCTS, 1970 TO 2000 1/
(In short tons)

Year	Nondurables: Nonfood Packaging	Nondurables: Clothing	Nondurables: Footwear	Nondurables: Miscellaneous Nondurables	Durables: Housewares	Durables: Toys	Durables: Records	Durables: Luggage	Durables: Consumer Electronics	Durables: Furniture	Durables: Appliances	Durables: Miscellaneous Durables	Total Lead in Pigments in Plastics in MSW
1970	444	7	11	36	51	33	6	3	-	20	23	13	647
1971	407	7	14	42	59	41	6	3	-	23	18	13	632
1972	439	14	26	47	65	46	6	3	-	27	16	13	703
1973	429	12	24	63	77	54	8	4	-	32	17	14	734
1974	418	14	21	66	93	83	8	4	-	37	17	16	776
1975	351	13	19	53	160	119	10	4	-	36	19	29	813
1976	395	10	21	152	153	114	10	4	-	43	18	26	946
1977	461	8	21	211	175	114	10	4	-	50	18	30	1,103
1978	430	8	22	203	165	127	13	4	-	57	18	33	1,080
1979	510	6	26	220	171	101	12	5	-	75	20	30	1,176
1980	353	5	24	165	122	64	25	8	-	127	38	34	967
1981	391	2	21	176	133	66	21	5	-	136	37	35	1,023
1982	331	1	14	148	148	67	22	6	-	146	35	153	1,071
1983	354	1	16	169	110	60	19	7	-	147	32	167	1,083
1984	377	1	12	173	125	62	19	6	-	131	30	200	1,136
1985	374	1	16	155	83	43	14	4	-	91	28	140	949
1986	370	1	15	152	94	51	16	5	-	102	26	158	990
1990	361	1	13	159	75	53	9	7	46	69	21	244	1,059
1995	361	1	13	159	75	47	4	5	26	58	26	185	961
2000	361	1	13	159	75	47	5	6	42	56	25	185	976

1/ Consumption of resins (Table 2-36) adjusted for lead in pigments (Table 2-37), manufacturing losses, exports/imports (Table 2-33) and life of products.

Table 2-39

DISCARDS OF LEAD IN PLASTICS IN MSW, 1970 TO 2000 1/
(In short tons)

	Nondurables				Durables								
Year	Nonfood Packaging	Clothing	Footwear	Miscellaneous Nondurables	Housewares	Toys	Records	Luggage	Consumer Electronics	Furniture	Appliances	Miscellaneous Durables	Total
1970	775	116	152	56	80	130	97	3	-	84	88	32	1,613
1971	732	110	194	64	94	153	104	3	-	101	66	32	1,651
1972	798	164	269	75	104	179	104	3	-	117	61	33	1,907
1973	794	155	266	103	122	202	131	4	-	135	62	33	2,007
1974	792	186	241	110	147	249	138	4	-	123	62	38	2,091
1975	689	182	342	89	227	354	166	4	-	155	74	61	2,343
1976	781	136	259	261	225	352	166	4	-	185	70	56	2,494
1977	919	114	269	365	260	358	171	4	-	214	66	66	2,805
1978	767	126	287	349	245	409	209	4	-	243	66	73	2,777
1979	1,160	95	358	408	260	334	199	5	-	322	78	68	3,286
1980	968	67	264	371	189	222	304	8	-	426	113	80	3,014
1981	1,043	31	341	403	206	232	270	5	-	479	116	80	3,206
1982	980	24	295	360	234	242	286	6	-	526	112	360	3,426
1983	1,100	29	328	438	170	163	262	7	-	545	105	441	3,587
1984	1,082	23	289	385	212	220	262	6	-	504	103	763	3,850
1985	916	31	372	377	166	183	209	4	-	368	98	742	3,466
1986	934	29	324	391	177	219	242	5	-	416	92	748	3,576
1990	1,003	30	290	390	137	176	215	7	46	362	148	758	3,562
1995	1,003	30	290	390	145	183	95	5	26	160	139	731	3,198
2000	1,003	30	290	390	145	183	120	6	42	177	153	731	3,270

1/ Discards of lead in stabilizers plus lead in pigments.

Figure 2-13. Discards of lead in plastics, 1970 to 2000.

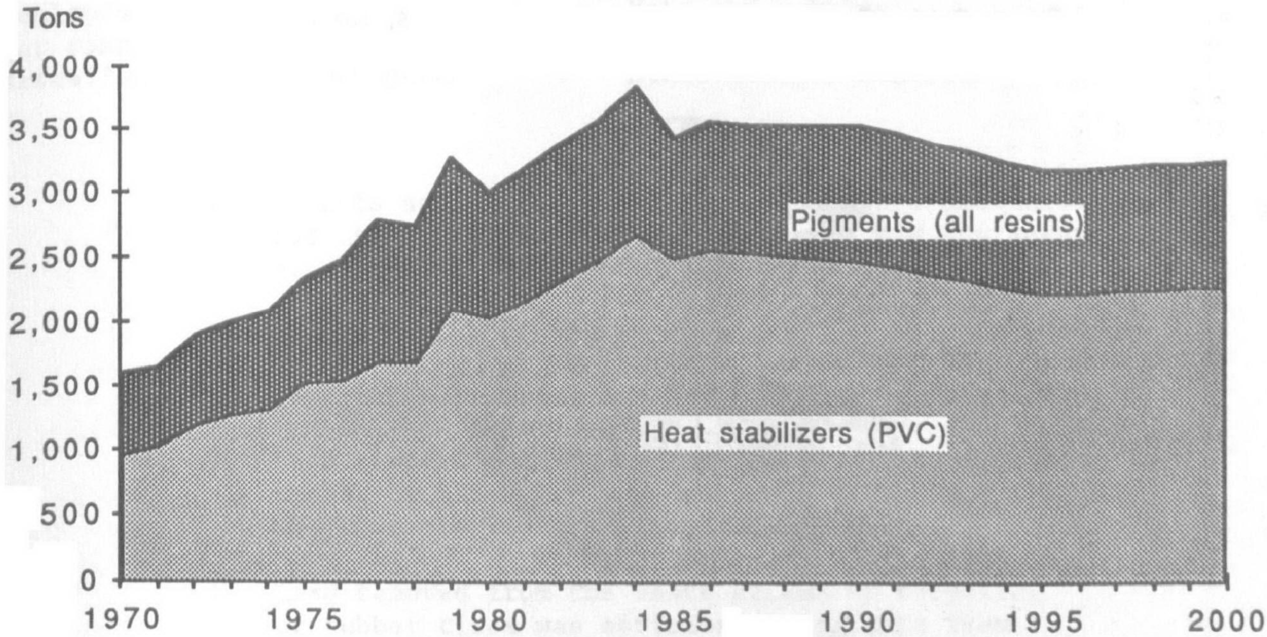


Figure 2-14. Sources of lead discards in plastics, 1986.

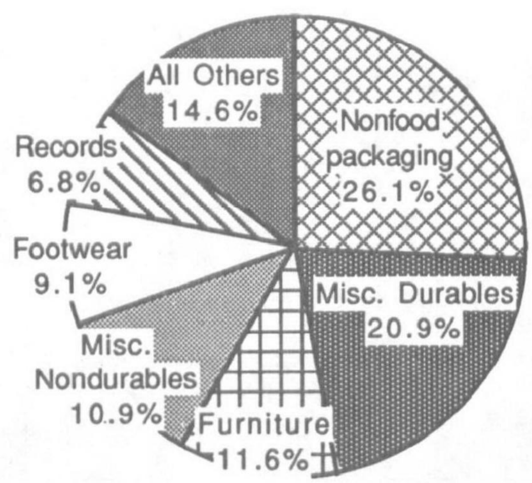


Table 2-40

END USES OF RUBBER THAT MAY CONTAIN LEAD AND/OR CADMIUM

Tires	Tank Linings
Inner tubes	High-voltage insulators
Cable coverings	Hose
Seals	Converyor belts and belting
Automotive radiator and heating hosing	Gaskets
Footwear	Flexible bellows
Vehicle suspension and body supports	Piers and boat bumpers
Bridge bearings	Springs
Vibration insulators	Packaging
"O" rings	Rubber-coated fabric
Sealants	Mats and matting
Jar rings	Flooring
Miscellaneous sporting goods	Miscellaneous sundries

1. Imports and exports of rubber tires were accounted for using data from the previous EPA MSW characterization study (20). This includes tires on imported cars.

2. Manufacturing losses of 3 percent for tire manufacture and 5 percent for manufacture of other rubber products were taken from the MSW characterization study (20).

3. Lead removed from the waste stream by the diversion of rubber by tire wear was estimated using data from the MSW characterization study (20).

4. Lead removed from the waste stream by recycling of rubber tires was estimated using data from the MSW characterization study (20).

5. Tires and other rubber products were assumed to be discarded two years after manufacture.

6. Projections were made based on past trends.

The results of these estimates are shown in Table 2-43 (tires and tire products), Tables 2-44 and 2-45 (nontire products), and Table 2-46 (gross discards, recovery, and net discards of lead in rubber products going to MSW). Figure 2-15 illustrates that the trend of discards of lead in rubber is expected to remain flat.

Table 2-41

LEAD CONSUMPTION AS A PIGMENT IN VARIOUS RUBBER PRODUCTS, 1968 TO 2000 1/
(In short tons)

Year	Lead in Tire Pigments	Lead in Footwear Pigments	Lead in Hose and Belting Pigments	Lead in Fabricated Products Pigments	Total Rubber Pigments
1968	45	2	6	50	103
1969	45	2	6	50	103
1970	45	2	6	50	103
1971	47	2	6	47	102
1972	47	2	6	47	102
1973	42	2	6	45	95
1974	48	2	6	46	102
1975	41	2	6	47	96
1976	59	3	10	75	147
1977	75	3	10	81	169
1978	77	4	13	102	196
1979	54	3	9	72	75
1980	35	2	6	45	78
1981	43	2	7	55	105
1982	39	2	6	50	97
1983	43	2	7	55	107
1984	47	3	8	60	118
1985	55	3	9	70	131
1986	51	3	8	65	127
1990	52	3	9	71	135
1995	52	3	9	71	135
2000	52	3	9	71	135

1/ From Department of Commerce and U.S. EPA reports (References 51 and 69). 1968-69 and projections by Franklin Associates, Ltd.

Table 2-42

LEAD CONSUMPTION IN THE RUBBER INDUSTRY, 1970 TO 2000
(In short tons)

Year	Lead Consumed by Rubber Industry 1/	Lead Consumed As a Pigment 2/	Lead Consumed by Rubber Industry (other than pigments) 3/
1970	1,200	103	1,097
1971	1,200	102	1,098
1972	1,212	102	1,110
1973	1,102	95	1,007
1974	1,212	102	1,110
1975	1,102	96	1,006
1976	1,653	147	1,506
1977	1,984	169	1,815
1978	2,204	196	2,008
1979	1,543	75	1,468
1980	992	78	914
1981	1,212	105	1,107
1982	1,102	97	1,005
1983	1,212	107	1,105
1984	1,322	118	1,204
1985	1,543	131	1,412
1986	1,433	127	1,306
1990	1,500	135	1,365
1995	1,500	135	1,365
2000	1,500	135	1,365

1/ Department of Commerce (Reference 51).
2/ From Table 2-41.
3/ By difference. Assumed not to enter MSW.

Table 2-43

CONSUMPTION OF LEAD IN TIRES AND TIRE PRODUCTS, 1968 TO 1998
(In short tons and percent)

Year	Domestic Consumption of Lead in Pigments for Tires and Tire Products 1/	Manufacturing Losses at 3 Percent 2/	Net Domestic Consumption of Lead in Pigments for Tires and Tire Products 3/	Adjustment for Imports/ Exports 4/	Adjusted Consumption of Lead in Pigments for Tires and Tire Products 5/
1968	45	1	44	1.03	45
1969	45	1	44	1.04	46
1970	45	1	44	1.07	47
1971	47	1	46	1.08	49
1972	47	1	46	1.10	50
1973	42	1	41	1.08	44
1974	48	1	47	1.15	53
1975	41	1	40	1.31	52
1976	59	2	57	1.04	59
1977	75	2	73	1.11	81
1978	77	2	75	1.11	83
1979	54	2	52	1.12	59
1980	35	1	34	1.12	38
1981	43	1	42	1.13	47
1982	39	1	38	1.17	44
1983	43	1	42	1.19	50
1984	47	1	46	1.23	56
1985	55	2	53	1.28	68
1986	51	2	49	1.32	65
1988	52	2	50	1.27	64
1993	52	2	50	1.31	66
1998	52	2	50	1.35	68

1/ 1972-1986: U.S. Department of Commerce (Reference 51). (1985 and 1986 are preliminary.) 1968-1971 and projections estimated by Franklin Associates, Ltd.
2/ Franklin Associates, Ltd. (Reference 20).
3/ Domestic consumption - converting losses.
4/ Derived from Reference 20.
5/ Net domestic consumption x adjustment factor.

Table 2-44

CONSUMPTION OF LEAD IN NONTIRE PRODUCTS ENTERING MSW, 1968 TO 1998
(In short tons)

Year	Lead in Hose and Bolting Pigments 1/	Lead in Hose and Belting Pigments Entering MSW 2/	Lead in Fabricated Products Pigments 1/	Lead in Fabricated Products Pigments Entering MSW 3/	Lead in Footwear Pigments 1/	Lead in Nontire Products Entering MSW 4/
1968	6	3	50	12	2	17
1969	6	3	50	12	2	17
1970	6	3	50	12	2	17
1971	6	3	47	12	2	17
1972	6	3	47	12	2	17
1973	6	3	45	11	2	16
1974	6	3	46	11	2	16
1975	6	3	47	12	2	17
1976	10	5	75	19	3	27
1977	10	5	81	20	3	28
1978	13	6	102	25	4	35
1979	9	4	72	18	3	25
1980	6	3	45	11	2	16
1981	7	3	55	14	2	19
1982	6	3	50	12	2	17
1983	7	3	55	14	2	19
1984	8	4	60	15	3	22
1985	9	4	70	17	3	24
1986	8	4	65	16	3	23
1988	9	4	71	18	3	25
1993	9	4	71	18	3	25
1998	9	4	71	18	3	25

Projections estimated by Franklin Associates, Ltd.

1/ From Table 2-41. All lead in footwear pigments assumed to enter MSW.
2/ Estimated to be 50 percent of total by Franklin Associates, Ltd.
3/ Estimated to be 25 percent of total by Franklin Associates, Ltd.
4/ Sum of lead in hose and belting pigments entering MSW, fabricated products entering MSW, and footwear pigments.

Table 2-45

NET CONSUMPTION OF LEAD IN NONTIRE PRODUCTS, 1968 TO 1998
(In short tons)

Year	Domestic Consumption of Lead Pigments for Nontire Products 1/	Manufacturing Losses at 5 Percent 2/	Net Domestic Consumption of Lead Pigments in Nontire Products 3/
1968	17	1	16
1969	17	1	16
1970	17	1	16
1971	17	1	16
1972	17	1	16
1973	16	1	15
1974	16	1	15
1975	17	1	16
1976	27	1	26
1977	28	1	27
1978	35	2	35
1979	25	1	24
1980	16	1	15
1981	19	1	18
1982	17	1	16
1983	19	1	18
1984	22	1	21
1985	24	1	23
1986	23	1	22
1988	25	1	24
1993	25	1	24
1998	25	1	24

1/ From Table 2-44.
2/ Franklin Associates, Ltd. (Reference 20).
3/ Net domestic consumption = domestic consumption - manufacturing losses.

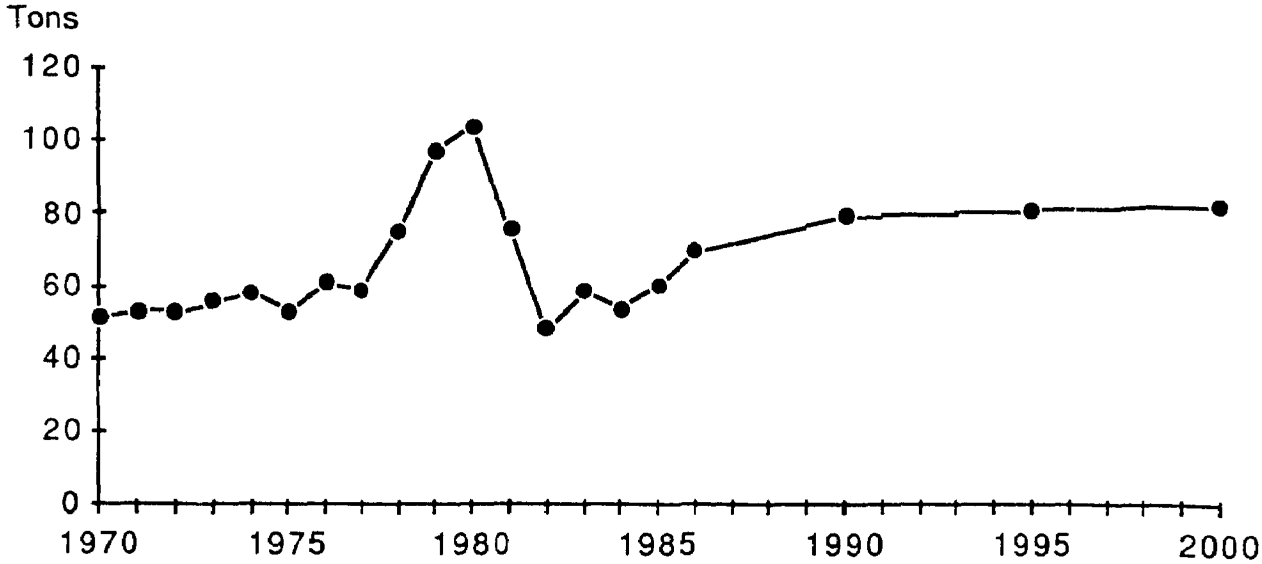
Table 2-46

GROSS DISCARDS, RECOVERY, AND NET DISCARDS OF LEAD IN RUBBER PRODUCTS, 1970 TO 2000
(In short tons and percent)

	Adjusted Discards of Lead							
Year	Pigments in Tires and Tire Products 1/	Adjustment Factor for Diversion 2/	Adjusted Pigments in Tires and Tire Products	Pigments in Nontire Products 3/	Total Gross Discards	Adjustment Factor for Recovery 2/	Recovery	Net Discards 4/
1970	45	0.07	42	16	58	0.15	6	52
1971	46	0.07	43	16	59	0.14	6	53
1972	47	0.10	43	16	59	0.14	6	53
1973	49	0.10	44	16	60	0.11	5	55
1974	50	0.08	46	16	62	0.09	4	58
1975	44	0.07	41	15	56	0.08	3	53
1976	53	0.07	49	15	64	0.07	4	61
1977	52	0.09	47	16	63	0.09	4	59
1978	59	0.08	54	26	80	0.09	5	75
1979	81	0.07	75	27	102	0.07	5	97
1980	83	0.09	75	33	108	0.06	5	104
1981	59	0.07	55	24	79	0.06	3	75
1982	38	0.07	36	15	51	0.06	2	48
1983	47	0.07	44	18	62	0.08	4	58
1984	44	0.07	41	16	57	0.09	3	54
1985	50	0.09	46	18	64	0.08	4	60
1986	56	0.08	51	21	72	0.05	3	70
1990	64	0.08	59	24	83	0.07	4	79
1995	66	0.08	61	24	85	0.07	4	81
2000	68	0.08	63	24	87	0.07	4	82

1/ From Table 2-43. Consumption is assumed to be discarded two years later.
2/ Derived from Reference 20. Applies to tires only.
3/ From Table 2-45. Consumption is assumed to be discarded two years later.
4/ Gross discards - recovery.

Figure 2-15. Discards of lead in pigments in rubber products, 1970 to 2000.



USED OIL

Used oil is generated from many sources, including automotive lubricating oils, industrial lubricating oils, and other uses. The most likely source of used oils in MSW is oil discarded by do-it-yourself (DIY) oil changers and very small quantity generators such as small industry automobile fleets and service stations. A 1983 technical background study for EPA estimated that about 24 percent of used oil was disposed or dumped by this type of generator (69).

Used oil can be a problem because it is contaminated by the breakdown of the additive package and by sources such as metal particles from engine wear, incomplete products of gasoline combustion, etc. An extensive EPA test program in the early 1980s showed median concentrations of 240 parts per million of lead and 3 parts per million of cadmium (69). The primary source of lead in used automotive oil is lead in gasoline additives; this quantity has been decreasing since the phaseout of lead permitted in gasoline began in 1970.

Discards of lead in used oil discarded in MSW were estimated using the following adjustments and assumptions:

1. Discards of used oil into MSW were assumed to remain at 24 percent of total used oil; this is probably high, since some is dumped on the ground or into the sewers rather than put into MSW.

2. It was assumed that used oil generated is proportional to gasoline sales.

3. It was assumed that lead in used oil is proportional to lead in gasoline. Use of lead in gasoline additives is reported on an annual basis by the Bureau of Mines (8).

4. While large amounts of used oil are reused and recycled, no additional recycling was assumed, since the 24 percent assumed to go to MSW is by definition not recycled.

5. The used oil was assumed to be discarded in the same year that the lead in gasoline additives was consumed.

6. Lead in used oil is projected to continue to decline because of the phaseout of lead in gasoline additives and the eventual removal from use of automobiles using leaded gasoline. Lead in used oil will not go to zero, however, because there are other sources of lead, such as engine wear.

The estimated discards of lead in used oil in MSW are summarized in Table 2-47 and Figure 2-16.

Table 2-47

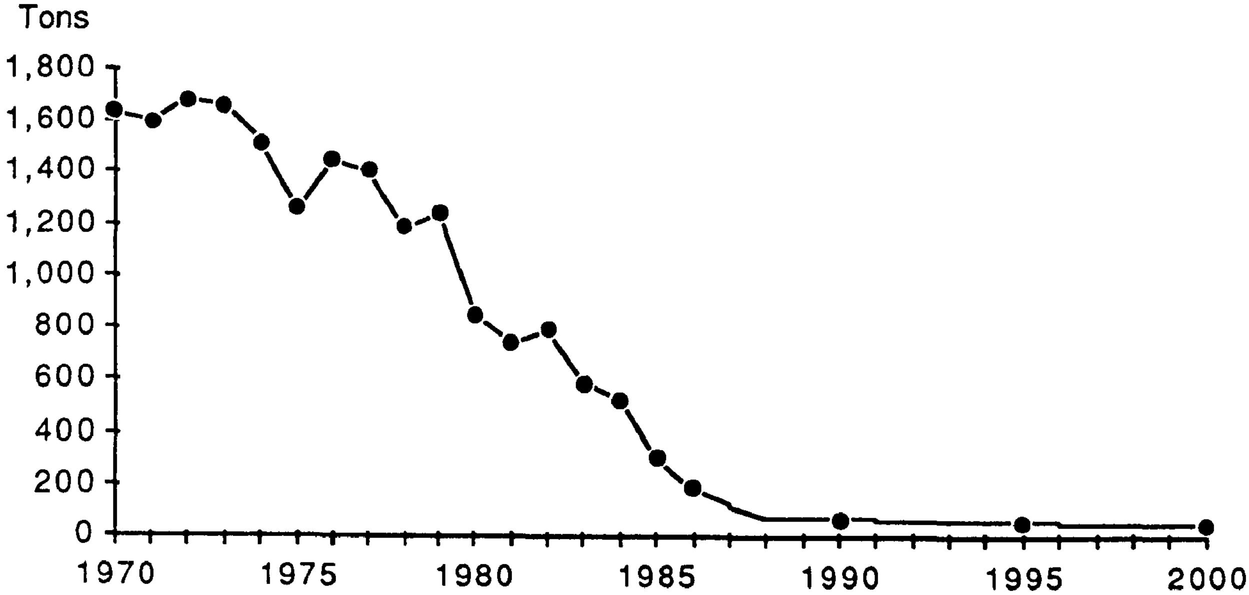
DISCARDS OF LEAD IN USED OIL IN MSW, 1970 TO 2000

Year	Estimated Used Oil in MSW (million gallons) 1/	Estimated Used Oil in MSW (tons) 2/	Average Lead in Used Oil (ppm) 3/	Net MSW Discards of Lead (tons)
1970	142	556,257	2,889	1,636
1971	149	594,760	2,686	1,598
1972	159	634,031	2,655	1,683
1973	166	662,534	2,504	1,659
1974	161	645,432	2,347	1,515
1975	165	661,900	1,606	1,261
1976	174	696,104	2,083	1,450
1977	179	716,372	1,966	1,408
1978	185	739,808	1,607	1,189
1979	178	713,839	1,746	1,246
1980	168	673,935	1,265	853
1981	165	660,000	1,125	742
1982	163	650,499	1,222	795
1983	165	660,000	900	594
1984	168	673,301	781	526
1985	172	689,770	442	305
1986	177	708,772	268	190
1987	178	712,572	170	121
1988	176	702,438	105	74
1990	171	684,069	102	70
1995	159	637,198	95	60
2000	157	628,964	77	48

1/ Based on gasoline sales (Reference 70) and information in Reference 69.
2/ Assumes 8 pounds per gallon.
3/ Based on consumption of lead in gasoline additives from the Bureau of Mines (Reference 8), and information in Reference 69.

Projections estimated by Franklin Associates, Ltd.

Figure 2-16. Discards of lead in used oil in MSW, 1970 to 2000.



MISCELLANEOUS PRODUCTS

The Bureau of Mines reports uses of lead in "Other Metal Products," which include lead foil; collapsible tubes; lead used in annealing, galvanizing, and plating; and ballast and weights (8). Only lead foil and collapsible tubes were identified as entering MSW in appreciable quantities. The Bureau of Mines reported these items as separate categories through 1977.

Lead Foil

Lead foil has three major applications:

1. as shielding for radioactive materials
2. as wrappers for some wine bottle corks
3. in paper-insulated filter capacitors.

Only wine bottle wrappers were considered to be discarded into MSW. Very little data were available on this application, but estimates of discards were made using the following assumptions and adjustments:

1. Lead foil wine wrappers constitute 10 percent of domestic lead foil consumption.

2. An adjustment was made for lead foil on imported wine bottles, assuming all have foil wrappers, which is not true, but a high percentage appear to have the wraps (71).

3. Manufacturing losses would be negligible.

4. There is no recycling of foil wrappers from MSW.

5. The wrappers are discarded in the same year that they are produced.

6. Projections were made assuming a continuing decline in use of lead foil wrappers.

The results of these estimates are shown in Table 2-48 and Figure 2-17. Using the assumptions above, use of lead foil in wine wrappers parallels the declining domestic consumption of total lead foil. The ratio of imported wine to domestic wine generally increased each year until 1982, but this ratio has since declined. Use of lead foil in wine wrappers is thus projected to continue to decrease.

Collapsible Tubes

Collapsible tubes made of lead are used for artists' colors and for highly-corrosive adhesives and glues. As reported by the Bureau of Mines (8), consumption of lead in collapsible tubes reached a peak in 1969 and has since declined. Franklin Associates estimated consumption after 1977 using

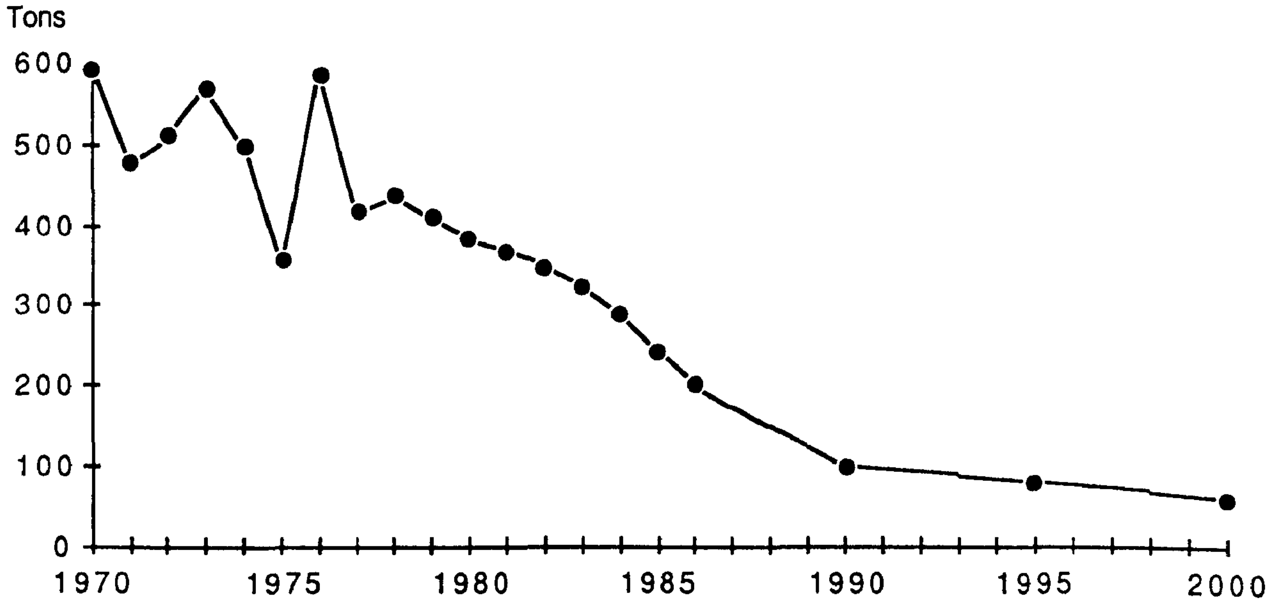
Table 2-48

DISCARDS OF LEAD IN FOIL IN MSW, 1969 TO 2000
(In short tons)

Year	Domestic Consumption of Lead in Foil 1/	Domestic Lead in Foil Wine Wraps Entering MSW 2/	Ratio of Net Wine Imports to Domestic 3/	Increase in Foil Wine Wraps Due to Imports 4	Adjusted Discards of Lead in Foil Wine Wraps 5/
1969	5,881	588	0.05	29	618
1970	5,521	552	0.07	39	591
1971	4,417	442	0.08	35	477
1972	4,592	459	0.11	51	510
1973	4,985	499	0.14	70	568
1974	4,404	440	0.13	57	498
1975	3,205	321	0.11	35	356
1976	5,126	513	0.14	72	584
1977	3,568	357	0.17	61	417
1978	3,546	355	0.23	82	436
1979	3,328	333	0.23	77	409
1980	3,111	311	0.23	72	383
1981	2,893	289	0.27	78	367
1982	2,676	268	0.30	80	348
1983	2,458	246	0.31	76	322
1984	2,241	224	0.28	63	287
1985	2,023	202	0.20	40	243
1986	1,806	181	0.12	22	202
1990					100
1995					80
2000					60

1/ Bureau of Mines (Reference 8).
2/ Assumed to be 10 percent of total.
3/ Derived from information in Reference 20.
4/ Import ratio x domestic lead foil use.
5/ Domestic lead foil use plus adjustment for imports.

Figure 2-17. Discards of lead foil in wine wrappers, 1970 to 2000.



some information from the Department of Commerce (51) The decline in use of lead in collapsible tubes is attributed to increasing use of aluminum for this purpose (72).

Discards of lead in collapsible tubes were estimated using the following assumptions:

1. No evidence was found of imports or exports of lead in collapsible tubes.

2. Manufacturing losses were assumed to be negligible.

3. The lifetime of lead tubes before discard was assumed to be two years.

4. Discards were projected to continue to decline.

These estimates of discards of lead in collapsible tubes are shown in Table 2-49 and Figure 2-18.

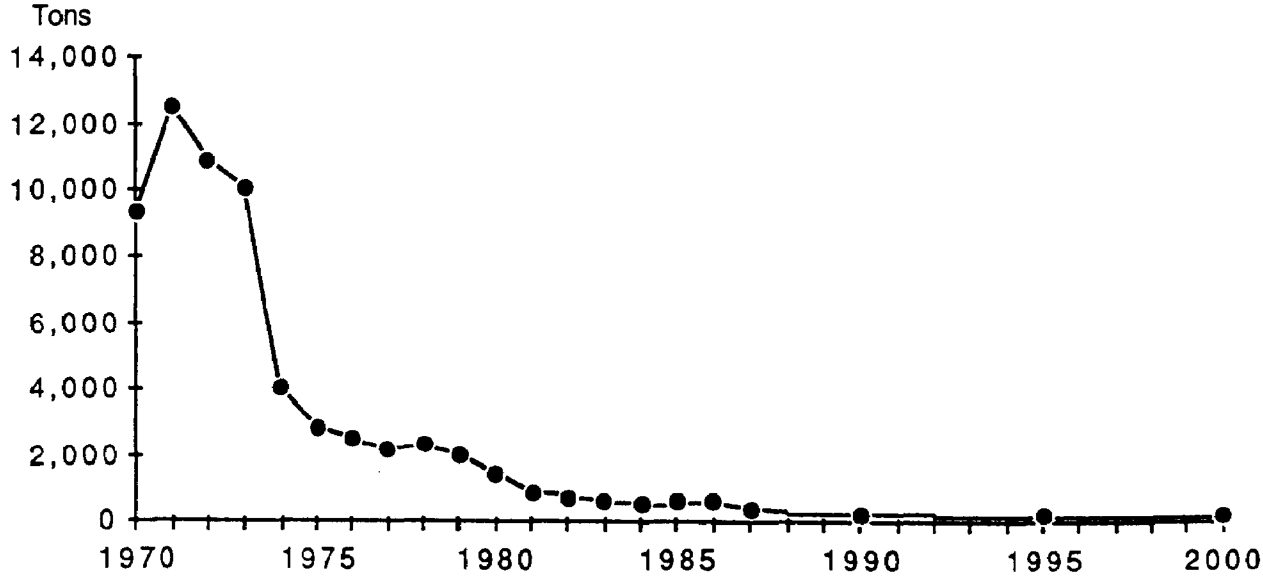
Table 2-49

DISCARDS OF LEAD IN COLLAPSIBLE TUBES IN MSW, 1970 TO 2000
(In short tons)

Year	Discards of Lead in Collapsible Tubes
1970	9,310
1971	12,484
1972	10,913
1973	10,041
1974	4,020
1975	2,860
1976	2,488
1977	2,216
1978	2,329
1979	2,054
1980	1,477
1981	900
1982	757
1983	613
1984	548
1985	607
1986	639
1990	240
1995	220
2000	200

Source: 1970-1977: Bureau of Mines (Reference 8). Assumes a two-year time lag before disposal.
1978-2000: Estimated by Franklin Associates, Ltd. based on Reference 51.

Figure 2-18. Discards of lead in collapsible tubes, 1970 to 2000.



Chapter 2

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Chapter 3

CADMIUM IN MUNICIPAL SOLID WASTE

BACKGROUND*

Cadmium is a relatively rare metal that has some unique characteristics that make it useful in a variety of products. It is silvery-white in color and is soft, ductile, and easily worked. It has good electrical and thermal conductivity. When exposed to moist air, cadmium oxidizes slowly to form a thin coating of cadmium oxide, which protects the metal from further corrosion.

Cadmium usually occurs as the mineral greenockite (CdS). It is usually mined in association with zinc, but sometimes with lead and copper ores. It is almost never found alone in economical quantities. Secondary (recycled) cadmium production is of minor significance in the United States. Unlike lead, which has been used since ancient times, cadmium has been refined and utilized relatively recently.

CADMIUM COMPOUNDS**

Some of the commonly-used compounds of cadmium are discussed in this section.

Cadmium Oxide (CdO) has many uses, often in the preparation of cadmium products. It is used in processes in the manufacture of nickel-cadmium batteries, stabilizers for PVC, glass, phosphors, semiconductors, electroplating, and ceramic glazes, among other uses.

Cadmium Sulfide (CdS) is the most widely used cadmium compound. It is also called cadmium yellow, and is used in red and yellow pigments, in phosphors, as a photoconductor, and other uses.

Cadmium Hydroxide (CdH_2O_2) is used mainly as the active material in the negative electrodes of nickel-cadmium batteries.

Cadmium Chloride ($CdCl_2$) is used in the manufacture of nickel-cadmium batteries. It is also used as a pigment in dyeing and calico printing and in phosphors.

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* Ullmann's Encyclopedia of Industrial Chemistry (Reference 1).

** This section is based on References 2, 3, and 4.

Cadmium Nitrate (CdN_2O_6) is used in the manufacture of nickel-cadmium batteries.

Cadmium Sulfate (CdO_4S) is used in the manufacture of nickel-cadmium batteries.

Cadmium Carboxcylates are incorporated in stabilizers for polyvinyl chloride (PVC).

Cadmium Acetate ($C_4H_6CdO_4$) is used for iridescent effects on pottery and porcelain and in electroplating.

Cadmium Fluoride (CdF_2) is used in the manufacture of phosphors and glass.

Cadmium Selenide (CdSe) is used in photoconductors, semiconductors, and phosphors.

Cadmium Telluride (CdTe) is used in phosphors and semiconductors.

Cadmium Salts are used as light stabilizers in plastics; cadmium/barium salts are used as heat stabilizers in plastics.

USE OF CADMIUM IN PRODUCTS

Consumption of cadmium by end use is reported by the Bureau of Mines (5). The end use categories are more limited that those reported for lead, however. The categories reported annually include: coating and plating, batteries, pigments, plastics stabilizers, and other (including alloys). Products in each of these categories enter the municipal waste stream.

While consumption of lead in the U.S. was over 1.2 million tons in 1986, consumption of cadmium was a relatively small 4,800 tons. Overall, the domestic consumption of cadmium in the U.S. declined until 1983, but it has increased since then. In percentage and tonnage, coating and plating and plastic stabilizers have declined since 1970. Use of cadmium in pigments grew in the early 1970s, but has remained about stable since 1975. Domestic use of cadmium in nickel-cadmium (Ni-Cd) batteries has been significant, although the tonnage has been fairly stable since 1976.

The remainder of this chapter is devoted to discussion and quantification of cadmium in products discarded into municipal solid waste.

APPLIANCES

A relatively small amount of cadmium plating is found in dishwashers and washing machines that were made some years ago. Cadmium plating of steel offers good resistance to corrosion, and thus it had application for coating nuts, bolts, and screws that were exposed to detergents, alkalis, and water. As more plastics are used in these appliances, the need for cadmium plating has decreased. There is a time lag, of course, in the discards of appliances, and thus cadmium from these applications continues to appear in the waste stream years after consumption in manufacture has declined.

Cadmium plating is still used in numerous applications by the automotive, aerospace, and military markets, but these are not defined as generators of MSW.

Discards of cadmium plating in appliances were estimated using the following adjustments and assumptions:

1. No adjustment for imports or exports was made, since there is only minor import/export activity for these appliances (6).

2. Manufacturing losses were assumed to be 10 percent based on information from a trade association (7).

3. An adjustment was made for removal of cadmium plating from the waste stream when ferrous metals from the appliances are recovered.

4. The lifetime of these appliances was assumed to be eight years based on the previous EPA MSW characterization study (6).

5. Discards of cadmium in plated parts in appliances were projected to continue to decrease.

Estimated discards of cadmium in appliances are shown in Tables 3-1 and 3-2 and Figure 3-1.

CONSUMER ELECTRONICS

In the past, cadmium was used to plate radio and television chassis (the square steel sheet used to hold all of the electronic parts together). Cadmium-plated chassis were used in about half of the televisions produced during the 1970s, but by 1980 the technology had advanced to the point that the steel chassis was no longer used (9)(10). The present chassis is a printed circuit board made of resin (11). Because televisions and radios are not discarded for some years after they are purchased, cadmium plating from this source is still discarded into MSW.

Estimates of cadmium-plated radio and television chassis were made using the following adjustments and assumptions:

1. Adjustments for imports and exports were made based on data from the U. S. Department of Commerce (12).

2. Manufacturing losses were assumed to be 10 percent based on information from a trade association (7).

Table 3-1

CADMIUM CONSUMPTION IN PLATED PARTS FOR DISHWASHERS AND WASHING MACHINES, 1962 TO 1992
(In short tons)

Year	Domestic Consumption in Plated Parts 1/	Manufacturing Losses 2/	Net Domestic Consumption in Plated Parts
1962	53	5	48
1963	51	5	46
1964	50	5	45
1965	48	5	43
1966	47	5	42
1967	45	5	40
1968	44	4	40
1969	42	4	38
1970	41	4	37
1971	39	4	35
1972	38	4	34
1973	46	5	41
1974	33	3	30
1975	33	3	30
1976	32	3	29
1977	30	3	27
1978	29	3	26
1979	30	3	27
1980	26	3	23
1981	24	2	22
1982	23	2	21
1983	21	2	19
1984	20	2	18
1985	18	2	16
1986	17	2	15
1987	15	2	13
1992	11	1	10

1/ Estimated by Franklin Associates, Ltd. using data from the U.S. Department of Commerce (Reference 8).
2/ Assumed to be 10 percent based on Reference 7.

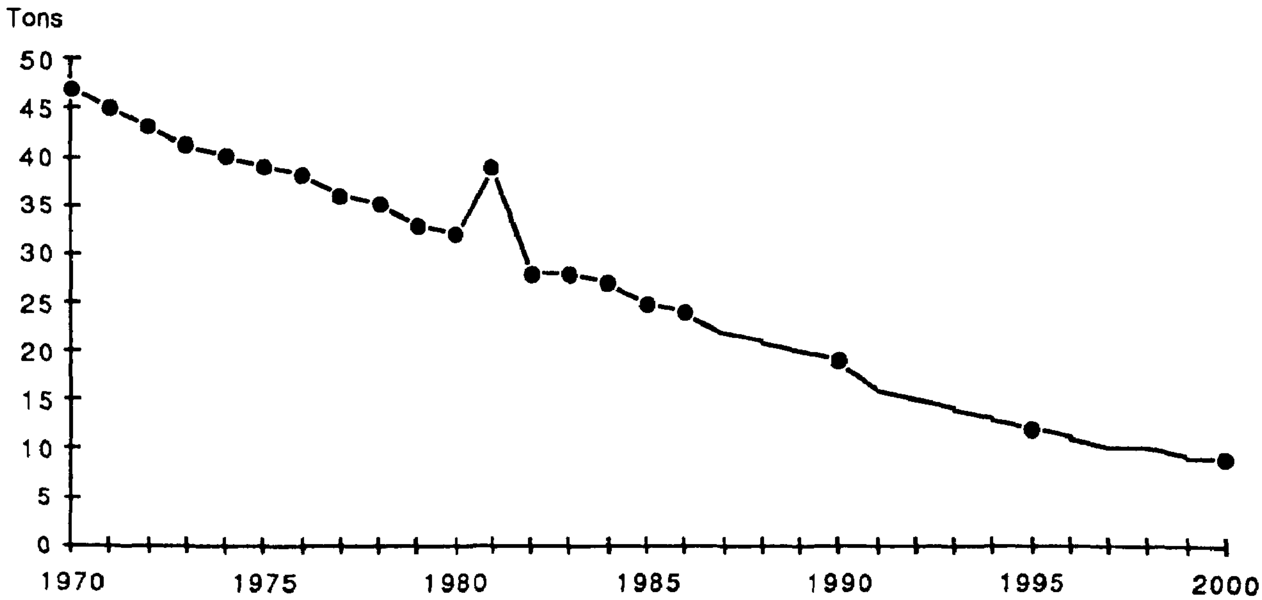
Table 3-2

DISCARDS OF CADMIUM PLATED PARTS FOR DISHWASHERS AND WASHING MACHINES, 1970 TO 2000
(In short tons)

Year	Gross Discards of Cadmium in Plated Parts 1/	Recovery of Cadmium in Plated Ferrous Parts 2/	Net Discards of Cadmium in Plated Parts
1970	48	1	47
1971	46	1	45
1972	45	2	43
1973	43	2	41
1974	42	2	40
1975	40	1	39
1976	40	2	38
1977	38	2	36
1978	37	2	35
1979	35	2	33
1980	34	2	32
1981	41	2	39
1982	30	2	28
1983	30	2	28
1984	29	2	27
1985	27	2	25
1986	26	2	24
1990	21	2	19
1995	14	2	12
2000	10	1	9

1/ From Table 3-1 using an average 8-year time lag (Reference 6).
2/ Derived from data in MSW Characterization Study (Reference 6).

Figure 3-1. Discards of cadmium in plated parts for dishwashers and washing machines, 1970 to 2000.



3. It was assumed that there is no recycling of radios and television sets (11).

4. The lifetime of radios and televisions was assumed to be eight years (13).

5. Projections were made based on past trends.

The results of these estimates are shown in Tables 3-3 and 3-4 and Figure 3-2.

Cadmium also is a component of plastics used in consumer electronics; these are discussed and quantified in the section on Plastics.

GLASS AND CERAMICS

Cadmium pigments are not used as extensively as they once were in glass, but are used in three ways: as a colorant in the glass itself, as a glaze for glass and ceramic products, and as a phosphor. It was not possible to quantify cadmium pigment use in any specific glass or ceramic product, but products that may contain cadmium were identified. It was assumed that the cadmium used in glass and ceramics is in the form of pigments and not in the form of metal.

Use of Cadmium in Glass and Ceramics

Cadmium sulfide (CdS) is a common base for cadmium pigments. The cadmium sulfide pigments include pure cadmium sulfides, various blends of cadmium sulfides with other metal sulfides (zincs), and with cadmium selenide (CdSe). Extensions of these pigments with barium sulfate ($BaSO_4$) extender pigments yield pigments called lithopones.

Cadmium oxide (CdO) can be added to glass to change its physical and optical properties, such as decreasing the thermal expansion coefficient and decreasing the tendency for crystallization. A more common use is to maintain the color of a cadmium pigment, for example, to maintain the red color of the cadmium sulfur-selenium pigments in signal glass. Cadmium oxide is also added for pigment production in the manufacture of yellow-colored light bulbs, where cadmium sulfide is used for the yellow pigmentation.

Glass or Ceramic Products Containing Cadmium that Enter MSW

Glass and ceramic products that may contain cadmium are shown in Table 3-5. Glass products containing cadmium that are likely to enter MSW include yellow-colored glass, such as yellow light bulbs, and some solders.

Cadmium sulfur-selenide pigments, which are a solid solution of cadmium selenide, cadmium sulfide, and zinc sulfide, are sometimes used in glazes for glass or ceramics. These pigments can make a range of colors from light yellow to dark maroon. They may be used on products such as ceramic dishes and pottery, glass soft drink containers, glass imported beer bottles, and glass cosmetic bottles, all of which are commonly discarded into MSW.

Table 3-3

CADMIUM CONSUMPTION IN PLATED PARTS
FOR RADIOS AND TVs, 1962 TO 1992
(In short tons)

Year	Domestic Cadmium Consumption in Radios and TVs 1/	Manufacturing Losses 2/	Adjustment for Imports/ Exports 3/	Net Consumption 4/
1962	218	22	375	571
1963	200	20	328	508
1964	180	18	279	441
1965	156	16	203	343
1966	141	14	181	308
1967	125	13	218	330
1968	108	11	194	291
1969	95	10	229	314
1970	76	8	216	284
1971	63	6	216	273
1972	44	4	136	176
1973	40	4	97	133
1974	30	3	116	143
1975	29	3	103	129
1976	29	3	124	150
1977	29	3	132	158
1978	28	3	136	161
1979	28	3	105	130
1980	26	3	72	95
1981	24	2	81	103
1982	22	2	81	101
1983	19	2	96	113
1984	18	2	61	77
1985	16	2	58	72
1986	14	1	55	68
1987	13	1	55	67
1992	9	1	12	20

1/ Based on data from References 8 and 14.
2/ 10 percent loss (Reference 7).
3/ Derived from import and export data (Reference 12).
4/ Net consumption = domestic consumption - manufacturing losses + import/export adjustment.

Table 3-4

CADMIUM DISCARDS IN PLATED PARTS FOR RADIOS AND TVs, 1970 TO 2000
(In short tons)

Year	Discards of Cadmium 1/
1970	571
1971	508
1972	441
1973	343
1974	308
1975	330
1976	291
1977	314
1978	284
1979	273
1980	176
1981	133
1982	143
1983	129
1984	150
1985	158
1986	161
1990	101
1995	67
2000	20

1/ From Table 3-3 using an 8-year lifetime of products (13).

Figure 3-2. Discards of cadmium in plated parts for radios and TVs, 1970 to 2000.

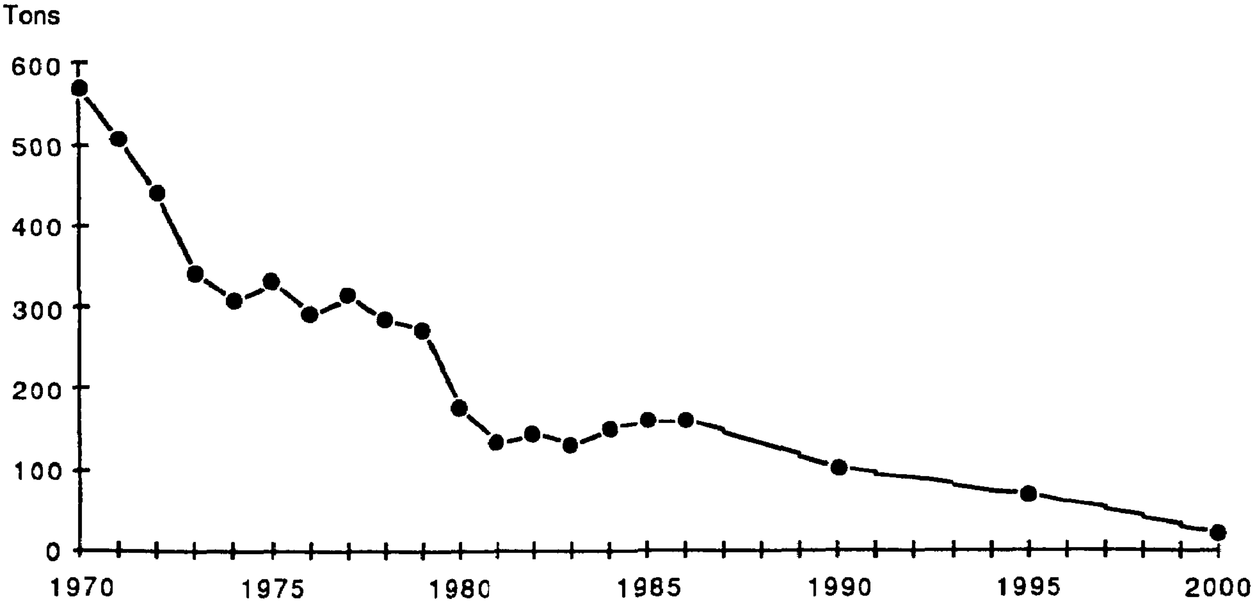


Table 3-5

GLASS AND CERAMIC PRODUCTS CONTAINING CADMIUM PIGMENTS

GLASS PRODUCTS

- yellow-colored light bulbs
- red signal glass for automobile, air, and train signal lamps
- photochromic glass
- architectural window coatings
- metal sealing solders
- microsphere optics

RED, ORANGE, AND YELLOW GLAZES

- ceramic dishes and pottery
- glass soft drink bottles
- glass imported beer bottles
- glass cosmetic bottles for foundation, nail polish, and cologne

PHOSPHORS

- mercury-vapor lamps
- fluorescent tubes

Source: From References 15, 16, 17, and 18.

Cadmium sulfide pigments are used in fluorescent light tubes because they emit in the blue-green to red spectral region. These tubes are generally discarded into MSW.

Products Containing Cadmium That Do Not Enter MSW

Some of the end uses for glass and ceramics that contain cadmium do not enter the municipal waste stream. Architectural window coatings are an example of this category. Cadmium sulfide is also used as a phosphor coating on some mercury-vapor lamps, which are commonly used in non-MSW applications such as street lights.

Cadmium Discarded in Glass and Ceramics

Discards of cadmium in glass and ceramics were estimated in the section on Pigments, based on a statement that this use accounts for 8 percent of total cadmium pigment use (19). This is summarized in Table 3-6 and Figure 3-3. The estimates shown in Table 3-6 include an adjustment for a 6 percent manufacturing loss, based on Reference 20. It was assumed that 50 percent of the total discards enters MSW.

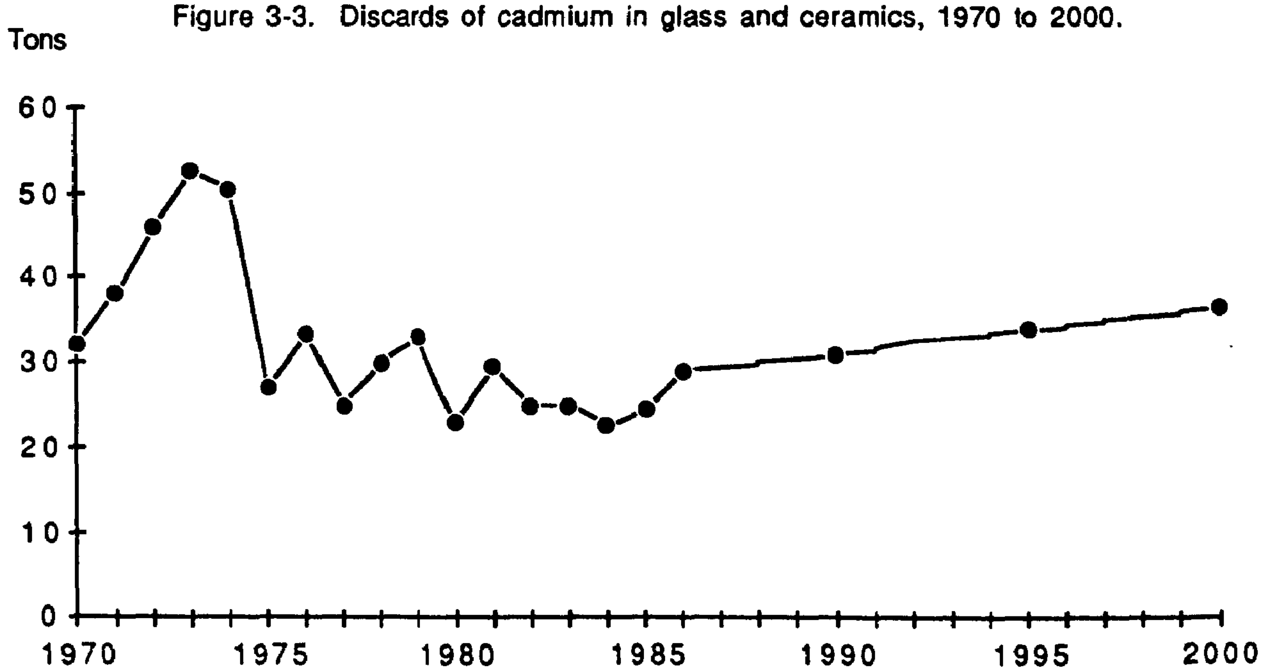
Table 3-6

DISCARDS OF CADMIUM IN GLASS AND CERAMICS, 1970 TO 2000
(In short tons)

Year	Cadmium Pigment Discards in Glass and Ceramics 1/	Cadmium Pigment Discards Into MSW 2/ 3/
1970	64	32
1971	76	38
1972	92	46
1973	105	53
1974	101	51
1975	54	27
1976	67	34
1977	50	25
1978	60	30
1979	66	33
1980	46	23
1981	59	30
1982	50	25
1983	50	25
1984	45	23
1985	49	25
1986	58	29
1990	63	32
1995	68	34
2000	73	37

1/ Estimated to be 8 percent of total cadmium pigment use (Reference 19). Franklin Associates assumes products discarded in the same year consumed.
2/ Franklin Associates, Ltd. estimates 50 percent of cadmium pigments used in glass and ceramics enters the MSW stream.
3/ Manufacturing losses estimated to be one percent and are negligible for this category.

Figure 3-3. Discards of cadmium in glass and ceramics, 1970 to 2000.



NICKEL-CADMIUM BATTERIES

There is a major market for batteries in the United States, with purchases of nearly three billion batteries yearly (21). There are two types of batteries: primary and secondary. Primary batteries, such as the traditional zinc-carbon household battery, are discarded when discharged. Secondary batteries are rechargeable. Examples of secondary batteries include lead-acid automotive batteries (see Chapter 2), and nickel-cadmium batteries.

Household batteries come in three basic shapes: cylinders, rectangles, and button-sized discs. There are hundreds of sizes; the most commonly-used are AA, AAA, C, D, and 9-volt. The size of the battery determines its lifetime, and products come designed to hold the most suitably-sized battery (21).

Types of Household Batteries

This section contains a brief discussion of the different types of household batteries, with a more detailed discussion of nickel-cadmium batteries, which are an important source of cadmium in municipal solid waste.

Carbon-zinc Batteries. These are known as general purpose and heavy-duty batteries. The carbon-zinc (or zinc-carbon) battery has been the traditional household battery, but it is being replaced by the alkaline battery (22). These batteries are relatively inexpensive, but lose their charge more quickly than other types (23).

Zinc is, of course, the primary metal in these batteries, ranging from 3 to 22 grams per battery (24). They also contain very small quantities of mercury, cadmium, and lead, in amounts between one and 50 milligrams per battery (24).

Alkaline Batteries. Alkaline-manganese batteries are the most commonly-used type in the United States today. They are more expensive than carbon-zinc batteries, but last longer (23). Zinc is the predominant metal in these batteries also; it is present in amounts between one and 24 grams per battery (24). They do contain small quantities of mercury (generally less than one gram per battery) and minute quantities of cadmium and lead (less than 10 milligrams per battery) (24).

Mercury Oxide Batteries. The mercury or mercuric oxide battery is a small button-sized battery containing 35 to 50 percent mercury (24)(25). These batteries are used for hearing aids, watches, pocket calculators, and the like.

These batteries contain zinc as well as mercury, but no appreciable quantities of lead or cadmium.

Silver Oxide Batteries. Silver oxide batteries come in the same sizes as mercury oxide batteries, and are used for the same purposes. They are gaining in popularity, whereas mercury batteries are less in demand (26). Silver oxide batteries contain mercury in the range of 0.5 to 1.0 percent (24)(25)(26), as well as zinc. They contain negligible amounts of cadmium and lead.

Zinc Air Batteries. Zinc air batteries also can substitute for mercury oxide batteries in hearing aids and similar applications, but they are more expensive. The governments of Denmark and Sweden intend to make this substitution (26). Zinc air batteries contain about 2 to 3 percent mercury as well as zinc (24)(26). They contain negligible amounts of cadmium and lead.

Lithium Batteries. Lithium batteries are a relatively new contender to replace the mercury battery (26), as well as alkaline or nickel-cadmium batteries for some applications, such as pacemakers, thin watches, hearing aids, and calculators. The lithium battery has a long life (perhaps up to 10 years), but is more expensive and is not yet marketed extensively (21)(23)(27)(28). These batteries contain zinc, but no mercury, cadmium, or lead.

Nickel-cadmium Batteries. Nickel-cadmium (Ni-Cd) batteries are a major consumer of cadmium in the United States, and are the focus of this section. Ni-Cd batteries were invented in the early 1900s, but were not used extensively until the mid-1940s, when they came into use in the military and industrial sectors. Ni-Cd batteries are secondary batteries (rechargeable).

In the early 1960s Ni-Cd batteries for consumer use were developed, but they did not gain real popularity until the early 1970s. Ni-Cd batteries are now used in many products: pocket calculators; toys; microprocessors; hand tools such as portable drills, flashlights, screwdrivers, hedge trimmers, and soldering irons; rechargeable appliances such as hand-held vacuums, mixers, can openers, VCRs, portable televisions, cameras, electric shavers, lawn mower engine starters, and alarm systems, to name some examples (27). Many consumer applications such as appliances have the Ni-Cd battery sealed in; the battery cannot be replaced by the owner.

New consumer uses for Ni-Cd batteries, such as portable lap computers and cellular telephones, are continually developed. Ni-Cd batteries are also competing with mercury batteries in hearing aids and pocket calculators (29) and with carbon-zinc and other primary batteries, because their initial higher cost can be offset as they are recharged (30).

Military and industrial uses of nickel-cadmium batteries include: railroad signaling, diesel locomotive starting, commercial and jet aircraft starting, satellites, missile guidance systems, naval signaling, television and camera lighting, portable hospital equipment, computer memories, pinball machines, and gasoline pumps. These uses were considered not to be discarded into MSW.

There are some variations on the nickel-cadmium battery. The silver-cadmium cell is costly and is used mainly in military and aerospace applications. Other uses include portable televisions, cameras, medical electronics, and instrumentation that demand high energy density and constant voltage (31). Mercury-cadmium batteries also have some limited applications, such as artillery fuses, missiles, and satellites (31). Cadmium consumption in silver-cadmium and mercury-cadmium batteries is not significant compared to the Ni-Cd battery (32).

Other competitors to the Ni-Cd battery include sealed lead-acid batteries (discussed in another section) and the lithium cell. A new nickel-zinc cell is also being developed (30), and a rechargeable metal hydride battery is reportedly being developed (33). Sales of these batteries are relatively insignificant at the present time.

Quantities of Cadmium Discarded in Batteries

Estimating the quantities of cadmium in batteries was difficult because reliable data on number of batteries sold were not available. Annual cadmium consumption in batteries as reported by the Bureau of Mines (5) was taken as the basic source. Estimates of cadmium discards in batteries were made using the following adjustments and assumptions:

1. It was assumed that all cadmium consumption in batteries is by Ni-Cd batteries, although very small amounts are used in other batteries, as discussed above.

2. An adjustment for imports and exports was made using Department of Commerce data (34). Imports of Ni-Cd batteries have been growing rapidly, from over 46 million in 1985 to over 88 million in 1987. It was assumed that the cadmium content of imported batteries is the same as those domestically produced.

3. Manufacturing losses were assumed to be 15 percent, based on information from industrial sources.

4. It was assumed that industrial and military uses account for 25 percent of cadmium consumption in batteries (24), and that these batteries are not discarded into MSW.

5. It was assumed that 80 percent of Ni-Cd batteries are sealed into a consumer product and are not replaceable (24)(35). The lifetime of these appliances (and batteries) was assumed to be four years (25)(30).

6. It was assumed that of the remaining 20 percent of Ni-Cd batteries, one half are no longer used within three months of purchase (25). The remaining one-half were assumed to be discarded in four years (25)(30).

7. It was assumed that there is no significant post-consumer recycling of Ni-Cd batteries, although some are received during household hazardous waste collections, and may be sent overseas for recycling (36).

8. Projections of cadmium discards in batteries were made assuming that Ni-Cd batteries will not be replaced by competitors.

The results of these estimates are summarized in Tables 3-7, 3-8, and 3-9, and Figure 3-4.

PIGMENTS

As discussed in Chapter 2 (Lead), pigments are intermediate products that become constituents in a wide variety of end products. Like lead, cadmium is found in many applications, although its use was once more diverse than it is today. It was not possible to quantify cadmium-containing pigments by end use, but this section contains a discussion of cadmium pigment compounds and their end uses. Finally, quantities of cadmium discarded in pigments in MSW are estimated.

Cadmium Pigment Compounds*

The major advantages of cadmium pigments include good alkali resistance, excellent heat resistance, an extensive range of colors, good hiding qualities, and ease of dispersability. Their disadvantages include poor tinting strength, poor weatherability, and acid sensitivity. Cadmium pigment compounds yield shades of yellow, orange, red, and maroon.

Cadmium sulfide (CdS) produces a golden-yellow pigment. Partial substitution of zinc or mercury for cadmium, and of sulfur for selenium, produces compounds for colors ranging from lemon-yellow to maroon. Extension of these pigments with barium sulfate ($BaSO_4$) extender pigments yields pigments called lithopones.

The majority of cadmium pigments (54 percent) are used to manufacture cadmium yellows (Figure 3-5) (37). Cadmium sulfoselenides are the next largest category at 29 percent, and mercadmiums constitute the remainder (17 percent).

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* Primary reference: Cadmium Council, Inc. (Reference 3).

Table 3-7

DOMESTIC CONSUMPTION OF CADMIUM IN BATTERIES, 1966 TO 2000
(In short tons)

Year	Domestic Consumption of Cadmium in Batteries 1/	Diversion to Military/ Industry 2/	Manufacturing Losses 3/	Total Losses	Net Domestic Consumption
1966	60 e	15	7	22	38
1967	189 e	47	21	68	142
1968	290 e	73	33	106	184
1969	390	98	44	142	248
1970	263	66	30	96	167
1971	308	77	35	112	196
1972	606	152	68	220	386
1973	772	193	87	280	492
1974	727	182	82	264	463
1975	540	135	61	196	344
1976	1,565	391	176	567	998
1977	1,113	278	125	403	710
1978	1,345	336	151	487	858
1979	1,488	372	167	539	949
1980	1,036	259	117	376	660
1981	1,301	325	146	471	830
1982	1,113	278	125	403	710
1983	1,125	281	127	408	717
1984	1,003	251	113	364	639
1985	1,107	277	125	401	706
1986	1,445 e	361	163	524	921
1988	1,488 e	372	167	539	949
1990	1,574 e	394	177	571	1,003
1991	1,617 e	404	182	586	1,031
1992	1,660 e	415	187	602	1,058
1995	1,789 e	447	201	648	1,141
1996	1,832 e	458	206	664	1,168
2000	2,004 e	501	225	726	1,278

1/ Bureau of Mines (Reference 5).
2/ 25% of cadmium consumption for nickel-cadmium batteries is other than consumer usage (Reference 24).
3/ Converting and manufacturing losses are 15%. Material does not re-enter process. Estimated by Franklin Associates, Ltd. based on industry sources.

e = Estimated by Franklin Associates, Ltd.

Table 3-8

CONSUMPTION OF CADMIUM IN BATTERIES FOR IMPORTS/EXPORTS, 1970 TO 2000
(In short tons)

Year	Net Domestic Consumption 1/	Cadmium Imported in Product 2/	Cadmium Exported in Product 2/	Adjusted Consumption
1970	167	NA	NA	167
1971	196	NA	NA	196
1972	386	NA	NA	386
1973	492	0 e	4 e	488
1974	463	0 e	8 e	455
1975	344	0 e	11 e	333
1976	998	36 e	15 e	1,019
1977	710	65 e	19 e	756
1978	858	87	23	919
1979	949	165	37	1,077
1980	660	178	46	792
1981	830	225	56	999
1982	710	222	43	889
1983	717	251	37	931
1984	639	358	54	943
1985	706	336	73	969
1986	893	450	75	1,268
1987	921	643	86	1,478
1988	949 e	674 e	92 e	1,531
1990	1,003 e	738 e	106 e	1,635
1991	1,031 e	767 e	113 e	1,685
1992	1,058 e	803 e	119 e	1,742
1995	1,141 e	931 e	139 e	1,933
1996	1,168 e	981 e	146 e	2,003
2000	1,278 e	1,180 e	173 e	2,285

1/ From Table 3-7.
2/ Based on U.S. Department of Commerce data (Reference 34).

e = Estimated by Franklin Associates, Ltd.

NA = Not available.

Table 3-9

DISCARDS OF CADMIUM IN NICKEL-CADMIUM BATTERIES, 1966 TO 2000
(In short tons)

Year	Adjusted Consumption 1/	Discarded in First Year (10 percent) 2/	Balance	Discarded in Four Years (90 percent) 3/	Discards of Cadmium in Batteries
1966	38	4	34	NA	4
1967	142	14	128	NA	14
1968	184	18	166	NA	18
1969	248	25	223	NA	25
1970	167	17	150	34	51
1971	196	20	176	128	148
1972	386	39	347	166	205
1973	488	49	439	223	272
1974	455	46	409	150	196
1975	333	33	300	176	209
1976	1,019	102	917	347	449
1977	756	76	680	439	515
1978	919	92	827	409	501
1979	1,077	108	969	300	408
1980	792	79	713	917	996
1981	999	100	899	680	780
1982	889	89	800	827	916
1983	931	93	838	969	1,062
1984	943	94	849	713	807
1985	969	97	872	899	996
1986	1,268	127	1,141	800	927
1987	1,478	148	1,330	838	986
1988	1,531	153	1,378	849	1,002
1990	1,635	164	1,471	1,114	1,305
1995	1,933	193	1,740	1,516	1,709
2000	2,285	229	2,056	1,803	2,032

1/ Consumption adjusted for imports/exports (Tables 3-7 and 3-8).
2/ 10% of all nickel-cadmium batteries are taken out of use by consumers in first year (Reference 25).
3/ 90% of all nickel-cadmium batteries will have a 4-year service life (Reference 25).

NA = Not Available.

Figure 3-4. Discards of cadmium in nickel-cadmium batteries, 1970 to 2000.

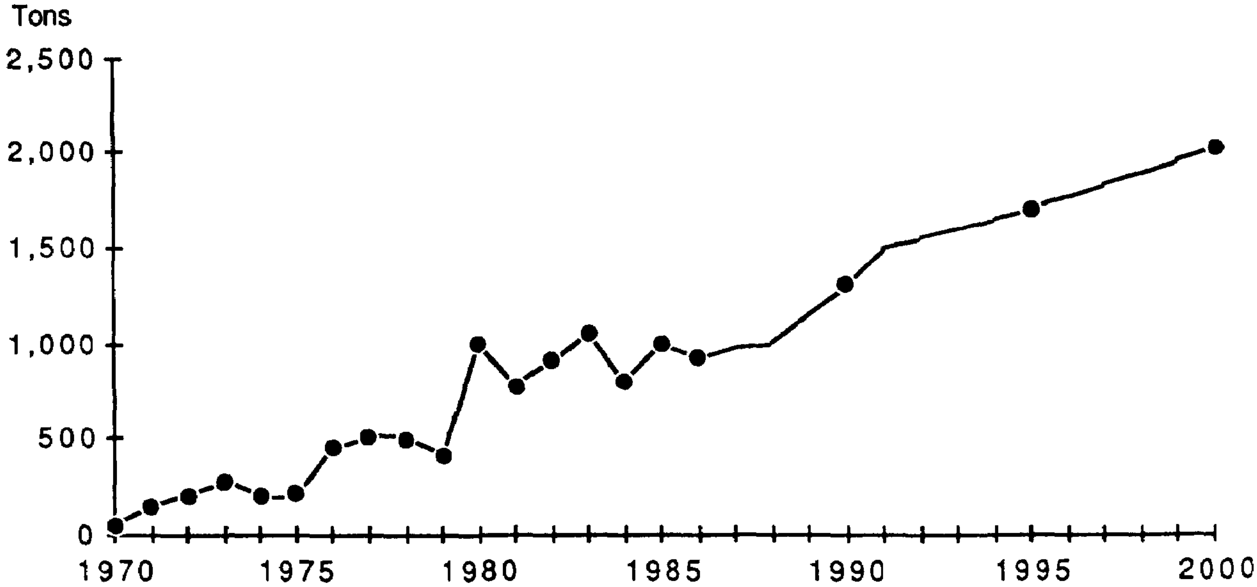
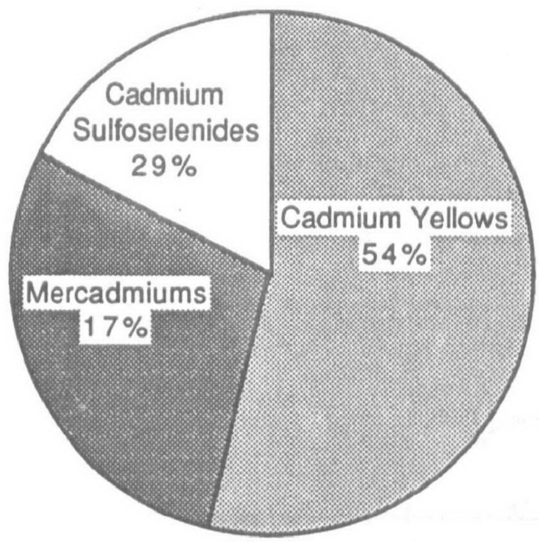


Figure 3-5. Cadmium pigment end uses by color compound.



End Uses of Pigments

Cadmium pigments find their greatest use in plastics. Ceramics, paints, and miscellaneous applications make up the remainder. Some specific applications are discussed below.

Paint. Extended cadmium pigments (lithopones) formerly were in common use for interior household paints, but their use has diminished. Red cadmium pigments are sometimes used in exterior architectural coatings. These uses are not considered to be discarded into MSW.

Printing Inks. Good data on cadmium use in printing inks were not available; the use of cadmium and other heavy metals in inks is discouraged by trade associations like the National Association of Printing Ink Manufacturers and the American Newspaper Publishers Association. Analyses of magazines and other color-printed materials in the 1970s did reveal the presence of cadmium in very small quantities of colored inks (38).

Textiles. Yellow pigments composed of cadmium sulfide, barium sulfate, and zinc sulfate are used in textile printing. The quantities used are very small, however, because of high costs and poor tinting capabilities. The same is true for cadmium orange or red pigments (cadmium sulfoselenide or mercadmium compounds).

Good data on quantities of cadmium pigments used in textile printing were not available, but the quantities are apparently very small.

Plastics. Plastics are the most important end use of cadmium pigments. These pigments disperse well in most polymers and give good color and high opacity and tinting strength. Cadmium pigments also are insoluble in organic solvents, and have good resistance to alkalis.

More information on cadmium pigments in plastics is included in the plastics section.

Artists' Paints. Cadmium-barium pigments (lithopones) are used for yellows, oranges, and reds in artists' paints. A cadmium-mercury sulfide is used in a vermillion pigment.

Overall, artists' paints represent a minor use of cadmium. It was not possible to quantify the amounts.

Elastomers. Cadmium pigments are used for several purposes in rubber products. These are discussed in more detail in the section on rubber.

Machinery and Automotive Finishes. Cadmium reds and maroons, the most durable of the cadmium pigments, are used in automobile finishes. Cadmium reds are coprecipitated and cocalcined mixtures of cadmium sulfide and cadmium selenide. Mercury cadmium pigments are also used occasionally.

Overall use of cadmium pigments has declined in automotive finishes (39), and discards of these products are not counted as municipal solid waste.

Discards of Pigments

Discards of cadmium in pigments in MSW were estimated using as the basic source consumption of cadmium reported by the Bureau of Mines (5). (Discards of cadmium pigments in rubber and plastics are discussed in those sections of this report.) Adjustments and assumptions were made, as follows:

1. An adjustment was made for imports and exports of cadmium in pigments using Department of Commerce data (40). Data were not available to determine pigments in products imported and exported, such as textiles.

2. Manufacturing losses were estimated to be six percent (20).

3. It was assumed that there is no recycling of these products.

4. It was assumed that the cadmium in pigments disposed in MSW is disposed the same year that the cadmium is consumed.

5. Projections were made using past trends.

These estimates are summarized in Tables 3-10, 3-11, and 3-12, and Figure 3-6. Estimates for cadmium in pigments and glass and ceramics, plastics, and rubber are discussed in the appropriate sections of this report.

PLASTICS

Like lead, cadmium is used for two purposes in the manufacture of plastics: as a stabilizer and as an ingredient in pigments. These uses are discussed and the quantities discarded into MSW are estimated in this section.

Stabilizers

Stabilizers containing cadmium compete directly with lead-containing stabilizers for application in many products. The primary application of both lead and cadmium stabilizers is in polyvinyl chloride (PVC) resins. Degradation of polyvinyl chloride by heat or light results in the release of hydrogen chloride and in color changes in the material (43).

Barium/cadmium stabilizers have for many years dominated the heat stabilizer market, accounting for about 40 percent of all heat stabilizers in 1986 (44). Cadmium chloride formed in the reaction with liberated hydrogen

Table 3-10

CONSUMPTION OF CADMIUM IN PIGMENTS, 1970 TO 2000
(In short tons)

Year	Domestic Consumption of Cadmium in Pigments 1/	Manufacturing Losses 2/	Adjustment for Imports/ Exports 3/	Net Consumption of Cadmium in Pigments 4/
1970	845	51	2	796
1971	1,005	60	2	947
1972	1,224	73	2	1,153
1973	1,400	84	3	1,319
1974	1,345	81	3	1,267
1975	717	43	2	676
1976	893	54	2	841
1977	661	40	1	622
1978	794	48	2	748
1979	882	53	3	832
1980	606	36	1	571
1981	783	47	2	738
1982	661	40	2	623
1983	661	40	1	622
1984	595	36	1	560
1985	656	39	2	619
1986	773	46	3	730
1990	835	50	3	788
1995	903	54	3	852
2000	976	59	3	920

1/ Bureau of Mines (Reference 5).
2/ Estimated to be 6 percent based on Reference 20.
3/ Derived from Department of Commerce data (Reference 40). Does not include pigments in imported/exported products.
4/ Domestic consumption - manufacturing losses + net imports.

chloride is acidic and capable of initiating further degradation. The presence of barium causes a rapid exchange of chlorine from cadmium to barium, thus preventing this type of degradation (43). Barium/cadmium zinc mixtures, barium/cadmium soaps, and cadmium salts are also used as stabilizers in plastics.

Table 3-11

CONSUMPTION OF CADMIUM IN PIGMENTS BY END USE, 1970 TO 2000
(In short tons)

Year	Net Consumption of Cadmium in Pigments 1/	Consumption of Cadmium as a Pigment in Rubber 2/	Consumption of Cadmium as a Pigment in Plastics 3/	Consumption of Cadmium as a Pigment in Glass and Ceramics 4/	Consumption of Cadmium as a Pigment in Other Products 5/	Consumption of Cadmium in Pigments Other Than MSW 6/	Net Consumption of Cadmium as a Pigment in Other Products in MSW 7/
1970	796	8	635	64	89	10	79
1971	947	10	756	76	105	14	91
1972	1,153	12	921	92	128	15	113
1973	1,319	14	1,053	105	147	19	128
1974	1,267	13	1,011	101	142	18	124
1975	676	7	539	54	76	11	65
1976	841	9	671	67	94	12	82
1977	622	7	497	50	68	9	59
1978	748	8	598	60	82	9	73
1979	832	9	663	66	94	10	84
1980	571	6	456	46	63	7	56
1981	738	8	589	59	82	9	73
1982	623	7	497	50	69	8	61
1983	622	7	497	50	68	7	61
1984	560	6	447	45	62	7	55
1985	619	7	493	49	70	11	59
1986	730	8	582	58	82	12	70
1990	788	8	628	63	89	11	78
1995	852	9	679	68	96	11	85
2000	920	9	734	73	104	11	93

1/ From Table 3-10.
2/ See Table 3-33 in Rubber section.
3/ See Table 3-14 in Plastics section.
4/ See Table 3-6 in Glass and Ceramics section.
5/ By difference.
6/ Estimated by Franklin Associates, Ltd. based on References 41 and 42. Includes automotive and machinery paints and architectural coatings.
7/ Includes paints, inks, textiles, artists' colors, and miscellaneous.

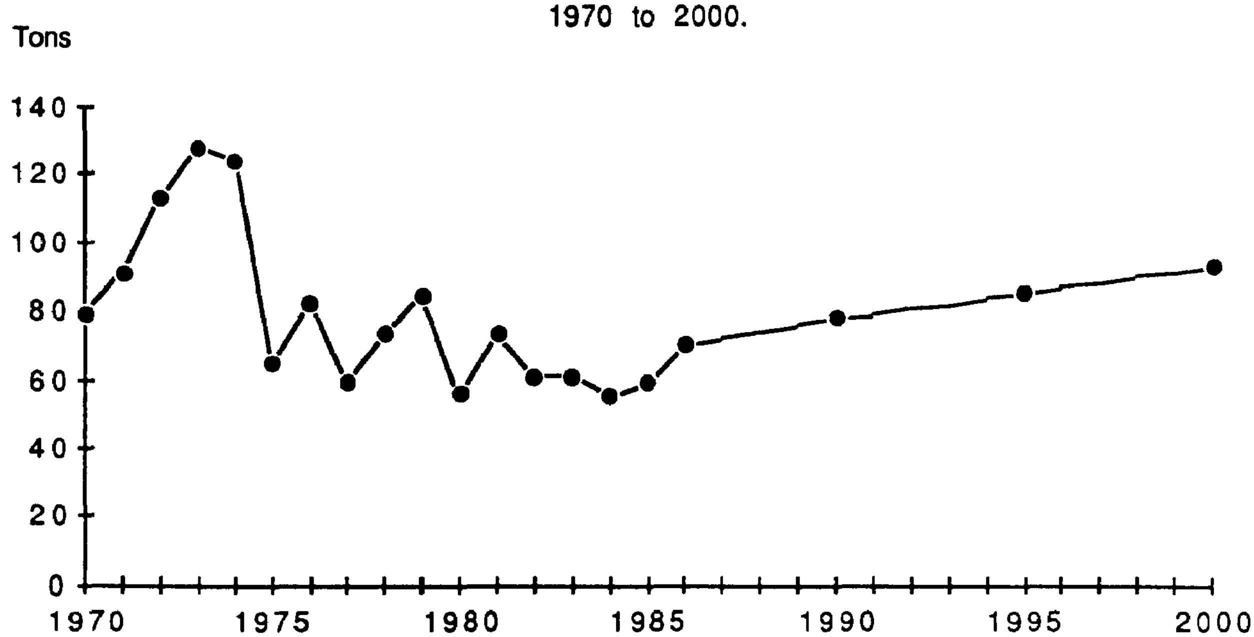
Table 3-12

DISCARDS OF CADMIUM PIGMENTS IN MISCELLANEOUS PRODUCTS, 1970 TO 2000
(In short tons)

Year	Discards of Cadmium Pigments in Misc. Products 1/	Discards of Cadmium Pigments in Printing Inks 2/	Discards of Cadmium Pigments in Textiles 2/	Discards of Cadmium Pigments in Leather Products 2/	Discards of Cadmium Pigments in Paints & Other Colorants 3/
1970	79	8	8	8	55
1971	91	10	10	10	61
1972	113	12	12	12	77
1973	128	14	14	14	86
1974	124	13	13	13	85
1975	65	7	7	7	44
1976	82	9	9	9	55
1977	59	7	7	7	38
1978	73	8	8	8	49
1979	84	9	9	9	57
1980	56	6	6	6	38
1981	73	8	8	8	49
1982	61	7	7	7	40
1983	61	7	7	7	40
1984	55	6	6	6	37
1985	59	7	7	7	38
1986	70	8	8	8	48
1990	78	8	8	8	54
1995	85	9	9	9	58
2000	93	9	9	9	64

1/ From Table 3-11. Discards are the same as consumption, since there is no recycling of these products.
2/ Estimated to be one percent of domestic consumption in pigments (Table 3-10), based on Materials and Design (Reference 37).
3/ By difference.

Figure 3-6. Discards of cadmium in pigments in miscellaneous products, 1970 to 2000.



The applications of cadmium stabilizers are similar to those for lead stabilizers. The cadmium compounds are somewhat more expensive.

Pigments

Cadmium sulfide, which occurs naturally as a yellow mineral, has been used as a colorant as least as far back as the eighteenth century. Use of cadmium pigments has historically been high in the plastics industry, and usage increased with the development of higher-temperature plastics processing.

Three basic types of cadmium pigments in use today are: cadmium yellow (sulfides of cadmium and sulfides of cadmium and zinc), cadmium reds (sulfoselenides of cadmium), and cadmium-mercury reds (sulfides of cadmium and mercury). Cadmium sulfide pigments impart colors from light yellow to orange, red, and deep maroon. Those formulated with mercury range in color from deep orange to dark red and maroon. Cadmium-mercury sulfides were developed as replacements for cadmium sulfoselenides.*

A major use of cadmium pigments is in acrylonitrile butadiene styrene (ABS) resins used in household appliances, telephones, refrigerator liners, and sporting goods (45). However, other resins used in a wide variety of applications also use cadmium pigments.

Estimates of Discards

Use of cadmium in the production of stabilizers and in pigments is reported by the Bureau of Mines (5). Allocation of plastic resin use to products in MSW followed the same methodology as that used for previous MSW characterization studies (6)(46).

As was the case with lead stabilizers, it was assumed that all cadmium in stabilizers is used in polyvinyl chloride resins (47), and that no cadmium stabilizers are used in food packaging.

Use of cadmium in pigments in plastics is widely dispersed among resins. Consumption of cadmium pigments by resin type is shown in Table 3-13,

* One of two major manufacturers of cadmium-mercury sulfide pigments worldwide recently ceased production of all cadmium and lead-based pigments (44).

Table 3-13

CONSUMPTION OF CADMIUM PIGMENTS IN PLASTIC RESINS
(In percent of total consumption)

Resin	Percent
Acrylonitrile-butadiene-styrene (ABS)	35
High-density polyethylene (HDPE)	25
Polypropylene (PP)	15
Low-density polyethylene (LDPE)	10
Polystyrene (PS)	10
Others*	5

* Assumed to be polyvinyl chloride (PVC).

Source: Lynch (Reference 19).

Additional adjustments and assumptions were made as follows:

1. It was assumed that cadmium in stabilizers is distributed evenly throughout the nonfood PVC uses. Consumption of PVC resin by end use was tabulated in Table 2-31 in Chapter 2.

2. Each MSW end use was adjusted for imports and exports as appropriate (Table 2-33 in Chapter 2). It was assumed that use of cadmium in these products is in the same proportion as domestic use.

3. Manufacturing losses in the manufacture of cadmium stabilizers were assumed to be 2 percent (20).

4. Manufacturing losses in the manufacture of cadmium pigments were assumed to be 6 percent (20).

5. Losses in the manufacture of plastic products were assumed to be one percent (6)(46).

6. It was assumed that 80 percent of total cadmium in pigments is used in plastics (19)(20).

7. It was assumed that there is no recycling of these products.

8. The lifetimes of the products were those used in previous MSW characterization studies (see the list in Chapter 2).

9. Projections were based on past trends.

Estimates of cadmium used in stabilizers and pigments in plastics are shown in Table 3-14. Allocation of cadmium to the various plastic resins and end uses in MSW is shown in Tables 3-15 through 3-31.

Total Cadmium in Plastics

Amounts of cadmium in stabilizers and pigments for each resin were added together to obtain total discards of cadmium in plastics (Table 3-32 and Figures 3-7 and 3-8).

RUBBER PRODUCTS

As discussed in Chapter 2, lead and cadmium may be used for a variety of purposes in rubber products, including use as pigments, fillers, activators, vulcanizers, curing activators, and plasticizers.

Cadmium oxide is used as an activator in rubber products. Cadmium sulfide is used to pigment white elastomers. Other cadmium-containing pigments used in rubber products include cadmium reds, cadmium maroons, mercury/cadmium reds, cadmium oranges, and cadmium yellows (48).

Discards of cadmium in rubber products in MSW were estimated using the following adjustments and assumptions:

1. All cadmium pigments in rubber were assumed to be in nontire products.

2. Consumption of cadmium pigments in rubber was assumed to be one percent of total consumption of cadmium pigments (36).

3. Manufacturing losses were assumed to be 5 percent (6).

4. No adjustments were made for imports/exports.

5. There was assumed to be no recycling of these products.

6. Rubber products were assumed to be discarded two years after manufacture.

7. Projections were made based on past trends.

The results of these calculations are shown in Tables 3-33 and 3-34.

MISCELLANEOUS PRODUCTS

This section describes estimates of cadmium contained in two products made of cadmium alloys: casings for alkaline and zinc-carbon batteries, and the heating elements in electric blankets and heating pads. In addition, cadmium content of used oil is discussed.

Table 3-14

ESTIMATES OF CADMIUM USED IN STABILIZERS AND PIGMENTS IN PLASTICS, 1970 TO 1986
(In short tons)

Year	Cadmium Consumed in Stabilizers 1/	Adjusted Cadmium Consumed in Stabilizers 2/	Total Cadmium Consumed in Pigments 1/	Adjusted Cadmium Consumed in Pigments 3/	Cadmium Consumed in Pigments in Plastics 4/	Total Cadmium Consumed in Plastics 5/
1970	1,363	1,336	845	794	635	1,971
1971	1,628	1,595	1,005	945	756	2,351
1972	1,488	1,458	1,224	1,151	920	2,379
1973	1,235	1,210	1,400	1,316	1,053	2,263
1974	1,213	1,189	1,345	1,264	1,011	2,200
1975	661	648	717	674	539	1,187
1976	794	778	893	839	672	1,450
1977	562	551	661	621	497	1,048
1978	650	637	794	746	597	1,234
1979	745	730	882	829	663	1,393
1980	518	508	606	570	456	963
1981	727	712	783	736	589	1,301
1982	617	605	661	621	497	1,102
1983	617	605	661	621	497	1,102
1984	562	551	595	559	447	998
1985	615	603	656	617	493	1,096
1986	725	711	773	727	581	1,292

1/ Bureau of Mines (Reference 5).
2/ Adjusted for manufacturing losses of 2 percent (Reference 20).
3/ Adjusted for manufacturing losses of 6 percent (Reference 20).
4/ Assumed that 80 percent of total cadmium in pigments is consumed in plastics (References 19, 20).
5/ Cadmium consumed in stabilizers plus cadmium consumed in pigments.

Table 3-15

ESTIMATES OF CADMIUM IN PVC, 1970 TO 1986
(In short tons)

Year	Total PVC Resin in Nonfood Applications 1/	Cadmium in Stabilizers in PVC 2/	Cadmium in Pigments in PVC 3/	Total Cadmium in PVC 4/	Cadmium per Ton of Resin 5/
1970	1,454,752	1,336	32	1,368	0.0009400
1971	1,560,982	1,595	38	1,633	0.0010463
1972	1,667,212	1,458	46	1,504	0.0009023
1973	1,773,442	1,210	53	1,263	0.0007121
1974	1,879,673	1,189	51	1,239	0.0006593
1975	1,985,903	648	27	675	0.0003398
1976	2,092,133	778	34	812	0.0003880
1977	2,231,000	551	25	576	0.0002580
1978	2,488,000	637	30	667	0.0002680
1979	2,590,000	730	33	763	0.0002947
1980	2,420,000	508	23	530	0.0002192
1981	2,526,000	712	29	742	0.0002937
1982	2,385,000	605	25	630	0.0002639
1983	2,488,000	605	25	630	0.0002530
1984	3,128,000	551	22	573	0.0001832
1985	3,151,000	603	25	627	0.0001991
1986	3,357,000	711	29	740	0.0002203

1/ Total resin in nonfood applications = total resin consumption (Reference 44) - resin for food applications.
2/ From Table 3-14.
3/ Cadmium consumed in plastic pigments x 0.05 (Table 3-14).
4/ Total cadmium in PVC = cadmium stabilizers + cadmium in pigments.
5/ Cadmium per ton of resin = total cadmium in PVC ÷ total PVC resin in nonfood applications.

Table 3-16

DISCARDS OF CADMIUM IN PVC IN PLASTIC PRODUCTS, 1970 TO 2000
(In short tons)

	Nondurables				Durables						
Year	Nonfood Packaging	Clothing	Footwear	Miscellaneous Nondurables	Housewares	Toys	Records	Furniture	Appliances	Miscellaneous Durables	Total
1970	77	15	19	5	4	14	12	9	9	3	166
1971	89	14	24	6	5	15	13	10	6	3	186
1972	91	35	57	7	5	18	13	12	6	3	247
1973	78	39	66	8	6	20	17	14	6	3	257
1974	77	44	56	9	7	23	18	12	6	3	254
1975	37	36	69	4	16	54	21	16	7	7	267
1976	49	26	49	14	20	65	21	19	7	8	278
1977	36	12	27	12	21	63	22	22	6	9	231
1978	41	15	34	18	17	60	26	25	6	8	251
1979	56	7	26	16	18	44	25	33	8	8	241
1980	37	8	29	12	7	20	65	70	18	5	271
1981	52	3	27	18	9	21	68	94	22	6	322
1982	49	1	17	16	7	14	67	96	20	16	304
1983	54	2	25	20	7	13	51	85	16	34	306
1984	47	2	21	14	7	14	50	77	15	48	295
1985	40	2	26	16	5	8	22	31	8	36	194
1986	48	2	20	20	7	14	29	40	8	47	236
1990	48	2	21	17	5	10	12	18	8	38	178
1995	48	2	21	17	5	10	7	7	8	41	166
2000	48	2	21	17	5	10	8	9	10	41	171

1/ Consumption of PVC resin (Table 2-31), adjusted for cadmium per ton (Table 3-15), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 3-17

CONSUMPTION OF ABS RESIN BY END USE, 1960 TO 1986 1/
(In thousand short tons)

Year	Nondurables	Durables					
	Nonfood Packaging	Toys	Luggage	Consumer Electronics	Furniture	Appliances	Miscellaneous Durables
1960	-	-	10	-	1	96	-
1961	-	-	10	-	1	72	-
1962	-	-	11	-	2	67	-
1963	-	-	11	-	2	70	-
1964	-	-	12	-	2	69	-
1965	-	22	12	-	2	80	2
1966	-	26	13	-	3	75	2
1967	-	29	13	-	3	73	2
1968	-	34	14	-	4	73	2
1969	-	38	15	-	5	85	2
1970	7	41	15	-	5	90	2
1971	7	46	11	-	6	93	2
1972	8	51	13	-	7	95	3
1973	8	61	17	-	7	97	4
1974	9	53	16	-	7	99	4
1975	8	41	11	-	6	100	5
1976	9	39	13	-	6	97	5
1977	10	37	10	37	7	100	21
1978	9	40	10	45	8	112	25
1979	3	30	12	42	7	80	45
1980	1	22	13	53	6	72	29
1981	2	28	14	66	7	94	33
1982	5	22	11	52	6	72	20
1983	2	23	10	39	2	80	18
1984	3	20	11	41	2	84	20
1985	3	15	9	32	2	89	27
1986	3	16	8	41	3	95	28

1/ Data for the years 1977-1986 from Modern Plastics (Reference 44). Data for previous years estimated by Franklin Associates, Ltd.

Table 3-18

ESTIMATES OF CADMIUM IN ABS, 1970 TO 1986
(In short tons)

Year	Total ABS Resin in Nonfood Applications 1/	Cadmium in Pigments in ABS 2/	Cadmium per Ton of Resin 3/
1970	505,321	222	0.0004401
1971	501,954	265	0.0005270
1972	498,570	322	0.0006462
1973	495,194	368	0.0007441
1974	491,818	354	0.0007198
1975	488,442	189	0.0003864
1976	485,067	235	0.0004845
1977	464,000	174	0.0003749
1978	519,000	209	0.0004027
1979	563,000	232	0.0004123
1980	429,000	159	0.0003718
1981	462,000	206	0.0004461
1982	304,000	174	0.0005723
1983	479,000	174	0.0003632
1984	503,000	157	0.0003113
1985	459,000	173	0.0003762
1986	483,000	203	0.0004212

1/ Total resin in nonfood applications = total resin consumption - resin for food applications (Reference 44).
2/ Cadmium consumption in plastic pigments x 0.35 (Table 3-14).
3/ Cadmium per ton of resin = cadmium in pigments ÷ total ABS resin in nonfood applications.

Table 3-19

DISCARDS OF CADMIUM IN ABS IN PLASTICS PRODUCTS, 1970 TO 2000 1/
(In short tons)

Year	Nondurables: Nonfood Packaging	Durables: Toys	Durables: Luggage	Durables: Consumer Electronics	Durables: Furniture	Durables: Appliances	Durables: Miscellaneous Durables
1970	3	13	5	-	<1	45	1
1971	4	14	5	-	<1	34	1
1972	5	17	5	-	1	31	1
1973	6	19	5	-	1	33	1
1974	6	20	6	-	1	32	1
1975	3	26	6	-	1	37	1
1976	4	35	7	-	1	35	1
1977	4	49	7	-	1	34	2
1978	4	42	7	-	2	34	3
1979	1	16	8	-	2	40	3
1980	0	21	8	-	2	39	2
1981	1	16	7	-	3	49	2
1982	3	18	10	-	4	61	8
1983	1	14	15	-	5	71	10
1984	1	10	14	-	5	71	18
1985	1	14	5	-	2	38	11
1986	1	15	8	-	3	47	15
1990	1	11	7	30	2	26	10
1995	1	11	6	31	1	33	9
2000	1	11	7	37	1	34	9

1/ Consumption of ABS resin (Table 3-17), adjusted for cadmium per ton (Table 3-18), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 3-20

CONSUMPTION OF HDPE RESIN BY END USE, 1965 TO 1986 1/
(In thousand tons)

Year	Nondurables		Durables		
	Nonfood Packaging	Nonfood Misc. Nondurables	Housewares	Toys	Miscellaneous Durables
1965	-	-	57	17	14
1966	-	-	65	21	14
1967	-	-	72	22	15
1968	-	-	86	26	16
1969	-	-	104	29	18
1970	262	5	94	36	18
1971	345	6	102	36	19
1972	337	7	130	39	24
1973	422	10	134	48	28
1974	453	12	151	57	28
1975	424	11	120	44	35
1976	487	31	134	42	37
1977	541	41	143	40	154
1978	631	73	66	42	188
1979	754	70	80	45	244
1980	655	58	73	41	197
1981	754	89	80	45	212
1982	676	80	89	49	229
1983	743	111	94	54	260
1984	936	124	107	65	277
1985	1,055	67	121	80	289
1986	1,121	72	130	81	303

1/ Data for the years 1977-1986 from Modern Plastics (Reference 44). Data for previous years estimated by Franklin Associates, Ltd.

Table 3-21

ESTIMATES OF CADMIUM IN HDPE, 1970 TO 1986
(In short tons)

Year	Total HDPE Resin in Nonfood Applications 1/	Cadmium Pigments in HDPE 2/	Cadmium per Ton of HDPE Resin 3/
1970	759,000	159	0.000209
1971	843,000	189	0.000224
1972	927,000	230	0.000248
1973	1,007,000	263	0.000261
1974	1,095,000	253	0.000231
1975	1,177,000	135	0.000115
1976	1,226,000	168	0.000137
1977	1,179,000	124	0.000105
1978	1,389,000	149	0.000107
1979	1,537,000	166	0.000108
1980	1,523,000	114	0.000075
1981	1,471,000	147	0.000100
1982	1,496,000	124	0.000083
1983	1,843,000	124	0.000067
1984	1,866,000	112	0.000060
1985	2,270,000	123	0.000054
1986	2,401,000	145	0.000061

1/ Total resin in nonfood applications = total resin consumption - resin for food applications (Reference 44).
2/ Cadmium consumed in plastic pigments x 0.25 (Table 3-14).
3/ Cadmium per ton of resin = cadmium in pigments ÷ total HDPE resin in nonfood applications.

Table 3-22

DISCARDS OF CADMIUM IN HDPE IN PLASTIC PRODUCTS, 1970 TO 2000
(In short tons)

	Nondurables		Durables		
Year	Nonfood Misc. Packaging	Nonfood Misc. Nondurables	Housewares	Toys	Miscellaneous Durables
1970	54	1	7	2	2
1971	77	1	9	3	2
1972	83	2	9	3	2
1973	109	3	11	4	2
1974	104	3	14	4	2
1975	48	1	19	8	4
1976	66	4	23	9	4
1977	56	4	32	10	4
1978	67	8	35	14	7
1979	80	7	35	14	6
1980	48	4	14	5	4
1981	75	9	18	6	5
1982	56	7	15	5	16
1983	50	7	7	5	20
1984	56	7	9	6	26
1985	57	4	5	4	15
1986	67	4	8	5	21
1990	57	6	7	7	16
1995	57	6	7	6	17
2000	57	6	7	6	17

1/ Consumption of HDPE resin (Table 3-20), adjusted for cadmium per ton (Table 3-21), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 2-23

CONSUMPTION OF POLYPROPYLENE RESIN BY END USE, 1960 TO 1986
(In thousand short tons)

	Nondurables		Durables					
Year	Nonfood Packaging	Miscellaneous Nondurables	Housewares	Toys	Luggage	Furniture	Appliances	Miscellaneous Durables
1960	-	-	-	-	4	2	33	-
1961	-	-	-	-	5	3	31	-
1962	-	-	-	-	4	3	32	-
1963	-	-	-	-	5	4	32	-
1964	-	-	-	-	4	5	37	19
1965	-	-	13	20	4	5	34	20
1966	-	-	15	24	4	5	33	20
1967	-	-	17	26	4	6	33	21
1968	-	-	20	30	4	7	39	24
1969	-	-	24	34	4	9	41	25
1970	109	4	24	37	5	9	46	26
1971	111	5	26	41	5	11	47	32
1972	132	6	33	45	3	13	48	39
1973	142	10	34	54	4	15	49	38
1974	153	11	38	47	5	14	50	37
1975	142	10	30	36	3	11	51	47
1976	163	28	34	35	4	13	49	49
1977	182	37	36	33	3	14	51	206
1978	228	55	46	41	8	17	52	235
1979	265	50	85	35	6	21	50	283
1980	270	50	85	40	6	20	43	268
1981	297	55	90	40	6	20	47	295
1982	307	47	67	15	3	22	36	247
1983	377	47	72	17	3	24	49	334
1984	416	58	78	19	2	25	61	361
1985	410	55	71	14	3	22	57	386
1986	448	60	74	15	3	23	65	398

1/ Data for the years 1977-1986 from *Modern Plastics* (Reference 44). Data for previous years estimated by Franklin Associates, Ltd.

Table 3-24

ESTIMATES OF CADMIUM IN POLYPROPYLENE, 1970 TO 1986
(In short tons)

Year	Total PP Resin in Nonfood Applications 1/	Cadmium Pigments in PP 2/	Cadmium per Ton of PP Resin 3/
1970	289,007	95	0.000330
1971	402,477	113	0.000282
1972	515,947	138	0.000268
1973	629,417	158	0.000251
1974	742,888	152	0.000204
1975	856,358	81	0.000094
1976	969,828	101	0.000104
1977	1,063,000	75	0.000070
1978	1,180,000	90	0.000076
1979	1,402,000	99	0.000071
1980	1,708,140	68	0.000040
1981	1,401,000	88	0.000063
1982	1,390,000	75	0.000054
1983	1,769,000	75	0.000042
1985	2,119,000	74	0.000035
1986	2,255,000	87	0.000039

1/ Total resin in nonfood applications = total resin consumption - resin for food applications (Reference 44).
2/ Cadmium consumed in plastic pigments x 0.15 (Table 3-14).
3/ Cadmium per ton of resin = cadmium in pigments ÷ total PP resin in nonfood applications.

Table 3-25

DISCARDS OF CADMIUM IN POLYPROPYLENE IN PLASTIC PRODUCTS, 1970 TO 2000
(In short tons)

	Nondurables		Durables					
Year	Nonfood Packaging	Miscellaneous Nondurables	Housewares	Toys	Luggage	Furniture	Appliances	Miscellaneous Durables
1970	36	1	2	2	0	0	4	2
1971	31	1	2	3	1	0	4	2
1972	35	2	2	3	1	0	4	3
1973	35	2	2	4	1	0	4	3
1974	31	2	3	4	1	1	4	3
1975	13	1	8	13	1	1	4	8
1976	17	3	7	12	1	1	4	9
1977	13	3	9	13	1	1	4	10
1978	17	4	8	15	1	1	5	9
1979	19	3	8	10	1	1	5	7
1980	11	2	3	3	2	3	15	4
1981	19	3	3	4	2	3	13	5
1982	16	3	2	3	1	3	13	14
1983	16	2	3	4	1	4	12	18
1984	17	2	6	3	1	3	10	20
1985	14	2	3	2	0	1	5	11
1986	17	2	6	3	1	1	5	18
1990	16	2	2	1	0	1	2	13
1995	16	2	3	1	0	1	2	14
2000	16	2	3	1	0	1	2	14

1/ Consumption of PP resin (Table 3-23), adjusted for cadmium per ton (Table 3-24), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 3-26

CONSUMPTION OF LDPE RESIN BY END USE, 1965 TO 1986 1/
(In thousand short tons)

	Nondurables		Durables
Year	Nonfood Packaging	Miscellaneous Nondurables	Housewares
1965	-	-	85
1966	-	-	95
1967	-	-	113
1968	-	-	113
1969	-	-	136
1970	645	88	134
1971	671	115	146
1972	799	142	185
1973	860	212	191
1974	924	241	217
1975	863	214	171
1976	993	628	192
1977	1,103	827	204
1978	1,150	901	220
1979	1,321	982	238
1980	1,173	963	193
1981	1,218	974	193
1982	1,201	978	176
1983	1,308	1,060	196
1984	1,363	1,103	193
1985	1,428	1,093	200
1986	1,462	1,104	201

1/ Data for the years 1977-1986 from Modern Plastics (Reference 44). Data for previous years estimated by Franklin Associates, Ltd.

Table 3-27

ESTIMATES OF CADMIUM IN LDPE, 1970 TO 1986
(In short tons)

Year	Total LDPE Resin in Nonfood Applications 1/	Cadmium Pigments in LDPE 2/	Cadmium per Ton of LDPE Resin 3/
1970	1,645,836	64	0.000039
1971	1,758,964	76	0.000043
1972	1,872,091	92	0.000049
1973	1,985,218	105	0.000053
1974	2,098,345	101	0.000048
1975	2,211,473	54	0.000024
1976	2,324,600	67	0.000029
1977	2,422,000	50	0.000021
1978	2,557,000	60	0.000023
1979	2,764,000	66	0.000024
1980	2,766,000	46	0.000017
1981	2,573,000	59	0.000023
1982	3,460,000	50	0.000014
1983	2,808,000	50	0.000018
1984	3,281,000	45	0.000014
1985	3,384,000	49	0.000014
1986	3,453,000	58	0.000017

1/ Total resin in nonfood applications = total resin consumption - resin for food applications (Reference 44).
2/ Cadmium consumed in plastic pigments x 0.10 (Table 3-14).
3/ Cadmium per ton of resin = cadmium in pigments ÷ total LDPE resin in nonfood applications.

Table 3-28

DISCARDS OF CADMIUM IN LDPE IN PLASTIC PRODUCTS, 1970 TO 2000
(In short tons)

Year	Nondurables		Durables
	Nonfood Packaging	Miscellaneous Nondurables	Housewares
1970	25	3	2
1971	29	5	3
1972	39	7	3
1973	45	11	3
1974	44	11	4
1975	21	5	5
1976	28	18	6
1977	23	17	9
1978	27	21	10
1979	31	23	10
1980	19	16	4
1981	28	22	5
1982	17	14	4
1983	23	19	5
1984	19	15	6
1985	20	16	3
1986	24	18	4
1990	21	16	3
1995	21	16	3
2000	21	16	3

1/ Consumption of LDPE resin (Table 3-26), adjusted for cadmium per ton (Table 3-27), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 3-29

CONSUMPTION OF POLYSTYRENE RESIN BY END USE, 1960 TO 1986 1/
(In short tons)

	Nondurables			Durables					
Year	Nonfood Packaging	Footwear	Nonfood Misc. Nondurables	Housewares	Toys	Consumer Electronics	Furniture	Appliances	Miscellaneous Durables
1960	-	-	-	-	-	-	8	45	-
1961	-	-	-	-	-	-	10	47	-
1962	-	-	-	-	-	-	11	49	-
1963	-	-	-	-	-	-	13	57	-
1964	-	-	-	-	-	-	15	56	-
1965	-	-	-	66	59	-	15	65	2
1966	-	-	-	76	70	-	18	61	2
1967	-	-	-	84	77	-	21	59	2
1968	-	7	-	100	89	-	24	59	2
1969	-	9	-	120	99	-	31	68	2
1970	236	11	16	119	109	-	30	73	3
1971	246	11	21	130	119	-	37	81	3
1972	293	11	26	164	133	-	44	84	3
1973	315	15	39	169	160	-	48	85	4
1974	338	11	44	192	139	-	47	87	4
1975	316	12	39	151	107	-	37	88	5
1976	364	12	114	170	102	-	42	85	5
1977	404	12	150	181	97	96	46	88	21
1978	352	12	90	130	100	86	51	88	24
1979	369	12	82	126	108	91	69	72	26
1980	297	10	64	99	93	93	61	57	25
1981	223	10	84	107	99	97	55	61	25
1982	225	6	65	89	83	98	44	54	22
1983	193	6	111	104	99	107	26	66	25
1984	159	3	128	101	101	105	41	60	25
1985	190	3	139	100	106	105	45	68	26
1986	202	3	148	107	117	135	49	78	29

1/ Data for the years 1977-1986 from Modern Plastics (Reference 44). Data for previous years estimated by Franklin Associates, Ltd.

Table 3-30

ESTIMATES OF CADMIUM IN POLYSTYRENE, 1970 TO 1986
(In short tons)

Year	Total PS Resin in Nonfood Applications 1/	Cadmium Pigments in PS 2/	Cadmium per Ton of PS Resin 3/
1970	1,007,000	64	0.000063
1971	1,119,000	76	0.000068
1972	1,229,000	92	0.000075
1973	1,336,000	105	0.000079
1974	1,452,000	101	0.000070
1975	1,561,000	54	0.000035
1976	1,627,000	67	0.000041
1977	1,564,000	50	0.000032
1978	1,211,000	60	0.000049
1979	1,171,000	66	0.000057
1980	1,162,000	46	0.000039
1981	1,044,000	59	0.000056
1982	1,045,000	50	0.000048
1983	1,254,000	50	0.000040
1984	1,289,000	45	0.000035
1985	1,337,000	49	0.000037
1986	1,451,000	58	0.000040

1/ Total resin in nonfood applications = total resin consumption - resin for food applications (Reference 44).
2/ Cadmium consumption in plastic pigments x 0.10 (Table 3-14).
3/ Cadmium per ton of resin = cadmium in pigments ÷ total PS resin in nonfood applications.

Table 3-31

DISCARDS OF CADMIUM IN POLYSTYRENE IN PLASTIC PRODUCTS, 1970 TO 2000
(In short tons)

Year	Nondurables			Durables					
	Nonfood Packaging	Footwear	Nonfood Misc. Nondurables	Housewares	Toys	Consumer Electronics	Furniture	Appliances	Miscellaneous Durables
1970	15	0	1	3	3	-	0	3	0
1971	16	1	1	4	4	-	1	2	0
1972	22	1	2	4	4	-	1	2	0
1973	25	1	3	5	5	-	1	3	0
1974	23	1	3	6	5	-	1	3	0
1975	11	2	1	7	8	-	1	3	0
1976	15	1	5	9	9	-	1	3	0
1977	13	1	5	12	11	-	1	3	0
1978	17	1	4	13	14	-	1	3	0
1979	21	1	5	13	11	-	2	3	0
1980	12	1	2	5	4	-	2	5	0
1981	12	1	5	7	5	-	2	5	0
1982	11	1	3	6	3	-	3	6	1
1983	8	1	4	6	6	-	4	7	1
1984	5	1	4	7	7	-	3	6	1
1985	7	1	5	4	4	-	1	3	1
1986	8	0	6	6	6	-	2	4	1
1990	8	0	5	4	6	6	2	2	1
1995	8	0	5	4	6	10	2	2	1
2000	8	0	5	4	6	10	2	3	1

1/ Consumption of PS resin (Table 3-29), adjusted for cadmium per ton (Table 3-30), one percent manufacturing losses, exports/imports (Table 2-33), and life of products. Cadmium per ton of resin for 1960-1969 is the average of 1970-1986.

Table 3-32

DISCARDS OF CADMIUM IN PLASTICS IN MSW, 1970 TO 2000 1/
(In short tons)

	Nondurables				Durables								
Year	Nonfood Packaging	Clothing	Footwear	Miscellaneous Nondurables	Housewares	Toys	Records	Luggage	Consumer Electronics	Furniture	Appliances	Miscellaneous Durables	Total
1970	209	15	19	11	19	34	12	5	-	10	60	8	403
1971	245	14	25	15	21	39	13	6	-	12	46	8	445
1972	275	35	58	19	24	45	13	6	-	14	44	8	541
1973	298	39	67	28	28	52	17	6	-	16	45	9	604
1974	285	44	57	29	34	57	18	6	-	14	45	9	597
1975	133	36	70	13	56	109	21	6	-	18	52	21	536
1976	179	26	50	43	65	130	21	7	-	22	49	23	616
1977	144	12	28	41	83	146	22	7	-	25	47	27	583
1978	173	15	35	55	83	143	26	8	-	29	48	28	644
1979	208	7	27	55	84	95	25	8	-	38	56	25	628
1980	128	8	31	37	33	53	65	9	-	77	77	15	532
1981	187	3	29	57	43	52	68	8	-	103	89	18	658
1982	152	1	18	42	34	43	67	11	-	108	99	55	631
1983	151	2	26	52	29	41	51	17	-	97	106	83	656
1984	144	2	22	43	35	39	50	15	-	88	102	114	653
1985	139	2	27	43	21	32	22	5	-	35	54	73	453
1986	166	2	21	51	31	44	29	9	-	46	64	103	564
1990	150	2	21	46	20	34	12	7	36	23	38	78	467
1995	150	2	21	46	22	33	7	6	41	11	46	82	467
2000	150	2	21	46	22	33	8	7	47	13	48	82	480

1/ Discards of cadmium in stabilizers plus pigments.

Figure 3-7. Discards of cadmium in plastics, 1970 to 2000.

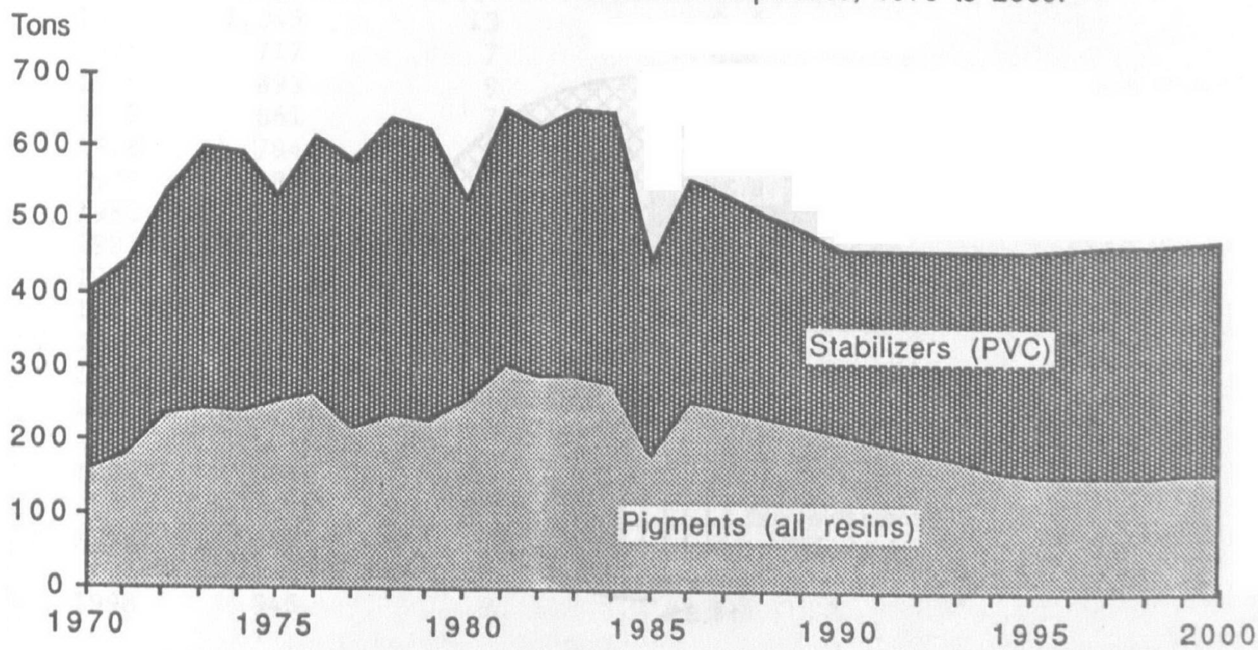


Figure 3-8. Sources of cadmium discards in plastics, 1986.

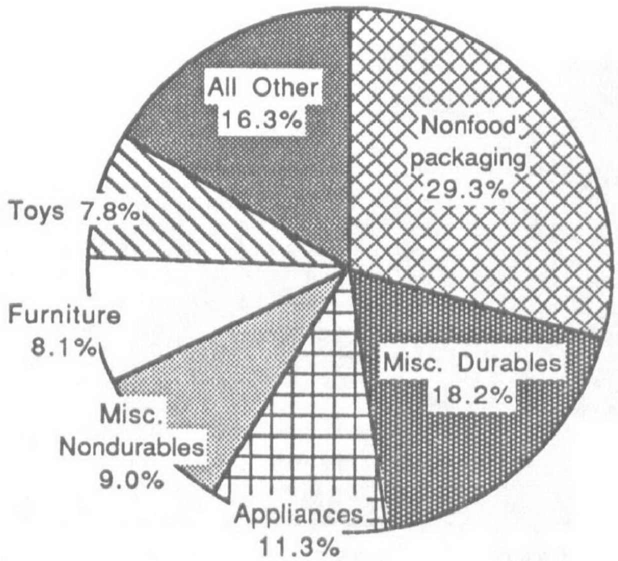


Table 3-33

CONSUMPTION OF CADMIUM IN PIGMENTS IN RUBBER, 1968 TO 1998
(In short tons)

Year	Domestic Consumption of Cadmium in Pigments 1/	Consumption of Cadmium in Rubber Products 2/	Manufacturing Losses 3/	Net Consumption of Cadmium in Rubber Products
1968	1,000	10	0.5	10
1969	971	10	0.5	9
1970	845	8	0.4	8
1971	1,005	10	0.5	10
1972	1,224	12	0.6	12
1973	1,400	14	0.7	13
1974	1,345	13	0.7	13
1975	717	7	0.4	7
1976	893	9	0.4	8
1977	661	7	0.3	6
1978	794	8	0.4	8
1979	882	9	0.4	8
1980	606	6	0.3	6
1981	783	8	0.4	7
1982	661	7	0.3	6
1983	661	7	0.3	6
1984	595	6	0.3	6
1985	656	7	0.3	6
1986	773	8	0.4	7
1988	804	8	0.4	8
1993	872	9	0.4	8
1998	945	9	0.5	9

1/ Bureau of Mines (Reference 5). 1968 estimated by Franklin Associates, Ltd.

2/ Estimated to be one percent of cadmium consumption in pigments, based on Reference 36.

3/ Estimated to be 5 percent (Reference 6).

Table 3-34

DISCARDS OF CADMIUM IN PIGMENTS IN RUBBER, 1970 TO 2000
(In short tons)

Year	Discards of Cadmium in Rubber Products 1/
1970	10
1971	9
1972	8
1973	10
1974	12
1975	13
1976	13
1977	7
1978	8
1979	6
1980	8
1981	8
1982	6
1983	7
1984	6
1985	6
1986	6
1990	8
1995	9
2000	9

1/ Consumption of cadmium in products is assumed to be discarded two years later. It is assumed that all discards are nontire products.

Casings for Dry Cell Batteries

The Bureau of Mines reports cadmium consumed in alloys and other products. Most of these products--cadmium solder used in industrial applications, trolley wire, cable sheaths, control elements for nuclear reactors, lens grinding blocks, etc.--are assumed not to be discarded into MSW. The casings for alkaline and zinc-carbon batteries do contain 0.02 percent by weight of cadmium (49). The cadmium is actually an impurity in the high-grade zinc used for the casings, but the amount is so small that it would be too expensive to further purify the zinc.

Discards of cadmium in dry cell battery casings were estimated using the following adjustments and assumptions:

1. The weight of cadmium discarded was based on the amount of cadmium in the most commonly-used battery (size AA), which contains 2.2 milligrams of cadmium per battery (49), and the estimated number of alkaline and zinc-carbon batteries sold each year--which was 62 percent of the total 2 billion batteries sold in 1986 (24) and was assumed to slowly decrease in earlier years.

2. An adjustment for imports and exports was not made because of the small amounts involved.

3. No adjustment for manufacturing losses was made because the amount of cadmium is based on the weight of the finished product.

4. It was assumed that there is no recycling of these batteries.

5. It was assumed that the lifetime of these batteries is one year.

6. Projections were based on past trends.

The results of these estimates are summarized in Table 3-35.

Electric Blankets and Heating Pads

The heating elements in electric blankets and heating pads have a synthetic fiber core with a 99 percent by weight copper, one percent by weight cadmium alloy wire wound around it. The wire is covered with vinyl to protect users. The cadmium discarded in electric blankets and heating pads was estimated using the following adjustments and assumptions:

Table 3-35

DISCARDS OF CADMIUM IN MISCELLANEOUS PRODUCTS, 1970 TO 2000
(In short tons)

Year	Cadmium in Dry Cell Casings 1/	Cadmium in Electric Blankets and Heating Pads 2/	Cadmium in Used Oil 3/
1970	2	1	1
1971	2	1	1
1972	2	1	1
1973	2	1	1
1974	2	1	1
1975	2	1	1
1976	2	1	1
1977	2	1	1
1978	2	1	1
1979	2	1	1
1980	2	1	1
1981	3	1	1
1982	3	1	1
1983	3	1	1
1984	3	1	1
1985	3	1	1
1986	3	1	1
1990	3	1	1
1995	3	1	1
2000	3	1	1

1/ An average 1-year lifetime was assumed.
2/ An average 8-year lifetime was assumed (Reference 13).
3/ Assumed to be discarded the same year consumed.

1. An average electric blanket has 0.00033 pounds of cadmium and approximately 4.7 million blankets are consumed per year (50)(51).

2. Imports and exports are negligible (51).

3. Manufacturing losses are already accounted for in the estimate.

4. There is no recycling of these products.

5. The lifetime of these products was assumed to be eight years (13).

6. Projections were based on past trends.

The results of these estimates are shown in Table 3-35.

Used Oil

A 1985 study for EPA (52) showed the median concentration of cadmium in automotive oils to be 1.4 ppm. Under the assumptions described in the used oil section of Chapter 2, about one ton per year of cadmium is discarded with used oil into MSW.

Chapter 3

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Appendix A

MATERIALS FLOW METHODOLOGY FOR ESTIMATING MSW DISCARDS

The materials flow methodology for estimating municipal solid waste generation was developed at EPA in the mid-1970s (1). It has been used periodically for EPA reports ever since (2 through 8). Most recently, this methodology was used to estimate MSW generation for use in EPA's Subtitle D studies (9)(10).

The materials flow methodology produces estimates for the United States as a whole; it cannot be used, except in a very general manner, to define wastes generated in a particular locality. The methodology requires making many assumptions, and thus it has been subject to numerous modifications and refinements over the years as additional information became available or new data sources were developed.

GENERAL DESCRIPTION OF METHODOLOGY

The materials flow methodology (Figure A-1) relies on published data series documenting historical production (or consumption) of materials and products that enter the municipal waste stream. U. S. Department of Commerce statistics have been used for many of the data series, with trade association data used in some instances. Deductions for manufacturing or converting losses of materials during the manufacturing process are made.

Imports and exports significantly affect consumption estimates for some products, and adjustments are made as appropriate. An adjustment is also made for products that are destroyed in use (such as tread wear on rubber tires) or diverted from the waste stream for long periods of time (e.g., books in libraries). After all necessary adjustments are made, discards are calculated, using an estimated lifetime for each product.

Estimates of product life have an important effect on discards. Some appliances and furniture, for example, have estimated lifetimes of 10 to 20 years, so there is a long lag between production and discards. Other products, such as packaging, are assumed to be discarded the same year they are produced. Changes in production numbers may thus show up rapidly or slowly, depending on product life.

In the general methodology, the discards are then adjusted for materials and energy recovery. The final result, called "Net Discards" in Figure A-1, would be the quantity of MSW landfilled or otherwise disposed.

LEAD/CADMIUM METHODOLOGY

The methodology used to estimate the quantities of lead and cadmium in products discarded into MSW followed the general steps as outlined above. Some modifications and additional steps were, however, required. The methodology is described step-by-step below (Figure A-2).

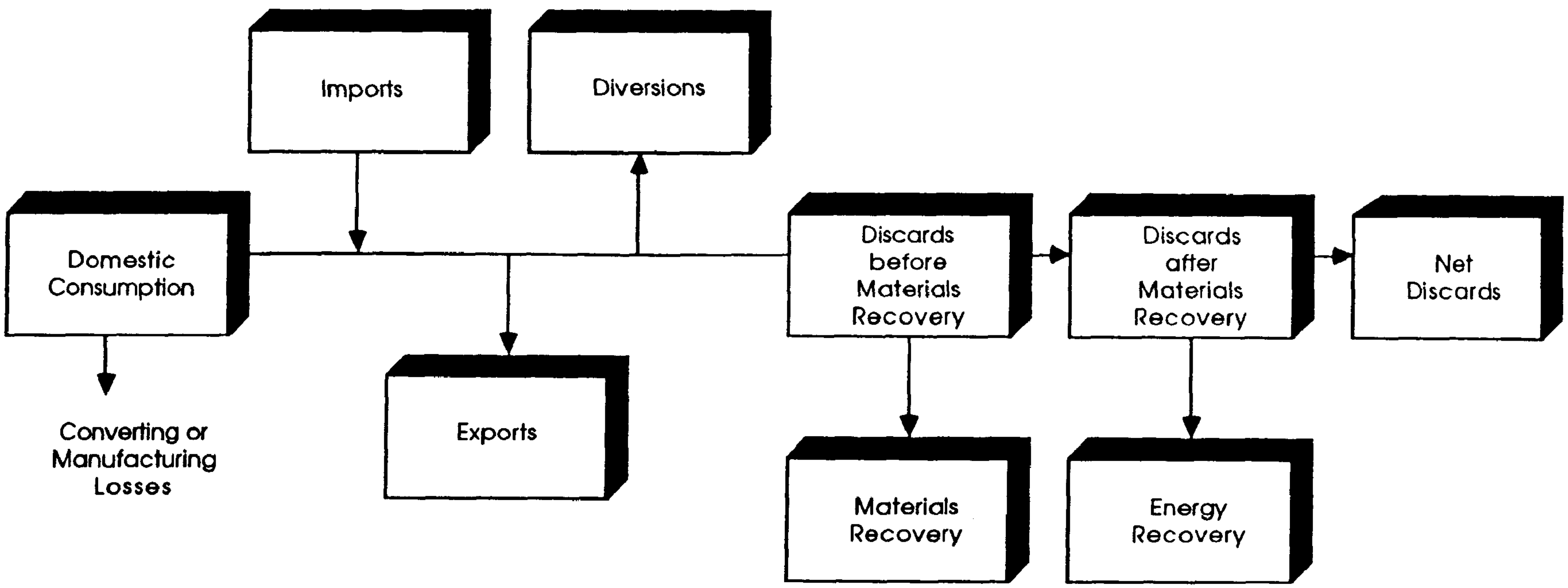

Figure A-1. Materials flow methodology for estimating MSW discards.

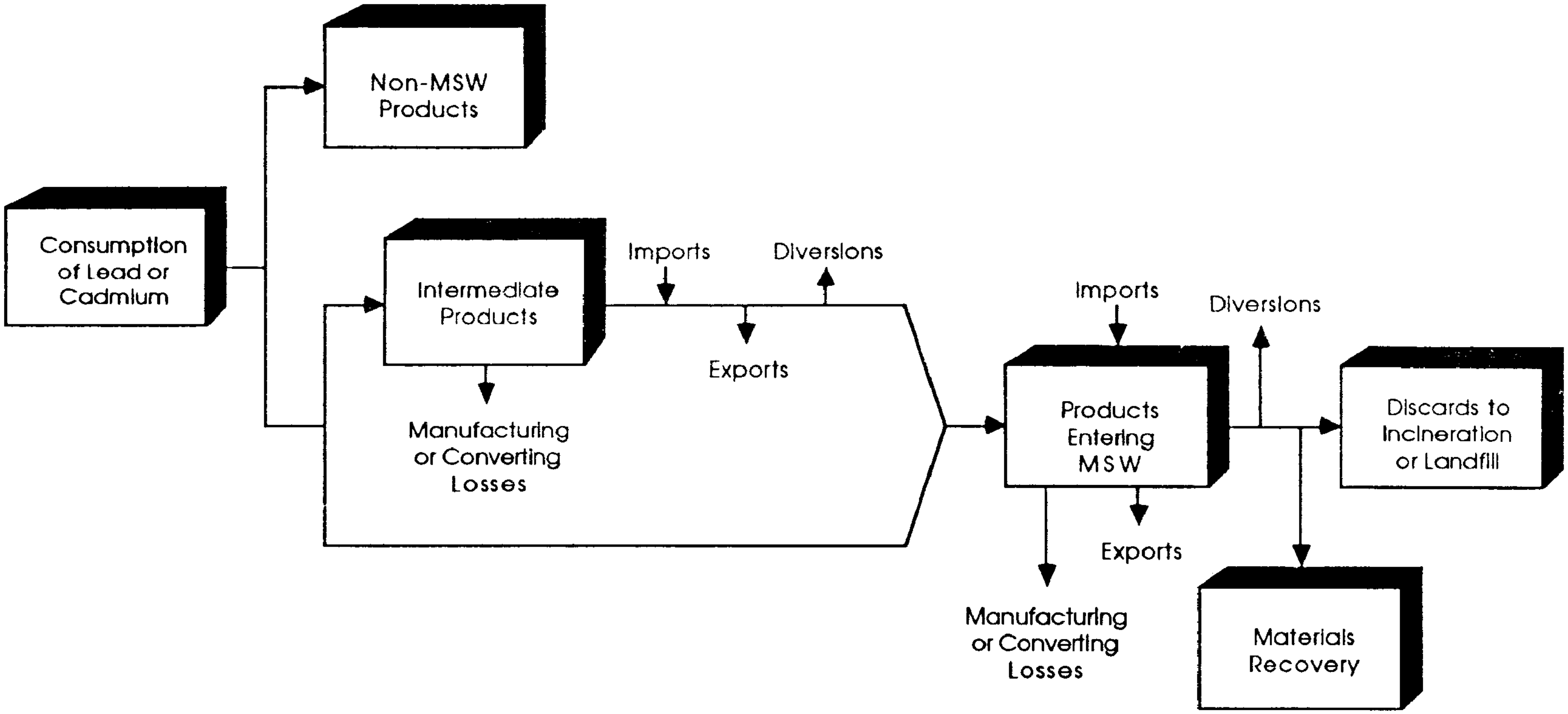

Figure A-2. Materials flow methodology for estimating lead and cadmium in MSW discards.

Data published annually by the Bureau of Mines (11) provided the basic data for consumption of lead and cadmium in the United States. These data account for imports and exports of the metals in ores and scrap, so further adjustments were not necessary in this step.

The Bureau of Mines data report end uses of the metals in some detail, especially for lead. An important step for each end use was assigning consumption to products that were assumed to enter MSW and those that do not. To cite an example: the data for lead consumption in solder include building construction, metal cans and shipping containers, electronic components and accessories, other electrical machinery and equipment, and motor vehicles and equipment as end uses. Solder in building construction was assumed to become demolition and construction waste rather than MSW, and solder in motor vehicles and equipment was assumed to become automotive waste, which also is not counted as MSW. The other categories of solder use were examined in detail to determine which end products would enter MSW.

In the next step, end uses of lead and cadmium were determined to be intermediate products or products that directly enter MSW. Unlike the materials and products that were considered in the previous work, lead and cadmium often occur as intermediate constituents of products. Lead, for example, is one of several constituents in many compounds used in making pigments. These pigments then are blended with many other ingredients to become paints, dyes, inks, or other colorants, which then become part of many other products--appliances, magazines, textiles, furniture, tires, etc.--that enter the municipal solid waste stream. Other end uses cited by the Bureau of Mines, such as lead-acid batteries, enter MSW without being reported as an intermediate product.

As described in the General Description of Methodology, adjustments were made as appropriate for manufacturing or converting losses, imports, and exports, and diversions of intermediate products and end products containing lead and cadmium that enter the municipal waste stream. For some products, e.g., television sets, estimates of imports are at least as important as domestic consumption of the metals.

Estimates of materials recovery and recycling were made for the appropriate products. Recovery and recycling of the lead in lead-acid batteries is an extremely important factor in determining the net discards of lead. In a few other instances, such as soldered cans and printing ink on newspapers, constituents containing lead or cadmium are removed from the municipal waste stream as a result of recycling activities, although the heavy metals themselves are not recycled.

The methodology for each product identified as containing lead or cadmium in MSW is described in the following chapters. Variations in the methodology were made as necessary; these are discussed in the appropriate sections.

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