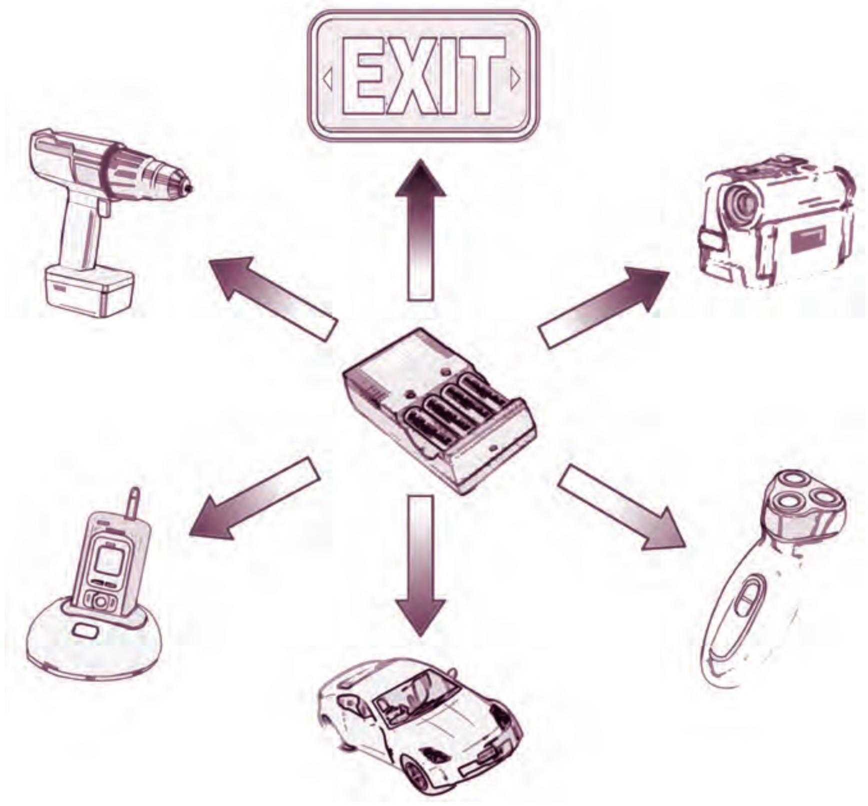
USGS
science for a changing world

Flow of Cadmium from Rechargeable Batteries in the United States, 1996–2007



Scientific Investigations Report 2007–5198
Version 2.0

U.S. Department of the Interior
U.S. Geological Survey

Flow of Cadmium from Rechargeable Batteries in the United States, 1996–2007

By David R. Wilburn

Scientific Investigations Report 2007–5198
Version 2.0

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2007
Revised: 2009

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment, visit http://www.usgs.gov or call 1-888-ASK-USGS

For an overview of USGS information products, including maps, imagery, and publications, visit http://www.usgs.gov/pubprod

To order this and other USGS information products, visit http://store.usgs.gov

Suggested citation:
Wilburn, D.R., 2009, Flow of cadmium from rechargeable batteries in the United States, 1996–2007 (ver. 2.0): U.S. Geological Survey Scientific Investigations Report 2007–5198, 26 p.

Contents

Figures

Tables

Conversion Factors

Multiply	By	To obtain
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)

Flow of Cadmium from Rechargeable Batteries in the United States, 1996–2007

By David R. Wilburn

Abstract

Cadmium metal has been found to be toxic to humans and the environment under certain conditions; therefore, a thorough understanding of the use and disposal of the metal is warranted. Most of the cadmium used in the United States comes from imported products. In 2007, more than 83 percent of the cadmium used in the United States was contained in batteries, mostly in rechargeable nickel-cadmium batteries used in popular consumer products such as cordless phones and power tools. The flow of cadmium contained in rechargeable nickel-cadmium batteries used in the United States was tracked for the years 1996 to 2007. The amount of cadmium metal contained in imported products in 2007 was estimated to be about 1,900 metric tons, or about 160 percent higher than the reported cadmium production in the United States from all primary and secondary sources. Although more than 40,000 metric tons of cadmium was estimated to be contained in nickel-cadmium rechargeable batteries that became obsolete during the 12-year study period, not all of this material was sent to municipal solid waste landfills. About 27 percent of the material available for recovery in the United States was recycled domestically in 2007; the balance was discarded in municipal solid waste landfills, exported for recycling, retained in temporary storage, or thrown away.

Introduction

More than 350 million rechargeable batteries are purchased annually in the United States (U.S. Environmental Protection Agency, 2002b). Rechargeable batteries may contain toxic heavy metals, which, when used and disposed of properly, present little threat to human health and the environment. These materials can cause harm to the environment and humans if they are discarded or incinerated improperly. In 1992, the U.S. Environmental Protection Agency (EPA) classified cadmium as a Group B1 probable human carcinogen (U.S. Environmental Protection Agency, 2000). In that same year, about 146,000 metric tons (t) of consumer batteries of all types, some of which contained cadmium, was discarded in the United States (Klimasauskas and others, 2006). In recognition of the potential environmental hazards associated with cadmium metal exposure, some States have limited cadmium use in some consumer products and are regulating cadmium disposal in order to encourage recycling and protect human health and the environment. Similarly, the European Union issued regulations in 1999 designed to regulate cadmium disposal. Recent regulatory emphasis appears to have shifted from the complete elimination of cadmium use to proper risk management of cadmium-containing products (Morrow, 2005).

Environmental concerns regarding the domestic use of cadmium, increasing substitution of other battery chemistries, stringent cadmium exposure regulations by the Occupational Safety and Health Administration, cost effective manufacture of more efficient nickel-cadmium (NiCd) rechargeable batteries in China, and increasing reliance on foreign imports of cadmium-containing products have contributed to reduced cadmium production and altered consumption patterns in the United States since 1990. Cadmium use in coating and plating, pigments, and plastics has dropped from 78 percent of cadmium apparent consumption in 1980 to 17 percent in 2007, whereas cadmium use in batteries has increased from 22 percent of cadmium apparent consumption in the United States in 1980 to 83 percent of apparent consumption in 2007. During the 12-year study period, overall demand for NiCd rechargeable batteries has decreased with increased substitution, first with nickel-metal-hydride batteries, then with lithium-ion batteries. As these rechargeable batteries wear out or are replaced by more efficient batteries, millions of batteries are discarded, retained by the users in temporary storage, or recycled. Available data suggest that the percentage of cadmium metal recovered from rechargeable batteries in the United States increased to about 27 percent of the total amount available for recovery in 2007 from 10 percent in 1996, when battery storage is considered. During the same period, cadmium use in batteries on a tonnage basis has decreased about 32 percent (Kuck, 2006).

In order to estimate the effects of cadmium from the battery sector on the environment, it is necessary to quantify the amounts of cadmium contained in batteries that are recycled or discarded as waste. There are several reasons why it is difficult to make such estimates. One impediment to quantifying the amount of cadmium that is being recycled from NiCd batteries is that data on the amount of obsolete NiCd batteries processed by small recyclers in the United States or the amount exported from the United States for recycling are not readily available. Detailed production data by International Metals Reclamation Co., Inc. (INMETCO), of Ellwood City, Penn., the principal cadmium recycler in the United States, are considered proprietary.

The United States passed legislation in 1996 [U.S.C. 14301–14336 (Battery Act)] which removed certain barriers to the collection and recycling of rechargeable batteries (U.S. Environmental Protection Agency, 2002b). Although no mandatory Federal regulations exist that require cadmium recycling, 13 States (as of 2004) have passed legislation regulating battery labeling and removeability from consumer products and 8 States have “takeback” requirements that apply to NiCd batteries (Klimasauskas and others, 2006). A voluntary collection program for rechargeable batteries in Canada and the United States was initiated in 1994 by the Rechargeable Battery Recycling Corporation (RBRC). The RBRC data are reported in terms of the weight of batteries recycled by battery chemistry. Statistics by specific industrial or consumer battery classifications and their cadmium content are not reported. Although RBRC is the largest rechargeable battery recovery organization in the United States, other organizations also collect batteries for recycling, and some larger manufacturers collect batteries internally and send them directly to INMETCO or European recyclers (Boehme and Panero, 2003, p. 41).

Another difficulty in estimating the cadmium battery recycling rate in the United States is the measurement of cadmium battery consumption in the Nation. Cadmium metal consumption data attributed to battery production are not collected by the U.S. Geological Survey (USGS), although estimates of apparent consumption by end-use sector are available (U.S. Geological Survey, 2005). Data on cadmium contained in manufactured products that are imported to or exported from the United States also are not reported by the USGS. The U.S. International Trade Commission (ITC) reports data on the number of individual NiCd batteries imported to and exported from the United States annually and separately reports data on the number of manufactured products that use NiCd batteries. Data on cadmium content of these batteries are not reported by the ITC. Trade information reported by the ITC are aggregated totals of data supplied directly by importing and exporting companies; the accuracy of these data depend on whether the raw data are categorized and entered correctly.

A third impediment to estimation of the domestic cadmium battery recycling rate is the lack of data showing the distribution of cadmium content among the numerous battery types and products that become available for recycling each year. Although large industrial batteries are easy to collect and are recycled at a reported rate of at least 80 percent globally, smaller consumer NiCd batteries have a much lower recycling rate (Klimasauskas and others, 2006). The reported recycling information available for the United States does not provide separate estimates of the metal content of consumer and industrial battery types, so it is difficult to quantify the amount of cadmium recovered from each type.

In an attempt to overcome these limitations, this study integrated information on the domestic production and consumption of batteries containing cadmium, the quantity of cadmium that was imported and exported either in separate batteries or contained in prepackaged products, and the quantity of cadmium that was recovered by recycling of both consumer and industrial NiCd batteries. The scope of this study was limited by its assumptions related to average battery weight, cadmium content by battery class, and trade category distribution. The assumptions that were made for this analysis are shown in the appendix. The study supplements USGS reported mineral production and mineral commodity consumption statistics, which provide information essential for government, nongovernmental organizations, and the general public to gain a better understanding of how and where materials are used and draw inferences as to their possible effect on the environment and society.

This report describes the flow of cadmium contained in rechargeable NiCd batteries used in the United States for the period 1996 to 2007 and presents estimates of the amount of cadmium that was in use, in consumer storage, and recovered by recycling during this period. It also presents an estimate of how much cadmium may have entered the municipal solid waste stream between 1996 and 2007.

Contribution of the NiCd Battery Sector to the Rechargeable Battery Industry in the United States

It is necessary to understand the contribution of the NiCd battery sector to the U.S. rechargeable battery industry before it is possible to determine the material flow of cadmium in the United States from this sector. Historical supply sources, outflows, and principal end uses of cadmium metal in the United States are shown in figure 1. Domestic production of cadmium metal in the United States occurs in two principal ways. It is a byproduct of the smelting and refining of zinc and other metals and a remnant of the recycling of scrap containing cadmium. Other sources of secondary cadmium, such as electric arc furnace dust, electroplating waste, filter cakes, and sludges, are small and diminishing (Plachy, 2003b), so are not considered in this study. Although domestic cadmium consumption data are not compiled by the USGS, end use distribution data are reported annually (U.S. Geological Survey, 2005; Kuck, 2006; Tolcin, 2008a) on the basis of global end-use distribution percentages reported in the Mining Journal’s Annual Mining Review (Hugh Morrow, president, International Cadmium Association, oral commun., 2007). Distribution data on mineral consumption in the United States are not readily available by individual end use, so international estimates were used in this study to estimate the amount attributed to batteries. For 2007, approximately 83 percent of the cadmium consumed in the United States was estimated to have been consumed in batteries (Tolcin, 2008b), and most of the cadmium that was consumed came from batteries imported primarily from China and Japan. Although battery end-use applications vary over time, the principal end uses for NiCd batteries in 2007, based upon the amount of cadmium contained in each type, are industrial batteries (such as batteries used for aircraft, railroad, and uninterruptable power source and telecommunication applications) and small consumer rechargeable batteries (such as batteries used in cordless phones, power tools, household appliances, toys, and watches). Batteries are imported separately and as part of prepackaged consumer products.

Environmental concerns about cadmium toxicity and technological advances have led to the development and increased use of alternative battery chemistries (such as the nickel-metal hydride and lithium-ion batteries) within the rechargeable battery sector. Data on rechargeable battery sales in the United States are not readily available, but worldwide data published by the Institute of Information Technology, Inc. (Takeshita, 2008) show that (1) NiCd battery sales peaked in 1992, (2) the NiCd battery-producing industry largely shifted from Japan to China in the late 1990s, (3) the nickel-metal hydride battery market share increased significantly between 1992 and 1995, remaining constant at 20 to 25 percent of market share until 2000, and (4) the market share for the lithium-ion rechargeable battery has grown rapidly since 2000. These trends are shown in figure 2 based on global

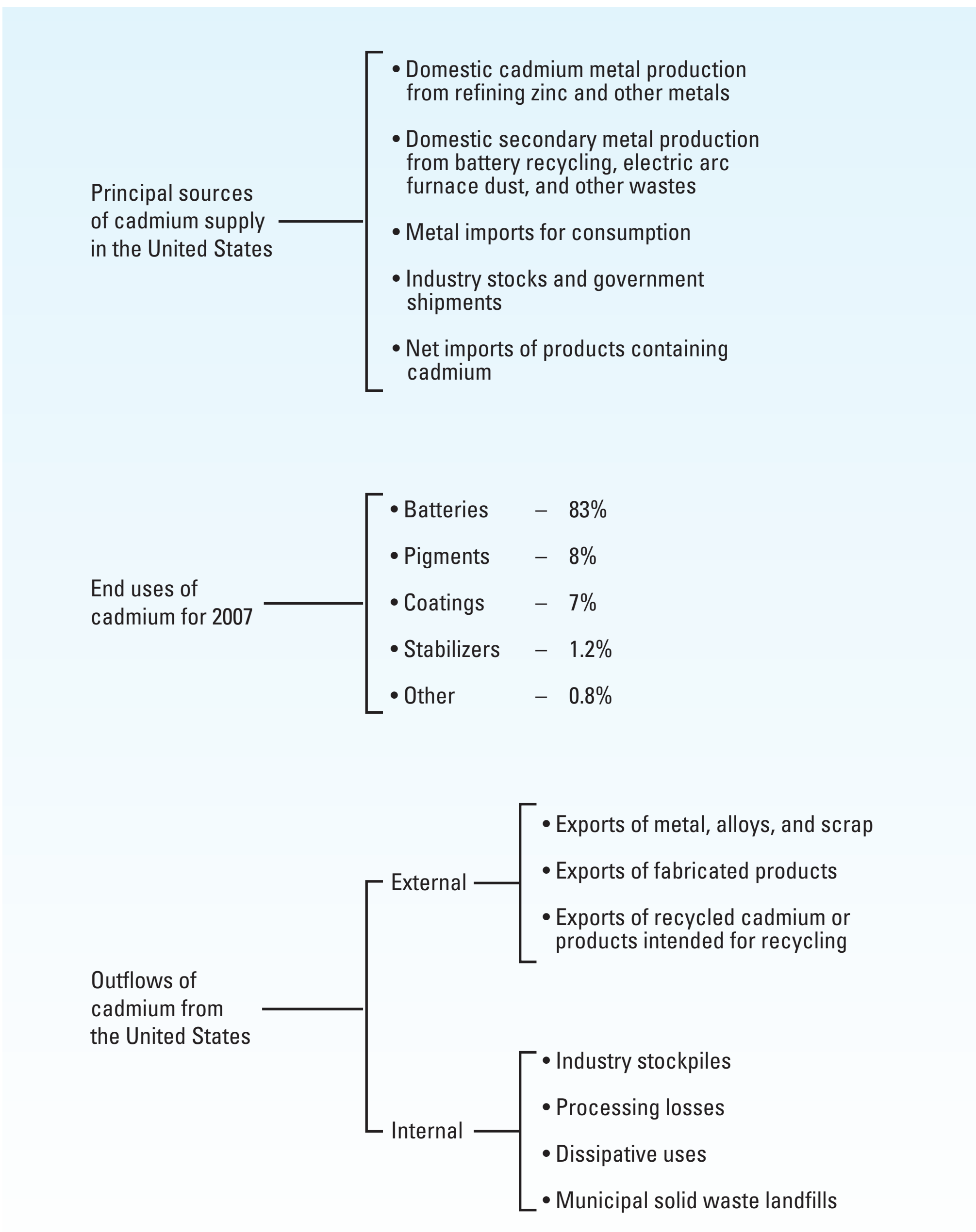


Figure 1. Principal cadmium end uses, outflows, and sources in the United States. Sources of cadmium in the United States and cadmium outflows from the United States as reported by Plachy (2003b). End use percentages reported for 2007 by Tolcin (2008b), and reflect global estimates.

NiCd battery sales (Takeshita, 2008). In 2007, NiCd batteries accounted for about 10 percent of the worldwide rechargeable battery market, nickel-metal hydride batteries accounted for about 10 percent, and lithium-based batteries accounted for about 80 percent when lithium-ion and lithium-polymer chemistries are included (Takeshita, 2008). In spite of declining NiCd battery sales, ITC data indicate that the United States imported more than 43 million NiCd batteries in 2007, and many more NiCd batteries were imported as part of prepackaged electronic products (U.S. International Trade Commission, 2009). Although this study focuses on the 1996 to 2007 period, some batteries produced prior to this period (when NiCd batteries accounted for a much larger market share, as shown in figure 2) are included when considering the amount of cadmium available for recycling during the study period.

Study Methodology

The study methodology applies a materials flow approach to help gain an understanding of what happens to materials we use from the time a material is extracted, through its processing and manufacturing, to its ultimate disposition. In order to describe the cadmium flows in the United States, it is necessary to estimate cadmium consumption in the Nation. Apparent consumption of cadmium metal in the United States, as calculated by the USGS using the production data of individual companies, U.S. foreign trade statistics, and reported inventory stock changes, is reported annually in the USGS Minerals Yearbook and USGS Mineral Commodity Summaries series. For this study, apparent consumption (*C*) is defined as mine production (*MP*) plus secondary refined production (*SP*) plus metal imports for consumption (*IM*) plus adjustments for industry and Government stock changes (*ADJ*) minus metal exports (*EX*).

$$C = MP + SP + IM + ADJ - EX$$

Such consumption data, however, do not include the amount of cadmium contained in manufactured products that are imported to and exported from the United States. Available data indicate that the amount of cadmium metal contained in products imported into the United States, particularly from the NiCd battery sector, is much larger than the amount of cadmium that is annually consumed from domestic refined metal production.

Import and export trade data, expressed in terms of the number of battery units, as reported by the ITC (U.S. International Trade Commission, 2009) were reviewed for this study. Data were available for 1996 to 2007, so this period was chosen for study. The 10-digit Harmonized Tariff Schedule of the United States (HTS) classifications were reviewed to determine which classifications contained NiCd batteries or products using these batteries. Import and export data were collected for each selected classification, including classifications for separate storage batteries and prepackaged products thought to contain NiCd batteries.

Because NiCd battery trade data are reported by the ITC in very general categories for separate batteries and batteries contained in prepackaged products, it was necessary to estimate the battery distribution within each category prior to determining the amount of cadmium included in that category. The distribution of some categories was straightforward; for others, many assumptions were required. Assumptions are presented in the appendix.

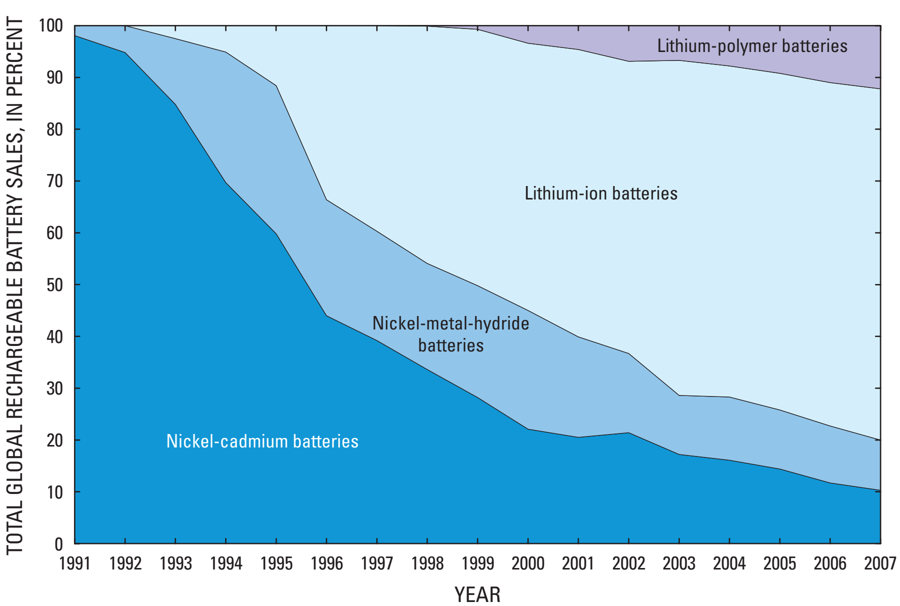


Figure 2. Percentage of global rechargeable sales for the principal battery types, 1986–2007. Data modified from Takeshita (2008).

Battery distribution assumptions related to the category "nickel-cadmium storage batteries, not elsewhere specified" (HTS code 8507.30.8090), which includes most industrial NiCd batteries, requires further discussion because of the quantity of batteries found in this category. The data indicate that this category includes large industrial batteries and small consumer batteries and battery components. Trade data were reported as both units of quantity and value, by country. After discussions with ITC personnel and the USGS cadmium specialist, it was decided that the calculated unit value would provide a means of estimating the relative percentage of distribution between these two imported battery types, by country. A sliding scale was set up to determine the percentage attributed to industrial batteries by using the reported unit value. In general, the higher the unit value reported for a particular country, the greater was the percentage of industrial batteries attributed to that country. The total number of units attributed as either industrial type batteries or consumer type batteries were developed by aggregating the estimates for the individual countries. Estimates were found to be in close agreement with nonpublic information available to the ITC, which provided support for this data estimation methodology.

Estimates of the average cadmium content included in each selected HTS NiCd battery classification were developed. Because individual HTS classifications may include more than one battery type, it was necessary to review each classification and make assumptions as to the distribution of battery types for each category. Worldwide market data were used as an approximation for the types of batteries included in each of the major battery applications in the United States (Pillot, 2004). Because data were most often expressed in terms of the quantity of batteries, an estimate for the average amount of cadmium contained within each battery or battery product classification was developed so that an estimate of the total amount of cadmium contained in that classification could be made. The amount of cadmium contained in NiCd batteries varies substantially with battery type and slightly by manufacturer. Estimates of cadmium content were based on data provided by selected battery manufacturers for various battery types. On the basis of the reported description for each classification, a specific battery or group of batteries was selected to depict the "average" battery for that classification. From the weights of these batteries as reported by the manufacturers and assuming a typical cadmium content for that battery type (Vangheluwe and others, 2005, p. 11), cadmium content for each classification was determined. The quantity of cadmium annually used in batteries enclosed in products for specific end-use applications was estimated by integrating ITC trade data for these specific products, estimates of battery consumption for that particular end-use sector as provided by the International Cadmium Association (Morrow, 2005; International Cadmium Association, 2008) and Avicenne Developpement (Pillot, 2004, 2005, 2008). In cases where the classification was known to use battery types other than NiCd batteries, the percentage attributable to NiCd batteries was developed. Estimates for the average amount of cadmium contained in generalized battery types are summarized in the appendix.

Analysis of the Data

Total Consumption

Estimates for the amount of cadmium contained in NiCd batteries imported to and exported from the United States for selected years within the 1996–2007 study period, based on ITC data, are summarized in table 1. Trade classifications included in this analysis also are reported in table 1. Estimates for the entire study period indicate that the United States imported many more NiCd batteries than it exported, classifying the country as a net importer of cadmium contained in rechargeable batteries. The distributions of cadmium metal contained in imported and exported NiCd batteries and battery products for the study period are shown in figures 3 and 4, respectively. In 2005, about 59 percent (by weight) of the imported cadmium in NiCd batteries was contained in batteries in prepackaged consumer products, about 26 percent of the cadmium was contained in small sealed consumer batteries, and about 15 percent of the cadmium was contained in industrial batteries. Although it may appear that the percentage attributed to industrial batteries increased between 2005 and 2007, export data suggest that many of these were reexported from the United States to other countries. In terms of cadmium content of exported batteries and battery products, more than one-half of the exported cadmium contained in NiCd batteries (by weight) was contained in batteries enclosed in prepackaged products for most of the study period. The United States imported about 1,500 t more cadmium in NiCd batteries than it exported in 2007.

Combining these data with cadmium production and consumption data reported annually by the USGS allows the total consumption of cadmium metal in the United States to be calculated for each year of the study period. For this part of the study, total consumption in the United States is defined as apparent consumption + cadmium contained in imported products – cadmium contained in exported products. The quantity of each component of total cadmium consumption in the United States for all sectors in 2007 is shown in figure 5; the battery sector accounted for 83 percent of cadmium consumption for all sectors in that year. For 2007, the United States apparent consumption of cadmium metal was reported to be 585 t (Tolcin, 2008a). When the quantity of cadmium contained in imported and exported manufactured products (shaded boxes) is taken into account, however, the total consumption of cadmium metal in the United States is estimated to be about 2,500 t. Much of the difference between the two estimates can be attributed to the inclusion of cadmium contained in imported and exported manufactured products in the total consumption data shown in figure 5.

Table 1. Estimates of the amount of cadmium metal contained in nickel-cadmium batteries imported to and exported from the United States, for selected years.

[Data are reported in metric tons of cadmium metal contained in selected batteries and products containing batteries and are modified from U.S. International Trade Commission data (2009) and discussions with Peter Kuck (U.S. Geological Survey commodity specialist, oral commun., 2006). Values may not add to totals shown because of rounding. g/unit, grams per unit; <, less than]

Classification	1996		1998		2000		2002		2004		2006	
	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
Industrial storage batteries												
Electrically-powered vehicle batteries[1]	<1	NA	<1	NA	<1	NA	<1	NA	<1	NA	<1	NA
Lamps/emergency lighting[2]	140	99	130	120	210	170	180	130	160	79	130	31
Military batteries, reported separately[3]	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Industrial batteries[4]	130	NA	82	NA	390	NA	150	NA	250	NA	220	NA
Subtotal: industrial nickel-cadmium batteries	**270**	**99**	**210**	**120**	**600**	**170**	**330**	**130**	**410**	**79**	**350**	**31**
Consumer storage batteries												
Sealed consumer batteries, separate[5]	1,600	130	1,000	150	960	140	630	85	530	41	440	42
Miscellaneous batteries, separate[6]	32	NA	31	NA	18	NA	13	NA	7	NA	7	NA
Subtotal: consumer nickel-cadmium batteries	**1,600**	**130**	**1,000**	**150**	**980**	**140**	**640**	**85**	**540**	**41**	**450**	**42**
Batteries enclosed in products												
Batteries enclosed in power tools[7]	150	28	250	33	380	19	460	0	560	0	640	0
Batteries enclosed in cordless phones[8]	140	7	210	19	250	21	270	29	250	20	220	16
Batteries enclosed in cameras/camcorders[9]	83	<1	47	<1	41	<1	42	<1	16	<1	2	<1
Batteries enclosed in portable radios[10]	1	<1	1	<1	1	<1	1	<1	<1	<1	<1	<1
Batteries enclosed in shavers[11]	13	<1	15	<1	16	<1	16	<1	33	<1	8	<1
Batteries enclosed in electric toothbrushes[12]	4	0	8	0	13	0	47	0	51	0	14	0
Batteries enclosed in portable vacuum cleaners[13]	27	36	34	20	45	13	67	15	34	19	8	7
Batteries enclosed in flashlights[14]	35	<1	50	<1	58	<1	56	<1	56	0	21	0
Clock batteries, reported separately[15]	1	<1	1	<1	2	<1	2	<1	2	<1	0	0
Subtotal: nickel-cadmium batteries in products	**460**	**71**	**620**	**72**	**810**	**53**	**960**	**44**	**1,010**	**39**	**920**	**23**
Total	**2,300**	**300**	**1,800**	**340**	**2,400**	**360**	**1,900**	**260**	**2,000**	**160**	**1,700**	**96**
Net cadmium from imported batteries[16]	**2,000**		**1,500**		**2,000**		**1,700**		**1,800**		**1,600**	

[1] Includes cadmium contained in separate nickel-cadmium storage batteries imported as Harmonized Tariff Schedule of the United States (HTS) code 8507.30.4000 (166 g/unit), as reported by the International Trade Commission.

[2] Includes cadmium contained in nickel-cadmium batteries enclosed in portable lamps imported as HTS code 8513.10.4000 and export code 8513.10.0000 (18 g/unit). These classifications include emergency lighting applications, but exclude flashlights. Note that most, if not all, of the imported material in this classification is re-exported.

[3] Includes cadmium contained in nickel-cadmium batteries enclosed in military products imported as HTS codes 91040000520, 9104.00.1020, 9104.00.2520, 9104.00.3020, 9104.00.4520, and 9104.00.5030, and HTS export code 9104.00.0000 (2.9 g/unit).

[4] Includes cadmium contained in separate nickel-cadmium storage batteries imported as HTS code 8507.30.8090 (1.2 kg/unit). Industrial batteries determined by country on a unit value basis.

[5] Includes cadmium contained in separate nickel-cadmium storage batteries imported as HTS code 8507.30.8010 (8.4 g/unit), and exported as HTS codes 8507300000 and 8507.30.0050 (8.4 g/unit).

[6] Includes cadmium contained in separate nickel-cadmium storage batteries imported as HTS code 8507.30.8090 (8.4 g/unit), estimated from residual after industrial battery component removed.

[7] Includes cadmium contained in nickel-cadmium batteries enclosed in power tools imported as HTS codes 8467.21.0000 and 8508.10.0010 and export code 8508.10.0010 (60 g/unit).

[8] Includes cadmium contained in nickel-cadmium batteries enclosed in cordless phones imported and exported as HTS code 8517.11.0000 (11.2 g/unit).

[9] Includes cadmium contained in nickel-cadmium batteries enclosed in camcorders imported and exported as HTS codes 8525.40.8020 and 8525.40.8050, and import codes 8525.40.0020 and 8525.40.0050 (22.4 g/unit). For the years 1996–1999, still image cameras containing nickel cadmium batteries HTS codes 8525.40.0090, 8525.40.4000, and 8525.40.8085 were included in this classification.

[10] Includes cadmium contained in nickel-cadmium batteries enclosed in portable radios imported and exported as HTS code 8527.12.0000 (2.9 g/unit).

[11] Includes cadmium contained in nickel-cadmium batteries enclosed in shavers imported and exported as HTS code 8510.10.0000 (2.9 g/unit).

[12] Includes cadmium contained in nickel-cadmium batteries enclosed in electric toothbrushes imported as HTS code 8509.80.0045 (2.9 g/unit).

[13] Includes cadmium contained in nickel-cadmium batteries enclosed in portable vacuum cleaners imported and exported as HTS code 8509.10.0020 (136 g/unit).

[14] Includes cadmium contained in nickel-cadmium batteries enclosed in flashlights imported as HTS code 8513.10.2000 (13.8 g/unit).

[15] Includes cadmium contained in nickel-cadmium batteries enclosed in clocks imported as HTS codes 9103.10.2020, 9103.10.2040, 9103.10.4030, 9103.10.4060, 9103.10.8030, 9103.10.8060, 9105.11.4030, 9105.11.4050, 9105.11.8040, 9105.11.8070, 9105.21.4030, 9105.21.8050, 9105.91.4030, 9105.91.8050, 9106.90.5520, 9109.11.1030, 9109.11.2030, 9109.11.4030, 9109.11.6030, 9109.19.1030, 9109.19.2030, 9109.19.4030, 9109.19.6030, and export code 9103.10.0000 (2.9 g/unit).

[16] Net value reflects quantity imported minus quantity exported; a positive number indicates that the quantity imported is greater than the quantity exported. Totals may not add owing to rounding of data.

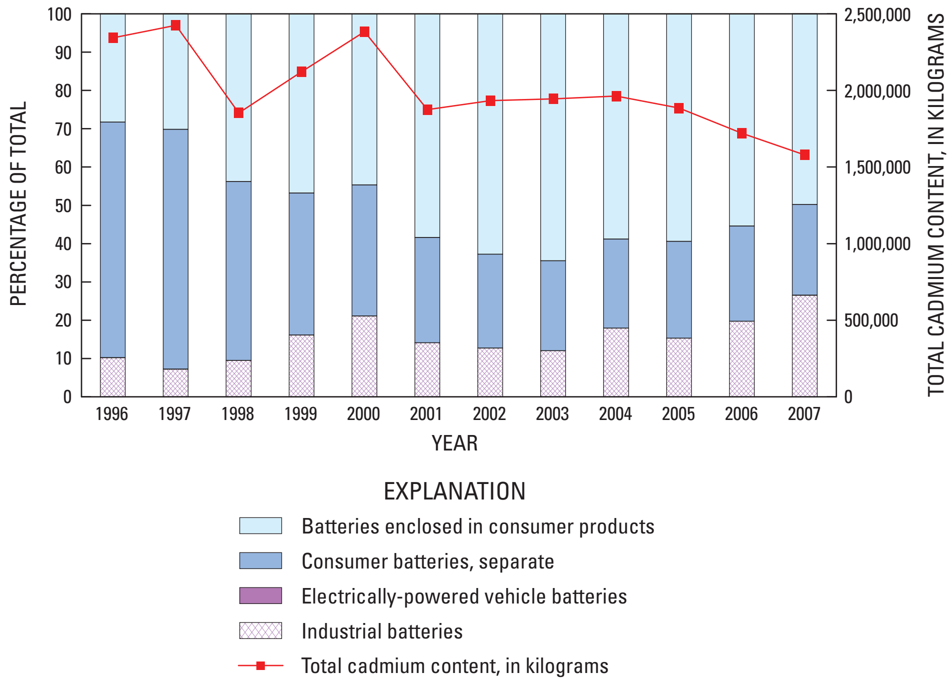


Figure 3. Distribution of cadmium metal contained in NiCd batteries and battery products imported to the United States, 1996–2007. Based on data available from the U.S. International Trade Commission (2009). Many of the industrial batteries imported into the United States are reexported.

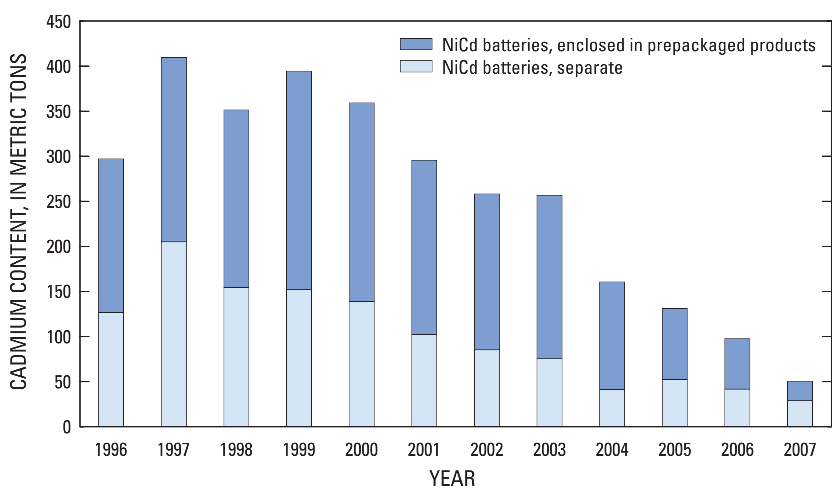


Figure 4. Distribution of cadmium metal contained in NiCd batteries and battery products exported from the United States, 1996–2007. [Based on data available from the U.S. International Trade Commission (2009).]

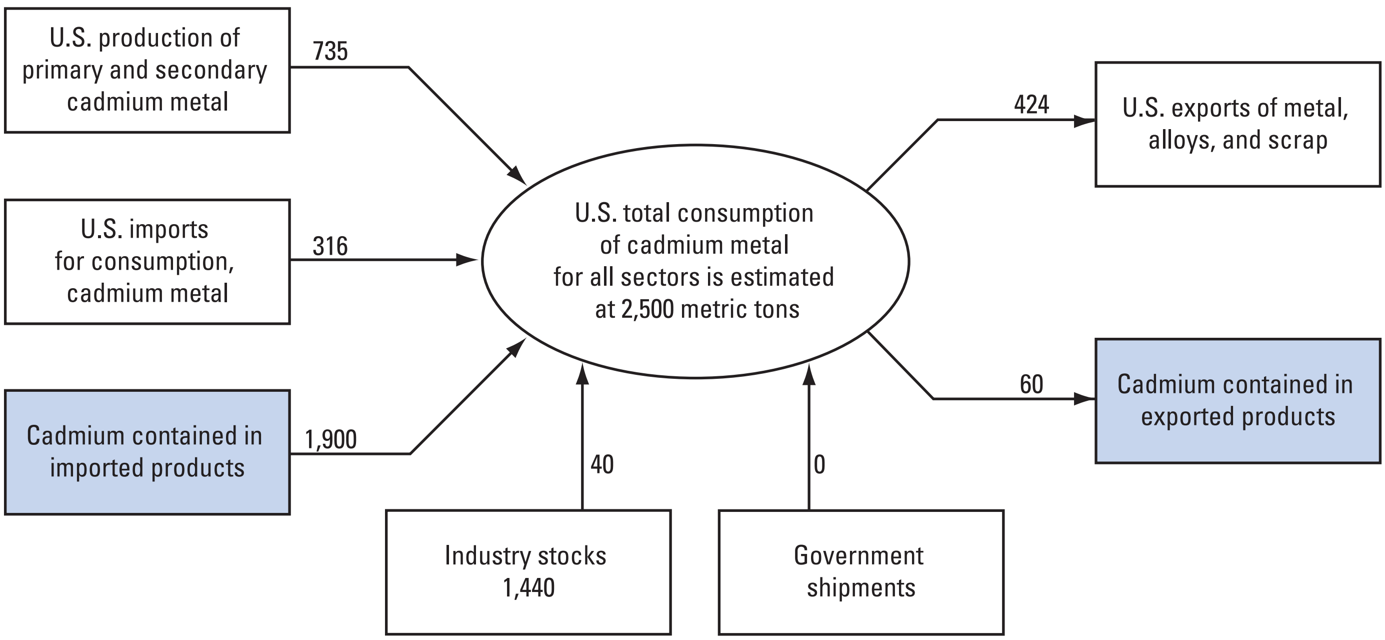


Figure 5. Total consumption of cadmium metal in the United States in 2007. Boxes represent inflow and output of cadmium. Values represent 2007 flow estimates expressed in metric tons of cadmium metal, as adapted from data reported by the U.S. International Trade Commission (2009) (shaded boxes), the U.S. Geological Survey Mineral Yearbook series 2005, 2006, 2007, and the U.S. Geological Survey Mineral Commodity Summaries 2008 (Tolcin, 2008). Values may not add to totals shown because of rounding.

Recycling

Estimates of the amount of cadmium that is available for recycling or disposal were developed by analysis of a number of factors. Data on cadmium metal apparent consumption and cadmium use attributed to batteries have been reported by the USGS (Plachy, 2001, 2002, 2003a, 2004, 2005; Kuck, 2006; U.S. Geological Survey, 2005; Tolcin, 2008b). Estimates of the net amount of cadmium contained in traded batteries (imports minus exports, as reported in table 1) were developed using ITC data (U.S. International Trade Commission, 2009). The length of time between battery production and recycling or disposal is a function of battery service life and the time the battery is retained by the user after it is considered obsolete. Battery service life distribution patterns (shown in figure 6 for an industrial battery with an assumed 15-year service life and an assumed storage life of 1 year and a consumer battery with an assumed 4-year service life and 4-year storage life) were developed on the basis of data reported by Sanyo Corporation (Sanyo Energy (USA) Corporation, 2006), discussions with C. Norman England, president, Rechargeable Battery Recycling Corporation (oral commun., 2006), and estimates from Takeshita (2008). Battery discards are assumed to be a function of rates of acquisition of replacement batteries or associated products by the consumer, battery or associated product failure, and rates of removal of obsolete batteries from storage. The discard rate was determined to be greatest near the end of battery life (fig. 6). The amount of cadmium contained in batteries discarded for each year within the 1996–2007 study period was estimated from battery consumption data from prior years, estimated battery service life distribution patterns, and battery end-use application. Further assumptions related to battery life are reported in the appendix. The amount of cadmium recovered from batteries annually recycled in the United States for the study period was determined based on a compilation of data from RBRC, INMETCO, and other small U.S. recyclers. Data on the amount of material exported for recycling was not available, so was not included in the recovery estimates. Table 2 lists estimates of the amount of cadmium contained in consumer batteries, industrial batteries, and batteries in products available for recovery and estimated cadmium recovery percentages in the United States for the period 1996 through 2007. If the amount of cadmium recovered from exported batteries was included, the overall recovery of cadmium from batteries consumed in the United States would be greater than the values shown in table 2. Figure 7 compares the amount of cadmium recovered from spent batteries with the amount of cadmium contained in batteries retained by users, exported for recycling, and sent for disposal.

Table 2 shows that the overall cadmium recovery rate has been increasing because (1) more batteries have reached the end of their service life, (2) advancements in battery technology have provided incentives for consumers to replace older batteries with newer, more efficient batteries, and (3)

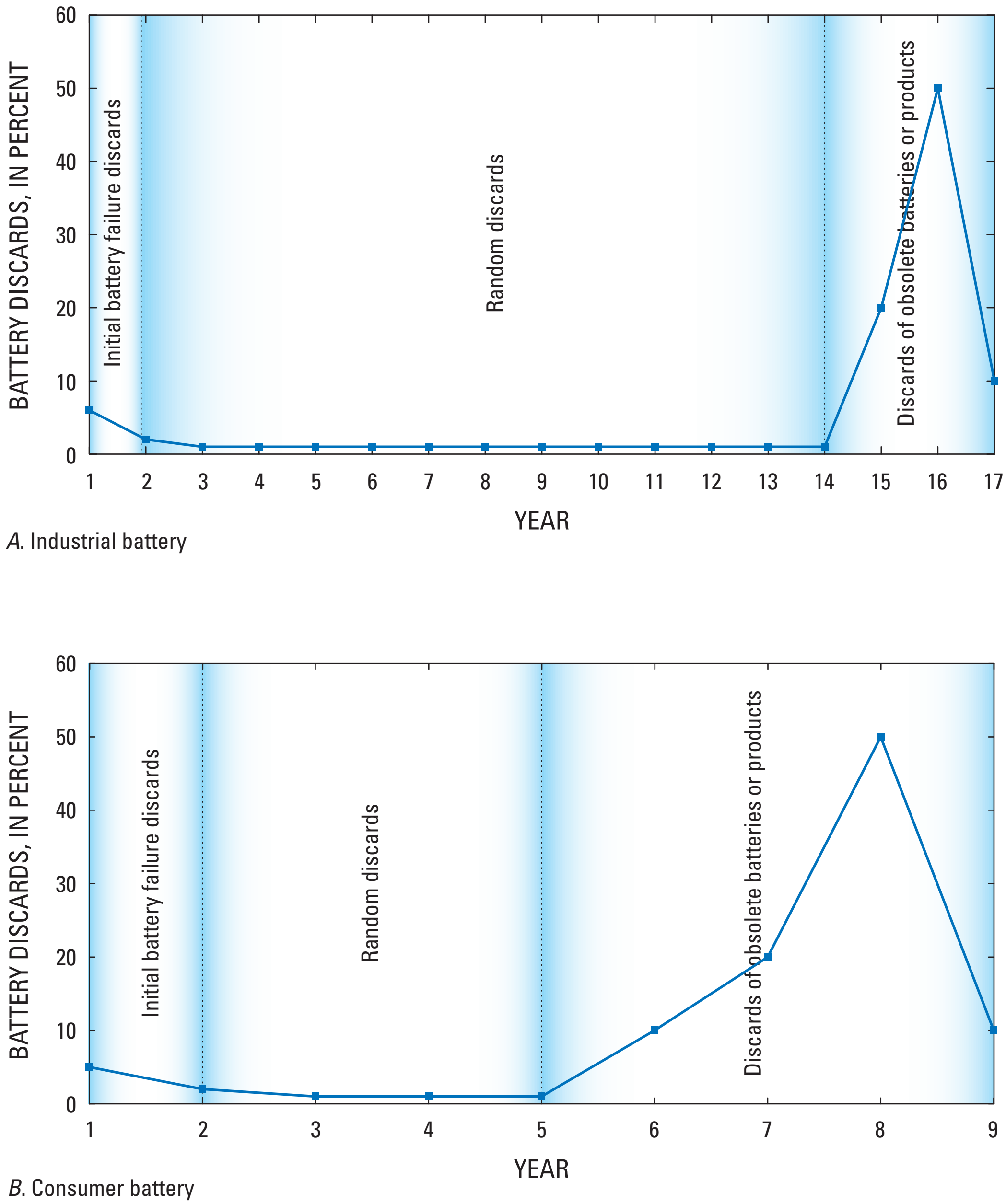


Figure 6. Distribution patterns for *A*, industrial battery with an estimated 15-year service and an average storage life of 1 year, and *B*, consumer battery with an estimated service life of 4 years and an average storage life of 4 years. Based on data provided by Sanyo Energy (USA) Corporation (2006) and C. Norman England, Rechargeable Battery Recycling Corporation, oral commun., 2009.

higher metal prices have encouraged recycling. The percentages reported in table 2 reflect a comparison of the amount of cadmium collected for recycling by year with the estimate of the amount available for recovery in that year for a mixture of industrial and consumer batteries. The amount available includes estimates of the amount contained in batteries that became obsolete and batteries that were discarded by consumers and industrial users. The amount of material retained by users in temporary storage was estimated annually, but that material was not included in the recovery estimate for that year; it was, however, considered in a later year as determined by the battery storage life. For example, a consumer battery that reached the end of its service life in 2001 was assumed to become available for recycling or disposal in 2005, or 4 years after its assumed obsolescence, based on an estimated average storage life of 4 years. The average amount of cadmium that was recovered from batteries increased from about 10 percent of the total amount of cadmium believed to be contained in such batteries in 1996 to about 27 percent in 2007. The values reported in table 2 reflect estimated cadmium recovery rates rather than battery recovery rates, as have been reported by RBRC (Burchill, 2000; Rechargeable Battery Recycling Corporation, 2005, 2006, 2008). The EPA issued a report in 2003 that stated that, although lead-acid batteries had the highest recycling rate in 2003 (about 93 percent) metals contained in consumer electronics (including cadmium in batteries) had a

Table 2. Estimated amount of contained cadmium in nickel-cadmium batteries available for recovery and recovery percentages in the United States for 1996–2007.

[Units reported in metric tons of contained cadmium. Battery life estimated using data reported by selected manufacturers. Values may not total because of rounding. Amounts available for recycling derived from Plachy (2001, 2002, 2003a, 2004, 2005), Kuck (2006), and U.S. International Trade Commission (2009). Amounts recycled derived from Burchell (2000), Rechargeable Battery Recycling Corporation (2006, 2007, 2008), and Warren (2006). NA, not available; --, not applicable]

	Industrial batteries	Consumer batteries	Batteries in products	Total all battery types	Percentage of cadmium metal recoverved from the reservoir of available NiCd batteries
Estimated battery service life (years)	15	4	4	NA	--
Estimated storage life (years)	1	4	4	NA	--
Cadmium available for recycling in 1996[1]	260	2,400	1,200	3,800	--
Cadmium in batteries collected for recycling in 1996[2]	NA	NA	NA	390	10
Cadmium available for recycling in 1997[1]	250	2,300	1,200	3,800	--
Cadmium in batteries collected for recycling in 1997[2]	NA	NA	NA	400	11
Cadmium available for recycling in 1998[1]	300	2,000	1,000	3,300	--
Cadmium in batteries collected for recycling in 1998[2]	NA	NA	NA	470	14
Cadmium available for recycling in 1999[1]	350	2,000	1,100	3,400	--
Cadmium in batteries collected for recycling in 1999[2]	NA	NA	NA	480	14
Cadmium available for recycling in 2000[1]	440	2,000	1,100	3,500	--
Cadmium in batteries collected for recycling in 2000[2]	NA	NA	NA	510	14
Cadmium available for recycling in 2001[1]	530	1,800	1,000	3,400	--
Cadmium in batteries collected for recycling in 2001[2]	NA	NA	NA	520	15
Cadmium available for recycling in 2002[1]	650	1,900	1,100	3,600	--
Cadmium in batteries collected for recycling in 2002[2]	NA	NA	NA	560	15
Cadmium available for recycling in 2003[1]	730	2,000	1,100	3,800	--
Cadmium in batteries collected for recycling in 2003[2]	NA	NA	NA	700	18
Cadmium available for recycling in 2004[1]	790	1,800	1,200	3,900	--
Cadmium in batteries recycled in 2004[3]	NA	NA	NA	700	18
Cadmium available for recycling in 2005[1]	750	1,300	1,400	3,500	--
Cadmium in batteries recycled in 2005[3]	NA	NA	NA	720	21
Cadmium available for recycling in 2006[1]	620	1,100	1,400	3,100	--
Cadmium in batteries recycled in 2006[4]	NA	NA	NA	770	25
Cadmium available for recycling in 2007[1]	640	980	1,500	3,100	--
Cadmium in batteries recycled in 2007[4]	NA	NA	NA	840	27
Total cadmium available for recycling 1996–2007	**6,300**	**22,000**	**14,000**	**42,000**	**--**

[1] Assumed using the battery service and storage lives as shown and using the distribution patterns shown in figure 6. Material is considered available for recycling after having been used for the specified service and subsequently stored for the specified numver of years.

[2] Calculated on the basis of reported pounds of batteries collected for recycling multiplied by contained cadmium percentage multiplied by assumed 95% refinery recovery rate.

[3] Calculated on the basis of battery recovery figures reported by Rechargeable Battery Recycling Corporation and unpublished data from International Metals Reclamation Company, Inc., oral commun. (2006).

[4] Calculated on the basis of battery recovery figures reported by Rechargeable Battery Recycling Corporation, unpublished data from International Metals Reclamation Company, Inc., oral commun. (2006), and data provided by Linda Gabor, Rechargeable Battery Recycling Corporation, oral commun. (2009).

recycling rate of about 10 percent (U.S. Environmental Protection Agency, 2003). Ancillary unpublished data provided by INMETCO indicated that the effective recovery rate of all types of consumer batteries in 2005 was about 16 percent; the effective recovery rate for industrial batteries was about 86 percent. These figures are generally in line with reported recycling rates of about 20 percent for consumer batteries and 80 percent for industrial batteries (Plachy, 2003b).

An important corollary to the cadmium recovery data reported in table 2 is shown in figure 7, which reveals that, although the amount of NiCd batteries collected for recycling (Warren, 2006) is gradually growing, the amount of cadmium recovered domestically from these batteries is still small in comparison to the amount that is unrecovered or sent overseas for recovery. After use, millions of NiCd batteries are "retired"; they are stored, exported for recycling, or discarded. The magnitude of unrecycled cadmium contained in batteries, estimated to be about 42,000 t for the 12-year period since 1996 (the implementation date of the Battery Act), is illustrated in figure 7. Even though there is a significant amount of cadmium that is being retained by users as batteries, exported for recycling, or sent for disposal, the overall trend since 1996 reflects increased recycling and the decreasing consumption of NiCd batteries in favor of other battery types.

A 2005 survey conducted by RBRC found that, in the United States, consumers daily use an average of six wireless products that require rechargeable batteries (Rechargeable Battery Recycling Corporation, 2005). About one-half of the survey respondents reported that they had obsolete batteries or old unused electronic products containing batteries of various types stored in their homes. Others reported that they had discarded obsolete batteries. The RBRC also assumed at least 50 percent of batteries not in use but not yet recycled are being "hoarded" (C. Norman England, Rechargeable Battery Recycling Corporation, oral commun., 2006). Similarly, in a study conducted by Franklin Associates, Ltd. for the EPA (U.S. Environmental Protection Agency, 2002a), it was assumed that 50 percent of NiCd rechargeable consumer batteries are discarded within the year purchased and 50 percent are retained for a period of up to 4 years. Therefore, for the purpose of estimating the quantity of batteries that are available for recycling in any year of the study period, it was assumed that up to 50 percent of the consumer batteries that become available for recycling in any given year do not immediately get recycled; a lag time of up to 4 years was assumed for this material.

Table 3 reports U.S. cadmium metal statistics as reported by the USGS (U.S. Geological Survey, 2005; Tolcin, 2008a) and estimates derived from this study. About 3,100 t of cadmium was contained in batteries available for recycling in 2007. This material came from three principal sources: (1) waste from battery production in the United States, (2) battery discards, and (3) cadmium contained in spent batteries previously held in temporary storage. Approximately 840 t of cadmium was recovered by recycling, about 1,300 t of cadmium

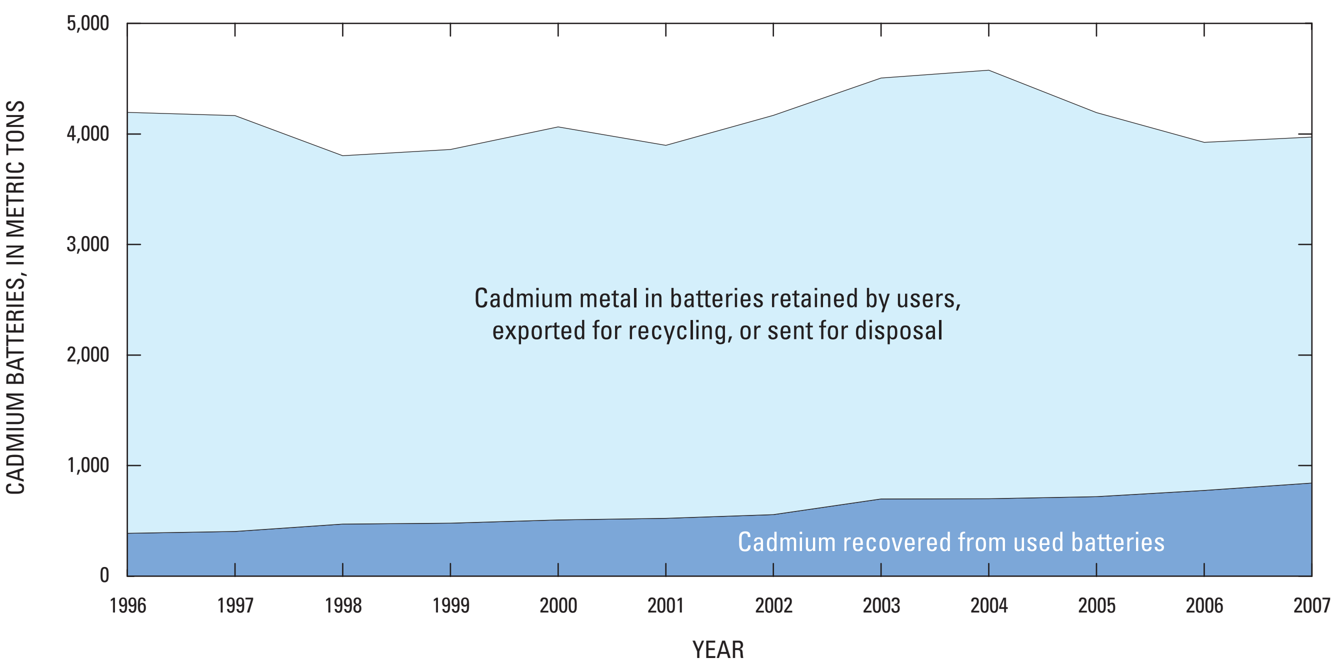


Figure 7. Estimated quantity of cadmium recovered from the recycling of batteries in the United States, 1996–2007. Estimated from U.S. International Trade Commission and U.S. Geological Survey data using a discrete distribution to estimate the amount of material available for recovery based on an assumed battery life (service plus storage) of 16 years for industrial batteries and 8 years for consumer batteries and those contained in prepackaged consumer products.

Table 3. Estimates of cadmium metal attributed to rechargeable batteries in the United States, 1996–2007.

[Weight units are reported in metric tons. Annual estimates of material available for recovery were developed using estimates for battery service life, the number and length of time spent batteries are stored or retained by users, and the amount recovered in the United States. Estimates of the quantity of batteries sent outside the United States for recovery are nor included in this analysis. Data are derived from U.S. Geological Survey (2005); Tolcin (2008); International Trade Commission (2009).]

Year	Cadmium metal used by the U.S. battery sector from domestic and imported sources	Cadmium metal in net battery trade	Cadmium metal contained in batteries available for recovery	Cadmium metal recovered from used batteries	Cadmium metal in spent batteries stored or retained by users	Cadmium metal sent for disposal	Percentage of cadmium metal recovered from the reservoir of available material when stored material is excluded
1996	1,500	2,000	3,800	390	1,800	1,600	20
1997	1,700	2,000	3,800	400	1,800	1,600	20
1998	1,500	1,500	3,300	470	1,500	1,300	26
1999	1,400	1,700	3,400	480	1,500	1,400	25
2000	1,500	2,000	3,500	510	1,600	1,400	27
2001	800	1,600	3,400	520	1,500	1,400	27
2002	1,300	1,700	3,600	560	1,500	1,500	27
2003	800	1,700	3,800	700	1,600	1,500	32
2004	1,400	1,800	3,900	700	1,600	1,600	30
2005	600	1,800	3,500	720	1,400	1,400	34
2006	500	1,600	3,100	770	1,300	1,000	43
2007	500	1,500	3,100	840	1,300	960	47

was contained in batteries retained in temporary storage by users, and about 960 t of cadmium was contained in batteries sent for disposal.

Estimates for recycling rates vary by battery chemistry and end-use. Generally, industrial batteries have a higher recycling rate than do small consumer batteries. Although small consumer batteries are often retained for significant periods before being discarded, industrial batteries are often recycled soon after they are considered obsolete. Because of uncertainty associated with the length of time and amount of material held in storage before disposal, some industry analysts do not consider stored material when estimating recycling rates. Table 3 reports estimates of the percentage of cadmium metal recovered from the reservoir of available batteries when stored material is excluded. As with the values reported in table 2, these show that the amount of cadmium recovered from recycled batteries has increased over the 12-year study period. Table 3 values show cadmium recovery from recycled batteries increased to 47 percent in 2007 from 20 percent in 1996.

Figure 8 summarizes estimates for cadmium municipal solid waste (MSW) generation in the United States for 2007 from NiCd batteries. The EPA reports that about 20 percent of the material that was not recycled was incinerated and about 80 percent was sent to landfills (U.S. Environmental Protection Agency, 2003). About 540 t (98 percent) of metals was recovered from incineration by air pollution abatement devices. Cadmium-bearing ash from the incineration process is collected and sent to MSW or hazardous waste landfills. In 2007, approximately 4 t of cadmium attributed to batteries entered the atmosphere from MSW incineration.

The EPA estimated that about 1,900 t of cadmium from household batteries was discarded as MSW in 2000 (U.S. Environmental Protection Agency, 2002a, p. 7, 157). Considering that this figure did not include industrial or military batteries (assumed by Franklin Associates, Ltd., to account for about 25 percent of cadmium in batteries), this estimate is higher than the estimate from this analysis for the same year (approximately 1,390 t of cadmium was contained in consumer batteries that entered the MSW stream).

Summary

Because cadmium is potentially toxic to humans and the environment under certain conditions, a thorough understanding of the use of products containing this metal and the pattern of use and disposal is warranted. In 2007, nickel-cadmium batteries accounted for 83 percent of the cadmium apparent consumption in the United States. The cadmium metal content of imported products (for all end uses) in 2007 was estimated to be about 1,900 t, or about 160 percent of the reported production of cadmium metal from all primary and secondary sources in the United States. Since nickel-cadmium batteries

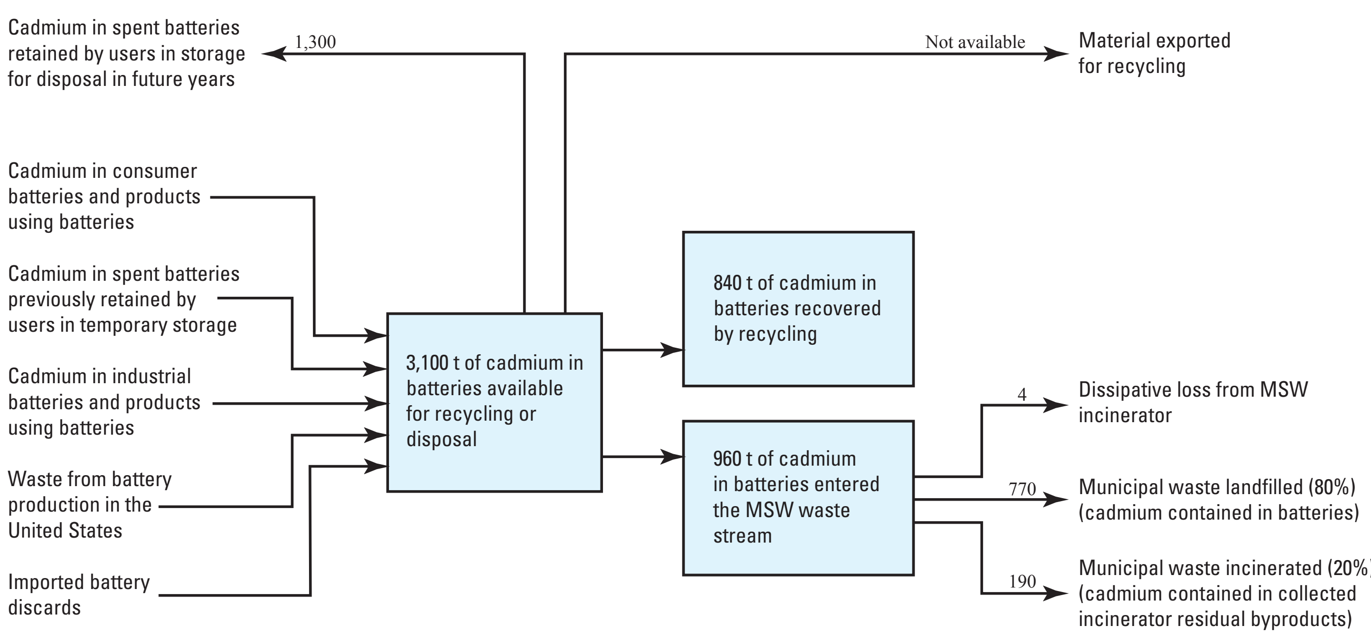


Figure 8. Estimates for cadmium municipal solid waste (MSW) generation in the United States for 2007 from nickel-cadmium batteries. Units are espressed in metric tons (t) and may not add to total shown owing to rounding. Estimates are based on the assumption that up to 50 percent of batteries spent in any given year remain in temporary storage for up to 4 years prior to entering the MSW stream (Rechargeable Battery Recycling Corporation, 2005) and that waste is split between incinerator (20%) and landfill disposition (80%) (U.S. Environmental Protection Agency, 2003). Values and percentages were found to vary from year to year.

began to be commercially recycled in 1995, cadmium recovery from batteries has steadily increased to the 2007 level of about 27 percent, much of which comes from the recycling of industrial and commercial battery types. Although the market share of nickel-cadmium batteries has decreased since 1996, many of these batteries are still being produced domestically or are imported into the United States each year; others continue to be used, are being stored, or have been discarded. More than 42,000 t of cadmium contained in batteries are estimated either to have been discarded over the 12-year study period or remain temporarily in household storage. In 2007, about 25 percent of the cadmium contained in batteries that were considered available for recovery ended up in municipal solid waste landfills. Dissipated losses from the incinerator accounted for about 4 t of cadmium in 2007.

Acknowledgments

The author would like to acknowledge the technical contributions of George Kerchner, Executive Director of the Portable Rechargeable Battery Association, Hugh Morrow, Northeast Regional Recycling Manager, Rechargeable Battery Recycling Corporation, and David Weinberg, a representative of both of these organizations.

References Cited

Battery Association of Japan, 2009, Secondary battery sales statistics by volume: Tokyo, Japan, Japanese Ministry of Economy, Trade, and Industry, accessed February 23, 2009, at *http://www.baj.or.jp/e/statistics/index06.html*.

Boehme, S.E., and Panero, M.A., 2003, Pollution prevention and management strategies for cadmium in the New York/New Jersey harbor: New York, New York Academy of Sciences, November, 64 p.

Burchill, Sean, 2000, Rechargeable Battery Recycling Corporation general overview: Municipal Waste Management Association, annual meeting, 20th, Seattle, Wash., accessed June 6, 2006, at *http://www.usmayors.org/uscm/mwma/presentations/burchill.ppt#370*.

International Cadmium Association, 2008, Cadmium market report: International Cadmium Association, general assembly of members, London, United Kingdom, October 16, 2008, presentation, 20 p.

Klimasaukas, E.P., Kuck, P.H., and Plunkert, P.A., 2006, Cadmium, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 2004, v. I, p. 15.1–15.5. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/cadmimyb04.pdf*.)

Kuck, P.H., 2006, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2006, p. 42–43. (Also available online at *http://minerals.er.usgs.gov/minerals/pubs/mcs/2006/mcs2006.pdf*.)

Morrow, Hugh, 2005, Cadmium markets and trends: United Nations Environment Programme, September, accessed June 6, 2006 at *http://www.chem.unep.ch/pb_and_cd/SR/Files?Submission%20NGO/ICdA/MARKET%20Review%20Sept2005-1.pdf*.

Pillot, Christophe, 2004, The world rechargeable battery market 2003–2008 , *in* Batteries 2004, Brussels, Belgium, April, 2004: Paris, France, Avicenne Developpement, Proceedings, 35 p. (Accessed April 24, 2006, at *http://www.avicenne.com/download/batteries/The%20Worldwide%20Rechargeable%20Battery%20Market%202003-2008,%20Recharge%20Brussels,%20April%202004,%20C.%20Pillot.pdf*.)

Pillot, Christophe, 2005, Main trends for the rechargeable battery market worldwide 2004–2010, *in* Batteries 2005, Paris, France, June 14–16, 2005: Paris, France, Avicenne Developpment, Proceedings, 26 p. (Accessed April 24, 2006, at *http://www.avicenne.com/download/batteries/Main%20Trends%20for%20the%20Rechargeable%20Battery%20Market%20Worldwide%202004-2010,%20Batteries%202005,%20June%202005,%20C.%20Pillot.pdf*.)

Pillot, Christophe, 2008, Main trends for the rechargeable battery market worldwide 2007–2015 , *in* Batteries 2008, Frankfurt, Germany, June 1–3, 2008: Paris, France, Avicenne Developpment, Proceedings, Batteries 2008, Frankfurt,Germany, June 1–3, 22 p., accessed February 3, 2009, at *http://www.avicenne.com/download/batteries/The%20Rechargeable %20Battery%20Market%202007-2015,%20-%20C.%20Pillot%20-%20July%202008.pdf*.

Plachy, Jozef, 2001, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2001, p. 38–39. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/14030.pdf*.)

Plachy, Jozef, 2002, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2002, p. 40–41. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/140302.pdf*.)

Plachy, Jozef, 2003a, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2003, p. 42–43. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/140303.pdf*.)

Plachy, Jozef, 2003b, Cadmium recycling in the United States in 2000: U.S. Geological Survey Circular 1196-O, accessed May 30, 2006, at *http://pubs.usgs.gov/circ/c1196o/*.

Plachy, Jozef, 2004, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2004, p. 40–41. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/cadmimcs04.pdf*.)

Plachy, Jozef, 2005, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2005, p. 40–41. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/commodity/cadmium/cadmimcs05.pdf*.)

Rechargeable Battery Recycling Corporation, 2005, New survey reveals the 'skinny' on what Americans stockpile in their closets: Atlanta, Ga., Rechargeable Battery Recycling Corporation, press release November 21, accessed April 20, 2006, at *http://www.rbrc.org/call2recycle/releases/PR_11_21_05.html*.

Rechargeable Battery Recycling Corporation, 2006, Nearly 5 million pounds of rechargeable batteries collected in 2005: Rechargeable Battery Recycling Corporation, press release, January 5. Accessed June 6, 2006, at *http://www.rbrc.org/call2recycle/releases/PR_1_5_06.html*.

Rechargeable Battery Recycling Corporation, 2008, Rechargeable Battery Recycling Corporation (RBRC) reports 12 percent increase in collection numbers for 2007: Rechargeable Battery Recycling Corporation. press release, January 23. Accessed January 29, 2008, at *http://www.rbrc.org/call2recycle/releases/PR_01232008.pdf*.

Sanyo Energy (USA) Corporation, 2006, Engineering handbook, Cadnica: Sanyo Energy (USA) Corporation, accessed August 24, 2006, at *http://www.sanyo.com/batteries/pdfs/cadnicaT_E.pdf*.

Takao, Mike, 2008, Recent BAJ/JBRC activity related to rechargeable battery recycling: World Rechargeable Battery Regulatory Forum, Tokyo, Japan, October 28, 2008, presentation, 29 p.

Takeshita, Hideo, 2008, Worldwide market update on NiMH, Li ion and polymer batteries for portable applications and HEVS: Tokyo, Japan, Institute of Information Technology, Ltd., The 25th International Battery Seminar and Exhibit, Tokyo, Japan, March 17, 2008, 26 p.

Tolcin, A.C., 2008a, Cadmium, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 2007, v. I, p. 15.1–15.9. (Also available at *http://minerals.usgs.gov/minerals/pubs/commodity/cadmium/myb1-2007-cadmi.pdf*.)

Tolcin, A.C., 2008b, Cadmium: U.S. Geological Survey Mineral Commodity Summaries 2008, p. 42–43. (Also available at *http://minerals.er.usgs.gov/minerals/pubs/mcs/2008/mcs2008.pdf*.)

U.S. Environmental Protection Agency, 2000, Cadmium compounds—Hazard summary: U.S. Environmental Protection Agency Air Toxics Website, accessed June 7, 2006, at *http://www.epa.gov/ttn/atw/hlthef/cadmium.html*.

U.S. Environmental Protection Agency, 2002a, Characterization of products containing lead and cadmium in municipal solid waste in the United States, 1970 to 2000: U.S. Environmental Protection Agency document EPA-5S30-SW-015A, 220 p., accessed June 7, 2006, at *http://www.p2pays.org/ref/03/02062.pdf*.

U.S. Environmental Protection Agency, 2002b, Enforcement alert—The Battery Act: U.S. Environmental Protection Agency enforcement and compliance assurance document 2248A, EPA-300-N-02-002, March, 4 p., accessed May 30, 2006, at *http://www.epa.gov/oeca/ore/enfalert/*.

U.S. Environmental Protection Agency, 2003, Municipal solid waste generation, recycling, and disposal in the United States—Facts and figures for 2003: U.S. Environmental Protection Agency, accessed June 29, 2006, at *http://www.epa.gov/msw/msw99.htm*.

U.S. Geological Survey, 2005, Cadmium end-use statistics, *in* Kelly, T.D., and Matos, G.R., comps., Historical statistics for mineral and material commodities in the United States (ver. 1.1): U.S. Geological Survey Data Series 2005–140, accessed May 30, 2006, at *http://minerals.usgs.gov/ds/2005/140/cadmium-use.pdf*.

U.S. International Trade Commission, 2009, ITC trade dataweb: U.S. International Trade Commission, accessed March 4, 2009, at *http://dataweb.usitc.gov*.

Vangheluwe, Marnix, Verdonck, Frederik, and Versonnen, Bram, 2005, Contribution of spent batteries to the metal flows of municipal solid waste: Brussels, Belgium, European Academy of Standardization, October, 79 p., accessed April 24, 2006, at *http://www.rechargebatteries.org/RelDoc_Metals_flow_of_MSW__2005_FL.pdf*.

Warren, Tim, 2006, Recycling rechargeable batteries: Kansas Department of Health and Environment Conference, March 2006, Great Bend, Kans., presentation, accessed June 6, 2006, at *http://www.kdheks.gov/waste/works/06GreatBend/presentations/TimWarrenRBRC.pdf*.

Zbattery, 2006, Camcorder batteries, cordless phone batteries, and digital camera batteries: Zbattery, accessed November 22, 2006 at *http://www.zbattery.com*.

Appendix 1

The estimates used in this study related to cadmium content of various battery types are summarized in table A-1. The table includes batteries designated as representative types, assumed battery weights assigned for principle classifications, and cadmium content assumptions. For each classification, the percentage estimate of NiCd batteries contained within that classification also is reported. For some classifications, different allocations for the percentage of NiCd batteries are assumed for 2003 through 2007 on the basis of recent trend data (Pillot, 2004, 2005, 2008; Takeshita, 2008; Battery Association of Japan, 2009). Variations were necessary owing to changing market trends for some applications.

HTS code 8507.30.8090, "nickel-cadmium storage batteries, not elsewhere specified," grouped multiple NiCd battery types into one category, so additional assumptions were needed regarding which batteries were included in this general category. Because specific information on batteries in this category was not available, a methodology using the average unit value, by country, as reported by the U.S. International Trade Commission was developed in order to estimate the relative distribution of batteries in this category into two general types, small consumer batteries with a relatively low unit value, and large industrial batteries with a higher average unit value. It was assumed that, on the basis of the unit values for consumer and industrial batteries, as reported by selected manufacturers, the price of a typical industrial battery or battery pack was greater than $300 per unit and the typical price of a consumer battery or battery pack is less than $15 per unit. Then the percent distribution of consumer and industrial battery imports by country was estimated using the unit value attributed to each importing country, which was based on the reported customs values and total number of batteries imported. The sliding scale of percentages allocated to industrial batteries, based on the reported unit value for each specified category, is shown in table A-2. Values, quantities, and percentages used are listed, by country, in table A-3. To obtain the most reliable estimate, the data were evaluated by country, rather than as a whole. For example, if the reported dollar-per-unit value of a specified category, as determined by ITC data, fell within the range of $75 to $150 per unit, then it was assumed that 75 percent of the batteries reported for that category were of the industrial type. Because of the rough nature of these assumptions, no adjustments were made for inflation over time or variations in country costs of production.

The assumptions made for average battery life and battery recovery distribution for consumer and industrial batteries and batteries contained in products are shown in table A-4. For each battery group, it was assumed that 10 percent of the batteries in that group would be recoverable in the year following the last year of battery storage life. These estimates were developed from information derived from Sanyo Energy (USA) Corporation (2006), Takeo (2008), and discussions with C. Norman England, president, RBRC (oral commun., 2006).

Table A–1. Selected material content assumptions and estimates for nickel-cadmium batteries used in this analysis to determine the flow of cadmium in the United States, 1996–2007.

[g, grams; NA, not available; --, not applicable]

Classification	Manufacturer and battery type assumed as representative[1]	Weight range[2] (g)	Average weight[2] (g)	Cadmium content[2] (percent)	Cadmium content/cell or pack[3] (g)	Cobalt content[2] (percent)	Cobalt content/ cell or pack[3] (g)	Nickel content[2] (percent)	Nickel content/ cell or pack[3] (g)	Nickel-cadmium, in percent of total estimate[4]
General nickel-cadmium storage battery[5]	NA	NA	NA	14	NA	0	NA	22	NA	NA
Storage batteries, separate										
Electrically-powered vehicle batteries	Saft STM	12,900–17,000	14,400	16	2,300	1	100	22	3,200	100
Sealed consumer batteries	Saft VRE	19–150	60	10–15	8.4	0.4–1	0.4	20–28	13.2	100
	Sanyo Cadnica	NA	NA	11–26	NA	0	0	13–29	NA	100
Industrial batteries	Saft SLM	1,000–45,000	14,900	8	1,200	0.2	30	9	1,300	100
	Saft SPH	NA	NA	16	NA	1	0	22	NA	100
Batteries enclosed in products										
Power tools	Saft VRE-C	NA	43	10–15	6	0.4–1	0.3	20–28	9.5	91
Cordless phones	Battery selection[6]	63–113	80	14	11.2	0.9	0.7	22	17.6	40
Camcorders	Battery selection[6]	59–376	160	14	22	0.9	1.4	22	35	(1996–2003) 30
	--	--	--	--	--	--	--	--	--	(2004) 18
	--	--	--	--	--	--	--	--	--	(2005) 6
Cameras	Battery selection[6]	20–318	130	14	19	0.5	0.5	22	29	(1996–2003) 30
	--	--	--	--	--	--	--	--	--	(2004) 18
	--	--	--	--	--	--	--	--	--	(2005) 6
Portable radios	Saft VRE-AA	14–32	21	10–15	2.9	0.4–1	0.1	20–28	4.6	6
	Sanyo Cadnica-AA	NA	NA	11–26	NA	0	0	13–29	NA	6
Shavers	Saft VRE-AA	14–32	21	10–15	2.9	0.4–1	0.1	20–28	4.6	(1996–2003) 45
	Sanyo Cadnica-AA	NA	NA	11–26	NA	0	0	13–29	NA	(2004) 34
	--	--	--	--	--	--	--	--	--	(2005) 22
Electric toothbrushes	Saft VRE-AA	14–32	21	10–15	2.9	0.4–1	0.1	20–28	4.6	(1996–2003) 45
	Sanyo Cadnica-AA	NA	NA	11–26	NA	0	0	13–29	NA	(2004) 34
	--	--	--	--	--	--	--	--	--	(2005) 22
Portable vacuum cleaners	Saft VRE-Cs	43–150	97	10–15	13.6	0.4–1	0.7	20–28	21.3	(1996–2003) 45
	Saft VRE-D	NA	NA	10–15	NA	0.4–1	NA	20–28	NA	(2004) 34
	--	--	--	--	--	--	--	--	--	(2005) 22
Flashlights	Sanyo Cadnica	19–145	49	11–26	6.9	0	0	13–29	10.8	(1996–2003) 4
	--	--	--	--	--	--	--	--	--	(2004) 3
	--	--	--	--	--	--	--	--	--	(2005) 2
	Energizer	NA	NA	13–22	NA	0.5–2	NA	20–32	NA	--
	Panasonic	26–51	40	NA	NA	NA	NA	NA	NA	--
Portable electric lamps (bicycle, for example)	Saft VE	18–150	64	10–15	9	0.4–1	0.4	20–28	14	(1996–2003) 24
	--	--	--	--	--	--	--	--	--	(2004) 18
	--	--	--	--	--	--	--	--	--	(2005) 12
Clock batteries, reported separately	Saft VRE-AA	14–32	21	10–15	2.9	0.4–1	0.1	20–28	4.6	(1996–2003) 4
	Sanyo Cadnica-AA	NA	NA	11–26	NA	0	0	13–29	NA	(2004) 3
	--	--	--	--	--	--	--	--	--	(2005) 2
Military batteries, reported separately	Saft VRE-AA	14–32	21	10–15	2.9	0.4–1	0.1	20–28	4.6	16
	Sanyo Cadnica-AA	NA	NA	11–26	NA	0	0	13–29	NA	16

[1]Manufacturer was selected on the basis of volume of production and availability of data. Battery selection was based on applicability to end-use category.

[2]Based on reported weights given by manufacturer for all batteries in that classification. Data obtained from specified manufacturer's website.

[3]Calculated using (average weight) multiplied by (selected commodity content). When a percent range is shown, the average percent, reported by Vangheluwe, Verdonck, and Versonnen (2005) was used for calculations.

[4]Percent allocation of the number of batteries attributed as nickel-cadmium batteries, based on end-use distributions reported by Pillot (2004, 2005, 2008). In some cases, the 2004 and 2005 percentages were reported to be lower than the percentages of prior years. Where no years are reported, value applies to entire study period.

[5]Vangheluwe, Verdonck, and Versonnen (2005).

[6]Based on a random selection of batteries used for each of these applications, as reported by Zbattery (2006).

Table A-2. Industrial battery allocation, by percent.

[Allocations were based on the premise that the typical price of a consumer battery is less than $15/unit. An allocation of the percentage of industrial batteries was assigned using the average unit value of batteries imported, by country, as shown in table A-3.]

Reported unit value	Percent attributed to industrial batteries
$0–$15	0
$16–$25	25
$26–$75	50
$76–$150	75
$151–$300	90
Greater than $300	100

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Antigua and Barbuda	Customs value	0	0	0	0	0	2,600	0	0	0	0
	Units of quantity	0	0	0	0	0	400	0	0	0	0
	Unit value ($/unit)	0	0	0	0	0	6.50	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Australia	Customs value	5,973	8,198	0	0	75,000	0	3,337	0	0	17,758
	Units of quantity	94	1,145	0	0	320,000	0	9	0	0	6
	Unit value ($/unit)	63.54	7.16	0	0	0.23	0	370.78	0	0	2,959.67
	% to industrial	50	0	0	0	0	0	100	0	0	100
	Industrial units	47	0	0	0	0	0	9	0	0	6
Austria	Customs value	0	0	0	0	0	0	0	7,848	0	0
	Units of quantity	0	0	0	0	0	0	0	255	0	0
	Unit value ($/unit)	0	0	0	0	0	0	0	30.78	0	0
	% to industrial	0	0	0	0	0	0	0	25	0	0
	Industrial units	0	0	0	0	0	0	0	64	0	0
Belgium	Customs value	18,795	1,546	213,847	4,203	119,909	191,519	187,367	0	5,774	0
	Units of quantity	895	50	736,140	900	36,050	35,715	44,077	0	41	0
	Unit value ($/unit)	21.00	30.92	0.29	4.67	3.33	5.36	4.25	0	140.83	0
	% to industrial	25	50	0	0	0	0	0	0	75	0
	Industrial units	224	25	0	0	0	0	0	0	31	0
British Virgin Islands	Customs value	0	0	0	0	0	30,570	0	0	0	0
	Units of quantity	0	0	0	0	0	2,150	0	0	0	0
	Unit value ($/unit)	0	0	0	0	0	14.22	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Brazil	Customs value	0	0	0	63,354	3,389	2,054	27,360	0	407,060	0
	Units of quantity	0	0	0	810	579	277	7,817	0	127,423	0
	Unit value ($/unit)	0	0	0	78.21	5.85	7.42	3.50	0	3.19	0
	% to industrial	0	0	0	75	0	0	0	0	0	0
	Industrial units	0	0	0	608	0	0	0	0	0	0
Bulgaria	Customs value	0	0	0	0	0	0	0	2,043	0	0
	Units of quantity	0	0	0	0	0	0	0	250	0	0
	Unit value ($/unit)	0	0	0	0	0	0	0	8.17	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Canada	Customs value	120,876	210,990	646,616	199,068	2,851,275	3,032,152	142,217	287,706	872,966	134,321
	Units of quantity	5,890	4,693	20,895	3,455	46,390	36,950	3,133	2,601	19,263	9,000
	Unit value ($/unit)	20.52	44.96	30.95	57.62	61.46	82.06	45.39	110.61	45.32	14.92
	% to industrial	25	50	50	50	50	75	50	75	50	0
	Industrial units	1,473	2,347	10,448	1,728	23,195	27,713	1,567	1,951	9,632	0

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
China	Customs value	6,988,651	6,365,376	7,495,091	13,990,978	23,569,804	6,922,996	8,905,977	9,704,339	9,326,632	14,628,192
	Units of quantity	2,547,016	3,454,307	3,831,207	5,827,274	5,326,195	3,935,637	3,745,607	5,622,212	4,965,911	5,453,973
	Unit value ($/unit)	2.74	1.84	1.96	2.40	4.43	1.76	2.38	1.73	1.88	2.68
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Colombia	Customs value	0	27,500	0	0	0	0	0	0	0	3,530
	Units of quantity	0	5,000	0	0	0	0	0	0	0	2
	Unit value ($/unit)	0	5.50	0	0	0	0	0	0	0	1,765.00
	% to industrial	0	0	0	0	0	0	0	0	0	100
	Industrial units	0	0	0	0	0	0	0	0	0	2
Cote d’Ivoire	Customs value	0	23,395	0	0	0	0	0	0	0	0
	Units of quantity	0	42,000	0	0	0	0	0	0	0	0
	Unit value ($/unit)	0	0.56	0	0	0	0	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Czech Republic	Customs value	0	31,548	101,139	967,815	1,963,941	1,552,973	1,905,401	663,038	754,218	414,440
	Units of quantity	0	1,900	3,311	8,034	15,006	20,161	36,151	17,393	5,430	4,133
	Unit value ($/unit)	0	16.60	30.55	120.46	130.88	77.03	52.71	38.12	138.90	100.28
	% to industrial	0	25	50	75	75	75	50	50	75	75
	Industrial units	0	475	1,656	6,026	11,255	15,121	18,076	8,697	4,073	3,100
Denmark	Customs value	0	37,719	73,728	10,615	11,186	6,166	19,434	7,728	4,070	10,800
	Units of quantity	0	320	7,347	213	186	52	111	155	100	69
	Unit value ($/unit)	0	117.87	10.04	49.84	60.14	118.58	175.08	49.86	40.70	156.52
	% to industrial	0	75	0	50	50	75	90	50	50	90
	Industrial units	0	240	0	107	93	39	100	78	50	62
Ecuador	Customs value	0	0	0	0	14,213	0	0	0	0	0
	Units of quantity	0	0	0	0	56	0	0	0	0	0
	Unit value ($/unit)	0	0	0	0	253.80	0	0	0	0	0
	% to industrial	0	0	0	0	90	0	0	0	0	0
	Industrial units	0	0	0	0	50	0	0	0	0	0
Finland	Customs value	11,756	465,419	29,031	21,992	103,610	82,840	10,348	23,690	22,635	47,214
	Units of quantity	110	46,268	2,353	1,705	1,076	560	198	347	375	686
	Unit value ($/unit)	106.87	10.06	12.34	12.90	96.29	147.93	52.26	68.27	60.36	68.83
	% to industrial	75	0	0	0	75	75	50	50	50	50
	Industrial units	83	0	0	0	807	420	99	174	188	343
France	Customs value	1,514,669	3,935,401	5,918,306	7,058,477	26,856,840	19,252,086	12,255,051	10,378,255	12,263,256	11,852,367
	Units of quantity	62,115	87,273	805,423	91,063	295,348	3,218,145	3,529,610	1,783,711	137,497	45,810
	Unit value ($/unit)	24.38	45.09	7.35	77.51	90.93	5.98	3.47	5.82	89.19	258.73
	% to industrial	25	50	0	75	75	0	0	0	75	90
	Industrial units	15,529	43,637	0	68,297	221,511	0	0	0	103,123	41,229

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Germany	Customs value	2,254,880	2,055,418	2,644,362	2,743,955	3,160,506	1,653,064	2,017,050	2,450,481	2,397,520	1,950,102
	Units of quantity	667,388	679,016	3,815,368	607,048	554,707	48,033	74,240	164,383	83,907	103,746
	Unit value ($/unit)	3.38	3.03	0.69	4.52	5.70	34.42	27.17	14.91	28.57	18.80
	% to industrial	0	0	0	0	0	50	50	0	50	25
	Industrial units	0	0	0	0	0	24,017	37,120	0	41,954	25,937
Hong Kong	Customs value	5,361,647	4,314,125	3,282,865	2,682,463	1,931,103	2,128,550	2,891,720	1,573,809	2,360,376	1,630,512
	Units of quantity	1,605,326	1,204,278	1,680,758	548,078	518,444	580,003	559,835	348,333	869,614	650,997
	Unit value ($/unit)	3.34	3.58	1.95	4.89	3.72	3.67	5.17	4.52	2.71	2.50
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Hungary	Customs value	0	0	0	0	0	0	46,672	59,054	0	0
	Units of quantity	0	0	0	0	0	0	15,000	1,104	0	0
	Unit value ($/unit)	0	0	0	0	0	0	3.11	53.49	0	0
	% to industrial	0	0	0	0	0	0	0	50	0	0
	Industrial units	0	0	0	0	0	0	0	552	0	0
Iceland	Customs value	3,825	5,641	0	0	0	0	0	0	0	0
	Units of quantity	15	24	0	0	0	0	0	0	0	0
	Unit value ($/unit)	255.00	235.04	0	0	0	0	0	0	0	0
	% to industrial	90	90	0	0	0	0	0	0	0	0
	Industrial units	14	22	0	0	0	0	0	0	0	0
India	Customs value	0	0	0	0	0	61,787	0	58,668	250,488	56,584
	Units of quantity	0	0	0	0	0	100,880	0	343	206	52
	Unit value ($/unit)	0	0	0	0	0	0.61	0.00	171.04	1,215.96	1,088.15
	% to industrial	0	0	0	0	0	0	0	90	100	100
	Industrial units	0	0	0	0	0	0	0	309	206	52
Indonesia	Customs value	4,243,040	5,282,748	6,002,549	4,330,341	4,143,484	1,613,919	397,662	183,385	140,894	36,784
	Units of quantity	2,244,072	2,790,075	2,939,889	2,771,510	2,581,526	1,074,387	780,242	145,524	237,101	64,800
	Unit value ($/unit)	1.89	1.89	2.04	1.56	1.61	1.50	0.51	1.26	0.59	0.57
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Ireland	Customs value	2,338,872	228,562	483,248	120,382	972,366	1,321,618	124,045	12,159	0	0
	Units of quantity	125,029	8,210	16,956	4,133	76,747	29,156	73,234	579	0	0
	Unit value ($/unit)	18.71	27.84	28.50	29.13	12.67	45.33	1.69	21.00	0	0
	% to industrial	25	50	50	50	0	50	0	25	0	0
	Industrial units	31,257	4,105	8,478	2,067	0	14,578	0	145	0	0
Israel	Customs value	630,497	146,800	374,353	423,548	111,181	90,008	90,000	2,070	0	0
	Units of quantity	10,664	8,960	29,000	25,350	10,630	6,422	90	43	0	0
	Unit value ($/unit)	59.12	16.38	12.91	16.71	10.46	14.02	1,000.00	48.14	0	0
	% to industrial	50	25	0	25	0	0	100	50	0	0
	Industrial units	5,332	2,240	0	6,338	0	0	90	22	0	0

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Italy	Customs value	27,077	3,201	20,986	0	7,127	209,728	606,271	316,158	669,179	946,284
	Units of quantity	4,866	415	104	0	500	714	295	11,642	787	22,165
	Unit value ($/unit)	5.56	7.71	201.79	0.00	14.25	293.74	2,055.16	27.16	850.29	42.69
	% to industrial	0	0	90	0	0	90	100	50	100	50
	Industrial units	0	0	94	0	0	643	295	5,821	787	11,083
Japan	Customs value	64,137,101	39,717,506	29,890,272	17,886,592	16,846,744	11,350,615	12,231,392	8,420,501	5,161,582	3,829,577
	Units of quantity	26,031,781	21,497,001	19,061,711	10,185,179	7,473,877	5,842,002	5,425,699	3,085,315	1,067,129	361,213
	Unit value ($/unit)	2.46	1.85	1.57	1.76	2.25	1.94	2.25	2.73	4.84	10.60
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Korea, Republic of	Customs value	1,100,749	1,712,919	1,531,293	1,962,190	2,046,271	1,051,063	290,031	216,172	353,265	204,242
	Units of quantity	1,085,316	191,788	79,232	1,158,414	960,340	329,921	92,361	15,083	24,819	13,433
	Unit value ($/unit)	1.01	8.93	19.33	1.69	2.13	3.19	3.14	14.33	14.23	15.20
	% to industrial	0	0	25	0	0	0	0	0	0	25
	Industrial units	0	0	19,808	0	0	0	0	0	0	3,358
Macao	Customs value	98,477	3,451,393	2,451,451	173,090	0	20,010	6,270	12,540	13,200	0
	Units of quantity	10,742	363,286	166,803	18,976	0	18,000	9,500	19,000	20,000	0
	Unit value ($/unit)	9.17	9.50	14.70	9.12	0	1.11	0.66	0.66	0.66	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Malaysia	Customs value	506,188	1,398,293	1,419,265	692,960	598,569	617,004	316,044	873,364	1,315,722	68,926
	Units of quantity	329,670	494,077	616,792	405,800	618,062	203,551	40,276	90,162	115,882	5,072
	Unit value ($/unit)	1.54	2.83	2.30	1.71	0.97	3.03	7.85	9.69	11.35	13.59
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Mali	Customs value	0	0	2,678	0	0	0	0	0	0	0
	Units of quantity	0	0	450	0	0	0	0	0	0	0
	Unit value ($/unit)	0	0	5.95	0	0	0	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Mexico	Customs value	1,200,213	1,561,435	837,718	1,169,393	1,363,013	8,693,746	2,277,300	699,458	1,399,204	104,723
	Units of quantity	173,691	330,669	251,708	386,502	382,323	1,468,185	441,745	111,856	177,136	12,025
	Unit value ($/unit)	6.91	4.72	3.33	3.03	3.57	5.92	5.16	6.25	7.90	8.71
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Morocco	Customs value	0	0	68,933	0	0	0	0	0	0	0
	Units of quantity	0	0	8,364	0	0	0	0	0	0	0
	Unit value ($/unit)	0	0	8.24	0	0	0	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Netherlands	Customs value	43,321	47,019	73,797	2,425	38,556	35,591	63,762	28,093	26,101	48,880
	Units of quantity	2,845	2,035	4,330	6	5,342	3,112	18	32	71	13
	Unit value ($/unit)	15.23	23.11	17.04	404.17	7.22	11.44	3,542.33	877.91	367.62	3,760.00
	% to industrial	25	25	25	100	0	0	100	100	100	100
	Industrial units	711	509	1,083	6	0	0	18	32	71	13
New Zealand	Customs value	5,087	15,000	0	0	8,000	189,309	136,112	328,612	64,378	157,856
	Units of quantity	168	151	0	0	40,000	5,397	4,267	13,650	2,282	6,774
	Unit value ($/unit)	30.28	99.34	0	0	0.20	35.08	31.90	24.07	28.21	23.30
	% to industrial	50	75	0	0	0	50	50	25	50	25
	Industrial units	84	113	0	0	0	2,699	2,134	3,413	1,141	1,694
Nigeria	Customs value	0	0	6,000	0	0	0	0	0	0	0
	Units of quantity	0	0	10	0	0	0	0	0	0	0
	Unit value ($/unit)	0	0	600.00	0	0	0	0	0	0	0
	% to industrial	0	0	100	0	0	0	0	0	0	0
	Industrial units	0	0	10	0	0	0	0	0	0	0
Norway	Customs value	49,391	42,677	4,648	18,422	3,212	19,563	9,704	38,074	0	3,034
	Units of quantity	1,210	698	105	168	59	41	36	173	0	60
	Unit value ($/unit)	40.82	61.14	44.27	109.65	54.44	477.15	269.56	220.08	0	50.57
	% to industrial	50	50	50	75	50	100	90	90	0	50
	Industrial units	605	349	53	126	30	41	32	156	0	30
Philippines	Customs value	56,763	3,365	0	227,643	45,256	60,265	82,247	3,553,420	36,813	14,815
	Units of quantity	7,759	71	0	416,445	2,504	13,434	3,125	3,359,090	666	1,164
	Unit value ($/unit)	7.32	47.39	0	0.55	18.07	4.49	26.32	1.06	55.27	12.73
	% to industrial	0	50	0	0	25	0	25	0	50	0
	Industrial units	0	36	0	0	626	0	781	0	333	0
Poland	Customs value	0	0	0	0	172,056	0	0	0	0	0
	Units of quantity	0	0	0	0	261,480	0	0	0	0	0
	Unit value ($/unit)	0	0	0	0	0.66	0	0	0	0	0
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Russia	Customs value	0	0	0	0	0	2,500	0	0	0	0
	Units of quantity	0	0	0	0	0	4	0	0	0	0
	Unit value ($/unit)	0	0	0	0	0	625.00	0	0	0	0
	% to industrial	0	0	0	0	0	100	0	0	0	0
	Industrial units	0	0	0	0	0	4	0	0	0	0
Singapore	Customs value	4,412,071	5,294,243	1,704,182	1,264,525	650,623	480,169	64,590	245,121	309,137	391,377
	Units of quantity	2,617,317	3,203,871	1,001,404	1,076,409	532,851	397,183	154,432	305,682	379,353	580,346
	Unit value ($/unit)	1.69	1.65	1.70	1.17	1.22	1.21	0.42	0.80	0.81	0.67
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Slovakia	Customs value	0	0	0	0	0	0	0	0	0	53,900
	Units of quantity	0	0	0	0	0	0	0	0	0	350
	Unit value ($/unit)	0	0	0	0	0	0	0	0	0	154.00
	% to industrial	0	0	0	0	0	0	0	0	0	90
	Industrial units	0	0	0	0	0	0	0	0	0	315
South Africa	Customs value	0	0	0	0	0	48,583	0	0	30,757	90,112
	Units of quantity	0	0	0	0	0	8,100	0	0	2,718	8,513
	Unit value ($/unit)	0	0	0	0	0	6.00	0	0	11.32	10.59
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Spain	Customs value	210,344	17,393	4,000	96,592	25,109	0	14,318	2,634	17,291	0
	Units of quantity	5,153	93	2	2,659	999	0	455	37	3,130	0
	Unit value ($/unit)	40.82	187.02	2,000.00	36.33	25.13	0	31.47	71.19	5.52	0
	% to industrial	50	90	100	50	50	0	50	50	0	0
	Industrial units	2,577	84	2	1,330	500	0	228	19	0	0
Sweden	Customs value	3,687,107	1,589,409	3,071,771	4,418,025	5,650,717	5,746,256	6,868,659	9,892,231	9,137,391	10,453,593
	Units of quantity	58,644	22,241	35,195	48,957	56,594	47,643	64,612	62,283	62,263	77,513
	Unit value ($/unit)	62.87	71.46	87.28	90.24	99.85	120.61	106.31	158.83	146.75	134.86
	% to industrial	50	50	75	75	75	75	75	90	75	75
	Industrial units	29,322	11,121	26,396	36,718	42,446	35,732	48,459	56,055	46,697	58,135
Switzerland	Customs value	187,649	179,252	554,812	1,498,424	1,043,832	614,673	661,137	515,328	192,455	187,218
	Units of quantity	28,336	44,010	78,889	34,282	20,462	35,899	14,025	26,652	3,756	18,410
	Unit value ($/unit)	6.62	4.07	7.03	43.71	51.01	17.12	47.14	19.34	51.24	10.17
	% to industrial	0	0	0	50	50	25	50	25	50	0
	Industrial units	0	0	0	17,141	10,231	8,975	7,013	6,663	1,878	0
Taiwan	Customs value	7,177,082	10,087,416	6,837,650	3,818,209	5,810,493	5,109,717	2,722,901	1,883,387	1,982,487	1,307,003
	Units of quantity	712,290	877,151	1,243,919	839,195	1,354,331	2,135,725	693,325	313,046	312,300	209,383
	Unit value ($/unit)	10.08	11.50	5.50	4.55	4.29	2.39	3.93	6.02	6.35	6.24
	% to industrial	0	0	0	0	0	0	0	0	0	0
	Industrial units	0	0	0	0	0	0	0	0	0	0
Thailand	Customs value	44,647	823,215	10,944	23,060	53,465	23,157	43,827	2,175	2,700	10,125
	Units of quantity	53,872	142,092	1,824	4,000	6,684	13,555	11,564	118	200	750
	Unit value ($/unit)	0.83	5.79	6.00	5.77	8.00	1.71	3.79	18.43	13.50	13.50
	% to industrial	0	0	0	0	0	0	0	25	0	0
	Industrial units	0	0	0	0	0	0	0	30	0	0
Turkey	Customs value	0	0	0	0	0	0	0	0	0	11,000
	Units of quantity	0	0	0	0	0	0	0	0	0	100
	Unit value ($/unit)	0	0	0	0	0	0	0	0	0	110.00
	% to industrial	0	0	0	0	0	0	0	0	0	75
	Industrial units	0	0	0	0	0	0	0	0	0	75

Table A-3. Values, quantities, and percentages used in the development of Harmonized Tariff Schedule of the United States (HTS) code 8507.30.8090, by country, for industrial and non-industrial batteries.—Continued

[By applying average cadmium content values for both industrial and non-industrial batteries (table A-1) to the number of industrial and nonindustrial units reported here, the amount of cadmium attributable to this HTS category was determined. $/unit, dollar per unit; %, percent]

Country		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
United Arab Emirates	Customs value	0	0	0	4,525	0	0	0	2,233	0	0
	Units of quantity	0	0	0	1	0	0	0	950	0	0
	Unit value ($/unit)	0	0	0	4,525.00	0	0	0	2.35	0	0
	% to industrial	0	0	0	100	0	0	0	0	0	0
	Industrial units	0	0	0	1	0	0	0	0	0	0
United Kingdom	Customs value	1,857,653	1,289,584	1,450,539	2,933,499	2,073,712	2,025,592	1,122,864	511,215	1,085,856	568,029
	Units of quantity	84,189	94,051	497,748	67,913	22,878	70,971	18,528	20,348	423,346	24,481
	Unit value ($/unit)	22.07	13.71	2.91	43.19	90.64	28.54	60.60	25.12	2.56	23.20
	% to industrial	25	0	0	50	75	50	50	50	0	25
	Industrial units	21,047	0	0	33,957	17,159	35,486	9,264	10,174	0	6,120
Venezuela	Customs value	0	0	0	0	0	0	4,800	0	0	0
	Units of quantity	0	0	0	0	0	0	12	0	0	0
	Unit value ($/unit)	0	0	0	0	0	0	400.00	0	0	0
	% to industrial	0	0	0	0	0	0	100	0	0	0
	Industrial units	0	0	0	0	0	0	12	0	0	0
Vietnam	Customs value	0	0	0	0	0	0	0	0	0	9,673
	Units of quantity	0	0	0	0	0	0	0	0	0	2
	Unit value ($/unit)	0	0	0	0	0	0	0	0	0	4,836.50
	% to industrial	0	0	0	0	0	0	0	0	0	100
	Industrial units	0	0	0	0	0	0	0	0	0	2
Total industrial units		**108,303**	**65,300**	**68,026**	**174,446**	**327,901**	**165,465**	**125,295**	**94,350**	**210,162**	**151,555**
Total units imported		38,476,463	35,597,219	36,937,237	24,534,479	21,522,226	19,682,365	15,843,629	15,522,352	9,042,706	7,675,041
Non industrial units		**38,368,160**	**35,531,919**	**36,869,211**	**24,360,033**	**21,194,325**	**19,516,900**	**15,718,334**	**15,428,002**	**8,832,544**	**7,523,486**

Table A-4. Assumptions related to battery service life and battery recovery distribution.

[Data are derived from Sanyo Energy (USA) Corporation (2006) and C. Norman England, Rechargeable Battery Recycling Corporation (oral commun., 2006). Values for years 1 to 17 are expressed in percent. --, not applicable]

Battery recovery distribution assumptions	Battery service life (years)	Battery storage life (years)	Year																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Industrial batteries	15	1	6	2	1	1	1	1	1	1	1	1	1	1	1	1	20	50	10
Consumer batteries	4	4	5	2	1	1	1	10	20	50	10	--	--	--	--	--	--	--	--
Batteries enclosed in products	4	4	5	2	1	1	1	10	20	50	10	--	--	--	--	--	--	--	--

For additional information, write to:
David Wilburn
U.S. Geological Survey
Box 25046, MS 750, Denver Federal Center
Denver, CO 80225

Document prepared by the Reston Publishing Service Center and the West Trenton Publishing Service Center

USGS

Wilburn—**Flow of Cadmium from Rechargeable Batteries in the United States, 1996–2005**—Scientific Investigations Report 2007–5198