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

Cadmium Recycling in the United States in 2000

By Jozef Plachy

U.S. GEOLOGICAL SURVEY CIRCULAR 1196–O

FLOW STUDIES FOR RECYCLING METAL COMMODITIES IN THE UNITED STATES

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

U.S. GEOLOGICAL SURVEY, RESTON, VIRGINIA : 2003
Version 1.0

Published online in the Eastern Region, Reston, Va., 2003.
Manuscript approved for publication July 28, 2003.

FOREWORD

As world population increases and the world economy expands, so does the demand for natural resources. An accurate assessment of the Nation's mineral resources must include not only the resources available in the ground but also those that become available through recycling. Supplying this information to decisionmakers is an essential part of the USGS commitment to providing the science that society needs to meet natural resource and environmental challenges.

The U.S. Geological Survey is authorized by Congress to collect, analyze, and disseminate data on the domestic and international supply of and demand for minerals essential to the U.S. economy and national security. This information on mineral occurrence, production, use, and recycling helps policymakers manage resources wisely.

USGS Circular 1196, "Flow Studies for Recycling Metal Commodities in the United States," presents the results of flow studies for recycling 26 metal commodities, from aluminum to zinc. These metals are a key component of the U.S. economy. Overall, recycling accounts for more than half of the U.S. metal supply by weight and roughly 40 percent by value.

Charles G. Groat
Director

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CONVERSION FACTORS

Multiply	By	To obtain
	Mass	
metric ton (t, 1,000 kg)	1.102	short ton (2,000 pounds)

For temperature conversions from degrees Celsius (°C) to degrees Fahrenheit (°F), use the following:

$$°F = (1.8 \times °C) + 32$$

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ABSTRACT

Recycling of cadmium is a young and growing industry that has been influenced by environmental concerns and regulatory constraints. Domestic recycling of cadmium began in 1989 as a byproduct of processing of spent nickel-cadmium batteries. In 1995, International Metals Reclamation Co. Inc. expanded its operations by building a dedicated cadmium recycling plant. In 2000, an estimated 13 percent of cadmium consumption in the United States was sourced from recycled cadmium, which is derived mainly from old scrap or, to lesser degree, new scrap. The easiest forms of old scrap to recycle are small spent nickel-cadmium batteries followed by flue dust generated during recycling of galvanized steel and small amounts of alloys that contain cadmium. Most of new scrap is generated during manufacturing processes, such as nickel-cadmium battery production. All other uses of cadmium are in low concentrations and, therefore, difficult to recycle. Consequently, much of this cadmium is dissipated and lost. The amount of cadmium in scrap that was unrecovered in 2000 was estimated to be 2,030 metric tons, and an estimated 285 tons was recovered. Recycling efficiency was estimated to be about 15 percent.

INTRODUCTION

The purpose of this report is to show trends in consumption and recycling[1] of cadmium in the United States during 2000. The amount of cadmium that is recycled, however, is difficult to estimate for a number of reasons. Because the production data by International Metals Reclamation Co. Inc. (INMETCO), which is the only cadmium recycler in the United States, is confidential, important information for this study is not available; INMETCO is located in Ellwood City, Pa. An additional reason is that the recovered cadmium from baghouse dust, which is generated by primary metal smelters, is processed during zinc refining and is usually included in the production statistics for primary cadmium metal. The main impediment to a study of cadmium recycling is that data on the amount of spent nickel-cadmium (NiCd) batteries in the marketplace are not readily available.

Cadmium is a soft, silver to bluish-white metal that is produced mainly as a byproduct from the mining, smelting, and refining of other nonferrous metals, mainly zinc. About 75 percent of cadmium is used for batteries followed by pigments (12 percent), coatings and plating (8 percent), and stabilizers for plastics and similar synthetic materials (4 percent). Because cadmium is a byproduct of other metals, its price is not subject to ordinary supply-and-demand dynamics. If zinc production increases, then cadmium supply will also increase, regardless of cadmium market demands. During the past few years, cadmium supply has generally exceeded cadmium demand, owing to overall growth in the zinc market and to tightening of regulatory controls. This imbalance has driven cadmium prices to such a low level that for many zinc smelters disposing of raw cadmium is more financially expeditious than refining it. For cadmium recyclers, most of the profit is in the fees collected from suppliers, not in the price of produced cadmium.

GLOBAL GEOLOGIC OCCURRENCE OF CADMIUM

Cadmium is a naturally occurring metallic element that is present in trace amounts of between 0.001 and 25,000 parts per million and less than 1 microgram per liter in the Earth's crust and oceans, respectively. Greenockite (CdS), which is the most common cadmium mineral, does not form its own deposits, but is usually associated with sphalerite (ZnS), which is the most common zinc ore mineral. About 80 percent of cadmium output worldwide is estimated to be a byproduct of primary zinc production. The average ratio between contained zinc and cadmium in sphalerite is about 250 to 1. The remaining 20 percent of cadmium is obtained from secondary sources, such as baghouse dust, recycled cadmium products, and the production of other primary metals, mainly lead and copper (Morrow, 2001, p. 1). The cadmium in lead and copper ores is associated with the zinc sulfide present rather than with the other minerals (Wedow, 1973).

The temperature of formation of zinc deposits has a partial bearing on cadmium concentration. In general, contact metamorphic and irregular replacement deposits that formed at relatively high temperatures have less cadmium content than intermediate hydrothermal ores and sedimentary deposits.

[1]Definitions for select words are found in the Appendix.

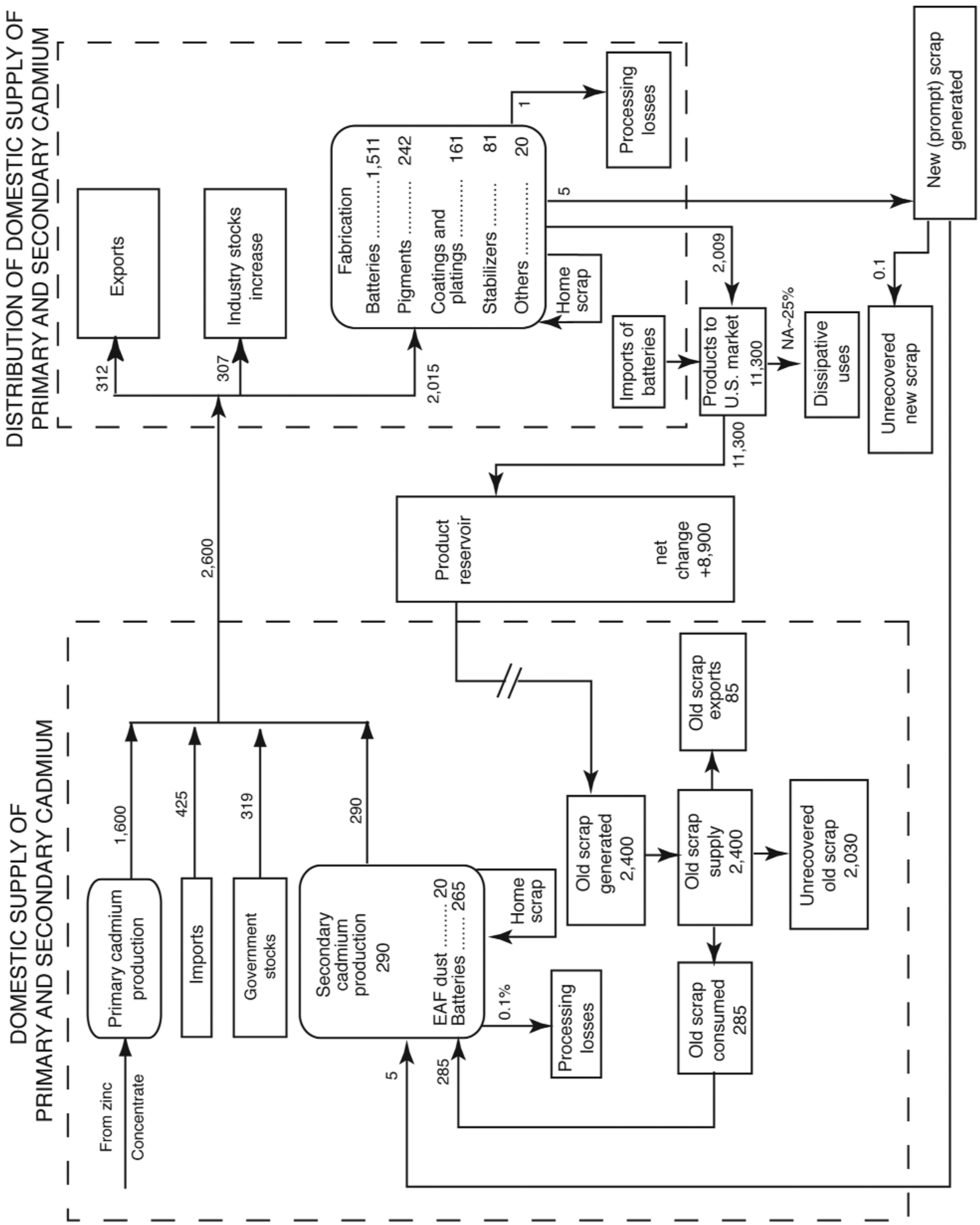

Figure 1. U.S. cadmium materials flow in 2000. Values are in metric tons of contained cadmium.

Table 1. Salient statistics for U.S. cadmium scrap in 2000.
[Values in metric tons of contained cadmium unless otherwise specified]

Old scrap:	
Generated[1]	2,400**
Consumed[2]	285**
Consumption value[3]	$100.5 thousand**
Recycling efficiency[4]	15 percent*
Supply[5]	2,400**
Unrecovered[6]	2.,030**
New scrap consumed[7]	5**
New-to-old-scrap ratio[8]	2:98**
Recycling rate[9]	14 percent**
U.S. net exports of scrap[10]	85**
Value of U.S. net exports of scrap[3]	$30 thousand**

[1]Cadmium content of products theoretically becoming obsolete in the United States in 2000.

[2]Cadmium content of products that were recycled in 2000.

[3]Value of cadmium scrap based on primary cadmium metal price.

[4](Old scrap consumed plus old scrap exported) divided by (old scrap generated plus old scrap imported plus any old scrap stock decrease or minus any old scrap stock increase). Some items were not available.

[5]Old scrap generated plus old scrap imported (not available) plus old scrap stock decrease (not available).

[6]Old scrap supply minus old scrap consumed minus old scrap exported (not available) minus old scrap stock increase (not available).

[7]Includes new (prompt) industrial scrap but excludes home scrap.

[8]Ratio of quantities consumed, in percent*(See Appendix—Definitions).

[9]Fraction of the metal apparent supply that is scrap on an annual basis. It is defined as (consumption of old scrap plus consumption of new scrap) divided by apparent supply (see appendix), measured in weight and expressed as a percentage.

[10]Trade in scrap is assumed to be principally in old scrap. Net exports are exports of old scrap minus imports of old scrap (not available).

Cadmium-containing zinc deposits occur in many diverse geological environments. Contact metamorphic, or skarn, deposits are deposits contained in metamorphosed sedimentary rocks, often limestone, that have been altered and enriched by zinc- and cadmium-bearing solutions from adjacent igneous intrusives. These deposits are usually low in cadmium, and U.S. deposits of this type are not important zinc or cadmium sources.

Another type of deposit, which is an evolution of the contact-metamorphic deposit, is the irregular replacement deposit. In these deposits, which tend to be higher in cadmium content, ore solutions migrate considerable distances from the igneous source. These zinc- and cadmium-bearing solutions seek out weaknesses in the surrounding rock and form irregularly shaped replacement deposits.

Vein-type deposits occur as tabular masses that fill faults and joints in the host rock. Generally, these deposits have planar walls. As zinc- and cadmium-bearing solutions move away from the point of origin, they deposit metals as a result of local temperature and pressure conditions. Hence, cadmium may be enriched greatly in certain parts of the deposit and depleted considerably in other parts.

Strata-bound-type zinc deposits are the most important commercially. In platform carbonates, they occur as thin zones of replacement mineralization or breccia fillings. These are the classic Mississippi Valley-type deposits, which may cover several hundred square kilometers (Wedow and others, 1973). Metamorphic equivalents of such deposits generally have mineralization in lenticular masses and are generally lower in cadmium. Stratiform deposits involve mineralization that forms lenticular masses at the contacts of metamorphosed sedimentary and interbedded volcanic rocks. Cadmium concentrations in these deposits are low to intermediate (Plunkert, 1985).

PRIMARY PRODUCTION AND PROCESSES

By the end of 2000, only Pasminco Zinc, Inc., was producing primary cadmium at its zinc smelter in Clarksville, Tenn. Big River Zinc Corp., Sauget, IL, ceased production of cadmium in 2000 owing to low prices and the loss of a major consumer, a NiCd battery manufacturer. Big River found it more economically expedient to dispose of raw cadmium in the slag than to process it. Both primary cadmium producers used an electrolytic process and recovered cadmium as a byproduct during the roasting and leaching of zinc concentrate. After removal of various impurities, cadmium is electrowon to a 99.99-percent or more purity and cast into 50-millimeter (mm)-diameter balls or 250-mm-long sticks or is oxidized to produce cadmium oxide powder.

SOURCES OF SECONDARY CADMIUM

OLD SCRAP GENERATED

Because data are not available on trade in NiCd batteries, and imported batteries are the major source of old scrap generated, estimating old scrap generated is difficult. Based on the author's calculations of the amount of cadmium recovered and Informinc (undated) estimates of cadmium discarded in 2000 in household batteries and appliances, old-scrap generated is estimated to be 2,400 metric tons.

During the past 30 years, cadmium applications have shifted steadily away from coatings, which accounted for about 50% of consumption in the 1960s, to NiCd batteries, which accounted for about 75 percent of consumption in 2000 (Plachy, 2001). Consequently, spent batteries are the major source of recycled cadmium, and the recycling rate for these batteries varies according to battery size. About 80 percent of large industrial batteries in the world, which contain about 20 percent of all cadmium used in batteries, is estimated to be recycled, but only about 20 percent of small consumer NiCd cells and batteries are recycled (Hugh Morrow, President, International Cadmium Association, oral commun., 2002). The calculated recycling rate for cadmium in the United States was 13 percent in 1998. Figure 1 shows

*Correction posted on June 29, 2009.
**Corrections posted on August 25, 2010.

the estimated quantity of old scrap generated, and the flow of this metal through processing and use. Table 1 lists salient statistics derived from figures shown in this flow chart.

Two major categories of batteries are recycled—wet cell and dry cell. Most wet cell batteries are lead-acid batteries primarily used in motor vehicles. Dry cell batteries, which are also known as consumer batteries, are either primary or rechargeable. About 80 percent of rechargeable batteries are made of nickel and cadmium. In 2000, an estimated 3.5 billion consumer batteries were sold in the United States, of which almost 10 percent were NiCd batteries (Informinc, undated). The market for rechargeable batteries is growing faster than the market for nonrechargeable (primary) batteries mainly owning to increased sales of portable and cordless products. About 80 percent of all rechargeable batteries are not sold separately, but instead are inclosed in consumer products; these products require a broad range of power requirements—from low-power drain (for example, portable computers) to high-power drain (for example, power tools). For low-power-drain applications, nearly all NiCd batteries have been replaced by batteries that use new technologies, such as nickel-metal hydride (NiMH) and lithium-ion (Li-ion) batteries. For high-power-drain applications, nearly all batteries are NiCd.

Quantities of other sources of secondary cadmium, such as electric arc furnace dust (flue dust), electroplating wastes, filter cakes, and sludges, are small and diminishing because of low cadmium prices. The amount of these other sources was not available for this study.

Figure 2 shows how the share of various end uses of cadmium has changed since 1980. Batteries have a much larger share, and coatings and plating, a much smaller share.

NEW SCRAP GENERATED

Almost all new scrap is generated at the plants that use cadmium, mainly battery manufacturing plants, and is recycled inhouse or through tolling arrangements with recyclers. Small amounts of new scrap are probably generated at pigment-manufacturing facilities, electroplating shops, alloy manufacturers, and plastic-stabilizer production facilities. The amount of cadmium produced from new scrap was estimated to be 5 t in 2000.

DISPOSITION OF CADMIUM SCRAP

All consumer batteries take up an estimated 1 percent of Municipal Solid Waste (MSW) but contribute a disproportionately high percentage of certain toxic metals, mainly mercury and cadmium, to the waste stream. Mercury has been used as a gas-suppressing additive in the batteries, and its use is being eliminated by changes in the internal design of batteries. Cadmium, however, is used as an electrode and, therefore, is the basic power source of the battery. Any reduction of cadmium would cause a proportionate reduction in the energy output. Consequently, reduction of cadmium in MSW could only be achieved by increased recycling or replacement of NiCd batteries with less toxic alternates. About 2,030 t of cadmium in household batteries is in appliances and was discarded and unrecovered in 2000 (Informinc, undated).

Because a high percentage of NiCd batteries are being discarded, cadmium can accumulate at the MSW disposal site and could slowly leach into ground and surface waters from these landfills. To lessen or even eliminate the likelihood of environmental contamination, public pressure forced local and Federal Governments to regulate disposal of toxic materials and to encourage recycling of those that are reusable. This has been the main motivating force in the creation of numerous cadmium recycling programs. Because small spent batteries are a major source of cadmium contamination when incinerated or disposed of in landfills, most of the collection and recycling programs were aimed at these batteries. The first Federal effort at regulation of all hazardous wastes was the Resource Conservation and Recovery Act of 1976. This regulation provided an exemption for residential use; different regulations applied to identical scrapped batteries depending on who had used them. The Universal Waste Rule of 1995 unified the treatment of all hazardous waste, regardless of the origin. Under the rule, the assumption that NiCd batteries are nonhazardous until they reached the recycling facility was especially beneficial for battery recycling. Individual States, however, were allowed to accept or reject the new rule. Those States that did not adopt the rule continued to consider NiCd batteries to be hazardous material and required special safeguards for transportation through those States. The different requirements by individual States made interstate transportation of collected NiCd batteries to the recycler too expensive. As a result, collection of recyclable batteries suffered despite the adoption of the Universal Waste Rule by 32 States by 1996. This obstacle was eliminated with the passage of the Mercury Containing and Rechargeable Battery Management Act (also called the Battery Act), which was signed into law on May 13, 1996. The Battery Act has two purposes—the phasing out of mercury in batteries and the efficient and cost-effective collection, transportation, recycling, and/or proper disposal of used NiCd batteries, used small sealed lead-acid batteries, and certain other regulated batteries. The Battery Act also established national uniform labeling requirements for regulated batteries and rechargeable consumer products and easy removability of batteries in these products that were manufactured domestically or imported and sold in the United States. Because the Battery Act is mandatory for all States, national organizations for the collection of spent NiCd batteries and guaranteed unhindered transportation of these batteries throughout the United States could be established. These two aspects became the needed impetus for the addition of a cadmium recycling facility at the stainless steel (Fe-Ni-Cr) recycling works of INMETCO and the rapid growth of Rechargeable Battery Recycling Corp. (RBRC).

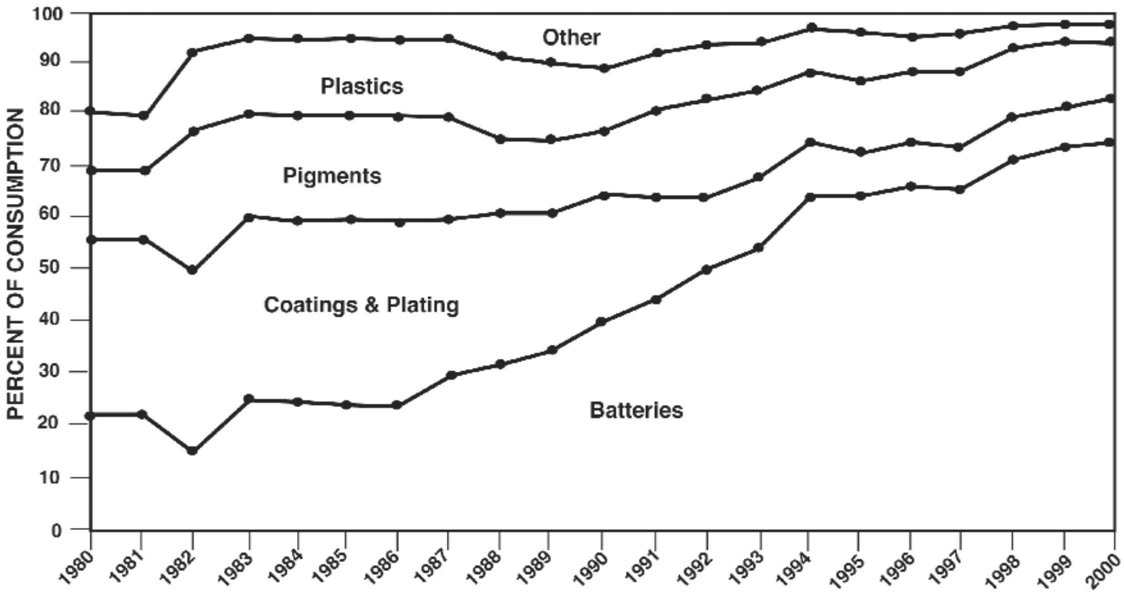

Figure 2. U.S. cadmium consumption by end-use pattern, from 1980 through 2000.

OLD SCRAP RECYCLING EFFICIENCY

Although trade in batteries is significant, data are not available, particularly for NiCd batteries. Because trade is an important factor in estimating old scrap generated and, therefore, old scrap recycling efficiency, making an estimate of old scrap recycling efficiency is difficult. On the basis of the study in Informinc (undated) and estimates of 2,032 t of cadmium discarded in 2000, a 15-percent recycling efficiency was calculated. This is thought to be an optimistic evaluation. With improved collection systems, however, this percentage could be raised significantly.

INFRASTRUCTURE OF CADMIUM SCRAP RECYCLING

Because large quantities of small batteries are discarded by a large number of individual consumers, most collection efforts are aimed at improving the recycling rate of these batteries. This, however, is proving to be the most difficult aspect of recycling because changing the attitudes and habits of the public is not easy. To make recycling as convenient as possible, several collection programs have been developed to meet the needs of battery manufacturers and the numerous consumers, firms, organizations, and agencies that use such diverse products as power tools, cordless phones, and personal computers.

Kinsbursky Brothers Inc. and RBRC are the two largest organizations that collect spent NiCd batteries. Kinsbursky Brothers is a California-based environmental management company that specializes in integrated waste management and resource recovery programs and services. The company was founded in the 1950s and gradually expanded to new areas, which included recycling lead acid and all nonlead acid battery chemistries, auto and petrochemical catalysts, and precious-metal refining. Kinsbursky Brothers latest expansion, in collaboration with RBRC, was into NiCd battery collection (Kinsbursky Brothers, Inc., undated).

A financially independent nonprofit organization, RBRC generates revenues for the recycling program by licensing its seal of approval to individual companies involved in the manufacture, import, and distribution of rechargeable batteries or battery-operated products. The collection program, which is called Charge Up to Recycle!, contains several key elements, such as uniform battery labeling, removability from appliances, national network of collection systems, regulatory relief to facilitate battery collection, and widespread publicity to encourage public participation, that are required by Federal and various State laws. To deal with batteries generated by many different sources, RBRC has set up separate collection systems for business and public agencies, communities, licensees, and retailers. Batteries from these collection systems are transported to two consolidation points located in Minnesota and New Jersey. All batteries from these consolidation points are shipped to INMETCO by the United Parcel Service (UPS) or by national common carriers. In 2000, RBRC and Kinsbursky Brothers collected 1,770 t of batteries (Norm England, Director, Portable Rechargeable Battery Association, oral commun., 2001). Most of the NiCd batteries collected by Kinsbursky Brothers in the 13 Western States were sent to a processing facility in France, and batteries collected by RBRC in the remaining States were sent to INMETCO.

In 1995, INMETCO began reclaiming cadmium from spent batteries at its newly built cadmium recycling plant and currently (2000) produces about 290 t of cadmium metal per year (Cassidy, 2001). The $5 million High Temperature

Metal Recovery plant addition, which was built by Davy International Ltd., was the first facility of its kind in the world. It is capable of processing more than 3,500 metric tons per year (t/yr) of spent NiCd batteries. During the past few years, the amount of industrial batteries that was recycled has remained constant, but recycling of small consumer batteries increased and now composes about 60% of all batteries recycled. To supplement RBRC's collection programs, INMETCO developed its own collection programs because a larger recycling operation lowers the unit cost of the secondary metal production. INMETCO'S programs also meet the varied needs of battery manufacturers and the numerous agencies, consumers, firms, and organizations that use the many diverse products that contain NiCd batteries. The most successful collection program is the prepaid container program in which companies that generate spent batteries purchase a 14-kilogram container for collection and shipment of spent batteries. The fee for the container includes shipping by UPS, handling, sorting, and processing. Additional collection programs include mail-back envelopes, a small package program, and so-called "milk runs." The mail-back program is used by companies that want to provide their individual customers with the means to recycle their batteries without using a consolidation location. The company sends their customers a prepaid envelope addressed to INMETCO when a new battery is purchased; there is no direct cost to the customer. The small package program is intended for small businesses that are not part of the RBRC program; the transportation cost for this program is the responsibility of the generator. The milk runs are used by generators that are too far from INMETCO and are willing to share transportation expenses. In this program, one transporter travels to several sites, usually in conjunction with other trucking business, to pick up several drums of spent batteries. Because industrial users of NiCd batteries are prohibited from discarding the batteries in municipal waste dumps, they are recycled through collection programs in which producers of these batteries collect and send their spent batteries to INMETCO (Money, Tomaszewski, and Bleakney, undated).

PROCESSING OF CADMIUM SCRAP

The processes of cadmium recovery from industrial and consumer sealed NiCd batteries differ only in the manner of battery preparation. Industrial batteries, which contain an average of 9 percent cadmium (up to 25 percent Cd), are drained of potassium hydroxide electrolyte, the battery tops are cut off, and the nickel and cadmium plates are manually separated. The cadmium plates are washed, dried, and sent to a cadmium recovery facility. Nickel plates, metal cases, and retort residues are smelted into remelt alloy pig for the stainless steel industry; they are not refined by INMETCO, but are sold directly to the stainless steel industry for making new stainless steel. Small sealed batteries that contain as much as 17 percent cadmium must be hand sorted because only newer batteries are color coded, and very few of them carry bar codes, which makes optical scanning and other automated sorting very difficult. At the request of recycling organizations, INMETCO collects not only NiCd batteries, but also other batteries, such as Ni-MH, Li-ion, and lead acid. Alkaline batteries that are inadvertently included in the shipment to INMETCO are disposed of in a landfill. All these batteries are manually sorted by three people, and NiCd batteries are then transported by conveyor belt to a 330-kilogram-per-hour (kg/h) crusher. About 20 percent of the total weight of small consumer batteries is plastic, which is reduced to about 7 percent by using magnetic separation of crushed batteries. The remaining plastic cover is burned off at the thermal oxidizer at a temperature of about 300° C When the temperature inside the oxidizer drops to about 200° C, because of a new charge, additional burners are engaged.

Since the installment of three original batch-type thermal oxidizer retort vessels at INMETCO in 1995, the supply of collected spent batteries soon outpaced the processing capacity, and a fourth retort furnace was added a year later. Soon this new addition proved to be inadequate. As battery recycling expanded, bottlenecks that had developed in the recycling flow had to be eliminated; during the past 3 years, improvements have cost about $3.3 million. First, a continuous-flow rotary thermal oxidizer that is capable of processing about 250 kg/h of NiCd batteries with virtually no operator involvement (there is only one operator for all oxidizers) was installed. Second, the capacity of the new rotary oxidizer was increased to more than 500 kg/h with the subsequent addition of a mechanical plastic removal mill. Third, three new retort furnaces dedicated entirely to portable NiCd battery recycling were added. And, last, the small battery receiving and sorting area was enlarged and improved, and the ventilation of welding fumes at the cadmium recovery equipment repair shop where retort furnaces and crucibles are repaired/welded was improved.

The washed and dried cadmium plates from industrial batteries and the crushed small batteries from which most of the plastic casing has been removed are charged into a cadmium recovery furnace called a crucible. The charge is augmented with carbon, which is added as a reductant. The furnace is heated to a temperature higher than the melting point of cadmium (321° C) but below the melting temperature of nickel (1,453° C). For a more-even heat in the oven, the crucible is equipped with burners at the bottom and in the middle. Melted cadmium is continuously collected in a water bath. The final products, which are called Cadmet shots, are small flattened discs, 4 to 6 mm in diameter, which facilitate handling and reduce erratic rolling. They have a purity of greater than 99.95 percent cadmium, some as high as 99.999 percent cadmium. As the final step, Cadmet shots are drummed, weighed, and assayed. Cadmets of at least 99.95 percent cadmium are shipped to NiCd battery manufacturers for reuse in new batteries. Lower purity (between 99.75 and 99.95 percent) Cadmets are used in the manufacture of corrosion-resistant coatings and cadmium-containing stabilizers, alloys, and/or pigments.

INMETCO processes other batteries but only to the degree that is possible with equipment that is already available. For example, NiMH batteries are shredded and melted at the company's rotary hearth furnace or submerged electric arc furnace (EAF) to produce an alloy. The rare-earth components from NiMH batteries are added to the nonhazardous slag, which is sold as a replacement for limestone used for roadbeds and construction fillers. Nickel-iron, nickel metal hydride, lithium ion, and mercury-free zinc carbon (also known as carbonaire) batteries are also shredded and then added to a rotary hearth or submerged EAF where most of the zinc is reduced and then fumed off into the waste-gas stream. The fume particulate is collected and sent offsite as a crude zinc oxide for zinc and lead recovery. The remaining zinc, manganese, and other metal portions are fed to an EAF where final zinc volatization takes place. The metal casing is smelted, and the bulk of the manganese is incorporated into the metal product. The carbon is used as a reductant, which is a replacement for coke, during cadmium distillation. Lithium ion and lithium polymer batteries are processed to recover cobalt, copper, and lithium. The metal casings are added to the EAF for smelting into a metal ingot that consists of iron (64 percent), chromium (14 percent), nickel (13 percent), and other elements. Lead acid and mercury batteries are not processed at INMETCO, but are sent to appropriate secondary lead and mercury producers (Mark Tomaszewski, International Metals Reclamation Co. Inc., oral commun., 2002).

In addition to the pyrometallurgical process in which cadmium vapor is collected and then solidified by condensation or oxidation, hydrometallurgical cadmium recycling processes are used. In these wet chemical processes, batteries are dissolved in strong acids and then subjected to selective precipitation or ion exchange reactions to separate cadmium compounds from nickel and iron compounds.

OUTLOOK

Statistics indicate that worldwide sales of rechargeable NiCd batteries have been declining by about 1 to 2 percent per year since 1993. This decline is mostly caused by the loss of certain market segments to other batteries, such as NiMH or Li-ion. NiCd batteries, however, are expected to maintain a good share of the market because they are renowned for their long life and minimum maintenance requirements, high power density, wide temperature operating range, good charge retention, and reasonable price. For many applications, such as cordless power tools and emergency lighting, no better alternative is currently (2000) available. At the same time as the sale of NiCd batteries declined, recycling rates have been increasing at an average rate of more than 6 percent per year since 1995 (Money and Griffin, 2000, p. B75). Both these trends bode well for the environment.

Recyclers are counting on increased recycling in the United States, and not only of NiCd batteries, but also of alkaline and Li-ion batteries. In 2001, Toxco Inc. (a subsidiary of Kinsbursky Brothers) acquired Moltech Corp.'s patented cadmium recovery facility and equipment for recycling NiCd batteries. Because about 80 percent of all batteries are alkaline, Toxco is also planning to recycle alkaline batteries at its Trail, British Columbia, Canada, facility. By using established technology, Toxco will be able to reintroduce the recycled materials into the manufacture of downstream metals. Ozark Fluorine Specialties (a division of Toxco in Tulsa, Okla.) is to produce lithium salts and electrolytes used in the manufacture of lithium batteries and ultra capacitors from recycled Li-ion batteries. With these new initiatives, Kinsbursky Brothers appears to be positioning itself as the foremost primary and rechargeable battery recycler (Kinsbursky Brothers, Inc., undated). These new initiatives in themselves, however, will not increase battery recycling. Their success will be determined by the extent to which the battery manufacturing industry is able increase the collection rate of spent batteries. This may turn out to be the biggest hurdle to overcome.

The rate of recycling could probably be improved by raising the awareness about the advantages of recycling as opposed to disposal of spent batteries or offering some type of other incentives. Increased recycling would reduce seepage of hazardous constituents from landfills and reduce harmful airborne components that are released during the incineration of waste. Recycling would also help to sustain our natural resources, not only by recycling the material content of batteries, but also by saving the energy used for processing of these materials. For example, INMETCO's recycling process is about 50-percent more energy efficient and more environmentally beneficial than metal production from virgin ore (Money and Griffin, 2000, p. B76). Less fuel consumption means less air pollution—an additional environmental benefit. Increases in the recycling rate would likely require a variety of efforts, such as an expensive multimedia advertisement campaign, Federal Government-mandated pealable stickers on products to remind consumers to recycle spent batteries, and so forth. At current (2000) prices for revenue-generating materials recovered from the spent batteries, especially nickel, and the realized benefit for the environment from less cadmium pollution, the expense that would be required to significantly increase the recycling rate may not be cost effective. Therefore, only a gradual increase in recycling rate can be expected in the near future.

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APPENDIX—DEFINITIONS

apparent consumption. Primary plus secondary production (old scrap) plus imports minus exports plus adjustments for Government and industry stock changes.

apparent supply. Apparent consumption plus consumption of new scrap.

dissipative use. A use in which the metal is dispersed or scattered, such as paints or fertilizers, making it exceptionally difficult and costly to recycle.

downgraded scrap. Scrap intended for use in making a metal product of lower value than the metal product from which the scrap was derived.

home scrap. Scrap generated as process scrap and consumed in the same plant where generated.

new scrap. Scrap produced during the manufacture of metals and articles for both intermediate and ultimate consumption, including all defective finished or semifinished articles that must be reworked. Examples of new scrap are borings, castings, clippings, drosses, skims, and turnings. New scrap includes scrap generated at facilities that consume old scrap. Included as new scrap is prompt industrial scrap—scrap obtained from a facility separate from the recycling refiner, smelter, or processor. Excluded from new scrap is home scrap that is generated as process scrap and used in the same plant.

new-to-old-scrap ratio. New scrap consumption compared with old scrap consumption, measured in weight and expressed in percent of new plus old scrap consumed (for example, 40:60).

old scrap. Scrap including (but not limited to) metal articles that have been discarded after serving a useful purpose. Typical examples of old scrap are electrical wiring, lead-acid batteries, silver from photographic materials, metals from shredded cars and appliances, used aluminum beverage cans, spent catalysts, and tool bits. This is also referred to as postconsumer scrap and may originate from industry or the general public. Expended or obsolete materials used dissipatively, such as paints and fertilizers, are not included.

old scrap generated. Metal content of products theoretically becoming obsolete in the United States in the year of consideration, excluding dissipative uses.

old scrap recycling efficiency. Amount of old scrap recovered and reused relative to the amount available to be recovered and reused. Defined as (consumption of old scrap (COS) plus exports of old scrap (OSE)) divided by (old scrap generated (OSG) plus imports of old scrap (OSI) plus a decrease in old scrap stocks (OSS) or minus an increase in old scrap stocks), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{OSE}}{\text{OSG} + \text{OSI} + \text{decrease in OSS or} - \text{increase in OSS}} \times 100$$

old scrap supply. Old scrap generated plus old scrap imported plus old scrap stock decrease.

old scrap unrecovered. Old scrap supply minus old scrap consumed minus old scrap exported minus old scrap stock increase.

primary metal commodity. Metal commodity produced or coproduced from metallic ore.

recycling. Reclamation of a metal in usable form from scrap or waste. This includes recovery as the refined metal or as alloys, mixtures, or compounds that are useful. Examples of reclamation are recovery of alloying metals (or other base metals) in steel, recovery of antimony in battery lead, recovery of copper in copper sulfate, and even the recovery of a metal where it is not desired but can be tolerated—such as tin from tinplate scrap that is incorporated in small quantities (and accepted) in some steels, only because the cost of removing it from tinplate scrap is too high and (or) tin stripping plants are too few. In all cases, what is consumed is the recoverable metal content of scrap.

recycling rate. Fraction of the apparent metal supply that is scrap on an annual basis. It is defined as (consumption of old scrap (COS) plus consumption of new scrap (CNS)) divided by apparent supply (AS), measured in weight and expressed as a percentage:

$$\frac{\text{COS} + \text{CNS}}{\text{AS}} \times 100$$

scrap consumption. Scrap added to the production flow of a metal or metal product.

secondary metal commodity. Metal commodity derived from or contained in scrap.