# CADMIUM

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In 1998, production of cadmium in the United States declined by nearly 9% compared with the unusually high production in 1997, while production of cadmium compounds increased by about 6% (tables 1 and 2). Apparent consumption declined by more than 6%, but, for the third consecutive year, exceeded production (table 3). The difference was made up by imports (table 6) and sales from the National Defense Stockpile (NDS). Prices continued to decrease during 1998 in response to the over-supplied world market.

Approximately 80% of world cadmium production was derived from the mining, smelting, and refining of zinc, and the remaining 20% came from copper and lead smelting and the recycling of cadmium products. In the United States, two companies, one in Illinois and one in Tennessee, produced primary cadmium as a byproduct of the smelting and refining of zinc concentrates in 1998. A third company, in Pennsylvania, recovered cadmium from scrap, mainly from spent nickel-cadmium (Ni-Cd) batteries. The value of cadmium produced in 1998 was calculated to be about $1.2 million. Although definitive consumption data do not exist, the International Cadmium Association (ICDA) has made the following estimates of cadmium consumption for various end uses: batteries, 72%; pigments, 13%; coatings and plating, 8%; stabilizers for plastics and similar synthetic products, 6%; and nonferrous alloys and other uses, 1% (Morrow, H., 1999, President, International Cadmium Association, sent May 13, 1999, from e-mail ICDAMorrow@aol.com).

In 1998, as in most years, the United States was a net importer of cadmium metal (table 1). The major source of imports was Canada, with nearly one-half of all imports, followed by Australia, Belgium, and Mexico (table 6). These four countries supplied nearly 97% of all imported cadmium metal. Cadmium compounds and pigments were subject to import duties, but unwrought and powdered metal, as well as waste and scrap, entered duty-free in all but a few cases. Cadmium, in all forms, from North American Free Trade Association member states (Canada and Mexico) entered the United States duty free. As in 1997, the United States was a net exporter of cadmium sulfide, all of which was exported to Germany, the Republic of Korea, and Taiwan (table 5). Trade data for other cadmium compounds were not available.

Cadmium was refined in 30 countries in 1998. The five largest producers, in decreasing order, were Japan, Canada, China, the United States, and Belgium. These countries accounted for one-half of world production; the United States accounted for nearly 10%. Identified world cadmium resources at yearend 1998 were estimated by the U.S. Geological Survey (USGS) to be 6 million metric tons (Mt), a figure based on zinc resources typically containing about 0.3% cadmium. The world reserve base was estimated to be 1.2 Mt, and reserves, 600,000 metric tons (t).

## Legislation and Government Programs

Cadmium was regulated by the U.S. Environmental Protection Agency (EPA) and some States under the Clean Water Act's National Pollutant Discharge Elimination System and General Pretreatment Regulations. EPA offices overseeing regulations and guidelines applicable to cadmium included Air Quality Planning and Standards, Drinking Water, Toxic Substances, Solid Waste, Pesticide Programs, and the Office of Emergency and Remedial Response. The Occupational Safety and Health Administration (OSHA) sets permissible limits for occupational exposures to cadmium. EPA has recently proposed a program aimed at reducing the exposure and risk to human health and the environment from persistent, bioaccumulative, and toxic (PBT) chemicals, and classified 11 metals (including cadmium) and their compounds as PBT chemicals. The program aims at a 25% reduction of PBT waste from the 1990 levels by 2000, mainly through source reduction or product substitution rather than by recycling.

## Production

Only two companies produced primary cadmium in the United States in 1998—Big River Zinc Corp., Sauget, IL, and Savage Zinc Inc., Clarksville, TN. Both companies used an electrolytic process and recovered the cadmium as a byproduct during roasting and leaching of zinc concentrate. The Sauget operation, owned by Korea Zinc Co. Ltd., can produce up to 82,000 metric tons per year (t/yr) of zinc and 900 t/yr of cadmium metal and oxide. About 80% of its concentrate feed was supplied by mines in Missouri and Tennessee, and the remaining 20% was imported, mainly from Canada, Mexico, and Peru (Mining Journal, 1999).

The cadmium content of zinc sulfide concentrate is usually between 0.1% and 0.8%. The zinc concentrate is roasted in fluidized bed roasters that produce an impure zinc oxide (calcine) suitable for acid leaching. Between 60% and 85% of the calcine, which contains cadmium and other impurities, is carried out with the sulfur dioxide gas. Calcine and fume are separated from the gas and collected in waste heat boilers, cyclones, and electrostatic precipitators. The collected calcine dust is combined with the unvolatilized portion of the calcine and dissolved in sulfuric acid in a leaching plant. Generally, manganese dioxide is added to the leaching tank to remove iron and significant amounts of other impurities. These insoluble residues are sold to other smelters for further processing as iron cake. The leachate is then sent to a series of cold and hot purification tanks where cadmium and other remaining undesirable metals are removed from the solution. At the first stage of zinc sulfate purification, discharged impurities form copper cake, which, like the previously captured leach residues, are sold for processing. The bulk of cadmium is precipitated in the second stage of purification, and the remainder, in a third stage. The cadmium precipitate is filtered and forms a cake containing about 12% cadmium, 25% zinc, and small amounts of other impurities. The cake is then redissolved in sulfuric acid. After two additional acid treatments, a reasonably pure cadmium sponge is produced, which is again dissolved in sulfuric acid, and the solution, if sufficiently pure, is passed into electrolytic cells where the cadmium is deposited on cathodes. The resulting more than 99.99%-pure cadmium metal is melted and cast into 50-millimeter-diameter ball anodes or 250-millimeter-long sticks or burned to make cadmium oxide powder. Higher purity cadmium for such special purposes as for semiconductors can be produced by vacuum distillation (U.S. Environmental Protection Agency, 1987).

In 1998, Savage Zinc, then the wholly owned subsidiary of Sydney-based Savage Resources Ltd. of Australia, went through a difficult year. The labor strike that began on August 3 at the Gordonsville Mine, 80 kilometers east of Nashville, TN, continued for the rest of the year. Ore production continued during the strike, albeit at a much lower level, using about 65 salaried employees as replacements for 211 striking miners. This loss of production was partially offset by increased output at the Clinch Valley Mine and accelerated purchases from other companies, mainly ASARCO Incorporated, which operated three underground mines in the Mascot-Jefferson City zinc district in east Tennessee. The difficulties in 1998 were compounded by an attempted hostile takeover of Savage Resources by Pasminco Ltd. of Australia. Savage Resources' Clarksville zinc refinery, which also produced primary cadmium, was the main target in the bid, jeopardizing a planned tripling of capacity of the smelter. After the bid was formally submitted on October 20, Savage Resources directors began negotiating with other companies either to counter Pasminco's bid or to establish a joint partnership. The takeover bid was described as opportunistic, timed to take advantage of low zinc prices, and stockholders were implored to reject it. By the beginning of 1999, however, the takeover bid succeeded, and Pasminco acquired the zinc operations of Savage Resources, including its U.S. subsidiary—Savage Zinc (Metal Bulletin, 1998).

In 1995, International Metals Reclamation Co. Inc. (INMETCO), a subsidiary of the International Nickel Co., began reclaiming cadmium from spent batteries at its Ellwood City plant, 56 kilometers northwest of Pittsburgh, PA. The $5 million cadmium High Temperature Metal Recovery (HTMR) addition, built by Davy International Ltd., was the first facility of its kind in the world. To date, cadmium recycling has been practical only for Ni-Cd batteries, some alloys, and dust from electric arc furnaces—which typically contained 0.003% to 0.07% cadmium.

The most difficult aspect of cadmium recycling is the collection of spent Ni-Cd batteries. Large industrial batteries, containing 25% of the cadmium used for batteries, are easy to collect and are recycled at a rate of about 80%. About 75% of the cadmium used in batteries goes into small consumer Ni-Cd cells and batteries that are usually discarded in municipal solid waste. Therefore, various organizations and Government agencies are devising ways to improve the collection of these small batteries. Economies of scale are very important, and the larger a recycling operation, the lower its unit cost is likely to be. Several different collection programs have been developed by INMETCO to meet the needs of battery manufacturers and users of such products as power tools and cellular phones, computer manufacturers, hospitals, emergency groups, fire, police, etc. The largest of these programs, the Rechargeable Battery Recycling Corp. (RBRC), is associated with the battery manufacturers and is operated by a nonprofit public service organization. The RBRC has undertaken an extensive public education campaign and established several recycling programs, such as the Retail Recycling Plan, the Community Recycling Plan, and the Public Agency Recycling Plan. During 1998, RBRC increased household collection sites in the United States to more than 24,000 and expanded Canadian collection, which began in 1997. According to the ICDA, about 25% of all Ni-Cd batteries were recycled in the United States in 1998. For the small consumer-sealed dry cell Ni-Cd batteries, INMETCO recruited manufacturers for mail-back of used batteries, community-based prepaid container programs, and other similar arrangements. Most of the industrial wet Ni-Cd batteries were recycled through collection programs where producers of industrial batteries collect and send their spent batteries to INMETCO by issuing a purchase order, then arranging their own transportation. A smaller portion of industrial batteries was collected and shipped by various environmental companies (Bleakney, 1998).

The process of cadmium recovery from industrial and consumer sealed batteries, both of which contain about 12% to 15% cadmium by weight, differs only in the manner of battery preparation. Shipments of industrial batteries from manufacturers tends to be free of undesirable metals. Processing consists of draining sodium hydroxide electrolyte, cutting the tops off the batteries, and separating nickel and cadmium plates. Small batteries must be hand-sorted because only a few newer batteries are color coded and almost none carried bar codes, making optical scanning and other automated sorting very difficult.

The cadmium plates from the industrial batteries and the small batteries, from which the plastic wrapping has been removed, are charged into a cadmium recovery furnace. In the furnace, cadmium is reduced by carbon, vaporized, and then condensed. The resulting cadmium metal, which is cast into small flattened discs, 4 to 6 millimeters in diameter, to facilitate handling and to reduce erratic rolling, has a purity of greater than 99.95%-pure Cd, some as high as 99.999%-pure Cd. These discs are usually shipped to Ni-Cd battery manufacturers for reuse in new batteries, but they also could be used in the manufacture of corrosion-resistant coatings or in paint pigments.

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

Although secondary production will likely increase in the future, primary production will probably remain basically unchanged for the next few years. Any future increases in production of virgin cadmium will likely come from the Crandon/Rhinelander zinc-copper deposit in northeastern Wisconsin. Its development will depend on the zinc market and on Nicolet Minerals Co., a wholly owned subsidiary of Rio Algom Mining Corp., acquiring some remaining permits from the Wisconsin State government. Location of the future mine near the headwaters of the Wolf River, however, aroused local opposition who feared the pollution of underground water and altered water levels of nearby lakes caused by pumping of water to keep the shafts dry. The deposit contains an estimated 62 Mt of ore grading 5.6% zinc, 1.1% copper, and 0.01% to 0.23% cadmium (Skillings' Mining Review, 1978). Sphalerite from one particular stratigraphic sequence, the Skunk Lake unit, consistently has had the highest cadmium values, averaging 0.09% cadmium (Lambe and Rowe, 1987). Pyrite is ubiquitous throughout most of the deposit. Development of the deposit would include the building of a 2-Mt-capacity mill with an annual production of between 200,000 and 300,000 t of zinc concentrate and about 20,000 t combined copper-lead concentrate (Metal Bulletin, 1996).

Another factor in the cadmium supply in recent years has been the sale of cadmium from the NDS. In 1991, the U.S. Congress authorized the disposal of the entire cadmium stockpile of 2,877 t as excess material. To date, about 1,200 t of the stockpile has been sold into the market, including 128 t in 1998 (Morrow, 1998).

### Environment

Cadmium is toxic, particularly in its soluble and respirable forms. Although it is commonly associated with zinc, the two behave somewhat differently in biological systems. Zinc is an essential element in almost all biological systems and plays an important role in metalloenzyme catalysis, metabolism, and the replication of genetic material. Cadmium, however, can adversely affect the renal and respiratory systems, depending upon exposure time and concentration, and is not easily eliminated. Inhaled cadmium fumes or fine dust are much more readily absorbed than ingested cadmium. Repeated exposure to excessive levels of dust or fumes can irreversibly injure the lungs, producing shortness of breath and emphysema. Dermal contact with cadmium results in negligible absorption. Because of its toxicity, the use of cadmium is controlled by the EPA and other American and European regulatory control agencies. In the United States, cadmium compounds are included on the list of 189 chemicals listed as hazardous air pollutants under Section 112 of the Clean Air Act , as amended by the U.S. Congress in 1990. Some of the cadmium chemicals are also designated as hazardous substances under Section 311 of the Federal Water Pollution Control Act; any discharge of these chemicals above a specific threshold level into navigable waters is subject to reporting requirements. Major industrial sources of cadmium waste are subject to specific regulatory limits. The International Agency for Research on Cancer lists cadmium metal and several of its compounds as carcinogens (Research Triangle Institute, 1997).

The four main environmental and human health concerns involved with Ni-Cd batteries are occupational exposure, manufacturing emissions and wastes, product use, and product disposal. As environmental and health problems connected with the production of Ni-Cd batteries can easily be controlled, most of the recent regulations are about disposal. Basically, only four disposal options were available—composting, incineration, landfilling, and recycling. The first two options were not practical; landfilling was the most frequently used; and recycling was the most preferred by the industry and environmentalists. Establishing an environmentally responsible collection and recycling system for spent batteries may be better than banning them. Because most cadmium is produced as a byproduct, mainly of zinc production, restriction on use of cadmium in batteries will likely increase the amount of cadmium deposited in landfills by zinc producers.

Many initiatives concerning carcinogenic elements in the environment originated in Europe because of higher density of population. In one of the latest efforts to reduce cadmium in the environment, the Organization for Economic Co-operation and Development (OECD) proposed a Cadmium Risk Reduction Program. This initiative consists of two parts—initiate an investigation of the long-term stability of cadmium in landfills and encourage the exchange of information on recycling of Ni-Cd batteries. The first part of the study, conducted in Switzerland, has thus far established that the cadmium concentration in about 90% of the leachates from landfills is below permissible maximum levels of cadmium contamination for drinking water established by the World Health Organization. Discussion about the second initiative—the promotion of effective collection and recycling—was conducted in three consecutive workshops. The latest workshop, held in Mexico City, Mexico, in December 1998, prepared documents designed to assist OECD nations in the collection and recycling of Ni-Cd batteries. The emphasis on recycling instead of banning of Ni-Cd batteries, as had been originally proposed by the European Commission, was a welcome change for the cadmium industry, as well as battery manufacturers (Organization for Economic Co-operation and Development, 1998).

Another area of concern for the OECD is the amount of cadmium and other impurities contained in the phosphate rock used for production of fertilizers. The content of impurities depends on the phosphate rock's geologic origin and the mining and beneficiation technologies applied to upgrade it. An estimated 2,600 t/yr of cadmium is released into the ground worldwide through the use of fertilizers. Excessive amounts of cadmium in phosphatic fertilizer could present ecological problems, such as run-off pollution and a steady buildup of toxic amounts in the ground. That the accumulated cadmium in the ground could be taken up by edible plants, thus entering the food chain, is a major concern. New evidence, however, indicates that in most plants, the uptake of cadmium is strongly affected by the presence of zinc in the ground. As a general rule, zinc inhibits uptake of cadmium. Soil pH, clay content, and soil chloride levels also have a significant influence on uptake of cadmium. In an effort to head off regulation, the European Fertilizer Manufacturers Association has voluntarily agreed to limit cadmium levels in its products to 60 milligrams (mg) of cadmium per kilogram of phosphorus pentoxide by 2005. The four most promising processes for removing cadmium from phosphoric acid are cocrystallization of cadmium with anhydrite, precipitation with inorganic sulfide salts, formation of complex cadmium chloride anions and subsequent removal by anion exchange, and removal by solvent extraction (Davister, 1996; Vermeul, 1996).

The OECD workshop also drafted a proposal for the disposal of used cars, the so-called "end-of-life vehicles." Among other things, it will require that components containing lead (with the exception of lead solder in electronic circuit boards), mercury, cadmium, and hexavalent chromium in motor vehicles produced after 2003 be stripped from end-of-life vehicles before shredding. Because the removal of most of these components prior to shredding is not practical, this proposal would, in effect, ban most uses of these metals in automobiles (Organization for Economic Co-operation and Development, 1998).

**Consumption**

The USGS does not collect actual consumption data on either cadmium metal or cadmium compounds. Apparent consumption of cadmium metal in the United States is calculated from production, trade, and stock changes. Apparent consumption decreased by more than 6%, compared with that of 1997 (table 3). All cadmium compounds are made from cadmium metal. Although cadmium consumption for batteries has grown steadily during the past 15 years, other cadmium markets, such as pigments, stabilizers, coatings, and alloys, are regarded as mature markets because they are not expected to grow; in fact, some of the uses have already started to decline. Consumption of cadmium in these easily dispersible products will continue to decline in OECD countries because of increasingly stringent environmental regulation, concerns of manufacturers about long-term liability, and the development of less toxic substitutes. Consumption patterns varied significantly among countries because of differences in environmental regulations, industrial development, natural resources, and trading patterns.

Cadmium compounds are still being used in the United States to stabilize polyvinyl chloride (PVC). Liquid stabilizers typically contain 1% to 8% cadmium in the form of cadmium 2-ethylhexanoate or cadmium oleate. Solid stabilizers contain 4% to 12% cadmium in the form of salts of saturated fatty acids (e.g., stearic acid and lauric acid). The finished PVC product usually contains no more than 0.2% cadmium. The cadmium is locked into the polymer matrix and has extremely low leachability (Donelly, 1996).

Cadmium metal forms stable alloys with copper, tin, and several other nonferrous metals. When aluminum, brass, copper, and steel are coated with cadmium metal, they become much more resistant to corrosion, especially in marine and alkaline environments. Few elements are superior to cadmium for coating and plating if cost and corrosion resistance are weighed equally. From 1940 until 1988, coating and plating constituted the largest use of the metal in the United States. Already in 1965, however, consumption of cadmium for coatings and plating had begun to decline because of human health and environmental concerns about the metal. By 1990, coatings and plating accounted for about 25% of total cadmium consumption in the United States. That same year, the corresponding figure for Europe was estimated to be only 9%, and a mere 1% for Japan.

At the time when the consumption of cadmium for coatings and platings began to decline, the ICDA found that occupational exposures in most cadmium plating shops were below the 2.5-microgram-of-cadmium-per-cubic-meter-of-air standard set by the OSHA. In addition to effluent cadmium, new safeguards were introduced in subsequent years—plating waste water must now be treated to remove any cadmium and other heavy metals before the water can be discharged; electroplating sludges are no longer landfilled and are being shipped to EPA-approved reclamation facilities for metal recovery; and recycling of cadmium metal is encouraged and often required. These safety requirements were essential for the continued use of cadmium plating in applications where the surface characteristics of the coating are critical (e.g., fasteners for aircraft, electrical connectors, parachute buckles). Cadmium coatings do not oxidize as readily as zinc coatings in marine or concentrated salt atmospheres, and they have low electrical resistivity and good soldering characteristics. In 1992, the communications sector accounted for 31% of the cadmium coatings marketed in the United States, followed by fasteners (20%), aircraft (15%), and automotive (15%) (Morrow, 1996).

Cadmium pigments are more stable than other coloring agents at elevated temperatures and are not easily degraded by light. Because of their excellent coloring properties, cadmium pigments are widely used in thermoplastics, ceramics, glazes, and artists' colors. Mixing various amounts of cadmium sulfide and cadmium selenide and related inorganic pigments can produce a broad spectrum of brilliant, strongly opaque colors. Organic alternatives still cannot match many of the more popular properties of cadmium pigments, especially color brightness, opacity, and processability.

Despite regulatory pressures, a significant amount of cadmium is still being used worldwide to make colorants for plastics. The U.S. colorant and pigment industry has restructured almost every aspect of production in response to the new Federal and State regulations. Many producers of plastic colorants plan to phase out cadmium along with barium, chromium, and lead to make their products more environmentally acceptable and replace them with nontoxic substitutes. One of the latest noncadmium colorants is Neolor, a cerium sulfide alternative to cadmium pigments that is safe and recyclable. It was developed by the French pharmaceutical and chemical company Rhône-Poulenc SA and will be distributed in the United States by Ferro Corp., Cleveland, OH. One of the drawbacks of Neolor is its cost—it is three to four times the price of cadmium pigments for equal tint strength. For some applications, however, no organic alternative on the market can match the brilliant yellow provided by a cadmium pigment. Replacement of key cadmium pigments by organic substitutes is not straightforward, especially for molding applications that require high-temperature or high-pressure processing. Organic substitutes are not as stable and are more difficult to work with under these conditions (American Metal Market, 1997).

## Prices

Until the late 1980's, cadmium was used mainly in pigments and alloys. After the Ni-Cd battery was developed, the battery market expanded by 20% per year, and the price of cadmium increased to $9.10 per pound by March 1988. With the exception of 1995, the 1990's were marked by a steady decline in cadmium prices. After reaching an average price of $1.84 per pound of metal in 1995, prices began spiraling downward in February 1996 to an average price of $0.28 per pound in 1998 (table 1), based on the New York dealer price for cadmium metal. The Asian economic crisis, large exports of cadmium metal, mainly by Bulgaria and Russia, and gradual replacement of Ni-Cd batteries with lithium-ion and nickel metal hydride batteries caused prices to fall and remain low. Recovery of cadmium from spent Ni-Cd batteries, often required by local regulations, further depressed the market.

## Current Research and Technology

New processing technology for depositing photovoltaic cells on glass, developed by Solar Cells Inc. (SCI) and the University of Toledo, OH, could make the use of solar energy more efficient. As recently as two decades ago, electricity generated by solar panels cost more than $100 per watt. It has since fallen to an average of $7.50 per watt, which the recent breakthrough will lower by about 50%. The new manufacturing process allows SCI to coat one 2 x 4-foot solar panel with cadmium-telluride (CdTe) every 30 seconds, compared with 6 hours for the closest rival. In addition to lower manufacturing cost, the conversion efficiency increased to 9.1% from the prevailing 7.5%. To comply with environmental restrictions, SCI developed a successful recycling system for its spent photovoltic modules. Although the CdTe solar cell market is at present (1998) very small, its growth rate in recent years has been high (40% in 1997), and the world's total energy market is large and growing. It could become a significant niche market for cadmium in the near future (Welles, 1998).

The use of vegetation to clean sites contaminated with heavy metals, called phytoremediation, may now be on the brink of commercialization. At least three new companies have formed during the past few years to use this new technology, which uses plants called "hyperaccumulators" because they absorb high levels of contaminants via their roots. According to a U.S. Department of Energy report on phytoremediation research, the best hyperaccumulators should exhibit the following characteristics: a high accumulation rate, even at low environmental concentrations of the contaminant; an ability to accumulate very high levels of contaminants; an ability to accumulate several heavy metals; fast growth; high biomass production; and resistance to diseases and pests. Closest to this description is a plant from the genus *Thlaspi*, or Alpine pennycress, which can accumulate significant amounts of cadmium, zinc, and, if certain chelators are added to soil, lead. Phytoextraction for only cadmium and zinc is more practical because they are usually co-occurring pollutants. Researchers are now working with plants that can accumulate up to 25,000 mg of zinc and 1,000 mg of cadmium per kilogram of dry plant matter. Phytoremediation has been estimated to cost one-third that of traditional methods of remediation (Journal of Metals, 1998).

## Outlook

A combination of historically low prices, limited growth in the use of the metal, and pending environmental restrictions are rather discouraging for the cadmium industry. Zinc miners, who produce cadmium as a byproduct, are beginning to regard the metal as a cost rather than a credit. The cost of producing cadmium, which is difficult to determine separate from zinc, may already exceed the sale price. The future of the cadmium industry rests largely on future use of Ni-Cd batteries and the development of new recycling technologies, not only for batteries, but also for other principal end products. Industrial Ni-Cd batteries retained nearly 100% of the market for emergency lighting, alarms, power tools, and rechargeable batteries and are growing at a rate between 2% and 4% per year. The rechargeable battery industry has been growing significantly in recent years and is expected to continue to grow well into the 21st century. For the recycling industry, the first step is the establishment of global collection of Ni-Cd spent batteries because they are 100% recyclable. This is rapidly becoming a reality. The collection and recycling rates must, however, continue to increase to reassure regulators and the general public that any human health or environmental risks associated with cadmium will be managed. Recycling of cadmium products other than batteries will be considerably more difficult. The proper disposal of discarded plastics, obsolete electronic parts, incinerator residues, and municipal sewer sludge—all of which often contain low levels of dispersed cadmium—is still a problem.

The U.S. collection and recycling program for small rechargeable batteries is in a period of rapid expansion. The RBRC generates revenue for the program by licensing its seal of approval to individual companies involved in the manufacturing, importation, and distribution of rechargeable batteries or battery-operated products. The Portable Rechargeable Battery Association (PRBA), one of the sponsors, has helped enlist the participation of county and municipal governments, hospitals, and fire departments. Spent Ni-Cd, nickel-metal hydride, lithium-ion, and small sealed lead-acid batteries are all being collected under the program. The PRBA believes that by 2001, roughly 70% of the spent Ni-Cd batteries generated in the United States will be recycled. According to the RBRC, about 22% of rechargeable batteries were recycled in 1997 (latest available data) representing more than 1,700 t of batteries. Assuming an average cadmium content of 18% per battery, more than 300 t of cadmium was recycled instead of being disposed of in landfills (Price, 1998).

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[1]Prior to January 1996, published by the U.S. Bureau of Mines.

TABLE 1
SALIENT CADMIUM STATISTICS 1/

(Metric tons, cadmium content, unless otherwise specified)

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| United States: | | | | | |
| Production of metal 2/ | 1,010 | 1,270 | 1,530 | 2,060 | 1,880 |
| Shipments of metal by producers 3/ | 1,290 | 1,280 | 1,310 | 1,370 | 1,230 |
| Exports of metal, alloys, and scrap | 1,450 | 1,050 | 201 | 554 | 606 |
| Imports for consumption, metal | 1,110 | 848 | 843 | 790 | 620 |
| Stocks of metal, Government, yearend | 2,480 | 2,260 | 2,030 | 1,870 | 1,740 |
| Apparent consumption of metal | 1,040 | 1,160 | 2,250 | 2,510 | 2,350 |
| Price, average per pound, New York dealer 4/ | $1.13 | $1.84 | $1.24 | $0.51 | $0.28 |
| World: Refinery production | 18,200 | 20,100 r/ | 19,000 r/ | 19,200 r/ | 19,600 e/ |

e/ Estimated. r/ Revised.
1/ Data are rounded to three significant digits, except prices.
2/ Primary and secondary cadmium metal. Includes equivalent metal content of cadmium sponge used directly in production of compounds.
3/ Includes metal consumed at producer plants.
4/ Price for 1- to 5-short-ton lots of metal having a minimum purity of 99.95%.

TABLE 2
U.S. PRODUCTION OF CADMIUM COMPOUNDS

(Metric tons, cadmium content)

| Year | Cadmium sulfide 1/ | Other cadmium compounds 2/ |
|---|---|---|
| 1997 | 113 | 607 |
| 1998 | 125 | 638 |

1/ Includes cadmium lithopone and cadmium sulfoselenide.
2/ Includes oxide and plating salts (acetate, carbonate, nitrate, sulfate, etc.).

TABLE 3
SUPPLY AND APPARENT CONSUMPTION OF CADMIUM METAL 1/

(Metric tons)

| | 1997 | 1998 |
|---|---|---|
| Industry stocks, January 1 | 1,140 | 1,090 |
| Production | 2,060 | 1,880 |
| Imports for consumption, metal | 790 | 620 |
| Shipments from Government stockpile excesses | 161 | 128 |
| Total supply | 4,150 | 3,720 |
| Exports of metal, alloys, and scrap | 554 | 606 |
| Industry stocks, December 31 | 1,090 | 763 |
| Consumption, apparent 2/ | 2,510 | 2,350 |

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Total supply minus exports and yearend stocks.

TABLE 4
INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

| | 1997 | | 1998 | |
|---|---|---|---|---|
| | Cadmium metal | Cadmium in compounds | Cadmium metal | Cadmium in compounds |
| Metal producers | 989 | W | 633 | W |
| Compound manufacturers | 67 | 35 | 94 | 36 |
| Distributors | W | (1/) | W | (1/) |
| Total | 1,060 | 35 | 727 | 36 |

W Withheld to avoid disclosing company proprietary data; included with "Compound manufacturers."
1/ Less than 1/2 unit.

TABLE 5
U.S. EXPORTS OF CADMIUM PRODUCTS, BY COUNTRY 1/

| Country | 1997 Quantity (kilograms) | 1997 Value | 1998 Quantity (kilograms) | 1998 Value |
|---|---|---|---|---|
| Cadmium metal: 2/ | | | | |
| Belgium | -- | -- | 46,800 | $1,300,000 |
| Canada | 1,600 | $15,000 | -- | -- |
| Chile | 929 | 34,400 | -- | -- |
| China | -- | -- | 6,680 | 10,700 |
| Finland | 8,220 | 18,100 | 18,700 | 771,000 |
| France | 116,000 | 80,700 | 57,100 | 51,100 |
| Germany | 77 | 47,900 | 2 | 6,720 |
| Hong Kong | 16,500 | 45,100 | -- | -- |
| India | 100,000 | 125,000 | 95,100 | 42,600 |
| Israel | 14 | 4,790 | -- | -- |
| Italy | 11,200 | 27,300 | -- | -- |
| Japan | 249,000 | 690,000 | 4,760 | 83,000 |
| Mexico | 669 | 18,300 | 7,270 | 67,800 |
| Netherlands | 24,300 | 60,600 | 322,000 | 3,230,000 |
| Singapore | 1,910 | 17,200 | -- | -- |
| Taiwan | 766 | 8,700 | -- | -- |
| United Kingdom | 20,200 | 50,100 | 46,900 | 1,020,000 |
| Other | 2,810 | 11,400 | 1,130 | 73,700 |
| Total | 554,000 | 1,250,000 | 606,000 | 6,050,000 |
| Cadmium sulfide (gross weight): | | | | |
| Canada | 375,000 | 173,000 | -- | -- |
| Germany | -- | -- | 10,900 | 5,650 |
| Italy | 17,300 | 9,000 | -- | -- |
| Korea, Republic of | -- | -- | 8,170 | 4,250 |
| Taiwan | 7,110 | 3,700 | 9,860 | 5,130 |
| Total | 399,000 | 186,000 | 28,900 | 15,000 |

1/ Data are rounded to three significant digits; may not add to totals shown.
2/ Includes exports of cadmium in alloys, dross, flue dust, residues, and scrap.

Source: Bureau of the Census.

TABLE 6
U.S. IMPORTS FOR CONSUMPTION OF CADMIUM PRODUCTS, BY COUNTRY 1/

| Country | 1997 Quantity (kilograms) | 1997 Value | 1998 Quantity (kilograms) | 1998 Value |
|---|---|---|---|---|
| Cadmium metal: | | | | |
| Australia | 76,000 | $65,000 | 114,000 | $55,300 |
| Belgium | 36,300 | 270,000 | 99,800 | 321,000 |
| Canada | 436,000 | 965,000 | 304,000 | 438,000 |
| China | 20 | 2,060 | -- | -- |
| Finland | -- | -- | 2,000 | 1,760 |
| Germany | 101,000 | 190,000 | 24 | 3,650 |
| Italy | 402 | 7,070 | -- | -- |
| Japan | 90 | 614,000 | 205 | 43,500 |
| Mexico | 104,000 | 78,800 | 80,900 | 39,500 |
| Norway | 3,000 | 12,600 | -- | -- |
| Peru | 32,900 | 38,900 | -- | -- |
| United Kingdom | 50 | 6,460 | 13 | 3,060 |
| Total | 790,000 | 2,250,000 | 620,000 | 917,000 |
| Cadmium sulfide (gross weight): | | | | |
| Australia | -- | -- | 92 | 3,500 |
| Japan | 10,100 | 63,300 | 1,340 | 93,900 |
| Russia | 87 | 11,800 | 88 | 8,010 |
| Switzerland | 10 | 4,680 | -- | -- |
| United Kingdom | 30,000 | 295,000 | 7,940 | 81,800 |
| Total | 40,100 | 375,000 | 9,460 | 187,000 |

1/ Data are rounded to three significant digits; may not add to totals shown.

Source: Bureau of the Census.

TABLE 7

CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

| Country | 1994 | 1995 | 1996 | 1997 | 1998 e/ |
|---|---|---|---|---|---|
| Algeria | 59 r/ | 59 r/ | 50 r/ e/ | 50 r/ | 50 |
| Argentina | 27 r/ | 43 r/ | 40 r/ | 45 3/ | 45 |
| Australia | 910 | 838 | 639 | 632 3/ | 600 |
| Belgium | 1,556 | 1,710 | 1,579 r/ 3/ | 1,420 r/ | 1,318 3/ |
| Brazil e/ | 300 | 300 | 300 | 300 | 300 |
| Bulgaria e/ | 286 3/ | 250 | 250 | 250 | 200 |
| Canada | 2,173 | 2,349 | 2,537 | 1,272 r/ | 2,310 |
| China e/ | 1,280 | 1,450 | 1,570 | 1,980 r/ | 2,000 |
| Congo (Kinshasa) e/ 4/ | 1 | -- | -- | -- | -- |
| Finland 5/ | 548 | 539 | 648 | 540 r/ e/ | 550 |
| France | 6 | -- e/ | 205 | 309 3/ | 177 3/ |
| Germany | 1,145 | 1,150 e/ | 1,150 e/ | 1,145 r/ 3/ | 1,150 |
| India | 216 | 254 | 271 r/ | 298 3/ | 300 |
| Italy | 475 | 308 | 296 | 287 r/ 3/ | 328 3/ |
| Japan | 2,629 | 2,652 | 2,344 r/ | 2,473 r/ | 2,336 3/ |
| Kazakhstan | 1,097 r/ 3/ | 794 r/ 3/ | 800 r/ e/ | 800 r/ e/ | 900 |
| Korea, North e/ | 100 | 100 | 100 | 100 | 100 |
| Korea, Republic of | 400 e/ | 1,665 | 501 | 570 3/ | 550 |
| Macedonia e/ | (6/) | (6/) | (6/) | (6/) | (6/) |
| Mexico 7/ | 646 | 689 | 784 | 1,223 r/ | 1,100 |
| Namibia | 19 | 15 | 14 r/ | 2 r/ | (8/) |
| Netherlands | 307 r/ | 704 r/ | 603 r/ | 718 r/ | 739 3/ |
| Norway | 288 | 317 | 274 | 290 r/ | 270 |
| Peru | 510 r/ | 560 | 405 r/ | 474 r/ | 474 3/ |
| Poland | 61 | -- | -- | -- e/ | -- |
| Romania | 4 | 5 | 5 e/ | 4 e/ | 4 |
| Russia | 600 | 725 | 730 | 790 e/ | 800 |
| Serbia and Montenegro | 3 | 11 | 79 | 80 e/ | 80 |
| Spain | 387 | 397 | 307 | 301 r/ 3/ | 320 |
| Thailand | 643 | 365 | 385 | 238 r/ | 240 |
| Turkey | 22 | 23 | 42 r/ 3/ | 45 r/ 3/ | 60 |
| Ukraine e/ | 10 3/ | 15 | 25 | 25 | 25 |
| United Kingdom 9/ | 469 | 549 | 541 e/ | 455 r/ | 440 |
| United States 9/ | 1,010 | 1,270 | 1,530 | 2,060 | 1,880 3/ |
| Total | 18,200 | 20,100 r/ | 19,000 r/ | 19,200 r/ | 19,600 |

e/ Estimated. r/ Revised.

1/ World totals, U.S. data, and estimated data are rounded to three significant digits; may not add to totals shown.

2/ This table gives unwrought production from ores, concentrates, flue dusts, and other materials of both domestic and imported origin. Sources generally do not indicate if secondary metal (recovered from scrap) is included or not; where known, this has been indicated by a footnote. Data derived in part from World Metal Statistics (published by World Bureau of Metal Statistics, Ware, the United Kingdom) and from Metal Statistics (published jointly by Metallgesellschaft AG, of Frankfurt am Main, Germany, and World Bureau of Metal Statistics). Cadmium is found in ores, concentrates, and/or flue dusts in several other countries, but these materials are exported for treatment elsewhere to recover cadmium metal; therefore, such output is not reported in this table to avoid double counting. This table includes data available through May 13, 1999.

3/ Reported figure.

4/ Formerly Zaire.

5/ Excludes secondary production from recycled nickel-cadmium batteries.

6/ Less than 1/2 unit.

7/ Excludes significant production of both cadmium oxide and cadmium contained in exported concentrates.

8/ Tsumeb Smelter closed in April 1, 1998.

9/ Includes secondary.