CADMIUM

By Peter H. Kuck

For more than a decade, the end-use pattern for cadmium (Cd) has been shifting towards rechargeable batteries. Increasingly stringent environmental regulations have discouraged the traditional, more dispersive uses of cadmium (e.g., electroplating, plastics additives, and pigments). Cadmium usage in nickel-cadmium (Ni-Cd) batteries, in contrast, has continued to grow and now constitutes the major end use for the element. The bulk of the batteries entering the United States are made in Japan, Mexico, China, France, or Hong Kong (in descending market share).

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.

The incineration of plastics containing cadmium pigments and stabilizers is of greater concern in Western Europe than in the United States. Landfilling, which locks up the cadmium, is not a viable option in the Benelux countries and other parts of Europe where the population density is extremely high and geologically secure sites are limited. Since 1991, health and safety regulations in the European Union (EU) have restricted manufacturers of flexible polyvinyl chloride (PVC), polyurethane, and other polymers from incorporating cadmium-based heat stabilizers in their products.

Most of the virgin cadmium currently being recovered is a byproduct of zinc refining. The cadmium is associated with the zinc in concentrates of sphalerite and related sulfide ore minerals. It is also recovered during the beneficiation and refining of some lead ores or complex copper-zinc ores.

Legislation and Government Programs

On May 11, 1995, the U.S. Environmental Protection Agency (EPA) promulgated streamlined regulations governing the collection and management of spent Ni-Cd batteries, mercury-containing thermostats, and certain other widely generated hazardous wastes.[1] The new regulations (Title 40, Code of Federal Regulations, part 273) are designed to encourage environmentally sound recycling of Ni-Cd batteries and keep them out of the municipal waste stream. No distinction is made on the basis of battery size or type of electrolyte. The new regulations are part of a package of regulations known as the "Universal Waste Rule."

In 1994, legislation was introduced in the Congress to make the recycling of consumer batteries (i.e., household batteries and batteries for electric vehicles [EV's]) more economically feasible and remove regulatory burdens from the battery recycling industry. A modified version of the legislation pertaining specifically to Ni-Cd batteries was taken up again by the 104th Congress, passed, and eventually enacted into law in March 1996. The legislation had the support of most battery manufacturers and many retailers.

The Defense Logistics Agency (DLA) continued to sell sticks and balls of cadmium metal from the National Defense Stockpile. The ongoing sales are part of a much larger downsizing of the stockpile approved under the Defense Authorization Act of 1992 (Public Law 102-484). When DLA began offering cadmium on March 22, 1993, there were 2,871 metric tons (6,328,570 pounds) of the metal in DLA warehouses. The first sales were sluggish, but by the beginning of 1995, uncommitted stocks had shrunk to 2,381 metric tons (5,250,135 pounds). An additional 214 metric tons (471,241 pounds) were turned over to purchasers during the year, leaving uncommitted stocks of 2,020 metric tons (4,452,635 pounds) on December 31, 1995. Total yearend stocks also included 243 metric tons (536,319 pounds) of committed material.

Production

Primary cadmium was produced by only two companies: Big River Zinc Corp., Sauget, IL; and Savage River Zinc Co., Clarksville, TN. Both companies recovered cadmium as a byproduct of smelting domestic and imported zinc concentrates. In mid-1995, Korea Zinc Co. Ltd. offered to buy Big River Zinc and the entire Sauget smelting and refining operation from its parent, Dillon Read & Co., for $52.5 million.[2] Terms of the purchase were still being negotiated at yearend. The Sauget operation can produce up to 80,000 metric tons per year of zinc and has been receiving about 80% of its feedstocks from mines in Tennessee and Missouri. The remaining 20% was being imported largely from Canada, Mexico, and Peru.

Korea Zinc has been recovering cadmium at its Onsan smelting and refining complex in Kyungsang-Namdo Province since startup of the operation in 1980. The Korean complex is much larger than Sauget, but is almost totally dependent on imported concentrates for feed. Onsan has an annual production capacity of 215,000 tons of zinc and 135,000 tons of lead.[3] The cadmium recovery circuit at Onsan originally had a design capacity of about 300 tons per year, but has been upgraded to at least 490 tons per year.

In March 1994, Savage Resources Ltd. of Australia acquired all of the zinc mining and processing operations controlled in the United States by the giant Union Minière Group. The purchase included the Clarksville refinery and four underground zinc mines—Clinch Valley, Cumberland, Elmwood/Gordonsville, and Jefferson City—all of which are in Tennessee. The new owners were considering expanding the Clarksville operation and initiated preliminary engineering studies.[4] The four mines supply Clarksville with 60% to 70% of its feedstocks. The balance is provided by Asarco Incorporated, which operates four underground zinc mines in the Mascot-Jefferson City District northeast of Knoxville. Clarksville could produce up to 100,000 tons per year of zinc. Most of the byproduct cadmium, gypsum, and sulfuric acid from Clarksville was being sold domestically.

On December 28, 1995, International Metals Reclamation Co., Inc. (INMETCO) began recovering cadmium from spent batteries at its reclamation plant in Ellwood City, PA. The first heat of cadmium metal was poured on December 30 and cast into shot. The $5 million cadmium addition was the only facility of its kind in the world and was built for INMETCO by Davy International. The cadmium, which has a purity greater than 99.95%, was to be shipped to Ni-Cd battery manufacturers for reuse. The new addition was capable of processing more than 2,500 tons of spent Ni-Cd batteries annually.[5] The company was also accepting nickel-metal hydride (Ni-MH) and nickel-iron batteries, but asked that the two be segregated from the Ni-Cd's whenever feasible. INMETCO is a subsidiary of Inco Ltd., the second largest producer of nickel in the world.

The Ellwood City facility was set up in 1978 to reclaim chromium and nickel from emission control dusts, swarf, grindings, and mill scale—all generated by the stainless steel industry. Over the next 15 years, the operation was extensively modified, permitting additional waste feed materials to be used (e.g., filter cakes, plating solutions, and spent catalysts). In 1995, INMETCO produced about 22,000 tons of chromium-nickel-iron alloy from 58,000 tons of solid waste and 710,000 gallons (roughly 3,400 tons) of liquid waste. The 58,000 tons of solids included 2,300 tons of spent consumer and industrial Ni-Cd batteries. The spent batteries had an average Cd content of 15%—generating 350 tons of secondary cadmium.

Before the new plant was commissioned, the cadmium from the batteries and other wastes was recovered as a baghouse dust and shipped offsite for further processing. All of this changed after INMETCO acquired key cadmium recovery technology from Saft Nife AB in May 1994. Today, workers dismantle the industrial batteries using power saws, drain off the electrolyte, and visually segregate the cadmium plates from their nickel counterparts. The cadmium plates then go directly into an electric-powered cadmium distillation furnace. The much smaller, consumer cells have to be shredded and then thermally oxidized to remove their plastic components before they can be charged into the distillation furnace. The cadmium fumes are distilled off, condensed, and cast into shot. The nickel and iron-rich residue left in the distillation furnace is later fed into the main chromium-nickel-iron feedstream.

Consumption

Apparent consumption of cadmium metal in the United States increased 11% between 1994 and 1995. The U.S. Geological Survey did not collect actual consumption data on either cadmium metal or cadmium compounds. However, for some time, the International Cadmium Association has been making annual estimates on an end-use basis for the Western World. Their breakdown for 1995 was as follows: batteries, 67%; pigments, 14%; stabilizers for plastics and similar synthetic products, 8%; coatings and plating, 8%; and alloys and miscellaneous, 3%.[6]

Many traditional consumers of cadmium were actively searching for substitutes for the metal. The shift away from cadmium was being driven primarily by concerns over product liability and possible future environmental litigation, especially litigation linked to the recycling or disposal of spent products and manufacturing waste. Some intermediate consumers have spent considerable money to bring their manufacturing facilities into compliance with new occupational exposure and effluent guidelines.

The use of barium-cadmium heat stabilizers in flexible PVC declined significantly as environmental concerns about the two elements grew.[7] In 1994, Witco Corp., a leading manufacturer of stabilizers, voluntarily phased out its entire line of cadmium-based stabilizers. A significant amount of cadmium was still being used to make colorants for plastics, despite regulatory pressures.[8] The colorant and pigment industry has restructured almost every aspect of production in response to the new Federal and State regulations. Producers of plastic colorants had planned to phase out cadmium along with barium, chromium, and lead in order to make their products more environmentally acceptable. However, for some applications there was no organic alternative on the market that could 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 pressure processing. Organic substitutes are not as stable and are more difficult to work with under these conditions. In other applications, more organic pigment is needed to duplicate the color effect produced by the cadmium, driving up costs. Some inorganic pigments sell for $2.30 to $2.80 per pound, while an equivalent organic alternative may cost as much as $80 per pound.

SCM Chemicals, a pigments manufacturer based in Baltimore, MD, pointed out the positive aspects of using cadmium and showed that cadmium pigments offer many environmental advantages to formulators of performance coating systems. Both Engelhard Corp. and SCM remained in the inorganic pigments market and continued to produce cadmium sulfide. A spokesperson for SCM correctly pointed out that the entire product life cycle has to be considered in determining environmental risk.[9]

When cadmium is converted into a pigment, its solubility is sharply reduced. After the pigment is incorporated into a resin system, the solubility drops even further. Thus, when a cadmium-bearing colored plastic is eventually disposed of as a solid waste and put into an uncontrolled landfill, the effective toxicity of the cadmium is greatly reduced. The plastic waste often meets the stringent limit of 1-part-per-million that EPA has established for cadmium, when measured by the Toxic Characteristic Leachate Procedure. A second important point made by SCM is that formulators may need less solvent to disperse a cadmium pigment than some competitive colorants. Less solvent consumption translates into lower emissions of volatile organic compounds—another EPA objective. Third, the good tinting strength and opacity of cadmium pigments permits formulators to use thinner coatings, an important, weight saving advantage in the aerospace industry.

Cadmium plating is still required for 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 have lower relative coefficients of friction, making for smoother surfaces. A new plating process being evaluated in the United Kingdom could offer an alternative to cadmium plating. The Stanzec 2 process, developed by the International Tin Research Institute Ltd. and Atotech, produced an 80%-tin/20%-zinc coating that reportedly offered corrosion protection comparable to that of pure cadmium.[10]

Cadmium was being used more and more in novel, technologically sophisticated equipment such as helium-cadmium lasers and cadmium-telluride-based solar cells. Omnichrome Corp. of Chino, CA, was one of several companies that manufactured helium-cadmium laser systems. One successful use of the Omnichrome violet/near-ultraviolet laser was to create parts in stereolithography. Besides imaging, the lasers had a wide variety of other applications in medicine, biology, nondestructive testing, and forensic science.

Prices

Prices strengthened in 1995, continuing their recovery from the historic low of 1993 when the average annual price dropped to $0.451. The New York dealer price for metal, published by *Metals Week* for the week ending January 6, 1995, ranged from $1.85 to $2.15 per pound. The monthly average price for January was $1.82, significantly higher than the 1994 annual average of $1.13. The monthly average price dipped slightly during the second quarter of 1995, but began climbing again in July. It leveled off at $2.00 in the third quarter and eventually peaked at $2.02 in November. At the very end of 1995, demand slackened and the price began to falter. For the week ending December 29, the New York dealer price ranged from $1.90 to $2.00. The average annual price for 1995 was $1.84.

World Review

Industry Structure.—World refinery production of cadmium was estimated at 18,500 tons in 1995. Japan was again the largest producer of refined cadmium products, followed by Canada. Canadian production of refined metal has increased substantially since 1990 and reached a record high of 2,360 tons in 1995.

Capacity.—World cadmium refining capacity for 1995 was estimated at 23,000 tons. Almost 40% of this capacity was in Europe or Central Eurasia.

World Resources.—Existing resources of cadmium should be adequate to meet demand far into the 21st century. For the near term, the principal source will continue to be concentrates of sphalerite. Several new zinc mines and smelters are currently under development to meet higher demand for that metal and with it will come increased production of cadmium. In Australia, the McArthur River Mine was to open in late 1996.[11] The new mine is in the northeast corner of the Northern Territory, about 100 kilometers south of the Gulf of Carpentaria. The Century project in northwest Queensland was going through the permitting and land acquisition process and could come on-line as early as 1997. Part of the concentrates from the proposed Century mill would go to a custom smelter operated by Pasminco Ltd. in the Netherlands. The Century deposit was being developed by the giant RTZ-CRA Group and reportedly had 188 million tons of ore grading 10.2% zinc (Zn).[12]

In Canada, the new Faro-Grum mining complex was expected to come on-line before the end of 1996. China, the largest zinc producing country, planned to open its new Lanping Mine in the year 2000. In Ireland, Arcon International Resources PLC was scheduled to begin shipping 120,000 tons per year of concentrates in late 1996 from its new Gamoy Mine in County Kilkenny. Also in Ireland, Ivernia West PLC and its partner, Minorco S.A. of Luxembourg, were ready to begin construction of their Lisheen Mine in County Tipperary. Lisheen would be one of the 10 largest zinc mines in the world. In Sweden, Boliden discovered major new zinc mineralization at its Renstrom Mine. In the United States, the long-delayed Crandon project could begin producing 200,000 tons per year of concentrates by the end of the century. Cominco Ltd. announced that it would be expanding production at its Red Dog Mine in Alaska in 1998. The Alaskan concentrates would continue to be smelted in Canada. Finally, Platinova A/S discovered high grade lead-zinc mineralization in Perry Land, at the northernmost tip of Greenland.

Korea Zinc was expected to begin construction of the world's largest zinc smelter in late 1996. The smelter was to be built in Australia—at Townsville, Queensland—and would initially produce 170,000 tons per year of zinc metal for the export market.

Phosphate rock is another potential but far less attractive resource of cadmium. Several member countries of the EU have raised concerns about cadmium levels in imported phosphate fertilizers.[13] The member countries are concerned that long-term use of high-cadmium fertilizers could cause the toxic metal to accumulate in edible plants and inadvertently enter the food chain. In an effort to head off regulation, the European Fertilizer Manufacturers Association has voluntarily agreed to limit cadmium levels in their products to 60 milligrams Cd per kilogram of phosphorus pentoxide (P_2O_5) by the year 2005.[14] A few fertilizer producers are working on technologies to extract cadmium from phosphate rock, but most processes evaluated to date are either uneconomical or have serious limitations.[15] Austria, Denmark, and Sweden already restrict cadmium levels to 100 milligrams of Cd per kilogram of P_2O_5. Finland has a more stringent limit of 50 milligrams. As part of the agreement, European fertilizer producers will switch suppliers, importing only feedstocks that fall below the new 60 milligram limit. Countries such as Senegal and Togo that mine phosphate rock with elevated levels of cadmium may have increasing difficulty marketing their production. Phosphate rock from some of their competitors (e.g. Florida, North Carolina, and South Africa) contains considerably less cadmium. If all of the technological barriers can be overcome, a cadmium extraction plant might conceivably generate 80 to 500 tons per year of byproduct metal.

China.—Sanyo Electric Co. of Japan has teamed up with Shenzhen Huaqiang Holding Ltd. of China to manufacture Ni-Cd batteries at Shenzhen in Guandong Province. The joint venture, Shenzhen Sanyo Huaqiang Energy Co., began assembling batteries in July 1995 and was planning to gradually increase the output of the plant over the next 5 years. By mid-1997, the plant was to be shipping 24 million units per year.[16]

European Union.— Union Minière (UM), a world leader in the nonferrous metals sector, launched a major restructuring program in 1995 to restore competitiveness and improve profitability.[17] The conglomerate's cadmium refining operations—S.A. Produits Chimiques Wiaux—are now part of the UM Cobalt and Energy Products business unit. Much of the efforts of the newly expanded unit will focus on developing and producing new materials for battery manufacturers and the catalyst industry.

The UM Group recovers crude cadmium at its two zinc refineries—one at Balen in Belgium and the other at Auby in France. This byproduct material is shipped to the S.A. Produits Chimiques Wiaux plant at Seneffe for further processing. The Seneffe plant is about 40 kilometers south of Brussels, near Charleroi. The plant was built in 1990 and is capable of producing 2,000 tons per year of cadmium oxide (CdO) and 200 tons per year of cadmium metal powder. The metal powder, which typically assays 98.50% elemental Cd and 1.50% CdO, is sold primarily to manufacturers of Ni-Cd batteries. The fine powder is made by distilling and condensing metallic cadmium vapor. The Seneffe plant also makes brown cadmium oxide, typically assaying 99.60% CdO, by reacting metallic vapor with air. A large part of the oxide is sold to battery manufacturers; some, however, is used as a stabilizer for PVC, incorporated into pigments, or employed in electroplating.

On July 1, 1995, the UM Group Minière sold its wholly owned Swedish subsidiary, Ammeberg Mining AB, to North Ltd. of Australia. North paid $178.6 million in cash for the Swedish company, which operates a lead-zinc mine at Zinkgruvan. In 1994, Zinkgruvan produced 114,281 tons of cadmium-bearing zinc concentrates together with 22,329 tons of lead concentrates. UM agreed to continue smelting concentrates from Zinkgruvan until the year 2000.

The zinc smelter at Budel-Dorplein continues to be closely scrutinized by the Dutch Government. The Dutch Government is concerned about the million tons of cadmium-bearing jarosite waste that have built up over the years at the site. The custom smelter is capable of producing about 210,000 tons per year of electrolytic zinc and 600 tons per year of cadmium, but generates about 100,000 tons per year of jarosite $[KFe_3(SO_4)_2(OH)_6]$ in the process. The smelter owner, Pasminco Ltd. of Australia, has been threatened with closure on several occasions, but has always been given a temporary reprieve.

Pasminco won its latest reprieve at the last minute by agreeing to import 450,000 tons per year of low-iron zinc concentrates from the still undeveloped Century deposit in Queensland, Australia.[18] The first concentrates were to have been shipped by June 1, 1998, but this milestone had to be postponed when negotiations to settle Native Title issues broke down between RTZ-CRA —the mine developer— and the local Aboriginal community. Construction has been stalled since the spring of 1996 by Aboriginal claims to part of the minesite. RTZ-CRA has already spent $A200 million assessing the Century deposit and was prepared to invest $A1 billion to bring the deposit into production.

Namibia.—Production of cadmium in Namibia will drop dramatically with the winding down of mining operations at Tsumeb. The world renowned copper-lead-silver mine has been in almost continuous operation since 1901 when Otavi Minen-und Eisenbahn-Gesellschaft sank the first shaft.

Tsumeb, located on the northern fringe of the Otavi Mountain Land, is famous for its 200 secondary minerals, of which 40 are unique to the mine. The principal ore minerals in the near-vertical, pipe-like deposit are galena, tennantite, sphalerite, chalcocite, bornite, and enargite (in descending order of importance).[19] Run-of-mill ore typically contains 400 parts per million Cd. The bulk of the cadmium occurs in three minerals: sphalerite (1.4% Cd), tennantite (0.15% Cd), and red-fluorescing calcite (0.28% Cd). Greenockite (75% to 77% Cd) and cadmian wurtzite (31.9% to 49.7% Cd) are also present, but only in trace amounts.

Ore reserves at Tsumeb are nearly exhausted. The current operator, Gold Fields Namibia, was to begin decommissioning the De Wet shaft in June 1996.[20] The Tsumeb copper smelter will be kept open by supplementing declining Tsumeb production with ore from the newly developed, but rather small, high-grade copper-silver deposit at Khusib Springs.

Current Research and Technology

PSA Peugeot Citroën and Renault are poised to produce Ni-Cd powered EV's on a large scale. In October 1995, Peugeot released detailed technical information on its new *106 Electrique* automobile to the news media.[21] The two-door hatchback has three packs of 6-volt Ni-Cd monobloc cells, for a total of 20 cells. Each pack is sealed in a casing cooled by a mixture of water and ethylene glycol. The 20 cells are in series and provide a total of 120 volts to the direct current motor. Each cell weighs 12.6 kilograms, 30% less than a lead-acid battery of the same size. All the cells and casings together weigh 342 kilograms.

The Ni-Cd monobloc cells will be serviced and maintained by the manufacturer, SAFT SA. In October 1995, SAFT inaugurated a Ni-Cd EV battery plant in Bordeaux, France, that will initially produce 5,000 batteries per year. The vehicle already has been extensively field tested as part of the La Rochelle project. In January 1995, the La Rochelle project was linked to a much larger 2½-year program being sponsored by the Commission of the European Union.[22] The normal driving range is expected to be 75 to 80 kilometers, but with care could be extended to 100 kilometers.

The principal problem facing cadmium consumers today is the safe and economic disposal of spent products that contain relatively low levels of dispersed cadmium. The seventh in a continuing series of international seminars on battery waste management was held on November 6-8, 1995, in Boca Raton, FL. The presidents of both the Rechargeable Battery Recycling Corp. (RBRC) and the Portable Rechargeable Battery Association (PRBA) discussed the national collection and recycling program for spent Ni-Cd batteries.[23] RBRC is a nonprofit public service corporation responsible for operating the newly established program and is funded by license fees paid by battery manufacturers and manufacturers of battery-powered products. PRBA serves as a spokesperson for most of the battery manufacturers in the United States, including those who make Ni-MH, lithium-ion, and small sealed lead-acid cells. The Ni-Cd recycling program is now operating in 19 States at more than 4,500 retail locations. Some 300 counties also have dropoff centers. By the beginning of 1997, the RBRC expects to have 6,000 retailers in 30 States participating in its program. If the new RBRC program grows as expected, INMETCO could be handling 10,000 tons of batteries by the year 2002.

A similar program exists in Japan. There, the program is being promoted by the Japan Storage Battery Association (JSBA), which represents 11 battery manufacturers.[24] In 1994, 880 million Ni-Cd cells were sold in Japan. Statistics collected by the JSBA indicate that 33% of the cells went into cellular telephones and other communications equipment. Another 27% went into home appliances (VCRs, shavers, etc.). The third largest market was power tools, which accounted for 15%.

On June 30, 1993, the Ministry of International Trade and Industry issued Ordinance No. 33, which requires all battery manufacturers in Japan and importers to clearly label their Ni-Cd products. Batteries more than 10 millimeters tall must bear the words "Ni-Cd" together with the international recycling symbol (i.e, three chasing arrows) in a band around the base of the battery. JSBA also requires its members to color code the band to facilitate visual sorting. The color is determined by the battery chemistry. A Ni-Cd battery has a yellow-green band. The Ni-MH band is orange; the lithium-ion band, blue. A second ordinance, No. 34, requires manufacturers of Ni-Cd powered products to design each product so that the consumer can easily remove the battery.

In 1993, Japan recycled 1,696 tons of spent Ni-Cd batteries and 2,006 tons of Ni-Cd battery scrap. The tonnage of spent batteries sent to recyclers is expected to rise dramatically between 1996 and the year 2000 as a result of the new regulations and improvements in the JSBA-supervised collection program.

Outlook

The market for Ni-Cd batteries is expected to grow significantly over the next 10 years even if American automobile manufacturers decide not to put Ni-Cd cells in their new electric vehicles. Ni-Cd batteries will still be used in rechargeable power tools, home appliances, and other household equipment because of cost constraints. The markets for battery-powered cellular telephones, camcorders, personal computers, and related electronic equipment are all surging. Many of the newest satellites and commercial aircraft are using advanced Ni-Cd's for secondary power sources. In general, Ni-Cd batteries have a greater service life than several competitors and are less likely to be damaged by accidental overcharging. However, because of technological advancements, Ni-Cd batteries now have to compete head-on with Ni-MH and lithium-ion alternatives. In Japan, Ni-MH batteries have already captured 49% of the office equipment market and 18% of the communications market.

Recent Federal legislation has spurred the collection and recycling of Ni-Cd batteries. On May 13, 1996, the President signed into law *The Mercury-Containing and Rechargeable Battery Act of 1996* (Public Law 104-142). Title I of the act establishes uniform, national labeling requirements for Ni-Cd, small sealed lead-acid, and certain other regulated batteries. The labeling requirements are similar to ones already adopted by the Japanese. Domestic battery manufacturers and importers must be in complete compliance with the labeling requirements by May 1998. Title I also provides for the streamlining of regulatory requirements governing battery collection and recycling. Voluntary industry programs are to be encouraged, and regulatory requirements are to be minimized so that collection and recycling programs can be efficient and cost-effective. EPA is responsible for enforcing most of the provisions of the act.

By the year 2005, roughly 70% of the spent Ni-Cd batteries being generated in the United States will be recycled. If domestic auto manufacturers decide to incorporate Ni-Cd batteries into some of their EV models, U.S. consumption of cadmium could soar. This scenario may never materialize, though, if existing Ni-MH and lithium-ion battery manufacturing processes can be successfully scaled up. No existing technology can presently meet all of the performance requirements established for EV's by the United States Advanced Battery Consortium.[25]

On March 29, 1996, the California Air Resources Board (CARB) unanimously approved a staff recommendation to restructure the board's electric vehicle mandate.[26] CARB still wants to have 800,000 EV's and other zero-emission automobiles on California highways by the year 2010. However, the board has decided to drop its earlier requirement that seven leading automobile manufacturers begin selling EV's in California in 1998. The old regulation would have required 2% of all automobiles sold in California to be EV's or some other type of zero-emission vehicle. This percentage was to escalate to 5% beginning with the 2001 model year. The two requirements were dropped after the auto manufacturers requested additional time to resolve technological problems. In exchange for being released from the 1998 requirement, the manufacturers have agreed to meet the existing 10% requirement for the year 2003 and to begin selling low-emission vehicles—the so-called 49-State car—in the 2001 model year. Projections by the International Cadmium Association suggest that world auto manufacturers may build 160,000 Ni-Cd powered EV's in the year 2003. The cells for these vehicles would require 6,000 tons of cadmium—about one-third of present world refinery production.[27]

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[27]Metal Bulletin (London). Cadmium Future Still Battery-Dependent. No. 7988, June 15, 1995, p. 9.

The following tables were prepared by Wannette E. Davis, who unexpectedly and tragically passed away during the preparation of this report.

TABLE 1
SALIENT CADMIUM STATISTICS 1/

(Metric tons, cadmium content, unless otherwise specified)

	1991	1992	1993	1994	1995
United States:					
Production of metal 2/	1,680	1,620	1,090	1,010	1,270
Shipments of metal by producers 3/	1,740	2,070	1,320	1,290	1,280
Exports of metal, alloys, and scrap 4/	448	213	38	1,450	1,050
Imports for consumption, metal	2,040	1,960	1,420	1,110	848
Stocks of metal, Government, yearend	2,870	2,870	2,690	2,480	2,260
Apparent consumption	3,080	3,270 r/	3,010 r/	1,040 r/	1,160
Price, average per pound, New York dealer 5/	$2.01	$0.91	$0.45	$1.13	$1.84
World: Refinery production	20,900	19,600 r/	18,700 r/	18,100	18,500 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/ New series of Harmonized Tariff Schedule codes.
5/ 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/
1994 r/	170	898
1995	105	936

r/ Revised.
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 1/

(Metric tons)

	1994	1995
Industry stocks, Jan. 1	579 r/	423
Production	1,010	1,270
Imports for consumption, metal	1,110	848
Shipments from Government stockpile excesses	209	214
Total supply	2,910	2,750
Exports, metal 2/	1,450	1,050
Industry stocks, Dec. 31	423 r/	542
Consumption, apparent 3/	1,040 r/	1,160

r/ Revised.
1/ Data are rounded to three significant digits; may not add to totals shown.
2/ New series of Harmonized Tariff Schedule codes.
3/ Total supply minus exports and yearend stocks.

TABLE 4
INDUSTRY STOCKS, DECEMBER 31

(Metric tons)

	1994		1995	
	Cadmium metal	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	55	W	139	W
Compound manufacturers	72	283 r/	82	321
Distributors	12	(1/)	W	(1/)
Total	139	283 r/	222	321

r/ Revised. 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/

	1994		1995	
Country	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cadmium metal: 2/				
Austria	--	--	212	$9,370
Belgium	--	--	157,000	6,040,000
Canada	23,400	$213,000	10,100	100,000
Chile	--	--	1,720	7,940
China	361,000	363,000	320,000	223,000
France	170,000	83,700	34,300	55,600
Germany	42,400	632,000	20	15,900
Hong Kong	725,000	662,000	474,000	369,000
India	77,700	76,900	--	--
Ireland	--	--	140	98,800
Israel	547	14,100	--	--
Japan	4,210	217,000	46,800	177,000
Korea, Republic of	523	6,440	3,440	29,600
Mexico	39,400	216,000	135	3,130
Netherlands	179	12,100	--	--
New Zealand	2,880	271,000	--	--
Norway	--	--	4,070	35,400
United Kingdom	165	6,710	15	4,210
Total	1,450,000	2,770,000	1,050,000	7,160,000
Cadmium sulfide: (gross weight)				
Australia	--	--	49,300	36,800
Canada	107,000	56,500	299,000	158,000
Colombia	--	--	20,400	5,650
Japan	38,800	8,000	126,000	67,600
Korea, Republic of	44,000	43,700	--	--
New Zealand	--	--	4,050	11,700
Other	15,100	11,200	7,570	3,940
Total	205,000	119,000	506,000	283,000

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	1994 Quantity (kilograms)	1994 Value	1995 Quantity (kilograms)	1995 Value
Cadmium metal:				
Argentina	--	--	18,000	$39,600
Australia	27,000	$74,700	5,000	19,700
Belgium	232,000	496,000	31,600	198,000
Bulgaria	40,700	76,700	--	--
Canada	591,000	1,150,000	466,000	1,670,000
China	24	12,500	28,500	32,400
Finland	6,000	9,970	--	--
France 2/	5,100	7,600	38,800	90,000
Germany	118,000	71,800	61,900	205,000
Japan	681	22,200	2,480	32,200
Mexico	17,800	76,800	41,100	124,000
Netherlands	25,000	94,000	--	--
Norway	34,500	60,900	39,100	96,800
Peru	10,000	16,500	36,000	111,000
Russia	--	--	95	3,060
Switzerland	--	--	79,100	90,900
Total	1,110,000	2,170,000	848,000	2,710,000
Cadmium sulfide: (gross weight)				
Austria	--	--	1,000	14,600
Belgium	3,600	42,600	4,580	61,000
Canada	2	5,380	--	--
India	--	--	34,400	18,500
Japan	28,100	83,500	13,300	76,600
Russia	--	--	75	5,850
United Kingdom	11,800	140,000	4,210	49,700
Total	43,500	272,000	57,600	226,000

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

2/ The data for France includes material removed from bonded warehouses. The 1994 total includes 5,000 kilograms of metal valued at $6,280; the 1995 total, 31,000 kilograms valued at $27,700.

Source: Bureau of the Census.

TABLE 7
CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY 1/ 2/

(Metric tons)

Country	1991	1992	1993	1994	1995 e/
Algeria	78	56 r/	65 r/	75 e/	75
Argentina	49	37	34 e/	35 e/	35
Australia	1,076	1,001	951	910	842 3/
Austria	19	--	--	--	--
Belgium	1,807	1,550	1,573	1,556	1,710 3/
Brazil e/	200	200	200	200	200
Bulgaria	232	194	265 r/	286 r/	250
Canada	1,829	1,963	1,944 r/	2,173 r/	2,360 3/
China e/	1,200	1,150	1,160	1,150	1,200
Finland	593	590	785	876 r/	850
France	271	252	137	6 r/	--
Germany	1,048	961 r/	1,056	1,145 r/	1,150
India	271	313	255	216 r/	251 3/
Italy	658	742	517	475 r/	308 3/
Japan	2,889	2,986	2,832	2,629	2,652 3/
Kazakstan	XX	1,000 e/	1,000 e/	995 r/	1,000
Korea, North e/	100	100	100	100	100
Korea, Republic of e/	750	750	815	800	750
Macedonia e/	XX	(4/) r/	(4/) r/	(4/) r/	(4/)
Mexico 5/	688	602	797	646	689 3/
Namibia	67	33	13	19 r/	15 3/
Netherlands	549	594	526	307 r/	300
Norway	227	247	213	288	250
Peru	138	149	157	160 e/	160
Poland	364	132	149 r/	61 r/	60
Romania e/	10	10	10	4 r/ 3/	5
Russia e/	XX	800	700	500	500
Serbia and Montenegro	XX	8	6	-- r/	11 3/
South Africa 6/	103	60	64 r/ e/	63 r/ e/	64
Spain	344	361 r/	365 r/	387 r/	350
Thailand	373	635	449	500 e/	500
Turkey	22	23	31	22 e/	30
U.S.S.R. e/ 7/	2,500	XX	XX	XX	XX
Ukraine	XX	5 r/	7 r/ e/	10 r/	15
United Kingdom 8/	449	383	458	469 r/	549 3/
United States 8/	1,680	1,620	1,090	1,010	1,270 3/
Yugoslavia 9/	250 e/	XX	XX	XX	XX
Zaire	65	84	12	1 e/	--
Total	20,900	19,600 r/	18,700 r/	18,100	18,500

e/ Estimated. r/ Revised. XX Not applicable.
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 July 31, 1996.
3/ Reported figure.
4/ Less than 1/2 unit.
5/ Excludes significant production of both cadmium oxide and cadmium contained in exported concentrates.
6/ Cadmium content of cadmium cake.
7/ Dissolved in Dec. 1991.
8/ Includes secondary.
9/ Dissolved in Apr. 1992.