CADMIUM

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In 1996, two companies produced primary cadmium (Cd) in the United States. These companies, one in Illinois and one in Tennessee, recovered the cadmium as a byproduct of the smelting and refining of zinc (Zn) concentrates. A third company, in Pennsylvania, recovered cadmium from spent nickel-cadmium (Ni-Cd) batteries. Based on the average New York dealer price, the combined output of primary and secondary metal in 1996 was valued at $4.2 million. The estimated consumption pattern included batteries, 67%; pigments, 14%; coatings and plating, 8%; stabilizers for engineering plastics and similar synthetic products, 8%; nonferrous alloys, 2%; and other, including electrooptics, 1%.

To date, cadmium recycling has been practical only for Ni-Cd batteries, some alloys, and dust from electric arc furnaces—the latter typically containing 0.003% to 0.07% Cd. At the beginning of 1996, 13 of the 50 States had laws regulating Ni-Cd's and other rechargeable batteries. Nine of the thirteen States also required the collection of rechargeable batteries. The Portable Rechargeable Battery Association (PRBA), a nonprofit trade association, composed of over 100 manufacturers, distributors, assemblers, users, and sellers of small rechargeable batteries was in the process of setting up a nationwide collection and recycling system.

The United States, as in most years, was a net importer of cadmium metal in 1996; so far this decade, it has been a net exporter only in 1994-95. The major import sources over the last 5-year period, 1992-96, have been Canada, 43%; Belgium, 13%; Mexico, 12%; and Germany, 7%. Cadmium compounds and pigments are subject to import duties, but unwrought and powdered metal, as well as waste and scrap, enter duty free in all but a few cases. At yearend, 2,034 metric tons of unwrought cadmium metal were held in the National Defense Stockpile, all of it authorized for sale or previously committed.

The U.S. dealer price for cadmium, which was characterized by considerable volatility in the last decade, fell in 1996 to two-thirds of the 1995 price.

Cadmium was refined in 32 countries in 1996. The three largest refiners—Japan, Canada, and Belgium—together accounted for 34% of world production, compared with 8% for the United States.

Identified world cadmium resources at yearend 1996 were estimated by the U.S. Geological Survey at 6 million tons, a figure based on zinc resources containing typically about 0.3% cadmium. The world reserve base was estimated at 970,000 tons and reserves at 540,000 tons. The United States has 22% of the world reserve base and 13% of the reserves. The United States, Canada, and Mexico, together, have 43% of the world reserve base and 34% of the reserves.

Legislation and Government Programs

In 1994, legislation was introduced in the Congress to make the reclamation of spent consumer batteries [i.e., household batteries, batteries for portable office equipment, 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 signed into law by the President on May 13, 1996. The new law was entitled "The Mercury-Containing and Rechargeable Battery Management Act of 1996" (Public Law 104-142). Title I of the act established uniform national labeling requirements for Ni-Cd, small sealed lead-acid, and certain other regulated batteries. Each battery or battery pack must bear a recycling symbol and a recycling phrase appropriate to its electrode chemistries. The labeling requirements are similar to ones already adopted by Japan. Domestic battery manufacturers and importers must be in complete compliance with the labeling requirements by May 1998. Title I also provided for the streamlining of regulations governing battery collection and recycling. Voluntary industry programs are to be encouraged, and regulatory requirements are to be minimized so that the collection and recycling programs can be efficient and cost-effective. Title II of the act phases out the use of batteries containing mercury.

The U.S. Environmental Protection Agency (EPA) is responsible for enforcing most of the provisions of the act. EPA can now promulgate regulations requiring manufacturers of rechargeable consumer products to redesign their products, if safety is not compromised, so that the batteries inside can be more easily removed. The agency also has been directed to work with battery manufacturers, manufacturers of consumer products, and retailers in disseminating proper handling and disposal information on batteries to the general public. The legislation had the support of most battery manufacturers and many retailers.

On December 13, 1996, the President of the United States signed an executive order designed to encourage the use of EV's and other alternative fueled vehicles (AFV's) in metropolitan areas of the country (Presidential Documents, 1996). Executive Order 13031 (Federal Alternative Fueled Vehicle Leadership) requires each federal agency to immediately develop and implement plans for acquiring alternative fueled vehicles. In fiscal year (FY) 1997, 33% of the general-use vehicles acquired were to be AFV's. This percentage increases to 50% in FY 1998, 75% in FY 1999, and 75% for subsequent years. The executive order was designed to reduce U.S. dependence on imported oil, provide an economic stimulus to domestic industry, and improve air quality in various parts of the country. Some industry analysts expect the order will spur production of nickel-metal hydride, advanced lead, and lithium-ion batteries for EV's in the United States. The effect of the order on the use of enhanced Ni-Cd batteries in U.S. vehicles was uncertain. No U.S. automobile manufacturer has announced plans to introduce a Ni-Cd powered automobile in the near future. However, Ni-Cd batteries are being used in at least one Japanese and two European models. Ni-Cd batteries offer some advantages over advanced lead competitors in terms of reliability, longevity, energy density, and recyclability. Ni-Cd batteries also have the potential to capture a large part of the market for electric motor scooters, electric bicycles, and electric wheelchairs. Tokyo R&D Co. Ltd. recently began selling a Ni-Cd powered electric scooter, which retails in Japan for ¥596,000 or about $5,030.

The Defense Logistics Agency (DLA) continued to sell sticks and balls of cadmium metal from the National Defense Stockpile as part of the huge 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. By the beginning of 1996, uncommitted stocks had shrunk to 2,020 tons (4,452,635 pounds). An additional 230 tons (506,533 pounds) were turned over to purchasers during the year, leaving uncommitted stocks of 1,920 tons (4,232,048 pounds) on December 31, 1996. Total yearend stocks also included 114 tons (250,373 pounds) of committed material.

Production

Most of the virgin cadmium currently being recovered around the world is a byproduct of zinc smelting and 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.

Only two companies produced primary cadmium in the United States in 1996: Big River Zinc Corp., Sauget, IL; and Savage Zinc Inc., Clarksville, TN. Both companies operated electrolytic zinc plants and recovered the cadmium as a byproduct precipitate after the zinc concentrates were roasted and leached.

In April 1996, Korea Zinc Co. Ltd. purchased Big River Zinc and the Sauget smelting and refining operation from its owner, Dillon Read & Co., for $52.5 million. The Sauget operation can produce up to 82,000 tons of zinc and 900 tons of cadmium per year and has been receiving about 80% of its feedstocks from mines in Missouri and Tennessee. The remaining 20% was being imported, largely from Canada, Mexico, and Peru (Mining Journal, 1996). Korea Zinc will provide technical expertise and financial support to improve production at Sauget. The Korean company is currently capable of producing about 215,000 tons of zinc, 135,000 tons of lead, and 550 tons of cadmium per year at its Onsan complex in Kyungsang-Namdo Province. Korea Zinc has agreed to construct a world-class lead-zinc smelting and refining complex at Townsville, Australia. (*See section on Australia.*)

Savage Zinc Inc. was preparing to expand its Clarksville smelting and refining operation in north-central Tennessee and was in the process of obtaining the necessary permits (Savage Resources Limited, 1996). Some 60% to 70% of the operation's feed comes from three underground zinc mines operated in the central and eastern part of the State. The balance is provided by ASARCO Incorporated, which operates four underground zinc mines in the Mascot-Jefferson City District northeast of Knoxville. Since Savage acquired the Tennessee operation in May 1994, the company has had an active exploration program in the State, particularly at its Gordonsville Mine east of Lebanon. The program has increased proved and probable ore reserves significantly. On June 30, 1996, Savage's three mines had combined reserves of 25.3 million tons grading 3.1% Zn. Most of the byproduct cadmium recovered at Clarksville was being sold domestically. The refinery's germanium residues continued to be shipped to Olen, Belgium, for eventual recovery by Clarksville's previous owner, the Union Minière Group. Asarco temporarily suspended operations at its New Market Mine near Strawberry Plains in Jefferson County because of declining ore grades and low zinc prices.

The cadmium recovery facilities at Asarco's Globe refinery in Denver, CO, were idle the entire year. Asarco shut down its cadmium line in spring 1993 and has no immediate plans to produce cadmium domestically.

On December 28, 1995, International Metals Reclamation Co., Inc. (INMETCO) began reclaiming cadmium from spent batteries at its high temperature metals recovery plant in Ellwood City, PA. The first heat of cadmium metal was poured on December 30, 1995, 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 metal, which has a purity greater than 99.95% Cd, was being shipped to Ni-Cd battery manufacturers for reuse. Some of the production runs have assayed as high as 99.999% Cd. The cadmium is made in the form of small flattened discs, 4 to 6 millimeters in diameter, to facilitate handling and reduce erratic rolling (Hanewald, Schweers, and Liotta, 1996).

The Ellwood City facility received more than 2,700 tons of spent Ni-Cd batteries from municipal authorities and industry in 1996 (International Metals Reclamation Co. Inc., 1997). The spent batteries reportedly had an average cadmium content of 12% to 15%. 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. Shipments from Motorola Inc., Black & Decker Inc., and other electronic appliance manufacturers tend to be relatively free of lead and other less desirable metals. However, batteries collected from the general public require considerable attention. At the present time, small sealed lead acid batteries and other nonconforming batteries have to be removed by hand prior to processing. Many of the spent batteries are more than 5 years old. Only a few of the newer batteries are color coded and almost none carry bar codes, making optical scanning and other automated sorting difficult to impossible.

The Ellwood City facility was set up in 1978 to reclaim chromium, nickel, and iron from a variety of wastes generated by specialty steelmaking operations in Canada and the United States. In 1996, in addition to cadmium, INMETCO produced about 21,400 tons of chromium-nickel-iron alloy containing 15,100 tons of iron, 3,400 tons of chromium, 2,600 tons of nickel, and 330 tons of molybdenum. In the past, all of this material would have been disposed of in landfills. INMETCO is a subsidiary of Inco Ltd., the second largest producer of nickel in the world.

The proposed Crandon Mine in northeastern Wisconsin is expected to be a significant source of cadmium by the year 2005. The massive sulfide deposit is about 9 kilometers south of Crandon, the seat of Forest County. The deposit contains an estimated 61 million tons of ore grading 5.6% Zn and 1.1% Cu (Lambe and Rowe, 1987). Pyrite is ubiquitous throughout most of the deposit. Sphalerite is the second most abundant sulfide and a major constituent of the massive ores, forming laminae interbedded with pyrite laminae in mineralized sedimentary beds. Lesser amounts of sphalerite also occur in some of the chalcopyrite-rich stringer ores of the footwall. Electron microprobe analyses of sphalerite from different parts of the deposit revealed that the cadmium content of the sphalerite is highly variable, ranging from less than 0.01% to 0.23% Cd (Lambe and Rowe, 1987). Sphalerite from one particular stratigraphic sequence—the Skunk Lake unit—consistently has the highest cadmium values, averaging 0.09% Cd.

In 1996, the Crandon Mining Co. completed development of its environmental impact report for the proposed underground zinc-copper mine (Tanner and Evans, 1997). The Wisconsin Department of Natural Resources was reviewing the report and scrutinizing models that might reveal potential disturbances in groundwater flow. The Crandon Mining Co. is a joint venture of Exxon Minerals Co. and Rio Algom Ltd. During the year, the joint venture signed agreements with the Town of Nashville, the Town of Lincoln, and Forest County that addressed issues of local concern. Exxon began exploring Wisconsin for massive sulfides in 1969 and discovered the Crandon deposit in 1975 when it drilled a promising electromagnetic anomaly near Skunk Lake. The original Exxon project was shelved in 1986 because of unfavorable economic conditions.

Environment

Cadmium is considered toxic, particularly in soluble and respirable forms, and must be handled with care. Although cadmium commonly is associated with zinc, the two behave somewhat differently in biological systems. Zinc is an essential element in almost all biological systems and plays important roles in metalloenzyme catalysis, metabolism, and the replication of genetic material. Cadmium, on the other hand, can adversely affect the renal and respiratory systems, depending upon exposure time and concentration, and is not readily excreted. Inhaled cadmium fumes or fine dust are much more readily absorbed than ingested cadmium. Repeated exposure to excessive levels of dust or fume can irreversibly injure the lungs, producing shortness of breath and emphysema. Dermal contact with cadmium results in negligible absorption. The International Agency for Research on Cancer lists cadmium metal and several of its compounds as carcinogens.

The incineration of plastics containing cadmium pigments and stabilizers is of greater concern in the European Union (EU) 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. Health and safety regulations in the EU prohibit or discourage manufacturers of flexible polyvinyl chloride (PVC), polyurethane, and other polymers from incorporating cadmium-based heat stabilizers in their products (Koot, 1996). The Netherlands and several other EU member countries also recently banned the use of cadmium pigments in most virgin engineering plastics. Exemptions permit the recycling of some cadmium-containing plastic waste, such as damaged bottle crates. Another major concern has been the amount of cadmium being released into the atmosphere by the combustion of coal and other fossil fuels.

A cadmium workshop and a followup session on risk reduction were held in Saltsjöbaden, Sweden, from October 16 to 21, 1995. The workshop was held under the auspices of the Organisation for Economic Co-operation and Development (OECD) and was cosponsored by the Swedish National Chemicals Inspectorate and the Dutch Ministry of Housing, Spatial Planning and Environment. The proceedings of the workshop were published in two monographs (Organisation for Economic Co-operation and Development, 1996a, b). The first monograph discusses sources and pathways of cadmium in the environment, while the second focuses on ways to limit or reduce the cadmium content of fertilizers. More than 12 anthropogenic sources of cadmium were reviewed at the Saltsjöbaden workshop, including: the burning of fossil fuels, municipal waste incinerators, base metal smelters, iron and steel works, cement plants, liming materials, phosphate fertilizers, other soil amendments, and sewage sludge.

Several member countries of the EU were especially concerned about cadmium levels in phosphate rock being imported into Europe for agricultural purposes and took the opportunity to lobby for more restrictive limits on the cadmium content of all fertilizers and municipal composts. Some EU regulatory agencies and environmental groups are worried that long-term use of high-cadmium fertilizers could cause the toxic metal to accumulate in the soil and be taken up by edible plants, inadvertently entering the food chain (Roberts, 1996). 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. 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. Four of the more promising processes for removing cadmium from phosphoric acid are: (1) cocrystallization of cadmium with anhydrite, (2) precipitation with inorganic sulfide salts, (3) formation of complex cadmium chloride anions and subsequent removal by anion exchange, and (4) removal by solvent extraction (Davister, 1996; Vermeul, 1996). Austria, Belgium, Denmark, Finland, Norway, Sweden, and Switzerland already restrict cadmium levels in phosphate fertilizers—with maximum allowable concentrations ranging from 22 milligrams Cd per kilogram P_2O_5 for Finland and Switzerland to 120 milligrams for Austria. Japan has a higher limit of 150 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 rocks from some of their competitors contain considerably less cadmium (e.g. Florida, the Kola Peninsula of Russia, and Phalaborwa, South Africa). Phosphate rocks of igneous origin normally contain less than 15 milligrams Cd per kilogram P_2O_5 compared with 20 to 245 milligrams for their sedimentary counterparts (Davister, 1996). Rock from Nauru has some of the highest cadmium levels found to date and averages 243 milligrams Cd. In 1996, the principal ocean shippers of phosphate rock (in descending order) were Morocco, Jordan, Togo, and Israel (SSY Consultancy and Research Ltd., 1997). U.S. exports of phosphate rock have fallen off dramatically since 1991. All five countries mine sedimentary phosphate deposits.

U.S. research agronomists argued at Saltsjöbaden that the risk of transferring cadmium from the soil to humans via the food-chain is not as serious as some regulatory authorities perceive (Chaney and others, 1996). Considerable emphasis has been placed on cadmium uptake studies carried out on rice plants during the 1970's and 1980's in China and Japan. These studies showed that rice grown in paddies contaminated by zinc mine wastes had abnormally high levels of cadmium and that the cadmium-rich rice, in turn, was responsible for certain rare kidney and bone diseases afflicting the subsistence farmers and their families who depended upon the rice as their principal food source. Soils with as little as 2 milligrams of Cd per kilogram dry weight had adverse health effects on the subsistence farmers. However, subsequent studies found that the farmers had diets that were seriously deficient in iron, zinc, and calcium which increased intestinal absorption of the cadmium. New evidence indicates that cadmium disease is not observed under similar conditions when exposure is via the vegetable food chain. Garden crops grown in the United Kingdom on soils contaminated with 50 to 150 milligrams Cd per kilogram and 5,000 to 15,000 milligrams Zn per kilogram did not induce cadmium disease. Rice is apparently a very atypical plant in terms of cadmium uptake. In most plants, the uptake of cadmium is strongly affected by the cadmium to zinc ratio in the soil. As a general rule, zinc inhibits cadmium uptake. The addition of small amounts of zinc fertilizer to the soil can solve many cadmium accumulation problems. Soil pH, clay content, and soil chloride levels also have a significant influence on uptake of the metal. Tobacco is a second atypical plant that presents special environmental risks (Chaney and others, 1996). Smokers tend to have higher kidney cadmium levels than nonsmokers.

Consumption

Apparent consumption of cadmium metal in the United States nearly doubled between 1995 and 1996. This increase was due largely to growing demand for Ni-Cd batteries throughout North America—producing a sharp drop in exports of both the unwrought metal and scrap. The rapidly expanding U.S. program for recycling industrial and household batteries has encouraged electronics manufacturers to continue to use Ni-Cd batteries in their products and even incorporate the batteries in future project designs. The U.S. Geological Survey (USGS) 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 1996 was as follows: batteries, 70%; pigments, 13%; stabilizers for plastics and similar synthetic products, 7%; coatings and plating, 8%; and alloys and other, 2% (Morrow, 1997). This breakdown differs somewhat from the USGS series quoted earlier for just the United States. Consumption patterns vary significantly within the OECD membership because of differences in environmental regulations, industrial development, natural resources, and trading partnerships. Relatively small but critical amounts of cadmium metal, alloys or compounds are frequently incorporated into solar cells, radiation detectors, lasers, and other electro-optical devices.

The traditional uses of cadmium in easily dispersible products continued to decline in OECD countries because of increasingly stringent environmental regulations, concerns of manufacturers about long term liability, and the development of less toxic substitutes. Environmental activists in the EU have been lobbying for further restrictions on the use of cadmium in such products. The use of cadmium in electroplating, plastics additives, and pigments has diminished significantly over the last two decades.

Cadmium compounds are still being used in the United States and the Far East to stabilize PVC. Liquid stabilizers typically contain 1% to 8% Cd in the form of cadmium 2-ethylhexanoate or cadmium oleate. Solid stabilizers contain 4% to 12% Cd in the form of salts of saturated fatty acids (e.g., stearic acid and lauric acid). The cadmium content of the finished PVC article usually contains no more than 0.2% Cd. The cadmium is locked into the polymer matrix and has extremely low leachability (Donelly, 1996). Still, cadmium-based stabilizers are banned in Sweden. The EU as a whole currently restricts certain uses of cadmium-based stabilizers and is encouraging the replacement of barium/cadmium systems by barium/zinc or other alternatives wherever technically feasible.

In contrast, the use of cadmium in rechargeable batteries has steadily grown over the same time period. Ni-Cd batteries are widely used in handheld power tools and a myriad of portable electronic devices, including compact disc players, pocket recorders, camcorders, cordless telephones, cellular telephones, scanner radios, and laptop computers. Two French automobile manufacturers—PSA Peugeot-Citroën and Renault—began limited production of Ni-Cd powered EV's in 1996. The batteries for the vehicles were being manufactured by SAFT S.A. at its new battery plant in Bordeaux, France. In 1996, the United States imported $673 million worth of Ni-Cd batteries. The bulk of the imported batteries were made in Mexico, Japan, China, or Hong Kong (in descending market share).

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, coatings and plating constituted the largest use of the metal in the United States.

Since 1965, consumption of cadmium for coatings and plating has declined more than 70% in the Western World because of human health and environmental concerns about the metal (Morrow, 1996). In 1990, coatings and plating accounted for only 9% of total cadmium consumption in Europe and a mere 1% in Japan. That same year, the corresponding figure for the United States was estimated to be 25%. Since 1965, the U.S. plating industry has taken a number of steps to make cadmium coatings more acceptable. A series of surveys by The Cadmium Council, Inc. (now part of the International Cadmium Association) found that occupational exposures in most cadmium plating shops were below the Action Level of 2.5 micrograms of cadmium per cubic meter of air set by the Occupational Safety and Health Administration, with many shops having levels equal to or less than 1.0 micrograms of cadmium per cubic meter of air. Plating wastewater 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. In 1996, at least three facilities were licensed to receive cadmium-bearing electroplating sludges for reclamation: INMETCO, Horsehead Resources Development Corp., and Encycle Inc.

U.S. industry took these steps because 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. Cadmium coatings also have low electrical resistivity and good soldering characteristics. In 1992, the communications sector accounted for 31% of the cadmium coatings market in the United States (Morrow, 1996). The next three largest applications were fasteners (20%), aircraft (15%), and automotive (15%).

Cadmium pigments are more stable than organic 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. When cadmium sulfide is mixed in differing amounts with cadmium selenide and related inorganic pigments, a broad spectrum of brilliant colors with strong opacity can be generated. Organic alternatives still cannot match many of the more popular properties of cadmium pigments, especially color brightness, opacity and processability.

A significant amount of cadmium was still being used worldwide to make colorants for plastics, despite regulatory pressures. 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 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.

Rhône-Poulenc of France has begun marketing a new family of cerium sulfide pigments that both overcomes the limitations of organic substitutes and completely sidesteps growing concerns about the recycling and ultimate disposal of plastics containing cadmium-based pigments (Industrial Minerals, 1995). Limited quantities of the new pigments are being produced at the company's Roches-Roussillon plant near Lyon, France, and are being sold under the Neolor trademark to the plastics industry. Both red and orange pigments are available, and Rhône-Poulenc is planning to expand the color range into the yellow part of the spectrum. In June 1994, Ferro Corporation, a U.S.-based supplier of inorganic pigments, agreed to help develop and distribute the Neolor pigments in the United States and Canada (Tourre, 1997).

Less than 1% of the cadmium consumed annually is used in electro-optics. However, cadmium plays an extremely critical role in this increasingly important end use because, to date, few other semiconducting materials have been able to satisfactorily substitute for cadmium compounds in key applications. Although small, these electro-optical devices can be costly to manufacture and have become extremely sophisticated technologically. Zinc sulfide powder activated with silver was one of the first materials used as a scintillator to detect and electronically count the alpha particles emitted during the radioactive decay of uranium and the other actinides. This early work led to the development of cadmium sulfide photoconductive films for lighting controls and eventually to small, liquid-nitrogen-cooled cadmium telluride semiconductor detectors for gamma-ray spectrometry. Today, a number of types of infrared photon detectors, blue/violet/ultraviolet lasers, and solar cells utilize some form of cadmium. Omnichrome Corp. of Chino, CA, and LiCONiX of Santa Clara, CA, were two of several companies that manufactured helium-cadmium laser systems. One successful use of the violet/ultraviolet laser was to create parts in stereolithography. Besides imaging, the lasers have a wide variety of other applications in medicine, biology, nondestructive testing, and forensic science.

After silicon and gallium arsenide, mercury cadmium telluride is one of the more important general purpose semiconductors. For more than 30 years, mercury cadmium telluride ($Hg_{1-x}Cd_xTe$) has been the semiconductor of choice for mid- and long-wavelength infrared photodetectors (Piotrowski and Perry, 1997). The material has a high specific detectivity (i.e., signal-to-noise ratio) for infrared photons, especially in the spectral range of 3 to 30 micrometers—an important region of the electromagnetic spectrum for remote temperature sensing and thermal imaging. The spectral cutoff of the detector can be shifted within this region for optimal detection by tailoring the chemical composition of the cadmium alloy. The x value in the formula is normally set somewhere between 0.17 and 0.50. The $Hg_{1-x}Cd_xTe$ absorber (i.e., the layer within the device that absorbs the infrared radiation) is grown, using epitaxial techniques, on a substrate of cadmium telluride, cadmium zinc telluride, or silicon metal. Infrared photodetectors have proven extremely useful for mapping the earth's surface at night because infrared photons scatter much less in the lower atmosphere than photons of visible light. For the same reason, related devices are useful to the U.S. Department of Defense for missile guidance and for detecting targets from high altitudes. More down to earth uses include pyrometers, instrumentation for analytical chemistry, laser radiation monitors, night-vision equipment, and burglar alarms.

Prices

Prices weakened significantly in 1996, dropping back to 1994 levels. The New York dealer price for metal, published by *Metals Week* for the week ending January 5, 1996, ranged from $1.90 to $2.00 per pound. The monthly average price for January was $1.90, slightly higher than the 1995 annual average of $1.84. However, the price began to weaken in February and continued to spiral downward for the rest of the year. Prices were even weaker during the first half of 1997. For the week ending December 27, 1996, the New York dealer price ranged from $0.80 to $0.92. The average annual price for 1996 was $1.24.

Some industry analysts attribute the extreme volatility of cadmium prices to the fact that only about 5% of the cadmium shipped from producers is actually sold on a spot basis. The remaining 95% is sold under long-term contracts which depend on price feedback from the spot market. This system amplifies the weight of published price changes associated with limited spot sales, making it relatively easy for speculators to influence the market. The growing importance of recycled cadmium in the marketplace is expected to dampen this amplification and promote price stability (Morrow, 1997).

World Review

Industry Structure.—World refinery production of cadmium was estimated at 18,900 tons in 1996. Canada replaced Japan as the largest producer of refined cadmium products. Belgium edged out the United States for third place.

Capacity.—World cadmium refining capacity 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. Australia has the world's largest demonstrated resources of cadmium—an estimated 190,000 tons contained in 95 million tons of sphalerite. Canada is a close second with about 170,000 tons contained in 83 million tons of sphalerite.

Australia.—Three new zinc mines and one electrolytic zinc refinery were in varying stages of development, increasing Australia's capacity to recover cadmium. Feasibility studies were being conducted on several other zinc projects, most of which were in Queensland or Western Australia. The McArthur River Mine was officially opened on September 6, 1995, but was still in the startup phase. The new zinc-lead-silver mine is near Borroloola in the northeast corner of the Northern Territory, about 100 kilometers south of the Gulf of Carpentaria. The underground mine is controlled by MIM Holdings Ltd. (70% equity) and has an annual production capacity of 160,000 tons of zinc and 45,000 tons of lead. More than one-half of the cadmium-bearing concentrates were being shipped to MIM's smelters in Germany and the United Kingdom, with the remainder going to custom smelters in Australia, Europe, and Japan. The capacity of the Woodcutters Mine—also in the Northern Territory—was being expanded from 70,000 tons of zinc per year to 97,000 tons. The Woodcutters Mine is owned by Normandy Metals Ltd. The Cannington Mine, being developed by BHP Minerals Ltd. near Cloncurry, Queensland, was scheduled to start up in 1997. The Cannington Mine has 45 million tons of ore reserves averaging 11.1% zinc.

The permitting and land acquisition process for the Century Zinc project at Lawn Hill in northwest Queensland was delayed by litigation over aboriginal rights to the property. Part of the concentrates from the proposed Century mill were to go to a custom smelter operated by Pasminco Ltd. at Budel-Dorpein in the Netherlands. The Century deposit was being developed by the giant Rio Tinto Zinc Corp.-Conzinc Riotinto of Australia (RTZ-CRA) and reportedly had 188 million tons of ore grading 10.2% zinc. In late 1996, RTZ-CRA pulled out of the project and sold both the Century deposit and the Dugald River zinc deposit to Pasminco for $275 million. Pasminco needs the low-iron concentrates from the Century Mine to meet limits that Dutch environmental authorities have placed on generation of waste jarosite at the Budel smelter. In 1996, Budelco B.V. produced 603 tons of cadmium.

Korea Zinc was to begin construction of the world's largest zinc smelting and refining complex in late 1996. The complex was to be built at Townsville, Queensland, and would initially produce 170,000 tons per year of zinc metal for the export market. More than 300 tons of byproduct cadmium would be recovered annually at the refinery. The capacity of the $375 million complex was to be doubled by the year 2005.

China.**—**In April 1996, a new electrolytic zinc refinery was commissioned at the Zhuzhou smelting complex in Hunan Province. The Government-owned lead-zinc complex has been in operation since 1959. The new refinery raised the electrolytic zinc capacity of the complex from 150,000 tons of zinc per year to 250,000 tons. At least 40% of the output was special high grade zinc destined for export. The expansion was expected to increase cadmium production to 800 tons per year. Both 99.99% and 99.95% Cd grades were being marketed, with sticks and balls being made in preference to ingot to take advantage of the price differential. Domestic mines provide about 95% of Zhuzhou's feed (Metal Bulletin, 1996c).

European Union.**—*****Italy.*****—**The state-owned resources group, Enirisorse SpA, has decided to privatize its lead-zinc mining, smelting, and refining operations in southwestern Sardinia. The lead and zinc concentrates used as feed are currently being imported. At one time, a large part of the concentrates came from the group's Masua and Monteponi Mines at Iglesias, but the output from these mines has fallen off dramatically since 1992 because of depleted reserves. The zinc is recovered at Porto Vesme in an Imperial Smelting Furnace and upgraded in an adjoining electrolytic refinery. The lead is recovered at Porto Vesme by the Imperial Smelting Process and the Kivcet Process. Enirisorse also has a lead refinery at San Gavino. Together, the two complexes produce about 300 tons of cadmium annually and have a combined annual capacity of about 160,000 tons of zinc and 120,000 tons of lead (Metal Bulletin, 1996b).

Enirisorse also has invited tenders for the purchase of its only other electrolytic zinc refinery—at Crotone on the eastern coast of Calabria—which has an annual capacity of 100,000 tons of zinc. The Crotone facility was commissioned in 1928 and was being run by a subsidiary, Pertusola Sud SpA. The operation had been recovering byproduct germanium and indium in addition to cadmium. In 1995, Italy produced 308 tons of cadmium metal, down significantly from a 7-year high of 742 tons in 1992.

Japan.**—**Japanese production of cadmium declined from 2,652 tons in 1995 to 2,343 tons in 1996. The 11% decrease was due to the closure of the Barajima electrolytic zinc refinery, near the port of Akita in Akita Prefecture. The refinery's owner, Mitsubishi Materials Corp., shut down the operation after it became more economical to import zinc metal, rather than to recover it from domestic and imported concentrates.

Japan continued to be the world's largest consumer of cadmium. About 87% of Japanese production is consumed domestically, with the remainder going primarily to China and the Republic of Korea. The 1996 decline in Japanese production was offset by increased imports of unwrought cadmium, in descending order, from Belgium, Canada, and Australia. In 1994, Japan consumed 7,131 tons of cadmium. An estimated 6,675 tons (or 94%) of the 7,131 tons was used in the manufacturing of Ni-Cd batteries (Fujimoto and Mukunoki, in press).

Kazakstan.**—**The lead-zinc industry recovered 1,200 tons of cadmium in 1996, almost the same tonnage as in 1995, largely as a byproduct of zinc refining. The typical sphalerite ores in Kazakstan contain about 0.007% Cd. Most of the ore came from mines operated by the Leninogorsk Polymetal Combine, the Ust-Kamenogorsk Lead-Zinc Integrated Works, and the Zyryanovsk Lead Combine. On November 29, 1996, the Government of Kazakstan announced that the three mining and metallurgical enterprises would be incorporated into a single stock company, Aktsionernoye Obschestvo Katztsink. The consolidation was to take effect in January 1997. Equity in the new company was to be divided as follows: Leninogorsk, 30.2%; Zyryanovsk, 27.5%; Ust-Kamenogorsk, 27.3%; and the Government of Kazakstan, 15%. The three enterprises are located within 300 kilometers of one another and are already connected by rail.

Peru.**—**On February 15, 1995, Cominco Ltd. and Marubeni Corp. jointly purchased the electrolytic zinc refinery at Cajamarquilla. The refinery is about 20 kilometers east of Lima and recovers significant cadmium as a byproduct. Cominco owns 82% of the shares of the holding company—Sociedad Minera Refinería de Zinc de Cajamarquilla S.A. Marubeni has 17% of the shares, with the refinery employees controlling the remaining 1%. Cominco is responsible for day-to-day operations and also provides technical and marketing support. The Cajamarquilla refinery was built in 1981 and is designed to produce up to 102,000 tons of zinc per year. The refinery operated at full capacity in 1996, making 105,400 tons of zinc—a new production record (Cominco Limited, 1996). Cadmium production was 279 tons, up 6% from 263 tons in 1995. In 1995, zinc production was only 80,800 tons because of problems with three of the refinery's four power transformers. Since then, two new transformers have been brought in from Canada and the older transformers have been refurbished.

The consortium was planning to spend $30 million in 1997 to raise the capacity of the refinery to 120,000 tons of zinc per year, increasing cadmium production accordingly. A study was underway to determine if it was feasible to double Cajamarquilla's output to 230,000 tons of zinc per year. All of the concentrate feed for Cajamarquilla comes from Peruvian mines, which currently produce four times more concentrate than the country's two refineries can process. The second refinery is at La Oroya and has an annual capacity of 70,000 tons of zinc.

Current Research and Technology

In France, PSA Peugeot Citroën and Renault began manufacturing Ni-Cd powered EV's on a limited scale. Peugeot Citroën, an alliance of Automobiles Peugeot and Automobiles Citroën, is Europe's third largest manufacturer of conventional automobiles. Peugeot Citroën currently has three EV models in production: the Peugeot 106 Electrique, the Citroën AX Electrique, and the Tulip. To date, the alliance has produced more than 1,000 standard Peugeot 106 and Citroën EV's. The Tulip is a small special two-seater EV designed to complement existing urban transit systems. The alliance is also producing a Ni-Cd battery-powered scooter that can attain a speed of 45 kilometers per hour.

During World War II, Peugeot developed a small three-wheeled EV to alleviate gasoline rationing. This vehicle was the forerunner of two prototype EV models introduced in 1989: the Peugeot J5 and the Citroën C25. For more than 6 years, Peugeot Citroën has been field testing some 50 EV's at the Atlantic port of La Rochelle. A network of recharging stations was set up around La Rochelle as part of the experiment. Peugeot formally introduced its new 106 Electrique in 1995. The two-door hatchback has three battery packs of 6-volt Ni-Cd monoblocks. The three packs (a total of 20 monoblocks in series) provide 120 volts to a direct current motor. The Ni-Cd batteries were being serviced by the manufacturer, SAFT SA, which has a brand new Ni-Cd battery manufacturing facility in Bordeaux. The 106 Electrique has a driving range of 80 kilometers and can accelerate from 0 to 50 kilometers per hour in 8.5 seconds (PSA Peugeot Citroën, 1997). The EV retails for $18,150.

In October 1996, British sponsors bought 14 Electrique's and were field testing them in the Midlands city of Coventry (Simonian, 1996). The handful of hatchbacks and vans were being used by the Coventry City Council, East Midlands Electricity, PowerGen, and the Royal Mail.

In 1994, Peugeot Citroën joined Générale de Transport et d'Industrie (GTI) and Cegelec to form the LISELEC Group, a futuristic EV rental company. The group is currently testing 10 Electrique's in the Paris region and is planning to set up a fleet of EV's for self-service operation throughout the region. Each LISELEC customer would be issued a pass and an associated personal code that would permit him or her to pick up an EV at any one of a network of parking stations and return it to any station of his or her choice. GTI, which operates public transit systems in 87 French towns, is responsible for designing the overall system and managing the parking stations. Cegelec will design and manufacture the necessary electronic door locks, the keyless ignition control, car phone, and charging terminals. Cegelec will also provide the central control system and the on-line computerized reservation/invoicing equipment. The Tulip would be the first rental EV used in the LISELEC system and is specially designed for this purpose. The vehicle is equipped with an on-board computer that communicates with the central control station. The Tulip network has the potential to dramatically improve the flexibility and net earnings of most metropolitan transit systems and could prove to be a major end use for cadmium.

Outlook

The future of the cadmium industry is tied to the development of new recycling technologies. A global system for recycling Ni-Cd batteries is rapidly becoming a reality. However, effective recycling systems still do not exist for some of the other principal end products. These new systems must be viable, resilient, economical, and—above all—be able to allay the environmental and health concerns that the general public currently has about the metal and its compounds. The proper disposal of damaged plastics, obsolete electronic parts, incinerator residues, and municipal sewer sludge—all of which often contain relatively low levels of dispersed cadmium—is still a problem. The U.S. cadmium industry already has taken a number of steps to minimize occupational exposure and has upgraded its facilities so that almost all more than meet the new Federal standards adopted since 1992.

The market for Ni-Cd batteries is expected to grow at least 6% per year 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 are strong contenders for the rapidly growing electric scooter/bicycle market and will still be used in rechargeable power tools, home appliances, and other household equipment because of cost constraints. Ni-Cd batteries continue to compete head-on with Ni-MH and lithium-ion alternatives in the portable electronics sector. However, over the last 3 years, lithium-ion and Ni-MH batteries have been gaining ground against nickel-cadmium for some electronic end uses. In Japan, Ni-MH batteries have already captured 49% of the office equipment market, 18% of the communications market, and 7% of the home applications market (Fujimoto and Mukunoki, in press).

The U.S. collection and recycling program for small rechargeable batteries is in a period of rapid expansion. The program is administered by the Rechargeable Battery Recycling Corporation (RBRC), a nonprofit public service corporation. 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. More than 175 companies are currently participating in the program. PRBA is also a sponsor and has helped to enlist the participation of county and municipal governments, hospitals, and fire departments. Spent Ni-Cd, Ni-MH, lithium-ion, and small sealed lead batteries are all being collected under the program. The program is now operating in 19 States at more than 4,500 retail locations. Some 300 counties also have drop-off centers. RBPRC believes that, by the year 2001, roughly 70% of the spent Ni-Cd batteries being generated in the United States will be recycled. The current recycling rate is about 15%. An estimated 85% of industrial Ni-Cd batteries are recycled. INMETCO was expecting receipts of spent Ni-Cd batteries in 1997 to be 20% to 25% greater than those of 1996. 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. 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%.

Spent Ni-Cd batteries are being recycled by at least nine foreign plants (Metal Bulletin, 1996a). The largest foreign recycler is Sté. Nouvelle d'Affinage des Métaux S.A.R.L. (SNAM), which has two plants in France—one at Viviez in the Massif Central region and another at St. Quentin Fallavier near Lyon. Together, the two recover about 650 tons of cadmium annually (Broad, 1997). SNAM is also responsible for the SAFT NIFE AB recycling operation in Sweden, which recovers about 225 tons. In Japan, the collection system supervised by JSBA feeds spent batteries into four regional recycling plants: Japan Recycle Center (3,000 tons of batteries per year), Mitsui Mining Co., Kansai Catalyst (500 tons per year), Mitsui Mining Co., and Toho Zinc Co. Ltd. (an electrolytic zinc refiner receiving 1,700 tons per year). Retailers, waste collectors, product manufacturers, and more than 1,900 municipalities all participate in the program (Fujimoto and Mukunoki, in press). The Japanese system is currently recovering about 600 tons per year of cadmium. Other foreign recyclers include Hydrometal SA (Belgium), Uniquel SA (Spain), and TNO/Esdex (Netherlands).

On March 29, 1996, the California Air Resources Board (CARB) unanimously approved a staff recommendation to restructure the board's electric vehicle mandate. The staff recommendation was based in part on the findings of an independent battery technical advisory panel. 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. The auto manufacturers are particularly concerned that the limited range of existing EV prototypes will seriously limit their marketability. 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. The board directed its staff to draw up a memorandum of agreement between the State of California and each of the seven automobile manufacturers. Special credits will be issued to manufacturers who market EV's before 2003.

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. 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.

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TABLE 1
SALIENT CADMIUM STATISTICS 1/

(Metric tons, cadmium content, unless otherwise specified)

	1992	1993	1994	1995	1996
United States:					
Production of metal 2/	1,620	1,090	1,010	1,270	1,530 p/
Shipments of metal by producers 3/	2,070	1,320	1,290	1,280	1,310 p/
Exports of metal, alloys, and scrap	213	38	1,450	1,050	201
Imports for consumption, metal	1,960	1,420	1,110	848	843
Stocks of metal, Government, yearend	2,870	2,690	2,480	2,260	2,030
Apparent consumption	3,270	3,010	1,040	1,160	2,250
Price, average per pound, New York dealer 4/	$0.91	$0.45	$1.13	$1.84	$1.24
World: Refinery production	19,800 r/	19,000 r/	18,500 r/	18,900 r/	18,900 e/

e/ Estimated. p/ Preliminary. 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/
1995	105	936
1996	119	720

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)

	1995	1996
Industry stocks, Jan. 1	423	542
Production	1,270	1,530
Imports for consumption, metal	848	843
Shipments from Government stockpile excesses	214	230
Total supply	2,750	3,140
Exports of metal, alloys, and scrap	1,050	201
Industry stocks, Dec. 31	542	693
Consumption, apparent 2/	1,160	2,250

NA Not available.
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)

	1995		1996	
	Cadmium metal	Cadmium in compounds	Cadmium metal	Cadmium in compounds
Metal producers	139	W	360	W
Compound manufacturers	82	321	120	214
Distributors	W	(1/)	W	(1/)
Total	222	321	479	214

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	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Cadmium metal: 2/				
Austria	212	$9,370	--	--
Belgium	157,000	6,040,000	18,100	$75,000
Brazil	--	--	500	12,400
Canada	10,100	100,000	2,920	20,800
Chile	1,720	7,940	--	--
China	320,000	223,000	7,060	18,400
France	34,300	55,600	52,200	121,000
Germany	20	15,900	225	32,300
Hong Kong	474,000	369,000	--	--
India	--	--	18,000	25,400
Ireland	140	98,800	--	--
Israel	--	--	215	34,100
Italy	--	--	5,620	13,600
Japan	46,800	177,000	18	10,600
Korea, Republic of	3,440	29,600	33,400	297,000
Mexico	135	3,130	2,070	42,600
Netherlands	--	--	17,900	43,000
Norway	4,070	35,400	--	--
Singapore	--	--	1,500	12,700
Sweden	--	--	1,790	126,000
Taiwan	--	--	47	19,000
United Kingdom	15	4,210	1,380	21,900
Uzbekistan	--	--	31,800	14,100
Other	--	--	6,070	88,800
Total	1,050,000	7,160,000	201,000	1,030,000
Cadmium sulfide: (gross weight)				
Australia	49,300	36,800	17,800	6,680
Belgium	--	--	6,330	3,290
Canada	299,000	158,000	659,000	349,000
Colombia	20,400	5,650	45,600	23,700
Japan	126,000	67,600	--	--
Korea, Republic of	--	--	10,200	5,310
New Zealand	4,050	11,700	--	--
Other	7,570	3,940	57,400	11,500
Total	506,000	283,000	797,000	399,000

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	1995 Quantity (kilograms)	1995 Value	1996 Quantity (kilograms)	1996 Value
Cadmium metal:				
Algeria	--	--	2,000	$8,380
Argentina	18,000	$39,600	--	--
Australia	5,000	19,700	48,000	93,500
Belgium	31,600	198,000	37,600	302,000
Canada	466,000	1,670,000	451,000	1,260,000
China	28,500	32,400	5,220	14,800
Finland	--	--	3,000	9,260
France 2/	38,800	90,000	3,540	29,600
Germany	61,900	205,000	50,700	110,000
Japan	2,480	32,200	492	62,600
Mexico	41,100	124,000	96,800	234,000
Netherlands	--	--	143,000	268,000
Norway	39,100	96,800	--	--
Peru	36,000	111,000	1,390	1,600
Russia	95	3,060	1	1,900
Switzerland	79,100	90,900	--	--
United Kingdom	--	--	15	3,430
Total	848,000	2,710,000	843,000	2,400,000
Cadmium sulfide: (gross weight)				
Austria	1,000	14,600	--	--
Belgium	4,580	61,000	455	1,300
Brazil	--	--	1,600	20,100
India	34,400	18,500	--	--
Japan	13,300	76,600	455	37,300
Russia	75	5,850	12	2,360
United Kingdom	4,210	49,700	11,100	94,900
Total	57,600	226,000	13,600	156,000

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

2/ The 1995 data for France includes 31,000 kilograms of metal removed from bonded warehouses. The stored metal was valued at $27,700.

Source: Bureau of the Census.

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

(Metric tons)

Country	1992	1993	1994	1995	1996 e/
Algeria	56	65	59 r/	59 r/	59
Argentina e/	37 3/	34	35	35	35
Australia	1,001	951	910	838 r/	682 3/
Belgium	1,549 r/	1,573	1,556	1,710	1,580
Brazil e/	200	200	300 r/	300 r/	300
Bulgaria	194	265	286	250 e/	250
Canada	1,963	1,944	2,173	2,349 r/	2,540
China e/	1,150	1,160	1,280 r/	1,200	1,300
Finland 4/	590	785	548 r/	539 r/	648 3/
France	252	137	6	-- e/	--
Germany	961	1,056	1,145	1,150 e/	1,150
India	313	255	216	254 r/	264 3/
Italy	742	517	475	308	296 3/
Japan	2,986	2,832	2,629	2,652	2,343 3/
Kazakstan	1,000 e/	1,000 e/	995	1,209 r/	1,200
Korea, North e/	100	100	100	100	100
Korea, Republic of e/	750	815	800	750	700
Macedonia e/	(5/)	(5/)	(5/)	(5/)	(5/)
Mexico 6/	602	797	646	689	675
Namibia	33	13	19	15	13
Netherlands	594	526	387 r/	300 e/	300
Norway	247	213	288	317 r/	274 3/
Peru	399 r/	472 r/	507 r/	510 r/ e/	510
Poland	132	149	61	-- r/	--
Romania e/	10	10	4 3/	5	5
Russia e/	800	700	500	500	550
Serbia and Montenegro	8	6	--	11	10
South Africa e/ 7/	60 3/	64	63	58 r/	63
Spain	361	329 r/	387	397 r/	307 3/
Thailand	635	449	643 r/	500 e/	600
Turkey	23	31	22 e/	23 r/ e/	20
Ukraine	5	7 e/	10	15 e/	15
United Kingdom 8/	383	458	469	549	541
United States 8/	1,620	1,090	1,010	1,270	1,530 p/ 3/
Zaire	84	12	1 e/	-- e/	--
Total	19,800 r/	19,000 r/	18,500 r/	18,900 r/	18,900

e/ Estimated. p/ Preliminary. r/ Revised.

1/ World totals, U.S. data, and estimated data have been 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, 1997.

3/ Reported figure.

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

5/ Less than 1/2 unit.

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

7/ Cadmium content of cadmium cake.

8/ Includes secondary.