science for a changing world

2005 Minerals Yearbook

CADMIUM

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

March 2007

Cadmium

By Moungar E. Cooper and Peter H. Kuck

Domestic survey data and tables were prepared by Amy C. Tolcin, statistical assistant, and the world production table was prepared by Regina R. Coleman, international data coordinator.

In the United States, three companies produced cadmium metal in 2005. Big River Zinc Corp. and Zinifex Ltd. (formerly Pasminco Ltd.) produced primary cadmium as a byproduct of the smelting and refining of zinc concentrates, while International Metals Reclamation Company Inc. (INMETCO) produced secondary cadmium from scrap, almost entirely from spent nickel-cadmium (NiCd) batteries. Cadmium metal production in the United States was 1,070 metric tons (t) in 2005, up 5% from that of 2004 (table 1). The total value of the 2005 output was estimated to be $3.5 million. Although definitive consumption data do not exist, the International Cadmium Association (ICdA) made the following estimates of cadmium consumption for various end uses in 2004: batteries, 81%; pigments, 10%; coatings and plating, 7%; stabilizers for plastics and similar synthetic products, 1.5%; and nonferrous alloys and other uses, 0.5% (Hugh Morrow, President, International Cadmium Association, oral commun., 2005). World production of refined cadmium metal has grown steadily since 2002, with more than 80% of the output being used to make NiCd batteries. The bulk of the additional output went to the rapidly growing battery industry in China.

The average New York dealer price of cadmium metal in 2005 was $3.30 per kilogram (or $1.50 per pound)—almost double the average for 2004 (table 1). Global prices for cadmium metal rose steadily between May 2004 and August 2005 owing to increased demand mainly from Chinese NiCd battery manufacturers. However, growing demand for zinc in the second half of 2005 resulted in increased byproduct cadmium output, causing cadmium prices to stabilize and later weaken. Increased secondary production, mainly from recycled NiCd batteries, also helped to stabilize prices. Some leading producers of primary cadmium in 2005 were Akita Smelting Co. Ltd. (Japan), Budel Zink BV (Netherlands), Falconbridge Ltd. (Canada), Hindustan Zinc Ltd. (India), Huludao Zinc Smelting Co. (China), JSC Chelyabinsk Electrolytic Zinc Plant (Russia), Korea Zinc Co., Ltd. (Republic of Korea), Met-Mex Peñoles, S.A. de C.V. (Mexico), Noranda, Inc. (Canada), Glencore AGPorto Vesme (Italy), Teck Cominco Ltd. (Canada), Toho Zinc Co. Ltd. (Japan), Zhuzhou Smelter Group Co., Ltd. (China), and Zinifex Ltd. (Australia).

Legislation and Government Programs

Government agencies around the world are making efforts to reduce the exposure of their citizens to cadmium. Prolonged exposure to excessive amounts of the element can damage the central nervous system, liver, and kidneys. Recent international studies also indicate a correlation between excessive cadmium and certain lung and pancreatic diseases (Kriegel and others, 2006; Nordberg, 2006). Environmental pollution is one of the main ways that ordinary citizens are exposed to dangerous levels of cadmium. The principal routes of exposure are ingestion and inhalation. Cadmium's relatively long biological half-life of about 10 years allows for considerable bioaccumulation. Owing to the fact that the tobacco plant concentrates cadmium effectively, smokers are particularly at a high risk for overexposure (Centers for Disease Control and Prevention, 2005§[1]). Within the body, cadmium can accumulate in the kidneys, leading to proteinuria, increased bone loss, and several cancers (Genova Diagnostics, 2005§). The human body contains metallothionen—a protein that binds heavy metals and lessens their impact on the body's systems. This protein reportedly binds cadmium in the liver, but its subsequent degradation in the kidneys leads to the release of intracellular cadmium. According to the Agency for Toxic Substances and Disease Registry (2005§), if the kidneys do not produce enough of the binding protein to sequester high levels of cadmium, renal dysfunction is possible. A recent study found a significant correlation between high serum cadmium levels and pancreatic cancer (Kriegel and others, 2006).

The U.S. Environmental Protection Agency (EPA) lists cadmium as a "priority" chemical, a designation intended to decrease the exposure of the general population to this toxic element. In 2005, the EPA reached its goal of reducing the release of priority chemicals in waste by 50% from the 1991 baseline. The EPA hopes to increase reduction an additional 10% by 2008 (U.S. Environmental Protection Agency, 2007§).

On July 21, the Centers for Disease Control and Prevention (CDC) reported that 5% of the population aged 20 years and older have urinary cadmium levels at or above the established safe level of 1 microgram per gram of creatinine. The CDC believes that cigarette smoking is the most probable source of this high level of cadmium (Centers for Disease Control and Prevention, 2005§).

In June, the EPA published a draft of its "Framework for Inorganic Metals Risk Assessment" for public comment. For more than a decade, the U.S. Government has worked to establish a scientific method for evaluating the effects of different metals on human health and the environment. Key issues have been the ecological effects of metals, their environmental chemistries, exposure pathways, and human health effects (with particular emphasis on bioaccumulation and bioavailability). In February, the EPA-nominated Science Advisory Board (SAB) reviewed the draft framework together with the public comments. The SAB recommended that the framework be restructured to improve the clarity of its overall purpose and that several major revisions be made. At the end of the year, the EPA's Office of Research and Development was in the process of restructuring the framework, with an emphasis

[1]References that include a section mark (§) are found in the Internet References Cited section.

on updating the human health and ecological sections of the document. The SAB panel agreed with the framework's authors that metals should be assessed differently than organic pollutants because metals do not degrade like most organic compounds. The SAB also pointed out that some metals are essential for living organisms.

In addition to Federal regulations, 13 States have passed legislation regulating battery labeling and removeability from consumer products. Eight States now have take-back requirements that apply to all NiCds. The most stringent take-back regulations are in Minnesota, where 90% of NiCd and small sealed lead-acid batteries must be recovered. In New Jersey, manufacturers are required to take responsibility for used rechargeable batteries and either recycle or dispose of them in an environmentally sound manner (Fishbein, 1996§). In California, retailers of cellular phones are required to recycle old telephones at no cost to consumers after July 1, 2006 (Recycling Today, 2004§). An estimated 40,000 cell phones per day were being thrown away in California (Ursery, 2004§).

Similar efforts are underway worldwide. The European Union (EU) has implemented several regulations limiting the usage of cadmium. On January 19, the Environmental Council of the European Union enacted a new directive (2002/95/EC) on batteries and accumulators. The directive was designed to halt unregulated dumping and incineration of waste batteries. The most controversial part of the directive was a partial ban on portable cadmium batteries which stated that the cadmium content of a battery cannot exceed 0.002% unless the battery is used in emergency or medical systems. In addition, NiCd batteries would have to be collected and recycled. Collection targets for portable household batteries were 25% and 45% to be achieved in 4 and 8 years, respectively, after the transposition of the directive into the laws of each member country (European Parliament and The Council of the European Union, 2003§; United Kingdom Department for Environment, Food and Rural Affairs, 2005§).

After December 31, companies manufacturing pure electric or hybrid-motor vehicles for sale in the EU are prohibited from using cadmium in their batteries. Honda Motor Co., Ltd. of Japan was one of the first automobile manufacturers to comply with the new EU regulations (Honda Motor Co., Ltd., 2005§). Beginning in 2009, NiCd batteries can only be sold in the EU as replacement parts for older, grandfathered vehicles.

In February 2003, the EU had adopted a set of environmental regulations that are having a profound impact on semiconductor and electronics manufacturing. The "Restriction of the Use of Hazardous Substances" (RoHS) directive, which went into effect on July 1, 2006, is affecting electronic-circuit design worldwide. The directive restricts the incorporation of cadmium, hexavalent chromium, lead, and mercury in most electrical and electronic equipment sold in the EU after the 2006 deadline. The directive covers computers, DVD players, electronic tools and toys, household appliances, radios, telephones, televisions, and many other products. However, cadmium plating is exempt from the RoHS. Under a related directive, "Waste from Electrical and Electronic Equipment" (WEEE), the EU holds manufacturers financially responsible for the collection and recycling of used electronic products. The WEEE directive went into effect on August 13, 2005 (Katz, 2005§).

Production

Primary.—All of the primary cadmium recovered in the United States in 2005 came from lead and/or zinc concentrates. At least 10 mines produced lead and/or zinc concentrates, the leading mine being the Red Dog Mine in Alaska. Red Dog, which is the leading zinc mine in the world, is operated by Teck Cominco Ltd. under an agreement with NANA Regional Corporation, Inc. Teck Cominco also operates the Pend Oreille zinc mine in the State of Washington. Part of the concentrates from these two mines were exported to Canada to the company's metallurgical complex at Trail, British Columbia. Lead and/or zinc concentrates were also produced in Alaska, Idaho, Missouri, and Montana..

Primary cadmium was recovered and refined in two States—Illinois and Tennessee. Big River Zinc complex (BRZ) at Sauget, IL, is the second ranked electrolytic zinc refinery in the United States and has been producing zinc since 1929. In 1997, Korea Zinc Ltd. purchased BRZ for $50 million and spent more than $80 million upgrading the operation. In the past, the refinery relied on zinc concentrates from Illinois, Missouri, and Tennessee, which contained relatively low iron. When the mines from these locations closed, BRZ was unable to source suitable zinc concentrates at an attractive price. Because the refinery does not have a hot acid leach circuit, it is unable to process zinc concentrates with a high iron content, exacerbating the feed purchasing problem. In December, Korea Zinc idled the Sauget plant and put it up for sale (American Metal Market, 2005a§). In early 2006, ZincOx Resources plc of Surrey, United Kingdom, acquired BRZ, with the intent of converting the Sauget plant in part to secondary zinc production (ZincOx Resources plc, 2006).

All of the Tennessee cadmium production was a byproduct of the zinc smelting and refining operations at Clarksville, 80 kilometers (km) northwest of Nashville, TN. The smelter, located in Montgomery County, is owned and operated by Zinifex Ltd. of Melbourne, Australia. Clarksville is the smallest of Zinifex's smelting and refining complexes and has a capacity of 110,000 metric tons per year (t/yr) of zinc metal (Zinifex Limited, 2005). The complex also produces 145,000 t/yr of byproduct sulfuric acid. Much of the cadmium produced at Clarksville in 2005 was recovered from zinc concentrates imported from Australia, Central America, Ireland, and South America. Prior to 2004, the Clarksville smelter obtained the bulk of its cadmium-bearing zinc concentrates from the Gordonsville and Clinch Valley Mines in Tennessee. Gordonsville (Smith County) was closed in 2003; Clinch Valley (Grainger County), in 2004.

The zinc operations of ASARCO LLC (Asarco) in northeastern Tennessee were idle throughout 2005 and did not produce any cadmium. In November 2001, Asarco suspended operations at its Coy, Immel, and Young underground mines in the Mascot-Jefferson City district. The Young mill at Strawberry Plains (Jefferson County) was placed on care-and-maintenance status at the same time. In November 2005, Glencore AG of Switzerland bought Asarco's Tennessee operations for an undisclosed sum (Metallurgical Industry of Russia, 2006§).

On November 9, HudBay Minerals Inc. (Canada) announced that it would reopen its Balmat No. 4 zinc mine in New York State. The underground mine, located on the western edge of Lawrence County, had been on care and maintenance since 2001.

Some sphalerite at Balmat reportedly contains 1,200 to 1,400 micrograms of cadmium per gram of zinc sulfide ZnS (Doe, 1960; Lenker, 1962). St. Lawrence Zinc Company (SLZ) (a wholly owned subsidiary of HudBay) will operate the mine. HudBay is the third ranked producer of zinc metal in Canada and operates mines and refineries in Manitoba and Saskatchewan. The Balmat Mine has 1.86 million metric tons (Mt) of ore reserves averaging 11.2% zinc and 1.39 Mt of additional, less defined resources averaging 12.9% zinc. At yearend, the existing 5,000-metric-ton-per-day concentrator was being overhauled. Production was scheduled to begin in June 2006 and was to be eventually ramped up to 60,000 t/yr of zinc in sphalerite concentrates. The concentrates would be shipped to the refinery of Canadian Electrolytic Zinc Limited in Valleyfield, Quebec, Canada, for further processing (HudBay Minerals Inc., 2005). The 60,000 t/yr of zinc equates to about 200 t/yr of cadmium.

Secondary.—Although primary cadmium production has declined somewhat since 2000, production of secondary cadmium has been increasing steadily. There are three major industry collection and recycling programs in the world—the Rechargeable Battery Recycling Corp. (RBRC) program in the United States and Canada, the Battery Association of Japan program, and the CollectNiCad program in Europe. The amount of cadmium being recycled, however, is difficult to estimate. The reported amount of NiCd batteries collected is fairly accurate, but there are no published data on the amounts of cadmium recovered from recycled batteries and other sources, such as electric arc furnace (EAF) dust, electroplating wastes, filter cakes, sludges, and other cadmium-containing materials. EAF dust typically contains about 0.05% cadmium.

The most difficult aspect of NiCd battery recycling has been the collection of spent batteries purchased for household use. Although large industrial batteries (containing about 20% of all cadmium used for batteries) are easy to collect and are recycled at a rate of about 80%, small consumer NiCd batteries are frequently discarded by the public. Voluntary industry-sponsored collection programs and government programs have been devised to improve the collection of these small consumer batteries and are continually being upgraded. Public participation is critical because, in addition to improving the environment, economies of scale are very important—larger recycling operations lower unit costs. The International Metals Reclamation Company, Inc. (INMETCO) has developed several different collection programs to meet the varied needs of battery manufacturers and the numerous consumers, firms, organizations, and agencies that use the many diverse products containing NiCd batteries (such as cordless phones, personal computers, and power tools). The most successful recycling program in the United States is operated by RBRC. Established when INMETCO began cadmium recycling in 1995, RBRC has organized a multifaceted collection program financed with proceeds from licensing its seal of approval to individual companies involved in the manufacturing, importation, and distribution of rechargeable batteries or battery-operated products. The RBRC recycling program includes uniform battery labeling, removeability from appliances, a national network of collection systems, regulatory relief to facilitate battery collection, and widespread publicity to encourage public participation. To increase participation, RBRC has undertaken an extensive public education campaign and has established numerous collection sites throughout the United States and Canada (Money and others, undated). In 2004, RBRC collected 1,500 t of NiCd batteries. In 2005, there was a 9.8% increase in the total number of rechargeable batteries collected by RBRC (Rechargeable Battery Recycling Corporation, 2006§).

Environmental Issues

For more than two decades, government agencies and nongovernmental environmental organizations worldwide have been expanding and improving their programs to monitor cadmium levels in the environment. The World Health Organization's (WHO) guideline for cadmium in drinking water is 0.003 milligrams per liter (mg/l) (World Health Organization, 2003§). Monitoring studies indicate that background levels are typically less than 0.002 mg/l. To improve detection, chemists at the University of New South Wales, Australia, have developed a voltammetric method for measuring cadmium ions using glutathione-modified gold electrodes and have reported a detection limit of 5 nanoMolar (Chow and others, 2005, p. 6).

The Agricultural Research Service (ARS) of the U.S. Department of Agriculture reported that acidifying cadmium-contaminated soil helped the plant alpine pennycress capture cadmium and zinc. The ARS believed that this technique could be very effective in decontaminating Asian rice paddies that have been contaminated with heavy metals from nearby mines (Agricultural Research Service, 2004§).

U.S. regulatory agencies cited and subsequently fined several companies for pollution-related violations linked to cadmium contamination. The Occupational Safety and Health Administration fined Project Management Services and Viasant L.L.C. for failing to comply with lead and cadmium standards, among other violations (Occupational Safety and Health Administration, 2006a§, b§). The EPA demanded that three companies, Container Properties L.L.C., Bayer Crop Science (successor of Rhone-Poulenc Inc.) and Rhodia Inc., pay more than $720,000 for failing to clean up the defunct Washington industrial chemical processing site in South Seattle, WA. Preliminary sampling detected heavy-metal contamination of surface groundwater flowing into the Lower Duwamish River, near the processing site. The river is home to the threatened Chinook salmon and is experiencing depressed steelhead runs (U.S. Environmental Protection Agency, 2005a§).

Asarco filed for Chapter 11 bankruptcy on August 17. Asarco, a leading smelter and refiner of nonferrous metals during the last century, has been accused of polluting the groundwater and soils of 22 Western States with arsenic, cadmium, and/or lead (U.S. Environmental Protection Agency, 2005c§). Asarco had more than 100 civil suits pending at the time of bankruptcy and could be required to spend more than $1 billion to clean up environmental contamination at 94 sites in 21 States (Millman and others, 2005).

The Government of the United Kingdom disclosed that some of its citizens had been intentionally exposed more than 40 years ago to above-background levels of cadmium. At the time, Ministry of Defense scientists wanted to simulate the airborne dissemination of chemicals in a possible airborne terrorist attack (British Broadcasting Corporation, 2005§). In five separate incidents from 1963-64, airplanes sprayed zinc cadmium chemicals over Suffolk, where the prevailing winds supposedly carried the dispersed chemicals northeast towards Norwich. An investigation was started to determine if the cadmium was linked to a suspected increase in esophageal cancer within the local population (Norwich Evening News, 2005§). After some investigation, public health officials concluded that it is unlikely that the zinc cadmium sulfide dispersion trials resulted in any long-term health effects.

Life Cycle Studies of Batteries.—Rydh and Karlström (2002) have studied the environmental impact of recycling portable NiCd batteries in Sweden. Their results showed that, in Sweden in 2001, 25% of NiCd batteries were recycled; 45%, incinerated; and 30%, landfilled. Their model indicated that batteries manufactured from recycled cadmium and nickel would have 16% lower primary energy requirements than if only virgin metals were used.

The European Commission has proposed stricter regulations on the disposal and end-of-life recycling of automobiles. Two major Japanese automakers recently revealed plans to produce cars with no cadmium, hexavalent chromium, lead, or mercury, except for the lead in lead-acid batteries (an end use where lead recycling exceeds 90%). Toyota Motor Corporation already has developed a mercury-free lamp and has ceased using lead in such parts as fuel tanks (Metal-Pages, 2004b§). Honda intended to abolish all applications of the four metals in its vehicles by yearend 2005, 2 years earlier than required by the Japan Manufacturers Association (Metal-Pages, 2005§).

Emissions From Lead and/or Zinc Smelters.—In March 2004, a team of environmental health specialists from the CDC visited the La Oroya copper and lead smelter in Peru (Doe Run Company, The, 2005§). Prolonged cadmium and lead emissions have been a concern at the Andean smelter for several decades. The Doe Run Company of St. Louis, MO, acquired Metaloroya (now Doe Run Peru) in 1997 from Centromin, a Peruvian parastatal, with the understanding that the U.S.-based company would improve operational efficiencies, reduce hazardous metal emissions, and dramatically increase industrial safety. Since then, Doe Run has spent $140 million on facility improvements designed to reduce plant emission and improve community life. The CDC team was to provide technical assistance to the project and recommend ways of further reducing exposure to lead, cadmium, and other contaminants. In May 2005, the team submitted its recommendations in a report to the Government of Peru and the U.S. Agency for International Development (Centers for Disease Control and Prevention, 2005). The long-term environmental remediation project currently underway at the La Oroya smelter illustrates how similar pollution problems can be alleviated at other nonferrous smelters worldwide (Doe Run Company, The, 2005§). As a result of these improvements, lead levels in the blood of Doe Run workers have fallen by more than 30% on average. Air lead emissions of the main stack are down by more than 35% since 1998 (Doe Run Company, The, 2005). Doe Run is planning to spend an additional $150 million on sulfur emissions abatement (Moore, 2005§). Remediation efforts to address historical soil contamination by arsenic, cadmium, and lead cannot be completely addressed until air emissions from the smelter are fully controlled.

Consumption

The U.S. Geological Survey (USGS) does not collect consumption data on cadmium metal or cadmium compounds. Apparent consumption of cadmium metal in the United States is calculated by the USGS using the production data of individual companies, U.S. foreign trade statistics, and reported stock changes (table 1).

According to the World Bureau of Metal Statistics, global consumption of refined cadmium in 2005 decreased to 16,100 t, 6% less than the tonnage for 2004 (World Metal Statistics, 2006, p. 35). Cadmium consumption in the 1990s was fueled by the growing NiCd rechargeable battery market. However, since 2002, consumption has weakened because of increasingly restrictive environmental regulations. During the 1990s, several battery manufacturing facilities relocated from Europe and North America to countries with less stringent environmental restrictions and lower labor costs. The main beneficiary of this transfer was China, which emerged as the leading cadmium consumer in the world, followed by Japan. Together, the two countries consumed more than one-half of world cadmium production in 2004 (Wilson, 2005). In 2005, China imported 6,800 t of cadmium metal, a 1% decrease from that of 2004; most of that imported cadmium was from the Republic of Korea, followed by Kazakhstan and the United States (Metal-Pages, 2006§). NiCd battery production in China was estimated to have increased to 800 million units in 2004, a 20% increase compared with that of 2003 (Wilson, 2005; Metal-Pages, 2004a§).

Recycling

In 2003 (latest available data), 150 million cell phones were in use in the United States, and they are replaced on average every 12 to 18 months. In 2003, 100 million cell phones were taken out of service in the United States, 60% to 70% was left by consumers in their home. Of the remaining 30% to 40%, only 5 million were refurbished or recycled, while at least 25 million were discarded in municipal waste sites. Although cell phones make up only a small percentage of the overall municipal waste stream, they may contain several toxic elements, such as cadmium, lead, and mercury (Wireless Recycling, 2004§).

In response to public concern about the environment, the cellular telephone industry in the United States joined the telephone recycling movement. As the stockpile of retired wireless devices continued to grow, the Cellular Telecommunications and Internet Association launched its initiative to promote environmentally sound recycling of used wireless products that contain cadmium, lead, lithium, and other hazardous metals. The association's "Wireless: The New Recyclable" program is designed to focus the public's attention on the importance and ease of recycling wireless devices (Recycle Wireless Phones, undated §).

The recycling of phones is typically carried out by contractors who turn consumer and industry discards into profit, reduce environmental waste, and at the same time help some nonprofit organizations. One of the latest companies to begin phone recycling is Global Refurbishment Corp. Wireless Recycling (GRC), headquartered in Miramar, FL. The company has formed a national partnership with businesses affected by the California Cell Phone Recycling Act of 2004. GRC pays $1 per pound or more for used telephones collected through 1,200 organizations in 49 States. The company has paid out more than $1.2 million since the partnership's establishment in 2001. About 70% of collected phones are refurbished and sold to buyers, mainly in Latin America, or given to nonprofit organizations. The remaining 30% is shredded and sold to nonferrous metal smelters for feed (Katz, 2004§).

Prices

In 2005, the average New York dealer price of cadmium increased to $1.50 per pound owing to increased demand from the battery industry and tightening supplies that carried into the summer (table 1). China was the main factor behind the 2005 price increase owing to the country's increased consumption (American Metal Market, 2005b§).

World Industry Structure

Worldwide production of cadmium in 2005 increased to 19,400 t from 18,700 t in 2004. Consumption declined by 8%, narrowing the gap between world production and consumption. The commissioning of new cadmium circuits at greenfield zinc mining and smelting complexes in Burkina Faso, China, and Russia offset the shutdown of older, less profitable operations in Belgium (table 5).

Worldwide consumption of cadmium for production of rechargeable batteries, which is the dominant use of cadmium, has been growing steadily for more than 15 years. Other cadmium markets, such as alloys, coatings, pigments, and stabilizers, are regarded as mature and are not expected to grow. Cadmium metal is commercially used as a corrosion-resistant coating on steel, aluminum, and other nonferrous metals, especially where low friction or low electrical resistivity is needed. Cadmium metal is also added to some nonferrous alloys to improve properties such as, castability, electrochemical behavior, hardness, strength, and wear resistance. Cadmium compounds are used in batteries, pigments, plastic stabilizers, and semiconductor applications.

Current Research and Technology

Ni-Cd Powered Buses.—Many cities are faced with the transportation challenge of getting commuters from houses to rails. Ebus Inc., Downey, CA, makes buses powered by NiCd batteries; these buses have four times the range of current electric buses. Among electric bus makers, Ebus has the most buses deployed in the United States (Fine, 2005§). Currently, there are 10 electric buses running in the main district of Santa Barbara, CA.

Solar Energy Applications.—A large portion of the solar energy operations around the world use cadmium in their photovoltaic (PV) modules. Cadmium sulfide acts as a 'window layer' because of its relative transparency. A cadmium telluride (CdTe) layer serves as the active region owing to its effective absorption throughout the solar spectrum (U.S. Department of Energy, 2005§). CdTe PV modules deliver virtually no greenhouse emissions, and cadmium emissions are considerably less than all other energy alternatives except natural gas (Fthenakis and Kim, 2006§). Each module contains less than 0.1% cadmium by weight and retains this cadmium for 20 to 30 years, after which it is recycled. CdTe PV modules represent a promising alternative to environmental discharge and NiCd batteries. According to the Brookhaven National Laboratory, CdTe modules provide 2,500 times more energy than NiCd batteries. Experts believe that there is more than enough cadmium to support this technology; the major downfall is cost. A considerable amount of energy is used in the production of each module, and more research is being done to decrease costs while increasing overall efficiency (National Renewable Energy Laboratory, 2005§).

Thin film PV solar panels may provide a more cost-effective alternative to traditional solar systems that rely on crystalline silicon wafers. Substantial progress has been made in improving CdTe-base thin-film solar cells. For more than 30 years, designers have relied on tin oxide (SnO_2)/cadmium sulfide (CdS)/CdTe device structures. Scientists at the National Renewable Energy Laboratory have improved the performance of these devices by incorporating cadmium stannate (Cd_2SnO_4) and zinc stannate (Zn_2SnO_4) into device structures. One such modified device had a total-area efficiency of 16.5%—the highest efficiency ever reported for CdTe solar cells (Wu and others, 2001, p. 2). This efficiency compares favorably with the efficiencies attained with thin-film copper indium aluminum diselenide devices (National Renewable Energy Laboratory, 2003a§, b§).

Semiconductor Applications.—In June 2004, TeraRecon, Inc. of San Mateo, CA, teamed up with Acrorad Co., Ltd. of Okinawa, Japan, to develop advanced CdTe semiconductor devices for use in direct conversion x- and gamma-ray detectors. CdTe is one of a few semiconductor materials that can convert x and gamma rays directly into electrical signals while attaining high conversion efficiency. Acrorad reportedly has overcome many of the difficulties that prevented competitors from manufacturing large monolithic CdTe crystals. Acrorad's facility on Okinawa reportedly is the largest CdTe production operation in the world in terms of volume. The two companies will focus their efforts initially on flat panel area-detectors and gamma-ray cameras. Both products would be sold to original equipment manufacturers and have numerous applications in the fields of industrial and medical imaging (TeraRecon, Inc., 2004).

Quantum Dots.—Cadmium selenide (CdSe) is being studied for its uses in biomedical imaging, lasers, luminescent materials, and optoelectronics. Quantum dots are tiny crystals of CdSe, a semiconducting material, that are used for their size-controlled fluorescence. Engineers at Johns Hopkins University have created a new method of identifying specific sequences of DNA by using quantum dots and their florescence under a microscope (Johns Hopkins University, 2005§). Owing to its increased sensitivity, this method can be used to find a specific DNA sequence or mutation. Researchers at the Massachusetts Institute of Technology are conducting animal studies which would use quantum dots to label cancerous tumors via Magnetic Resonance Imaging (Science Daily, 2006§). Scientists at the Los Alamos National Laboratory discovered that nanocrystals of cadmium compounds respond to photons by producing multiple electrons in a process called carrier multiplication (Los Alamos National Laboratory, 2006§). This technology could be used to make more efficient solar cells.

When CdSe is heated to several hundred degrees Celsius under the flow of nitrogen gas and a gold catalyst, it forms one-dimensional nanostructures—nanobelts, nanosaws, and nanowires. Georgia Institute of Technology scientists have determined the optimal conditions for growing each of these structures (Science Daily, 2005b§). Prior to 2005, quantum dots cost more than $2,000 per gram, with the production solvent octadecane contributing to 90% of this cost. Rice University scientists developed a new method that replaces octadecane with Dowtherm, a heat transfer oil, which decreases the cost of quantum dots by 80% (Science Daily, 2005a§).

Outlook

Cadmium producers and consumers face an unusual situation. Environmentalists oppose the proliferation of cadmium in any form because of the metal's toxicity. Consumers, meanwhile, are demanding computers, power tools, and other electric products that require the use of relatively inexpensive NiCd batteries. To date, nickel-metal hydride (NiMH) and lithium-ion batteries have been more expensive to manufacture than NiCd batteries and are not being used in many low-end products. The commercialization of novel nickel-zinc (Ni-Zn) batteries may change the current situation. San Diego, CA-based PowerGenix Corporation has developed and patented the next generation Ni-Zn battery that is up to ten times more powerful than traditional NiCd, NiMH, or lead-acid batteries, while up to 75% lighter and about 30% smaller. Venture capitalists have invested $13 million in Ni-Zn battery research hoping that the new battery will become an economically viable and environmentally friendly alternative to NiCd batteries (Metal-Pages, 2004c§). Chinese and Indian markets will continue to drive NiCd battery demand in the foreseeable future. China currently consumes more than twice as much cadmium as it produces, mainly to feed the country's burgeoning NiCd battery manufacturing industry (Plachy, 2005, p. 15.4).

If cadmium prices continue to strengthen, the growing supply deficit will be partially offset by improved recycling rates and the increased availability of recycled cadmium. According to a 1999 survey conducted by the RBRC, 95% of Americans own cordless electronic products, but only about 16% recycle their power sources (American Metal Market, 1999). Another survey conducted by the RBRC has highlighted America's growing reliance on cordless electronic products. The average U.S. household has five or more of these products, which include camcorders, cordless and cellular telephones, cordless power tools, electric toothbrushes, handheld mini-vacuums, laptop computers, and remote-controlled toys. The survey found that more than one-half of respondents would recycle their rechargeable batteries if the batteries were collected together with other recyclables through curbside collection programs at home, at businesses, or at retail stores that sell replacement batteries (Rechargeable Battery Recycling Corp., 2002§).

References Cited

American Metal Market, 1999, Most NiCd batteries wind up in landfills, trade group claims: American Metal Market, v. 107, no. 223, November 18, p. 7.

Centers for Disease Control and Prevention, National Center for Environmental Health, 2005, Development of an integrated intervention plan to reduce exposure to lead and other contaminants in the mining center of La Oroya, Peru: Atlanta, GA, Centers for Disease Control and Prevention, May, 44 p.

Chow, Edith, Hibbert, D.B,, and Gooding, J.J., 2005, Voltammetric detection of cadmium ions at glutathione-modified gold electrodes: Sydney, Australia, School of Chemistry, The University of New South Wales, April, 7 p.

Doe, B.R., 1960, The distribution and composition of sulfide minerals at Balmat, New York: Pasadena, CA, California Institute of Technology, Ph.D. dissertation, 236 p.

Doe Run Company, The, 2005, Doe Run supports CDC recommendations for La Oroya: St. Louis, MO, The Doe Run Company press release, August 11, 2 p.

HudBay Minerals Inc., 2005, HudBay announces reopening of Balmat no. 4 zinc mine: Winnipeg, Manitoba, Canada, HudBay Minerals Inc. press release, November 9, 2 p.

Kriegel, A.M., Soliman, A.S., Zhang, Qing, El-Ghawalby, Nabih, Ezzat, Farouk, Soultan, Ahmed, Abdel-Wahab, Mohamed, Fathy, Omar, Ebidi, Gamal, Bassiouni, Nadia, Hamilton, S.R., Abbruzzese, J.L., Lacey, M.R., and Blake, D.A., 2006, Serum cadmium levels in pancreatic cancer patients from the East Nile Delta region of Egypt: Environmental Health Perspectives, v. 114, no. 1, January, p. 113-119.

Lenker, E.S., 1962, A trace element study of selected sulfide minerals from the eastern United States: University Park, PA, The Pennsylvania State University, Ph.D. dissertation, 151 p.

Millman, John, Aeppel, Timothy, and McKay, P.A., 2005, Asarco files for chapter 11, cites costs, strikes: The Wall Street Journal, August 11, p. A3, A8.

Money, Kenneth, Tomaszewski, Mark, and Bleakney, Russell, [undated], Pyrometallurgical battery reclamation at the International Metals Reclamation Company: Ellwood City, PA, The International Metals Reclamation Company, Inc., 16 p.

Nordberg, G.F., 2006, Lung cancer and exposure to environmental cadmium: The Lancet Oncology, v. 7, issue 2, February, p. 99-101.

Plachy, Jozef, 2005, Cadmium, *in* Metals and minerals: U.S. Geological Survey Minerals Yearbook 2003, v. I, p. 15.1-15.7.

Rydh, C.J., and Karlström, M., 2002, Life-cycle inventory of recycling portable nickel-cadmium batteries: Resources, Conservation and Recycling, v. 34, no. 4, March, p. 289-309.

TeraRecon, Inc., 2004, TeraRecon enters flat-panel area detector market through strategic investment in Acrorad: San Mateo, CA, TeraRecon, Inc. press release, June 8, 2 p.

Wilson, Rob, 2005, Indium, germanium and cadmium market overview: Minor Metals Conference, Lisbon, Portugal, June 2, 2005, Presentation, 35 slides.

World Metal Statistics, 2006, Cadmium—World refined consumption: World Bureau of Metal Statistics, v. 59, no. 10, October 18, p. 35.

Wu, X., Dhere, R.G., Albin, D.S., Gessert, T.A., DeHart, C., Keane, J.C., Duda, A., Coutts, T.J., Asher, S., Levi, D.H., Moutinho, H.R., Yan, Y., Moriarty, T., Johnston, S., Emery, K., and Sheldon, P., 2001, High-efficiency CTO/ZTO/CdS/CdTe polycrystalline thin-film solar cells, *in* National Center for Photovoltaics Program Review Meeting, Lakewood, CO, October 14-17, 2001, Presentation: Golden, CO, National Renewable Energy Laboratory NREL/CP-520-31025, 4 p.

ZincOx Resources plc, 2006, Big River Zinc smelter acquisition agreement signed: Surrey, United Kingdom, ZincOx Resources plc press release, June 5, 3 p.

Zinifex Limited, 2005, Annual report—2004: Melbourne, Australia, Zinifex Limited, 56 p.

Internet References Cited

Agency for Toxic Substances and Disease Registry, 2005 (November), Interaction profile for arsenic, cadmium, chromium, and lead, accessed July 20, 2006, at URL http://www.atsdr.cdc.gov/interactionprofiles/IP-metals1/ip04-c2.pdf.

Agricultural Research Service, 2004, Dainty plant outpowers cadmium-contaminated soils, accessed August 10, 2006, at URL http://www.ars.usda.gov/is/AR/archive/sep04/plant0904.htm.

American Metal Market, 2005a, Big River Zinc set to halt output as costs take toll, accessed August 10, 2006, at URL http://www.findarticles.com/p/articles/mi_m3MKT/is_47-4_113/ai_n15933906.

American Metal Market, 2005b, Cadmium prices swell on Chinese demand, accessed January 1, 2006, at URL http://www.findarticles.com/p/articles/mi_m3MKT/is_24-4_113/ai_n14708177.

British Broadcasting Corporation, 2005, New figures on spray cancer claim, accessed June 6, 2006, at URL http://news.bbc.co.uk/2/hi/uk_news/england/norfolk/4342668.stm.

Centers for Disease Control and Prevention, 2005, Third annual report on human exposure to environmental chemicals, accessed June 26, 2006, at URL http://www.cdc.gov/exposurereport/pdf/factsheet_cadmium.pdf.

Doe Run Company, The, 2005, La Oroya, Peru, accessed August 24, 2005, at URL http://www.doerun.com/whatwedo/laoroya.aspx.
European Parliament and The Council of the European Union, 2003, Directive 2002/95/EC of the European Parliament, accessed June 20, 2006, at URL http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf.
Fine, Howard, 2005, Magic bus—Battery-turbine power is seen as response to transportation issues, Los Angeles Business Journal, accessed June 10, 2006, at URL http://www.findarticles.com/p/articles/mi_m5072.
Fishbein, Bette, 1996, Industry program to collect nickel-cadmium (Ni-Cd) batteries, accessed December 22, 2004, at URL http://www.informinc.org/recyclenicd.php.
Fthenakis, V.M., and Kim, H.C., 2006, Greenhouse gas emissions from solar electric and nuclear power—A life cycle study, accessed August 17, 2006, at URL http://www.seas.columbia.edu/clca/papers/Greenhouse_Gas_Emissions_Solar_Nuclear_Energy_Policy-inPress.pdf.
Genova Diagnostics, 2005, Toxic elements, accessed June 10, 2006, at URL http://www.gdx.net/home/images/reportpdf/ToxElemNutrtChart.pdf.
Honda Motor Co., Ltd., 2005, Promotion of green purchasing, accessed December 19, 2006, at URL http://world.honda.com/environment/2005report/10purchasing/green/index.html.
John Hopkins University, 2005, New nanosensor uses quantum dots to detect DNA, accessed August 10, 2006, at URL http://www.jhu.edu/news_info/news/home05/dec05/dnanano.html.
Katz, Anne, 2005, RoHS compliance—What products are affected?, accessed August 24, 2005, via URL http://www.idt.com.
Katz, Ian, 2004 (August 30), Doing well while doing good, Sun-Sentinel, accessed January 24, 2005, via URL http://www.grcrecycling.com.
Los Alamos National Laboratory, 2006, Tiny crystals promise big benefits for solar technologies, accessed June 10, 2006, at URL http://www.lanl.gov/news/index.php?fuseaction=home.story&story_id=7727.
Metal-Pages, 2004a (October 1), Battery Ni consumption on rise, accessed October 7, 2004, via URL http://www.metal-pages.com.
Metal-Pages, 2004b (December 22), Toyota's bid to reduce harmful waste, accessed December 22, 2004, via URL http://www.metal-pages.com.
Metal-Pages, 2004c (December 2), Zn key for new battery, accessed December 2, 2004, via URL http://www.metal-pages.com.
Metal-Pages, 2005 (March 22), Honda to cease using heavy metals, accessed March 22, 2005, via URL http://www.metal-pages.com.
Metal-Pages, 2006 (February 16), China cadmium imports down in 2005, accessed February 16, 2006, via URL http://www.metal-pages.com.
Metallurgical Industry of Russia, 2006, One company's zinc bearing waste is another company's treasure, accessed June 9, 2006, at URL http://www.rusmet.net/news.php?act=by_id&news_id=49148.
Moore, Patrick, 2005 (August), Corporate social responsibility in Peru, accessed August 23, 2005, via URL http://www.eco-imperialism.com.
National Renewable Energy Laboratory, 2003a, Cadmium facts and handy comparisons, accessed August 10, 2006, at URL http://www.nrel.gov/cdte/pdfs/cdte_factsheet.pdf.
National Renewable Energy Laboratory, 2003b, Cadmium use in photovoltaics—The perceived risk and scientific evidence, accessed June 10, 2006, via URL http://www.nrel.gov/cdte.
National Renewable Energy Laboratory, 2005, CdTe PV—Real and perceived EHS risks, accessed June 19, 2006, at URL http://www.nrel.gov/cdte/pdfs/real_perceived_risks.pdf.
Norwich Evening News, 2005, MoD tests affected most of country, accessed June 14, 2006, via URL http://www.eveningnew24.co.uk.
Occupational Safety and Health Administration, 2006a, OSHA fines Arlington Heights company $209,500 for unsafe hazardous waste clean-up activities at shuttered battery plant, accessed August 10, 2006, at URL http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=12251.
Occupational Safety and Health Administration, 2006b, OSHA fines Ohio company $134,000 for unsafe hazardous waste clean-up activities in Chicago, accessed August 10, 2006, at URL http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=12208.
Rechargeable Battery Recycling Corp., 2002, 54% of consumers power their daily life with four or more cordless electronic products, accessed May 7, 2002, via URL http://www.rbrc.org.
Rechargeable Battery Recycling Corporation, 2006, 2005 annual report, accessed August 10, 2006, at URL www.rbrc.org/call2recycle/docs/year_in_review.pdf.
Recycling Today, 2004 (July 14), E-scrap 2004 announces dates, accessed January 26, 2005, via URL http://www.recyclingtoday.com.
Recycle Wireless Phones, [undated], Ever wonder what to do with your old wireless phone?, accessed February 20, 2004, via URL http://www.recyclewirelessphones.com.
Science Daily, 2005a (September 9), Method slashes quantum dot costs by 80 percent, accessed July 12, 2006, at URL http://www.sciencedaily.com/releases/2005/09/050909073701.htm.
Science Daily, 2005b (October 30), Nanomanufacturing—First systematic study of cadmium selenide nanostructure growth yields production "road map", accessed July 10 2006, at URL http://www.sciencedaily.com/releases/2005/10/051028140332.htm.
Science Daily, 2006 (May 2), Nanoparticles may help detect, treat tumors, accessed June 10, 2006, at URL http://www.sciencedaily.com/releases/2006/05/060501231153.htm.
United Kingdom Department for Environment, Food and Rural Affairs, 2005, Producer responsibility—Batteries directive, accessed August 17, 2005, at URL http://www.defra.gov.uk/environment/waste/topics/batteries/index.htm.
Ursery, Stephen, 2004 (November 1), Cell phone history, Waste Age, accessed August 17, 2005, via URL http://www.findarticles.com.
U.S. Department of Energy, 2005, Solar Energy Technologies Program, accessed September 12, 2005, at URL http://www.eere.energy.gov/solar/tf_polycrystalline.html.
U.S. Environmental Protection Agency, 2005a, EPA demands $720,250 from three companies for failure to clean up former Rhone-Poulenc site, News Release, accessed August 4, 2006, via URL http://www.epa.gov/region1.
U.S. Environmental Protection Agency, 2005b (June 28), Framework for inorganic metals risk assessment (external review draft), accessed September 12, 2005, at URL http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=88903.
U.S. Environmental Protection Agency, 2005c, Asarco Inc., Globe Plant, accessed August 10, 2006, at URL http://www.epa.gov/region8/superfund/sites/co/asarcoglb.html.
U.S. Environmental Protection Agency, 2007, Resource conservation challenge—Five year strategic plan, accessed January 30, 2007, at URL http://www.epa.gov/epaoswer/osw/conserve/strat-plan/strat-plan.htm.
Wireless Recycling, 2004 (September 23), Old cell phones pile up by the millions, accessed January 24, 2005, via URL http://www.wirelessrecycling.com.
World Health Organization, 2003, Chemical fact sheets—Cadmium, accessed August 10, 2006, at URL http://www.who.int/water_sanitation_health/dwq/chemicals/cadmiumsum.pdf.

GENERAL SOURCES OF INFORMATION

U.S. Geological Survey Publications

Cadmium. Ch. in Mineral Commodity Summaries, annual.
Cadmium. Ch. in United States Mineral Resources, Professional Paper 820, 1973.

Other

American Metal Market, daily.
Cadmium. Ch. in Mineral Facts and Problems, U.S. Bureau of Mines Bulletin 675, 1985.
Energy Efficiency and Renewable Energy. Solar Energy Technologies Program, U.S. Department of Energy, 2006
International Cadmium Association technical publications.
Metal Bulletin, semiweekly and monthly.
Platts Metals Week, weekly.

TABLE 1

SALIENT CADMIUM STATISTICS[1, 2]

		2001	2002	2003	2004	2005
United States:						
Production of metal[3]	metric tons	1,450 r, 4	1,430 r, 4	1,420 r, 4	1,010 r, 4	1,070
Shipments of metal by producers[5]	do.	1,040 r	1,020 r, 4	995 r, 4	1,060 r, 4	1,050
Exports of metal, alloys, scrap	do.	216 r	264 r	615 r	154 r	686
Imports for consumption, metal, alloys, and scrap	do.	107 r	81 r	112 r	263 r	288
Stocks of metal, U.S. Government, yearend[6]	do.	773	146 r	--	--	--
Apparent consumption of metal	do.	1,000 r	1,460 r	637 r	1,170 r	656
Price, average, New York dealer[7]	dollars per pound	0.23	0.29 r	0.59 r	0.55 r	1.50
Do.[7]	dollars per kilogram	0.50	0.64	1.31	1.20	3.30
World, refinery production	metric tons	20,000 r	18,000 r	18,500	18,700 r	19,400 e

[e]Estimated. [r]Revised. -- Zero.

[1]Data are rounded to no more than three significant digits, except prices.

[2]Cadmium content.

[3]Primary and secondary cadmium metal. Includes equivalent metal content of cadmium sponge used directly in production of compounds.

[4]Partially estimated.

[5]Includes metal consumed at producer plants to make oxide and other cadmium compounds.

[6]Defense National Stockpile Center, December 31. Includes material for sale pending shipment.

[7]Price for 1- to 5-short-ton lots of metal having a minimum purity of 99.95% (Platts Metals Week).

TABLE 2

SUPPLY AND APPARENT CONSUMPTION OF CADMIUM METAL[1, 2]

(Metric tons)

	2001[r]	2002[r]	2003[r]	2004	2005
Producer stocks, January 1[3]	1,350	1,540	2,160	2,580 r	2,540
Production[3]	1,450	1,430	1,420	1,010 r	1,070
Imports for consumption of metal, alloy, scrap	107	81	112	263 r	288
Shipments from Government stockpile excesses	68	627	146	--	--
Total supply	2,970	3,890	3,840	3,860 r	3,890
Exports of metal, alloys, scrap	216	264	615	154 r	686
Producer stocks, December 31[3]	1,750	2,160	2,580	2,540 r	2,550
Consumption, apparent[4]	1,000	1,460	637	1,170 r	656

[r]Revised. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Excludes supply and apparent consumption of cadmium sulfide, cadmium telluride, and related cadmium chemicals.

[3]Partially estimated.

[4]Total supply minus exports and yearend stocks.

TABLE 3

U.S. EXPORTS OF CADMIUM PRODUCTS, BY COUNTRY AND TYPES[1]

	2001		2002		2003		2004		2005	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cadmium metal:[2]										
Belgium	--	--	--	--	79,900	$80,000	--	--	--	--
Brazil	9,110	$1,180,000	--	--	--	--	--	--	--	--
Canada	19,700	284,000	32,900	$509,000	10,700	229,000	20,200	$440,000	8,590	$211,000
Chile	--	--	1,150	11,700	--	--	2,080	3,600	--	--
China	72,700	196,000	156,000	143,000	183,000	211,000	19,900	18,200	337,000	421,000
Colombia	--	--	--	--	404	275,000	--	--	--	--
Costa Rica	--	--	6,610	15,200	--	--	--	--	--	--
Ecuador	--	--	121	2,840	--	--	--	--	--	--
Egypt	4,540	5,960	--	--	--	--	--	--	--	--
France	26,500	35,300	21,300	31,600	66,700	78,900	16,400	19,500	34,800	129,000
Germany	7,600	258,000	8,330	354,000	118	88,500	37,500	209,000	275	118,000
Hong Kong	3	2,510	--	--	--	--	--	--	--	--
India	--	--	14,500	8,810	38,500	12,000	--	--	--	--
Ireland	--	--	--	--	--	--	2	3,220	--	--
Israel	--	--	--	--	16,100	65,400	24,300	99,000	112	16,000
Japan	4,210	17,100	--	--	--	--	1	2,600	--	--
Jordan	9,550	16,000	21,900	19,200	--	--	--	--	--	--
Korea, Republic of	--	--	--	--	7	8,220	--	--	295,000	343,000
Mexico	1,160	324,000	297	47,900	125	23,300	2,640	19,800	110	56,400
Netherlands	--	--	--	--	168,000	219,000	--	--	--	--
New Zealand	85	8,440	--	--	--	--	--	--	--	--
Pakistan	37,600	76,000	--	--	--	--	21,100	24,500	--	--
Singapore	--	--	--	--	7,110	16,100	10,300	60,400	6,690	37,000
South Africa	5,200	17,700	1,000	101,000	--	--	--	--	--	--
Sweden	10	12,100	232	106,000	--	--	--	--	--	--
Switzerland	--	--	2	4,350	--	--	--	--	629	4,510
Taiwan	36	3,060	--	--	--	--	--	--	2,810	27,800
Thailand	--	--	--	--	3	2,610	--	--	--	--
United Kingdom	18,200	57,700	--	--	40,500	70,600	--	--	--	--
Venezuela	--	--	--	--	3,540	3,000	--	--	--	--
Total	216,000	2,500,000	264,000	1,350,000	615,000	1,380,000	154,000	899,000	686,000	1,360,000
Of which:										
Unwrought and powder	9,930	679,000	95,400	72,300	38,500	299,000	22,300	34,200	141	7,270
Waste and scrap	(3)	(3)	369	7,520	18,100	27,900	192	4,000	17,900	25,900
Other	206,000	1,820,000	168,000	1,270,000	558,000	1,060,000	132,000	861,000	668,000	1,330,000
Total	216,000	2,500,000	264,000	1,350,000	615,000	1,380,000	154,000	899,000	686,000	1,360,000

See footnotes at end of table.

TABLE 3—Continued

U.S. EXPORTS OF CADMIUM PRODUCTS, BY COUNTRY AND TYPES[1]

	2001		2002		2003		2004		2005	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cadmium sulfide, gross weight:										
Australia	--	--	--	--	--	--	--	--	12,900	$6,710
Belgium	--	--	--	--	--	--	25,600	$13,800	--	--
Canada	--	--	--	--	--	--	--	--	89,400	38,900
Chile	--	--	--	--	--	--	--	--	5,830	3,030
China	--	--	--	--	70,600	$36,700	--	--	--	--
Colombia	--	--	--	--	--	--	6,350	3,300	--	--
Germany	13,500	$7,000	12,100	$6,300	--	--	--	--	4,820	2,510
Israel	--	--	--	--	--	--	6,720	3,500	--	--
Japan	--	--	13,300	6,900	43,900	22,800	--	--	--	--
Korea, Republic of	--	--	--	--	--	--	38,500	12,300	--	--
Mexico	--	--	--	--	69,800	37,600	83,200	43,300	--	--
Philippines	30,800	16,000	--	--	--	--	--	--	--	--
Saudi Arabia	5,100	2,650	--	--	--	--	--	--	--	--
Singapore	3,000	6,000	--	--	--	--	--	--	--	--
Switzerland	--	--	--	--	--	--	--	--	7,440	3,870
Total	52,400	31,700	25,400	13,200	184,000	97,100	160,000	76,200	120,000	55,000
Total, calculated Cd content	40,800	XX	19,800	XX	143,000	XX	125,000	XX	93,700	XX

XX Not applicable. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes exports of cadmium in alloys (Schedule B 8107.90) and scrap (Schedule B 8107.30).

[3]Prior to 2002, trade data on unwrought metal were combined with the data for waste and scrap in Schedule B 8107.10.

Source: U.S. Census Bureau.

TABLE 4

U.S. IMPORTS FOR CONSUMPTION OF CADMIUM PRODUCTS, BY COUNTRY AND TYPES[1]

	2001		2002		2003		2004		2005	
	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value	Quantity (kilograms)	Value
Cadmium metal:[2]										
Australia	58,900	$40,100	37,000	$32,600	37,000	$46,500	77,000	$97,300	53,000	$126,000
Belgium	15,700	126,000	12,600	154,000	9,090	119,000	8,530	121,000	12,100	192,000
Canada	13,200	1,630,000	15,100	1,450,000	27,000	756,000	19,100	332,000	41,400	1,000,000
China	--	--	34	16,200	20,100	197,000	22	6,700	39,000	116,000
Finland	--	--	--	--	2,000	2,890	--	--	--	--
France	--	--	89	14,400	--	--	14	30,300	--	--
Germany	2	2,490	--	--	24	4,090	80	16,100	243	37,300
Hong Kong	32	4,300	--	--	--	--	--	--	5,650	22,500
Japan	--	--	10	9,950	2	6,630	--	--	--	--
Mexico	16,400	13,600	16,400	8,820	16,400	26,300	37,900	51,500	97,000	239,000
Netherlands	--	--	--	--	--	--	2	8,540	--	--
Peru	--	--	--	--	--	--	--	--	40,000	89,000
Russia	--	--	--	--	--	--	--	--	3	24,300
United Kingdom	3,200	17,600	22	6,360	1	2,050	120,000	914,000	--	--
Total	107,000	1,830,000	81,200	1,700,000	112,000	1,160,000	263,000	1,580,000	288,000	1,850,000
Of which:										
Unwrought and powder	97,900	1,280,000	56,500	719,000	73,600	595,000	102,000	543,000	207,000	811,000
Waste and scrap	(3)	(3)	--	--	20,000	182,000	122,000	908,000	--	--
Other	9,400	558,000	24,700	978,000	18,000	383,000	38,000	127,000	81,300	1,040,000
Total	107,000	1,830,000	81,200	1,700,000	112,000	1,160,000	263,000	1,580,000	288,000	1,850,000
Cadmium sulfide, gross weight:										
China	--	--	20	9,280	3,840	10,600	--	--	50	5,000
Japan	5,160	24,000	--	--	--	--	--	--	--	--
Russia	106	11,600	--	--	--	--	--	--	6,890	47,000
United Kingdom	2,280	26,600	6,690	78,500	3,630	42,300	1,810	22,600	1,810	22,600
Total	7,550	62,200	6,710	87,700	7,470	52,900	1,810	22,600	8,760	74,600
Total, calculated Cd content	5,870	XX	5,220	XX	5,810	XX	1,410	XX	6,810	XX

XX Not applicable. -- Zero.

[1]Data are rounded to no more than three significant digits; may not add to totals shown.

[2]Includes imports of cadmium in alloys [Harmonized Tariff Schedule of the United States (HTS) 8107.90] and waste and scrap (HTS 8107.30).

[3]Prior to 2002, trade data on unwrought metal were combined with data for waste and scrap in HTS 8107.10.

Source: U.S. Census Bureau.

TABLE 5

CADMIUM: WORLD REFINERY PRODUCTION, BY COUNTRY[1, 2]

(Metric tons)

Country[3]	2001	2002	2003	2004	2005[e]
Algeria[e]	10	8	5	--	--
Argentina	34	--	25	25 [e]	25
Australia	378	350	350 [e]	350 [e]	374
Belgium	1,236	117	-- [r]	-- [r]	--
Brazil[4]	120 [r]	151 [r]	189 [r]	187 [r]	200
Bulgaria	333	345	307	356 [r]	319 [5]
Canada[6]	1,493	1,706	1,759	1,880 [r]	1,703 [p]
China[e]	2,510	2,440	2,710	2,800	3,000
Finland[7]	604	4	-- [e]	--	--
France[7]	176	63 [r]	-- [r]	-- [r]	--
Germany	539	422	640 [r]	640 [r, e]	640
India	436	466	477	489	417 [5]
Italy	313 [r]	391	22 [r]	-- [r]	--
Japan	2,460	2,444	2,497	2,233	2,297 [5]
Kazakhstan	1,250 [e]	1,300	1,351	1,900	2,000
Korea, North[e]	200 [r]	200 [r]	200 [r]	200 [r]	200
Korea, Republic of	1,879	1,825 [r]	2,175 [r]	2,362 [r]	2,900
Macedonia[e]	73 [r]	111 [r]	75 [r]	-- [r]	--
Mexico[8]	1,421 [r]	1,382	1,590	1,594 [r]	1,600
Netherlands	455	485	495 [r]	572 [r]	575
Norway	372	209	331	260	260 [5]
Peru	485 [r]	422	529	532	481 [5]
Poland, metal, primary refined	330	440	375 [r]	356 [r]	350
Russia[e]	950	950	950	950	1,000
Ukraine[e]	25	25	25	25	25
United Kingdom	425 [r]	292 [r]	22 [r]	-- [r]	--
United States	1,450 [r, 9]	1,430 [r, 9]	1,420 [r, 9]	1,010 [r, 9]	1,070 [5]
Total	20,000 [r]	18,000 [r]	18,500	18,700 [r]	19,400

[e]Estimated. [p]Preliminary. [r]Revised. -- Zero.

[1]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, 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, 2006.

[2]World totals, U.S. data, and estimated data are rounded to no more than three significant digits; may not add to totals shown.

[3]Romania, Thailand, and Uzbekistan may produce primary cadmium metal or oxide, but information is inadequate to make reliable estimates of output.

[4]Exports from Anuário Mineral Brasileiro (Departamento Nacional de Produção Mineral).

[5]Reported figure.

[6]Includes secondary.

[7]Excludes secondary production from recycled nickel-cadmium batteries.

[8]Excludes significant production of both cadmium oxide and cadmium contained in exported concentrates.

[9]Partially estimated.