5. PRODUCTION, IMPORT/EXPORT, USE, AND DISPOSAL

5.1 PRODUCTION

Cadmium is a widely but sparsely distributed element found in the earth's crust at concentrations ranging from 0.1 to 5 ppm, primarily as sulfide minerals in association with zinc ores, zinc-bearing lead ores, and or complex copper-lead-zinc ores (Morrow 2001). Approximately 3 kg of cadmium for each ton of zinc are produced (OECD 1995). About 80% of cadmium production is associated with zinc production, while the other 20% is associated with lead and copper byproduct production and the recapture of cadmium from finished products (Morrow 2001). Between 2003 and 2006, the annual cadmium refinery production in the United States declined from 1,450 to 700 metric tons, dropping 52% between 2005 and 2006 (USGS 2007, 2008). Demand for cadmium in the nickel-cadmium (Ni-Cd) battery industry is strengthening as demand in other areas, like coatings and pigments, has been decreasing due to environmental concerns and regulations. Despite this demand, primary production of cadmium may decrease as zinc prices increase, since producers may choose to discard the cadmium byproduct instead of refining it (USGS 2008).

One company produced primary cadmium in the United States during 2007: Clarksville (Zinifex Ltd.), Clarksville, Tennessee. The Big River Zinc Corporation (Korea Zinc Co, Ltd), Sauget, Illinois operation was closed in 2006, citing mine closures and the increasing price of zinc concentrate (USGS 2008). In June 2006, it was purchased by ZincOx Resources plc, Surrey, United Kingdom (USGS 2007). A third company in Ellwood, Pennsylvania, International Metals Reclamation Co. Inc. (INMETCO), recovers cadmium from spent nickel-cadmium batteries, which began reclaiming cadmium in 1995 (USGS 2007). In 2005, it was estimated that the total cadmium recovery rate was only 12%, with an estimated 40,000 tons of cadmium being disposed of in municipal waste or held in household storage or industry stockpiles between 1996 and 2005 (USGS 2007).

The following companies are currently cited as major producers of cadmium compounds: GFS Chemicals Inc., Columbus, Ohio (cadmium chloride, cadmium sulfate); CERAC Inc., Milwaukee, Wisconsin (cadmium sulfide); and EP Scientific Products, LLC (cadmium sulfide) (SRI 2007). BASF Catalysts LLC, Louisville, Kentucky was specifically cited as a major producer of cadmium sulfide/ sulfoselenide pigments (SRI 2007).

Tables 5-1 and 5-2 list the facilities in each state that manufacture or process cadmium and cadmium compounds, respectively, the intended use, and the range of maximum amounts stored on site. The data

Table 5-1. Facilities that Produce, Process, or Use Cadmium

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AL	19	0	999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
AR	14	0	999,999	1, 2, 3, 5, 6, 7, 8, 10, 12, 13, 14
AZ	12	0	999,999	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 13
CA	41	0	99,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
CO	8	1,000	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 12
CT	5	0	99,999	7, 8, 10, 11
FL	6	0	99,999	1, 2, 3, 4, 6, 7, 8, 10, 12
GA	8	0	999,999	1, 3, 6, 8, 13, 14
IA	9	0	99,999	1, 5, 7, 8, 12, 13
ID	6	10,000	999,999	1, 3, 5, 12, 13
IL	25	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14
IN	10	0	999,999	1, 2, 5, 7, 8, 9, 10, 12
KS	6	100	99,999	1, 3, 7, 8, 12
KY	11	0	999,999	1, 2, 3, 5, 6, 7, 8, 11
LA	7	0	999,999	1, 3, 5, 6, 8, 10, 12, 13
MA	13	0	99,999	1, 2, 3, 4, 7, 8, 10
MD	5	100	49,999,999	1, 2, 4, 5, 6, 13
MI	19	0	99,999	1, 2, 3, 5, 6, 7, 8, 10, 12, 13, 14
MN	10	0	999,999	1, 3, 4, 7, 8, 9, 10, 11, 12, 13
MO	7	0	999,999	1, 2, 3, 4, 5, 6, 8, 14
MS	7	0	9,999	5, 7, 8, 12
NC	13	0	9,999,999	1, 5, 7, 8, 9, 10, 12, 14
NE	9	100	99,999	1, 2, 5, 7, 8, 12
NH	4	0	999	1, 3, 8, 12
NJ	18	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
NV	2	10,000	99,999	1, 2, 3, 5, 12, 13
NY	21	0	9,999,999	2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14
OH	32	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OK	16	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 12, 13
OR	7	0	9,999,999	1, 5, 8, 12
PA	35	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
PR	1	0	99	8
RI	4	0	9,999	2, 3, 7, 8
SC	20	0	9,999,999	1, 3, 5, 6, 7, 8, 9, 10, 11, 12
TN	17	0	9,999,999	1, 2, 3, 4, 5, 7, 8, 9, 11, 12, 13
TX	28	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13, 14
UT	8	0	99,999	1, 5, 6, 7, 8, 12, 13

Table 5-1. Facilities that Produce, Process, or Use Cadmium

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
VA	12	0	99,999	1, 5, 7, 8, 9, 10, 11, 13
WA	5	0	9,999	1, 2, 3, 5, 10, 13
WI	14	0	49,999,999	3, 7, 8, 10, 11, 12
WV	3	100	99,999	7, 8, 12
WY	1	0	99	1, 13

[a]Post office state abbreviations used.
[b]Amounts on site reported by facilities in each state.
[c]Activities/Uses:

1. Produce
2. Import
3. Onsite use/processing
4. Sale/Distribution
5. Byproduct
6. Impurity
7. Reactant
8. Formulation Component
9. Article Component
10. Repackaging
11. Chemical Processing Aid
12. Manufacturing Aid
13. Ancillary/Other Uses
14. Process Impurity

Source: TRI09 2011 (Data are from 2009)

Table 5-2. Facilities that Produce, Process, or Use Cadmium Compounds

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
AK	14	0	499,999,999	1, 5, 7, 9, 11, 12, 14
AL	31	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13, 14
AR	19	100	999,999	1, 2, 3, 5, 7, 8, 12, 13, 14
AZ	30	0	99,999,999	1, 2, 3, 4, 5, 6, 7, 8, 12, 13, 14
CA	28	0	49,999,999	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13
CO	10	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
CT	28	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
DE	2	100	9,999	1, 5
FL	11	0	999,999	1, 2, 3, 5, 6, 8, 12, 13, 14
GA	15	0	999,999	1, 2, 3, 5, 6, 7, 8, 13
IA	5	0	99,999	1, 5, 7, 8, 9, 12
ID	14	100	9,999,999	1, 5, 6, 7, 11, 12, 13, 14
IL	46	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 13, 14
IN	19	0	999,999	1, 5, 7, 8, 13, 14
KS	7	0	99,999	1, 7, 8, 11, 13
KY	19	100	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 12, 13
LA	12	0	999,999	1, 2, 3, 5, 7, 8, 12, 13
MA	14	0	999,999	1, 3, 4, 5, 6, 7, 8, 12, 13
MD	9	1,000	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 13
MI	24	0	99,999,999	1, 3, 5, 6, 7, 8, 10, 11, 12, 13
MN	10	100	999,999	1, 5, 7, 8, 9, 13
MO	14	0	499,999,999	1, 2, 3, 4, 5, 6, 7, 8, 13
MS	9	0	999,999	1, 5, 7, 8, 12
MT	3	1,000	9,999,999	1, 2, 3, 4, 5, 6, 13
NC	14	0	49,999,999	1, 7, 8, 13
NE	8	1,000	999,999	1, 2, 5, 8, 12, 13, 14
NH	1	1,000	9,999	7, 10
NJ	35	0	9,999,999	1, 2, 3, 4, 6, 7, 8, 9, 10, 12
NM	6	1,000	9,999,999	1, 5, 13
NV	22	100	49,999,999	1, 2, 3, 5, 6, 7, 9, 10, 12, 13, 14
NY	26	0	49,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
OH	82	0	999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14
OK	19	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13
OR	4	100	99,999	1, 5, 8
PA	67	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13
PR	1	100	999	8

Table 5-2. Facilities that Produce, Process, or Use Cadmium Compounds

State[a]	Number of facilities	Minimum amount on site in pounds[b]	Maximum amount on site in pounds[b]	Activities and uses[c]
RI	8	100	99,999	2, 3, 7, 8, 11
SC	18	0	999,999	1, 4, 5, 6, 7, 8, 11, 12, 13, 14
TN	35	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 14
TX	36	0	9,999,999	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14
UT	15	1,000	49,999,999	1, 5, 6, 7, 8, 12, 13
VA	11	0	99,999	1, 5, 7, 8, 12, 14
WA	17	0	999,999	1, 2, 3, 5, 6, 7, 8, 9, 11, 12, 13, 14
WI	14	100	49,999,999	1, 3, 5, 7, 8, 10, 11, 12
WV	8	0	999,999	1, 2, 3, 7, 8, 11, 12, 13

[a]Post office state abbreviations used.
[b]Amounts on site reported by facilities in each state.
[c]Activities/Uses:

1. Produce
2. Import
3. Onsite use/processing
4. Sale/Distribution
5. Byproduct
6. Impurity
7. Reactant
8. Formulation Component
9. Article Component
10. Repackaging
11. Chemical Processing Aid
12. Manufacturing Aid
13. Ancillary/Other Uses
14. Process Impurity

Source: TRI09 2011 (Data are from 2009)

listed in Tables 5-1 and 5-2 are derived from the Toxics Release Inventory (TRI) (TRI09 2011). Because only certain types of facilities were required to report, this is not an exhaustive list.

Cadmium metal is available in purities ranging from 99.5 to 99.999% in the following grades: technical, powder, pure sticks, ingots, slabs, and high-purity crystals (<10 ppm impurities) (HSDB 2008). Cadmium (as cadmium oxide) is obtained mainly as a byproduct during the processing of zinc-bearing ores (e.g., sphalerites), and also from the refining of lead and copper from sulfide ores (e.g., galena) (Morrow 2001). Cadmium oxide produced during roasting of ores is reduced with coke, and cadmium metal is separated by distillation or electrodeposition (Elinder 1985a). Commercial-grade cadmium oxide is available in purities ranging from 99 to 99.9999%; common impurities are lead and thallium (NTP 2005). Cadmium chloride is produced by reacting molten cadmium with chlorine gas at 600 °C or by dissolving cadmium metal or the oxide, carbonate, sulfide, or hydroxide in hydrochloric acid and subsequently vaporizing the solution to produce a hydrated crystal (HSDB 2008; IARC 1993). In preparing the anhydrous cadmium chloride salt, the hydrate is refluxed with thionyl chloride or calcined in a hydrogen chloride atmosphere (HSDB 2008). Commercial cadmium chloride is available as a hydrate mixture with a purity range of 95.0–99.999% (NTP 2005).

The commercial preparation of cadmium sulfate usually involves dissolution of the metal oxide, carbonate, or sulfide in sulfuric acid with subsequent cooling or evaporation (HSDB 2008). Anhydrous cadmium sulfate is prepared by oxidation of the sulfide or sulfite at elevated temperatures (Herron 2003); or by melting cadmium with ammonium or sodium peroxodisulfate (Schulte-Schrepping and Piscator 2002). Cadmium sulfate monohydrate, which is the cadmium compound most often marketed, is produced by evaporating a cadmium sulfate solution above 41.5 °C (Schulte-Schrepping and Piscator 2002). Cadmium sulfate is available in technical and C.P. (chemically pure) grades (Lewis 2001). Cadmium sulfide can be prepared by a direct reaction with hydrogen sulfide and cadmium vapor or between sulfur and cadmium metal or cadmium oxide (Herron 2003). Cadmium sulfide is available in technical, N.F. (national formulary grade), and high-purity (single crystals) (Lewis 2001). Cadmium carbonate is produced by heating an acidified solution of cadmium chloride and urea in a sealed tube at 200 °C, the slow absorption of carbon dioxide to cadmium oxide, or the precipitation of the hemihydrate from reaction of ammonium carbonate in cadmium ion solution (Herron 2003).

5.2 IMPORT/EXPORT

Imports of cadmium into the United States declined steadily from 1994 through 1998, dropping from 1,110 metric tons per year to an estimated 650 metric tons in 1998 (USGS 1999). In 1986, imports of cadmium metal for consumption increased significantly to 3,000 metric tons, but continually decreased into the 1990s. From 2003 to 2005, cadmium imports of metal, alloys, and scrap increased from 112 to 288 tons, 74–207 tons of which were metal-only imports (USGS 2008). Cadmium imports peaked in 2005 and then declined through 2007, with 172 tons of cadmium metal only and 174 tons of metal, alloys, and scrap imported (USGS 2008). The principal supplying countries were Australia (41%), Canada (20%), China (10%), and Peru (9%) (USGS 2008).

In the mid-1990s, exports varied widely from 38 metric tons in 1993, to 1,450 metric tons in 1994, to 550 metric tons in 1997. In 2003, cadmium exports (reported as metal, alloys, and scraps) were 615 tons, with exports decreasing to only 154 tons the following year (USGS 2008). Exports surged again in 2005 to 686 tons, but have since been steadily decreasing from 483 tons in 2006 to 304 tons in 2007 (USGS 2008).

5.3 USE

Cadmium, its alloys, and its compounds are used in a variety of consumer and industrial materials. The dominant use of cadmium is in active electrode materials in Ni-Cd batteries (83% of total cadmium use) (USGS 2008). Cadmium demand for other uses such as pigments for plastics, ceramics, and glasses; stabilizers for polyvinyl chloride (PVC) against heat and light; engineering coatings on steel and some nonferrous metals; and components of various specialized alloys have been decreasing. (Elinder 1992; IARC 1993; Thornton 1992; USGS 2008). Cadmium salts have been used in a limited capacity as a fungicide for golf courses and home lawns (EPA 2006b). Cadmium chloride is used in photography, photocopying, dyeing, calico printing, vacuum tube manufacture, pigment manufacture, galvanoplasty, lubricants, ice-nucleation agents, and in the manufacture of special mirrors (Herron 2003). However, the significance of cadmium chloride as a commercial product is declining (IARC 1993).

Cadmium-based colorants are used mainly in engineering plastics, ceramics, glasses, and enamels (IARC 1993; OECD 1995). Cadmium sulfide is especially important in this industry, especially in glasses and plastics; however, environmental and health concerns have contributed to a decrease in its production (Herron 2003). Cadmium sulfide (yellow) and cadmium selenide (red) are combined to create solid C.P. toners ranging in color from yellows and oranges to reds and maroons (Herron 2003). Cadmium sulfide and cadmium telluride are used in solar cells and a variety of electronic devices which depend on cadmium's semiconducting properties (Herron 2003; IARC 1993; OECD 1995). The photoconductive and electroluminescent properties of cadmium sulfide have been applied in manufacturing a variety of consumer goods (IARC 1993). Cadmium sulfate solution is used in standard Weston cells (Herron 2003).

Though cadmium metal consumption for batteries has grown steadily since the 1980s and currently consumes 83% of the cadmium produced, other uses of cadmium began declining in the mid 1990s. Pigment, stabilizer, coating, and alloy markets for cadmium are decreasing due to environmental concerns (USGS 1997, 2008). Proposed legislation, particularly in the European Union, restricting cadmium in consumer products may have a negative effect on cadmium demand (USGS 2008). Excessive exports from Bulgaria and Russia in 1997 caused a drop in the average price of cadmium from $1.84 per pound in 1995 to $0.51 per pound in 1997. Also, Ni-Cd batteries have been replaced in some markets by lithium-ion and nickel metal hydride batteries (USGS 2008). As of 2006, Ni-Cd batteries made up 18% of the rechargeable battery market, down from 56% in 1996 with global sales decreasing 16% between 2005 and 2006 (USGS 2008). Despite this trend, demand for cadmium may increase due to new market opportunities for Ni-Cd batteries (USGS 2008). Regulations by local authorities have forced the recycling of cadmium in Ni-Cd batteries, further depressing the demand for primary cadmium metal (USGS 1999).

5.4 DISPOSAL

Cadmium-containing wastes are subject to regulations concerning their treatment, storage, and disposal (see Chapter 8) (EPA 1982a; HSDB 2008; U.S. Bureau of Mines 1990). In many states, the disposal of Ni-Cd batteries as municipal waste is prohibited (USGS 2007). Incineration of municipal wastes, particularly from older, poorly controlled facilities, is a potential environmental source of cadmium. In modern incineration plants, about 99.9% of cadmium was captured in boilers and control equipment (OECD 1995).

A range of physicochemical processes is available for treatment of cadmium in liquid waste process streams, including ion exchange, electrolysis, cementation, and adsorption. Both ion exchange and sulfide precipitation are used as alternate processes aimed at achieving low cadmium residuals in liquid wastes (UN 1985). Combining processes, for example, conducting the primary precipitation of cadmium as hydroxide followed by secondary precipitation of residual cadmium as sulfide, has also been adopted. The more general application of the sulfide precipitation technique, however, is constrained due to a tendency for formation of colloidal precipitate, the toxicity and odor of hydrogen sulfide, and the necessity to oxidize residual sulfide occurring in emissions prior to discharge (UN 1985).

The most widely used treatment process involves the alkaline precipitation of cadmium as hydroxide or basic salts (UN 1985). Removal of specific metal species during hydroxide precipitation is pH-dependent, and some components of the waste stream can influence the solubility of cadmium hydroxide. After filtration, the sludge formed from the conversion of soluble cadmium compounds to insoluble compounds can be deposited in a suitable landfill (UN 1985).

Various cadmium-bearing wastes are subject to aggressive leaching in refuse media, particularly under aerobic conditions (UN 1985). While liquid wastes are banned from land disposal, the leaching tendency is accentuated in the presence of brine solutions. Also, the mobility of cadmium in landfill conditions could be enhanced in the presence of mineral acids, which tend to solubilize cadmium compounds, or amine-containing materials, which tend to complex cadmium ions. Waste containing mineral acids, cyanides, organic solvents, and amine-type substances should not be landfilled near cadmium-bearing wastes (UN 1985).

In the laboratory, a recommended method for recovering cadmium from small quantities of cadmium oxide wastes uses a minimum amount of concentrated nitric acid to form nitrates. The solution is evaporated in a hood to form a thin paste, and then diluted with water and saturated with hydrogen sulfide. After the filtration, the precipitate is washed, dried, and returned to the supplier (UN 1985).

Cadmium recovery from scrap metals and batteries is becoming increasingly popular, with the main emphasis being on recycling Ni-Cd batteries (Morrow 2001). Battery recycling is relatively easy and can be achieved using pyrometallurgical (high temperature) or hydrometallurgical (wet chemical) processes (Morrow 2001). In these processes, the metallic waste that contains iron, nickel, cadmium, and their oxides and hydroxides are separated from the other battery components and then converted back to a metal that has a technical purity required for the production of new batteries (Morrow 2001). Cadmium-based coatings can be recycled using electric-arc furnace (EAF) dust, which is obtained through the re-melting of scrap steel that contains cadmium coatings and cadmium impurities (Morrow 2001). INMETCO in Ellwood, Pennsylvania recovers cadmium from spent Ni-Cd batteries, and has developed several collection programs to help facilitate battery recycling (USGS 2007). Although participation in battery recycling has increased in businesses, communities, and retailers, the total recovery of cadmium in 2005 was only 12% (USGS 2007).