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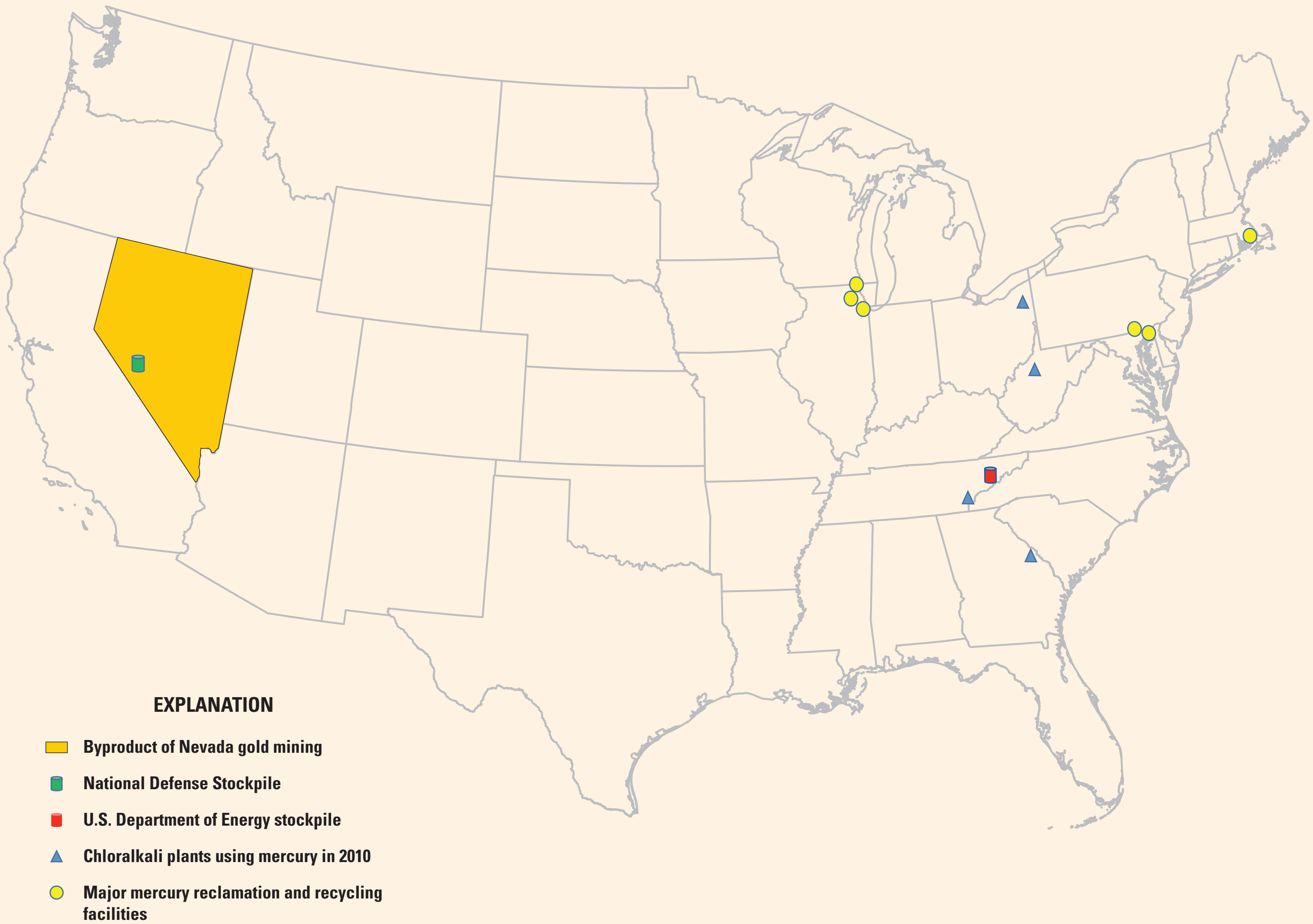
Changing Patterns in the Use, Recycling, and Material Substitution of Mercury in the United States



Scientific Investigations Report 2013–5137

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

Cover: Map showing location of leading production sources and inventories of mercury in the United States in 2010.

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By David R. Wilburn

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U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors, Datum, and Abbreviations

Inch/Pound to SI

Multiply	By	To obtain
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.453592	kilogram (kg)
ton, short (2,000 lb)	0.9072	metric ton (t)
ton (short) per year (ton/yr)	0.9072	megagram per year (Mg/yr)
ton (short) per year (ton/yr)	0.9072	metric ton per year (t/yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$°F=(1.8\times°C)+32$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$°C=(°F-32)/1.8$

Abbreviations

ABS	antilock brake
ALMR	Association of Lighting and Mercury Recyclers
BAT	best available technology
CFL	compact fluorescent lamp
DOE	U.S. Department of Energy
ECOS	Environmental Council of States
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GSFL	general service fluorescent lamp
HID	high-intensity discharge
IMERC	Interstate Mercury Education and Reduction Clearinghouse
LCD	liquid-crystal display
LED	light-emitting diode
MCRBMA	Mercury Containing and Rechargeable Battery Management Act
MEBA	Mercury Export Ban Act of 2008
NDS	National Defense Stockpile
NEMA	National Electrical Manufacturers Association
NEWMOA	Northeast Waste Management Officials Association
NIST	National Institute of Standards and Technology
NVMSRP	National Vehicle Mercury Switch Recovery Program
ppm	parts per million
RCRA	Resource Conservation and Recovery Act
TCLP	toxicity characteristic leaching procedure
TRC	Thermostat Recycling Corporation
UNEP	United Nations Environment Programme
USGS	U.S. Geological Survey

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By David R. Wilburn

Abstract

Environmental concerns have led to numerous regulations that have dramatically decreased the reported production and use of mercury in the United States since the 1980s. Government legislation and subsequent industry actions have led to increased collection of mercury-containing materials and the recovery of mercury through recycling. Mercury emissions have been reduced and effective alternatives to mercury products have been developed for many applications. This study updates and quantifies the changes in demand, supply, use, and material flow for mercury in various sectors in the United States that have taken place since 1996.

Nearly all primary mercury produced in the United States is derived as a byproduct of processing of gold and silver ore in Nevada. Since 2001, annual production of mercury from gold and silver mining in Nevada has decreased by 22 percent overall because ore from greater depths containing low grade mercury is recovered, and mercury emissions from this source have decreased by 95 percent as a result of increased regulation and improved collection and suppression technology.

The distribution of consumption of mercury in the United States has changed as a result of regulation (elimination of large-scale mercury use in the paint and battery sectors), reduction by consumers (decommissioning of mercury-cell chloralkali manufacturing capacity), and technological advances (improvements in dental, lighting, and electrical and electronic sectors).

Mercury use in the chloralkali sector, the leading end-use sector in the United States in 1996, has declined by 98 percent from 136 metric tons (t) in 1996 to about 0.3 t in 2010 because of increased processing and recycling efficiencies and plant closures or conversion to other technologies. As plants were closed, mercury recovered from the infrastructure of decommissioned plants has been exported, making the United States a net exporter of mercury, even though no mercury has been produced as the primary product from mines in the United States since 1992.

In 1996, the three leading end-use sectors for mercury in the United States were chloralkali manufacturing (accounting for 38 percent of consumption), electrical and electronic instrumentation (13 percent of consumption), and instruments and measuring devices (11 percent of consumption). In 2010, the three leading end-use sectors were dental amalgam (accounting for between 35 and 57 percent of consumption), electrical and electronic instrumentation (29 percent of consumption), and batteries (8 percent of consumption). Mercury use in lighting is increasing because incandescent lights are being phased out in favor of mercury-containing compact fluorescent bulbs, but the demand for mercury per unit produced is small.

Dental amalgam constituted the largest amount of mercury in use in the United States. One study reported about 290 t of mercury in dental amalgam was estimated to be contained in human mouths, an estimated 30 t of mercury amalgam was treated as waste, 28.5 t of mercury amalgam was released to the environment, 6 t of amalgam was recycled, and 3.5 t was treated and stored in landfills in 2009.

Mercury contained in products recovered by State, municipal, or industry collection activities is recycled, but the estimated overall recycling rate is less than 10 percent. Increasingly, the U.S. mercury recycling industry has been processing a significant amount of mercury-containing material derived from foreign gold mining operations or decommissioned mercury-cell chloralkali plants.

Regulation of mercury export and storage is expected to result in surplus mercury inventories in the United States. The Mercury Export Ban Act of 2008 limits elemental mercury exports for unregulated uses such as artisanal gold mining after January 1, 2013, and requires development of adequate long-term storage facilities in the United States for elemental mercury. During the past 4 years, producers and recyclers of elemental mercury have been exporting large quantities of mercury in anticipation of this regulation, but the U.S. inventory of mercury in 2010 was estimated to have exceeded 7,000 t from Government stockpiles and industry stocks. Costs attributed to long-term storage may affect the competitiveness of mercury recycling.

Introduction

Mercury and its compounds have a long history of human use, dating back about 3,500 years in Egypt. Mercury is the only metal that is liquid at room temperature (20 degrees Celsius). It is a good electrical conductor, is highly resistant to corrosion, and has a high charge-density-to-weight ratio. The volatility of mercury at relatively low temperatures permits the metal to be readily separated from other materials through the application of heat and to be recovered with few impurities. Mercury has been used in a wide variety of applications, including batteries, catalysts, chloralkali production, dental amalgams, electrical switches and relays, electrochemistry, explosives, flow meters, fungicides, gold recovery, preservatives, reagents, thermometers, and thermostats (Sznopek and Goonan, 2000).

Although the high solubility of mercury in water as methylmercury and the ease of vaporization of methylmercury can be an advantage in some applications, these properties make mercury very mobile in the environment. Atmospheric releases of mercury vapor can be carried large distances and be deposited into lakes and streams. Under anaerobic conditions, mercury is converted into methylmercury, an organic form of mercury, which has been proven to be a neurotoxin that is easily bioaccumulated organisms (Griesbauer, 2007). Methylmercury can enter the food chain and accumulate in fish tissues at levels that can endanger animal and human populations further up the food chain.

Management and regulatory responses to environmental problems that are possibly related to mercury were initially constrained by a lack of reliable information on biological significance, chemical interaction with the environment, methods of transport, and manmade sources. Research advances since the 1980s have allowed scientists to assess the level of mercury in the environment; the data from these assessments have provided the baselines to develop regulatory actions and voluntary controls. Government legislation and industry actions have resulted in a reduction in the production and use of mercury since the late 1980s and an increase in the recovery of mercury through recycling. Research in recent years has led to improved mercury emissions collection technology and development of cost-effective alternatives to mercury-bearing products for many applications.

Materials flow studies provide insights into the factors that affect the flow of materials and quantify the amount of these materials from one form or location to another. Such studies provide background information for decisionmakers when balancing or weighing competing interests, managing resources, or formulating policy. A materials flow study of mercury in the United States was last published by the U.S. Geological Survey (USGS) in 2000 and contained data as of 1996. A mercury recycling study was published by the USGS in 2005 using data as of 2000. This report, though not a global materials flow study or comprehensive recycling study, updates and quantifies the changes in use and flows of mercury that took place in the United States since 1996 in response to perceived health risks of mercury and consequent Government regulation. The report also identifies recurrent recycling activities and, where possible, quantifies the amount of mercury recycling that is taking place in the United States by end-use application. Factors influencing the magnitude of recycling also are discussed. The report identifies significant sources and stocks of mercury and discusses uses where significant substitution is taking place. The report evaluates industry use of mercury in light of existing and planned regulatory framework and assesses the possible effects of legislation on material use. The methodology used for this report is similar to that used in the Matos and Brooks (2005).

Because the report focuses on nonfuel mineral sources, it does not include mercury flows from coal-burning powerplants. Coal accounts for about half of the total U.S. manmade mercury emissions (U.S. Environmental Protection Agency, 2012e). About 75 metric tons (t) of mercury is burned in coal consumed at powerplants in the United States, and about 25 t of mercury is captured through pollution control equipment (Bowen and Irwin, 2007). In November 2012, the U.S. Environmental Protection Agency (EPA) proposed updated emission limits for new powerplants (U.S. Environmental Protection Agency, 2012b).

Historical Use, Production, and Legislation of Mercury

Changes that have taken place in the primary and secondary (recycled) mercury industry in the United States reflect concern over the effects of mercury on the environment and human health and the resulting Federal and State regulatory actions implemented to reduce contamination of the environment from manmade mercury sources and to limit the use, export, and disposal of mercury. Figure 1 illustrates consumption, production, stocks, and prices of mercury in the United States from 1971 through 2010; significant Federal legislative and regulatory action from 1970 through 2011 is listed in table 1.

A number of States have implemented regulatory actions related to production, emissions, use, transport, and disposal of mercury. In the 1960s, strong demand for mercury in batteries, chloralkali manufacturing, and as a paint additive coupled with a relatively limited supply resulted in high mercury prices. However, after mercury was designated a toxic pollutant in 1971, regulations were promulgated to reduce mercury emissions and use. Demand for mercury subsequently decreased, resulting in a decrease in the price of mercury.

As shown in figure 1, the price of mercury in 1998 constant dollars generally decreased from 1971 through 2001 and increased from 2001 through 2010, although there was a large fluctuation in price from 1974 through 1980. The greatest increase in mercury price since 1971 took place from 2009 to 2010. Impending mercury export bans in the European Union (2011) and the United States (2013) in combination with rising gold and silver prices have affected the price of mercury. Mercury is used in small-scale artisanal gold mining in many parts of the world, and the rising price of gold has influenced the global demand for mercury (Brooks, 2012). Many artisanal gold deposits contain a significant amount of silver; the greater the amount of silver present in the deposit, the more mercury is required to recover the gold (Artisanal Gold Council, 2011). The price of mercury was also affected by diminishing supplies of mercury recycled from end-of-use mercury-containing products and limited availability of mercury from China and Kyrgyzstan (Brooks, 2012).

No mines have produced mercury as a principal product in the United States since the McDermitt Mine in northern Nevada closed in 1992 (Brooks, 2012). The largest production of byproduct mercury took place at several precious metal mines in Nevada in 2010, although mercury may be recovered in other areas such as base metal mines in Alaska (Red Dog Mine) and New York (Balmat district). Much of the base metal ore mined in Alaska is processed in Canada, and mercury production statistics are not available. In 2010, byproduct mercury production in the United States was estimated to be about 92 t. Since the early 1970s, annual demand for mercury in the United States has declined from about 2,000 t (U.S. Bureau of Mines, 1973–96; U.S. Geological Survey, 1997–2011) to an estimated 70 t in 2010.

In spite of limited production of mercury, the United States has a substantial amount of elemental mercury in Government and industry stocks. The National Defense Stockpile (NDS) held an inventory of 4,436 t of mercury at several sites in the United States in 2012. Mercury sales from the NDS were suspended in 1994 in response to environmental concerns. The U.S. Department of Energy (DOE) has stockpiled an additional 1,200 t of mercury in storage facilities in Oak Ridge, Tennessee (Virta, 2013). At yearend 2009, industry

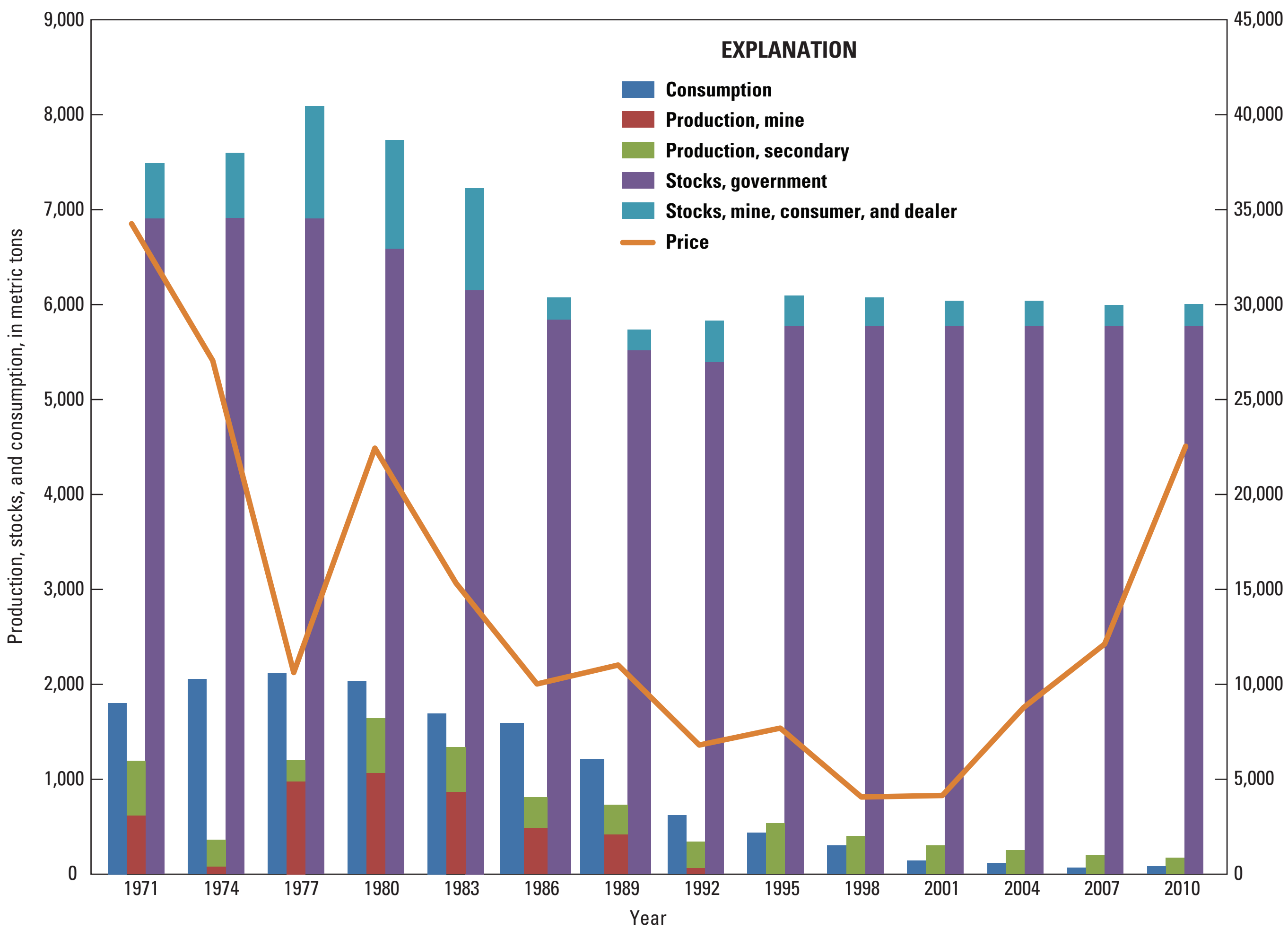

Figure 1. Mercury production, consumption, stocks, and prices from 1971 through 2010 in the United States. Secondary production includes byproduct production from gold, recycled material, and sales from Government stockpiles before 1994. Data are from U.S. Bureau of Mines (1973–96) and U.S. Geological Survey (1997–2011, 2012). Prices in constant 1998 dollars are from U.S. Geological Survey (2012).

Table 1. Federal legislation governing mercury in the United States.

Year	Legislation
1970	The Clean Air Act authorized the U.S.Environmental Protection Agency (EPA) to set national standards for hazardous air pollutants.
1971	Mercury designated as a hazardous pollutant.
1972	The Federal Insecticide, Fungicide, Rodenticide Act prohibited the use of many pesticides containing mercury.
1972	The Federal Water Pollution Control Act authorized the EPA to regulate mercury discharges into waterways.
1973	The Mercury was designated as a toxic pollutant. Standards were enacted for mercury ore-processing facilities and chloralkali plants.
1974	The Safe Drinking Water Act authorized the EPA to set standards for hazardous substances in drinking water.
1978	The Resource Conservation and Recovery Act established regulations for the disposal of mercury-bearing waste.
1980	The Comprehensive, Environmental Response, Compensation, and Liability Act enacted Superfund to clean toxic waste sites.
1992	The EPA banned land disposal of high mercury content wastes generated from chloralkali plants.
1993	The EPA canceled registrations of the last two mercury-containing fungicides at the request of manufacturers.
1994	Congress suspended mercury sales from National Defense Stockpile until environmental issues resolved.
1996	The Mercury-Containing and Rechargeable Battery Management Act prohibited the sales of regulated batteries without recyclability or disposal labels and phased out most batteries containing intentionally added mercury.
2000	The EPA announced ban on discharges of various bioaccumulative chemicals, including mercury, in the Great Lakes Basin.
2002	The EPA set a limit of 2 parts per billion mercury in drinking water. The U.S. Food and Drug Administration (FDA) set a limit of 1 part per million of methylmercury in seafood. The Occupational Safety and Health Administration (OSHA) set a limit of 0.05 milligram per cubic meter of mercury in workplace air.
2002	The EPA banned the sale of mercury-containing thermometers.
2003	The Omnibus Mercury Emissions Reduction Act mandated reduced mercury emissions from all major sources, directed the EPA to issue revised standards, and set a timetable for the reduction of mercury emissions.
2007	The Energy Independence and Security Act included provisions phasing out incandescent light bulbs in favor of energy-efficient, compact fluorescent lights (CFLs), which contain mercury.
2008	The Mercury Export Ban Act prohibited the export of mercury after January 1, 2013, sale and transfer of elemental mercury, and addressed long term storage of elemental mercury.
2010	The EPA issued new rule under the Toxic Substances Control Act to be notified at least 90 days before the beginning of production of mercury-containing devices (such as flow meters, natural gas manometers, and pyrometers) that come into service after September 11, 2009.
2010	The EPA published revised national emissions standards for hazardous air pollutants, including mercury, from gold and silver production facilities. The standards reduce the maximum mercury emission level from 59 kilograms of mercury per 1 million metric tons of ore processed to 38 kilograms of mercury per 1 million metric tons of ore processed.
2011	The EPA finalized rules for performance standards and emission guidelines for sewage sludge incineration designed to reduce the amount of waste generated from dental offices.

stocks of mercury from consumers and dealers in the United States are reported to be 30 t, but these stocks exclude material included as process inventory, in structures, or as site waste of the chloralkali manufacturing industry (Brooks, 2011).

Consumption and emissions of mercury in the United States have decreased as a direct result of increasingly stringent regulations that have limited use of mercury. The amounts of mercury produced from gold mining and mercury that is recycled in the United States also has changed slightly since 1970. The most recent U.S. legislation on mercury is the Mercury Export Ban Act of 2008 (MEBA), which prohibited Federal sales and the export of elemental mercury from the United States beginning on January 1, 2013. Increased amounts of surplus mercury were being exported in 2008 and 2009 in anticipation of the mercury export ban. Supply or stocks of mercury in the United States that had not been exported before 2013 and are not designated for short-term use in the United States must be stored under stringent conditions outlined by the MEBA.

Primary Production and Processes

Mercury has not been produced as a principal mineral commodity in the United States since 1992, but it has been recovered as a byproduct from processing of gold- and silver-ore at several mines in Nevada. Unlike small artisanal mining operations in developing countries, mercury is not used to extract gold or silver at mines in Nevada. The presence of mercury in ores from these mines is a result of the coincidence of mercury in certain gold ores, which is released during processing. Retorts are used to recover elemental mercury from mercury-containing precipitates and from calomel collected from pollution control devices installed on roasters. A small amount of byproduct mercury is generated from the mining of copper, lead, silver, and zinc, although no data are available on the quantity of mercury produced from these sources. Mercury concentrations vary substantially from mine to mine, ranging from less than 0.1 gram per metric ton (g/t) of ore to about 8 g/t of ore, but the mercury content of most commercial ores is less than 1 g/t of ore (Miller, 2007). The USGS reported byproduct mercury production data from gold mining operations until 1992 when the McDermitt Mine closed and mercury production information was withheld to avoid disclosing proprietary data from the sole remaining producer. The average annual amount of byproduct mercury production from 1990 to 1992 was 79 t (Matos and Brooks, 2005).

In 2000, the United States imported 103 t of elemental mercury, mainly from Australia and Germany (Matos and Brooks, 2005). In 2010, the United States imported 294 t of mercury, believed to have been derived primarily as a byproduct from precious metals mining operations in Chile and Peru (Brooks, 2011). It is likely that the 11 t of mercury that was imported in 2010 from Germany was in anticipation of a ban of exports of mercury from the European Union to be implemented in 2011.

A variety of methods are used to recover mercury from gold ore owing to variation in composition and concentration of gold found in the deposits. During pretreatment, roasting or autoclaving volatilize the mercury, making it available for capture by air pollution control devices (Miller, 2007). Roasting can recover about 95 percent of the mercury at a commercial grade of at least 99.9 percent purity (Nowak and Singer, 1995). A roaster processing 2 million metric tons of ore with a mercury content of 2 g/t can yield 3.2 to 3.6 t of elemental mercury (Miller, 2007). If a cyanide leaching process is used, then gold and mercury cyanide complexes are retained on the activated carbon; mercury may be stripped from the carbon and recovered using electrowinning or the Merrill Crow process, but mercury recovery from carbon is difficult and expensive and not all the mercury is recoverable. Mercury-bearing sludge from the electrolytic process and mercury-zinc precipitate from the Merrill Crow process is retorted both onsite and offsite to vaporize and remove the mercury from the gold and silver. Mercury vapor is condensed and the elemental mercury produced is then sold (van Zyl and Eurick, 2000; Miller, 2007).

Common mercury pollution control systems include quenching of off-gasses by water spraying, particulate removal systems, sulfur dioxide scrubbers, and carbon adsorption. Calomel can be recovered from waste treatment of metal mining. The Boliden-Norzink process can be used to remove mercury from flue gases to make calomel (U.S. Environmental Protection Agency, 2009).

Mercury in various forms is sold to U.S. recycling companies. Some gold processing operations process byproduct elemental mercury onsite and sell it through contracts to U.S. recycling companies, whereas others send calomel, mercury-bearing sludge, mercury-zinc precipitates, and (or) mercury collected on pollution control devices to recyclers for further processing . Because these byproducts are not considered waste, companies are not required to report production data to the Toxics Release Inventory database (U.S. Environmental Protection Agency, 2009, p. 19). Since 2006, however, the Nevada Mercury Control Program requires that companies that produce mercury compounds in Nevada must report annual mercury production and emission statistics to the Nevada Division of Environmental Protection. Data from 2006 to 2010 were used in preparing figure 2.

Figure 2 shows an estimate of the amount of mercury recovered from gold mining in Nevada from 2001 through 2011, based on the amount of ore processed annually at selected sites as reported by the company and historical mercury production figures from selected mines (Miller, 2007; Nevada Division of Environmental Protection, 2012). The estimates shown in figure 2 are in general agreement with other estimates of the amount of mercury produced from the region. Miller (2007) estimated Nevada byproduct mercury production in 2001 to be 97 t. Data reported by the Nevada Division of Environmental Protection include mercury contained in calomel, sludge, and recovered elemental mercury. The leading source of mercury from Nevada gold mines is the Goldstrike

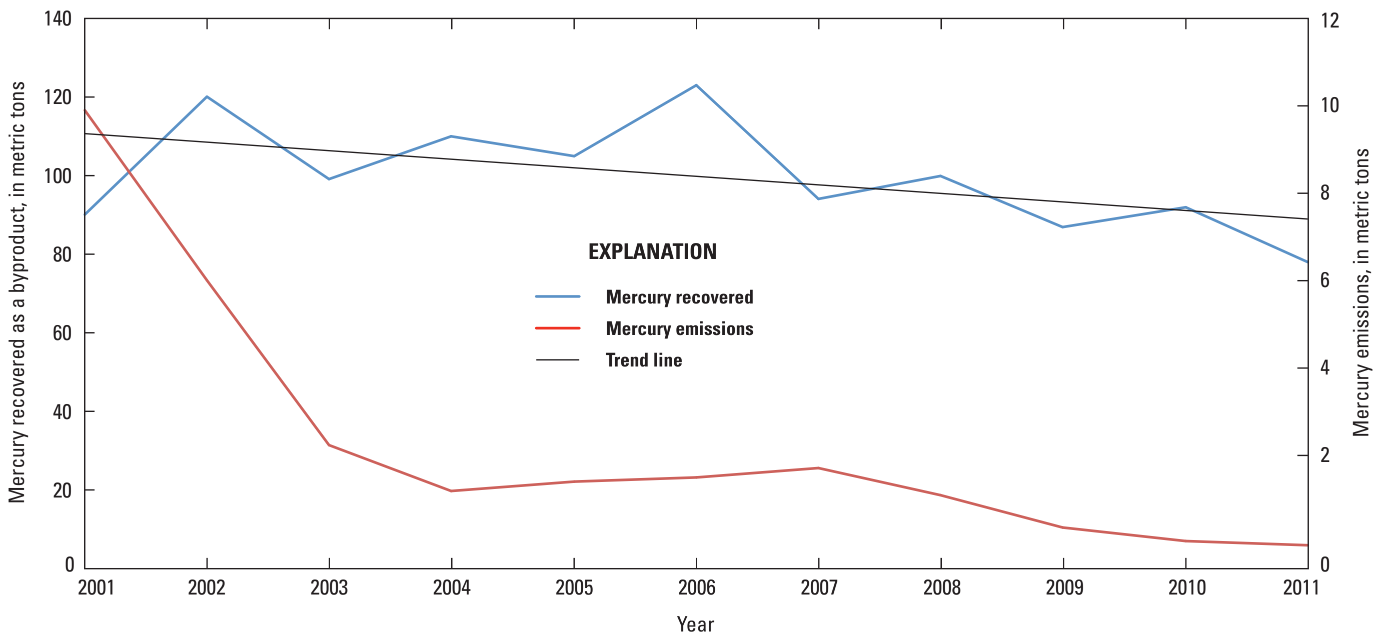

Figure 2. Mercury emissions and mercury recovered annually from Nevada gold mining operations from 2001 through 2011. The trend line shows an overall 22 percent decrease in mercury recovery from 2001 through 2011. The average annual amount of mercury recovered is estimated to be 96 metric tons. This average estimate is in general agreement with Miller (2007) and U.S. Environmental Protection Agency (2007) and was generated based on reported mine site production levels and historical mercury production statistics reported to the Nevada Division of Environmental Protection. Mercury emission levels are reported by the Nevada Division of Environmental Protection (2012).

Mine owned by Barrick Gold Corporation. In 2010, about 41 t of calomel and 13 t of elemental mercury were recovered from roasting and retorting operations at Goldstrike (Nevada Division of Environmental Protection, 2012). Available data of reported production and historical mercury production at selected mine sites allow for the calculation of estimates of about 90 t of contained mercury recovered in 2001 and 92 t of elemental mercury and mercury contained in compounds recovered in 2010 by gold companies and mercury recycling companies in the United States. For 2001 through 2011, an average of 96 t of contained mercury was recovered annually from Nevada gold mining operations, but that amount varies depending on mercury content of the ore. Production has decreased an average of 22 percent annually since 2000.

In 2006, the Nevada Division of Environmental Protection instituted the Nevada Mercury Control Program, which applies to all precious metal mining operations with thermal process units and requires the use of best available technology for maximum reduction in mercury emissions (Elges, 2011). In 2010, the EPA published revised national emissions standards for hazardous air pollutants, including mercury, from gold- and silver- production facilities. Mercury emission levels (Nevada Division of Environmental Protection, 2012) suggest that the availability of improved collection and suppression technology, increasing regulation, and technological improvements made by the industry have led to the decrease in mercury emissions from Nevada mines of about 95 percent from 2001 to 2011 that is shown in figure 2 (Elges, 2011).

Historically, elemental byproduct mercury (grading 99.9 percent pure) recovered from gold ore and calomel collected on pollution-control equipment used in Nevada gold mining has been sold or transferred to three mercury processing and recycling facilities in the United States—Bethlehem Apparatus Company, Inc., Hellertown, Pennsylvania; D.F. Goldsmith Chemical and Metal Corp. (subsidiary DFG Mercury Corp.), Evanston, Illinois; and WM Solutions, Union Grove, Wisconsin (Miller, 2007). The EPA monitors mercury emissions from each of these companies. These facilities also process or recycle mercury from other mercury-containing products and chemicals. For example, Bethlehem Apparatus uses equipment capable of recovering elemental mercury from calomel. Other leading U.S. recycling companies recover mercury from a variety of products include AERC Inc., Allentown, Pa.; Clean Harbors Environmental Services Inc., Braintree, Massachusetts; and Veolia Environmental Services Inc., Lombard, Ill.

Secondary Sources of Mercury

In the United States, less than 100 t of mercury was produced annually from 1996 through 2010 as a byproduct of gold and silver mining, primarily in Nevada (Nevada Division of Environmental Protection, 2012), so recycled mercury is the leading source of production of mercury in the United States. Recycled mercury is also recovered in the United States from mercury-containing products, such as batteries; compact and traditional fluorescent lamps; dental amalgam; electrical switches, relays, sensors; measuring instrumentation and thermostats; and medical devices. Although thermostats contain a switch, they have been classified with instruments and measuring devices to conform to the reporting format used by the USGS in the past. Mercury-containing scrap and industrial waste materials are imported into the United States through established contracts with U.S. recyclers for the recovery of elemental mercury.

The increase in mercury regulation has resulted in an overall reduction in the amount of mercury used in consumer products as well as an increase in mercury recycling, particularly in those jurisdictions where recycling of mercury in products is mandated. More than 60 companies recycle mercury-containing products in the United States (Association of Lighting and Mercury Recyclers, 2012). These recycling companies and State and local government recycling collection agencies separate out mercury waste for further processing at the six leading mercury recycling companies in the United States. Mercury recycling information is limited because companies are not required to report recycling statistics, many mercury wastes are reported generically as hazardous wastes, and there is no data collection or reporting program at the national level. Recycling data may be available from summaries of periodic recovery programs, selected State or municipal statistical reports, and data provided by individual recyclers.

Part of the difficulty in reporting national mercury recycling statistics is a result of the different product mixes and processes used by the major mercury recycling companies to recover mercury metal. The capacity of each facility to reprocess or recover mercury is different from that of other facilities, and each operation varies with the type and form of mercury product that is received. Mercury recovery technology is often different for different mercury-bearing products, and each company uses a combination of proprietary methods to extract mercury from their product waste stream.

In the United States, treatment and disposal of many mercury-containing wastes are managed under the Resource Conservation and Recovery Act (RCRA), which requires that wastes or materials listed in the RCRA that fail the TCLP test be managed as hazardous waste. However, some wastes that contain mercury are not regulated as hazardous wastes under the RCRA (U.S. Government Accountability Office, 2005). Such materials include mine overburden and tailings, which can be landfilled; lamps and mercury-containing equipment, commonly treated as universal waste and managed separately before retort; and household waste, which can be landfilled or incinerated under the household exclusion to hazardous waste of the RCRA. Wastes can be exported to facilities outside the United States that meet standards equivalent to those in the RCRA (such as Canadian regulations allowing the stabilization and landfill of this material), and U.S. companies export mercury waste to Canada for treatment and disposal.

Thermal distillation and retort systems are most commonly used to recovery mercury, but separate retorts must be used for fluorescent lamps and other electrical or electronic devices and instrumentation. Depending on processing technology, mercury recovery rates can vary from 50 percent to more than 99.5 percent (Bethlehem Apparatus Company, Inc., 2012c). The amount of mercury metal that is treated, produced, landfilled, or sold to domestic or overseas markets by U.S. recyclers of mercury can vary from year to year owing to fluctuations in the price of mercury and changes in market demand. The global mercury recycling rate is estimated to be less than 10 percent (United Nations Environment Programme, 2011), and the U.S. mercury recycling rate for sectors where product recycling is taking place is less than 25 percent, except for the chloralkali manufacturing and the gold mining sectors. The mercury recycling rate attributed to chloralkali manufacturing has been estimated to be 50 percent (Maxson, 2006); the mercury recycling rate for the gold mining sector has not been reported.

In the past 4 to 5 years, the majority of mercury recycled by the major companies has been from imported mercury-containing materials and mercury from closed chloralkali plants. Because a large part of the source of mercury for large recyclers is derived from short-term supply contracts (the amount of material sent to a recycling facility fluctuates greatly from year to year from hundreds of tons of material to nothing, static (single-year) data reporting can be misleading (Bruce Lawrence, present, Bethlehem Apparatus Company, Inc., written commun., September 20, 2012).

AERC Incorporated reprocesses 21 to 30 t of mercury annually (Carpenter and others, 2011). Bethlehem Apparatus processes more than 900 t of mercury waste annually (Bethlehem Apparatus Company, Inc., 2012b). D.F. Goldsmith Chemical and Metal Corporation (DFG), which is not permitted to handle hazardous wastes, processes about 20 t of mercury annually from its distillation plant, but acts as a mercury broker by purchasing mercury from other recyclers for domestic or foreign resale. DFG also appears to be a buyer of mercury from closed chloralkali plants in the United States (Carpenter and others, 2011), but this could not be substantiated. WM Solutions Incorporated (formerly Mercury Waste Solutions) treats mercury waste containing an unknown mercury content from a variety of sources; the company processes more than 1,633 t of waste annually (Carpenter and others, 2011).

Because the amount of mercury in products such as lamps is nominal, the large recyclers have lost some business to small recyclers that specialize in lamp recycling. Overall, the U.S. lamp recycling rate is about 24 percent. In 2012, about 600 million lamps were available for recycling (Association of Lighting and Mercury Recyclers, 2012).

Available data suggest that the total amount of mercury recovered annually from recycled products in the United States is likely to range from 50 t to 265 t, depending on the level of supply of material from imports or closed chloralkali plants in a given year. Concorde reported that an estimated 115 t of mercury was recovered from products in the United States in 2006; this estimate did not include material from the chloralkali or gold mining industries (Maxson, 2006). Increased demand for mercury from artisanal gold producers and increased recycling of dental amalgam, fluorescent lights and CFLs, and mercury-containing thermostats has led to increased recycling in the United States. The DOE provided an average annual estimate of about 62.5 t from mercury waste and recycling operations in the final environmental impact statement for long-term management and storage of elemental mercury (U.S. Department of Energy, 2011, p. 3). This amount is likely to decrease once the mercury export ban is implemented in 2018 because the ban will likely reduce mercury imports to a level sufficient to meet U.S. demand, reducing the amount that is recycled in the United States because processed mercury could not be re-exported under the MEBA.

Discarded mercury-containing products, such as automobile convenience switches, batteries, chemicals, dental amalgam, electrical and electronic instrumentation, instruments and measuring devices, lighting, and thermostats, are the primary sources of old mercury scrap. Some of these products are collected locally or regionally but few nationwide programs exist for collecting mercury products. Most collected mercury-containing products are processed at a few major recycling companies. Bethlehem Apparatus, for example, processes more than 50 types of mercury-bearing chemicals, devices, and materials (Bethlehem Apparatus Company, Inc., 2012a). WM Solutions (a subsidiary of Waste Management, Inc.) processes batteries, computer boards, lamps, medical devices, and waste soil and water from chloralkali manufacturing, dental facilities, and gold mining.

Uses of Mercury

In 1980, the three principal industrial uses of mercury were batteries (1,000 t), chloralkali manufacturing (330 t), and paint (300 t) (Matos and Brooks, 2005). By 1990, primarily as the result of regulation and technological advances, mercury use in batteries had decreased to about 100 t and paint use was about 20 t; the primary use of mercury was in chloralkali manufacturing (250 t) and instruments and measuring devices (110 t). By 2000, mercury was used only in small, button-cell batteries; manufacturers of most fungicides and paint were no longer using mercury, and annual use in chloralkali manufacturing had decreased by 76 percent from 1980 to 80 t. In 2001, mercury use in products (excluding chloralkali manufacturing) accounted for 245 t in wiring devices and switches (42 percent), instruments and measuring devices (28 percent), dental equipment and supplies (14 percent), and electrical lighting (9 percent), and other applications (7 percent) (U.S. Environmental Protection Agency, 2007). Figure 3 illustrates the amount of mercury used in the principal end-use categories for selected years from 1980 through 2010.

Over time, the distribution of mercury use has changed significantly as Federal and State regulations have limited some uses (such as paint and batteries), consumers (such as chloralkali manufacturers) have voluntarily reduced their use of mercury, and new technology has increased mercury use in lamps used in lighting. In 2007, consumption of mercury in the United States was estimated to be 67 t, primarily in switches and relays (42 percent), dental amalgam (22 percent), and lighting (14 percent) (Wienert, 2009). In 2010, estimated mercury recovery was about 52 t from recycling of products in the United States. Principal sources of mercury from recycled products in the United States included dental amalgam (estimated in this report to account for 57 percent of U.S. recycled product supply) and switches and relays (29 percent). In 2010, the chloralkali industry in the United States consumed less than 1 t of mercury. Additional sources of mercury supply in the United States in 2010 included imported mercury (294 t), byproduct mercury from gold mining (92 t), and mercury contained in imported products and scrap (38 t). The mercury that was produced from these sources and was not required to meet demand for mercury in the United States was processed, then exported. Mercury imports and exports from 2008 through 2010 were at a level higher than previous years in anticipation of the mercury export bans that were enacted in the European Union in 2011 and scheduled to be enacted in the in the United States in 2013.

Use of mercury in the chloralkali industry decreased as mercury-cell plants were closed or converted to nonmercury technologies. In 1996, there were 14 mercury-cell chloralkali plants in operation in the United States. By 2010, four plants were in operation, and by the end of 2012, only two plants were operating as mercury-cell chloralkali plants; one plant closed and one plant was converted to membrane technology, which does not use mercury. The passage of the MEBA in 2008 accelerated plans for closures of mercury-producing or mercury-refining plants in anticipation of the ban on mercury exports. As mercury-cell plants are decommissioned, much of the mercury recovered from processing equipment, structures, and waste is exported because the large volume (typically more than 200 t) of mercury recovered from these facilities is greater than U.S. demand for mercury (U.S. Environmental Protection Agency, 2009). As global regulations make it more difficult to import, sell, or dispose of mercury, industries using mercury must increasingly rely on recycled mercury for their needed supply or find acceptable substitutes for mercury for each end-use application (table 2). End-use markets are discussed individually in this report because of consumption, recyclability, and supply differences among the markets.

There are no Federal mandates for mercury recycling, except for large methylmercury batteries. Recycling mercury from other products varies from State to State depending on the extent to which the State promotes mercury recycling.

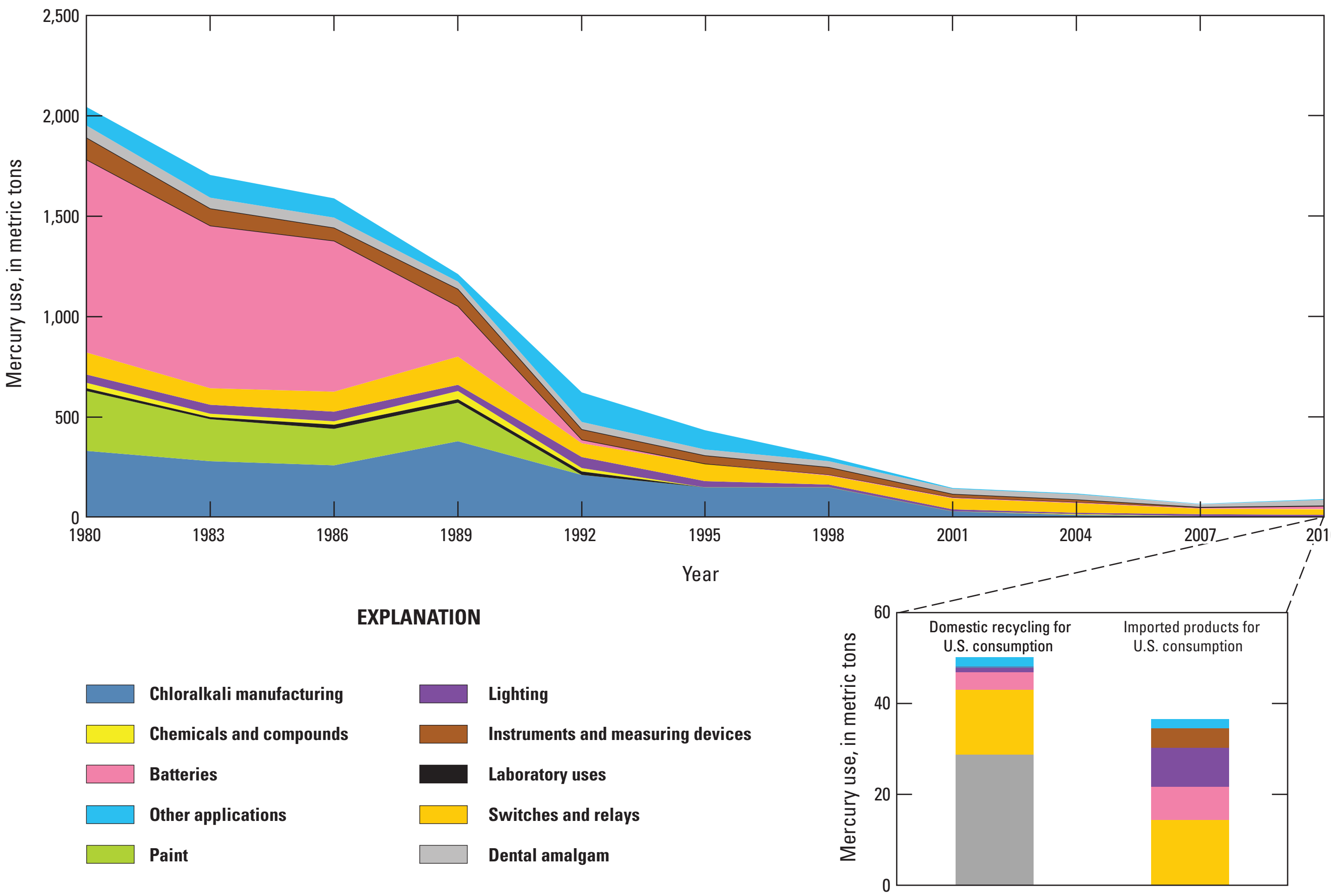

Figure 3. Principal end uses of mercury in the United States for selected years since 1980. Data for 1980 through 1998 are from Matos and Brooks (2005), for 2001 through 2007 are from Wienert (2009), and estimates for 2010 were generated for this report.

Some States have well developed mercury recycling programs and others have none. Thus, available mercury collection data vary by State and product. In 2001, the Interstate Mercury Education and Reduction Clearinghouse (IMERC) was created to collect data on mercury reduction activities and programs offered by States. In 2007, the IMERC collected mercury recycling data from 15 member States. In 2011, six companies accounted for the majority of recycled mercury recovery in the United States. Mercury-containing automobile convenience switches, barometers, computers, dental amalgam, fluorescent lamps, medical devices, thermostats, and some mercury-containing toys were collected through State- and city-sponsored programs, industry-sponsored programs, or from individuals, sorted and processed by as many as 50 small companies, then shipped to the six large companies for retorting and reclamation of the mercury. Excess mercury processed and recovered by recyclers is sold on international markets (U.S. Environmental Protection Agency, 2009).

The largest nationwide recycling programs for which data are available are the National Vehicle Mercury Switch Recovery Program (NVMSRP), started in 2006 by the EPA to reduce mercury emissions when vehicles are scrapped and parts are reused or remanufactured, and the mercury-switch recycling program conducted by the Thermostat Recycling Corporation since 1997. Data collected by the NVMSRP are provided by vehicle manufacturers to End of Life Vehicle Solutions Corporation, an organization that maintains and promotes the environmental activities of the automotive industry. Available recycling data derived from these programs and other sources are reported in the following discussions.

Figure 4 summarizes the principal sources and distribution of the supply of primary and recycled mercury and quantifies the flow of mercury in the United States in 2000 and 2010. Much of the data in figure 4 is estimated, and the values and volumes of many categories of mercury-containing material described here and in the following discussions have changed significantly since 2000. It should be noted that data can change from year to year with variations in mercury collection activities, changes in the amount of mercury that is imported for processing, and closure of chloralkali plants, which can add to mercury supply and cause flow estimates to vary from average levels. Reliable annual data are difficult to obtain

Table 2. Principal end uses of mercury and possible mercury-free substitutes.

[Data are from United Nations Environment Programme (2002, p. 141–144). BAT, best available technology; CFL, compact fluorescent light; LED, light emitting diode]

Product or application	Alternatives	Cost relative to mercury technology
Mercury cell process, used in chlor-alkali manufacturing	BAT is mercury-free membrane technology. Non-asbestos diaphram technology also considered BAT	Overall alternative technology costs are similar to higher than mercury-cell costs, primarily because conversion costs are significant; however membrane process costs for waste disposal, electricity, and raw materials are lower than for the mercury cell process.
Dental amalgam	Wide variety of potential alternative materials that include gold, silver, gallium, ceramic, porcelain, polymers, and composites are available, but not all are fully capable of substitution	Costs vary from less to more; some more easy to apply and others more difficult; none of the alternatives require specialized wastewater treatment required when using mercury amalgam.
Mercuric-oxide and mercury-zinc button cell batteries	Mercury-free zinc-air batteries and other alternatives containing less than 10 milligrams of mercury are available. Button cell batteries are still produced for selected applications	Battery cost can be higher, but collection and disposal of alternative battery types are not necessary, so these costs can be avoided.
Batteries of other types	Standard and rechargeable mercury- and cadmium-free batteries available	Standard mercury-free batteries cost about the same as those being replaced; purchase costs of cadmium-free rechargeable batteries are significantly higher, but costs become less expensive if battery is recharged more than 10 to 15 times.
Medical thermometers	Many alternatives, including single-use, electronic, and glass thermometers containing a gallium-indium-tin alloy	When first initiated, digital thermometers were more expensive; the cost of gallium-indium-tin thermometers should approach the cost of mercury thermometers over time as more are produced.
Other thermometers	Nonmedical thermometer alternatives to mercury include digital sensors (most common) or thermometers that use gas or other liquids; choice depends on the temperature range, application, and need for precision (for a small number of precision applications, mercury thermometers are still preferred)	Large variation in price; long life of an electronic thermometer may make cost competitive with mercury thermometer if price annualized.
Laboratory equipment	Alternative technologies are available	Costs are generally similar.
Pesticides	Banned in many countries; principal alternatives include processes not requiring pesticides or easily degradible, narrow targeted substances with minimal environmental effect	It is likely that in most cases the costs are comparable, and environmental benefits are considerable; effectiveness of alternatives not documented.
Pressure measuring and control equipment	Alternatives include flexible membranes, piezoelectric crystals and other sensors, and fiberoptic pressure sensors; in U-tube meters, barometers, manometers, mercury can be replaced by another liquid or gas; for remote transmission of readings, a mercury transmitter containing up to 8 grams of mercury can be replaced with a potentiometer or a differential transformer that transmits an electronic signal (a diaphragm sensor is also commonly used)	Costs are generally similar.
Tilt-switch used in circuit control, thermostats, or communications	Manual, rolling ball, alternative fluid, microswitch	Costs are generally similar.

Table 2. Principal end uses of mercury and possible mercury-free substitutes.—Continued

[Data are from United Nations Environment Programme (2002, p. 141–144). BAT, best available technology; CFL, compact fluorescent light; LED, light emitting diode]

Product or application	Alternatives	Cost relative to mercury technology
Electronic switch used in circuit control, thermostats, or communications	Solid-state switch, optical switch	Costs are generally similar.
Reed-switch	Solid-state switch, electrical-optical switch, semiconductor	Costs are generally similar.
Proximity sensor	Inductive sensor, capacitive sensor, photoelectric sensor	Costs are generally similar.
Energy-efficient (CFL) lamps	LED-based lamps	Costs are higher than traditional lamps.
Artisanal gold extraction	Possible alternatives include a nonmercury electrolytic process used in Brazil, but not widely accepted, or the Minataur process developed in South Africa	Costs are higher because only used on a small scale.

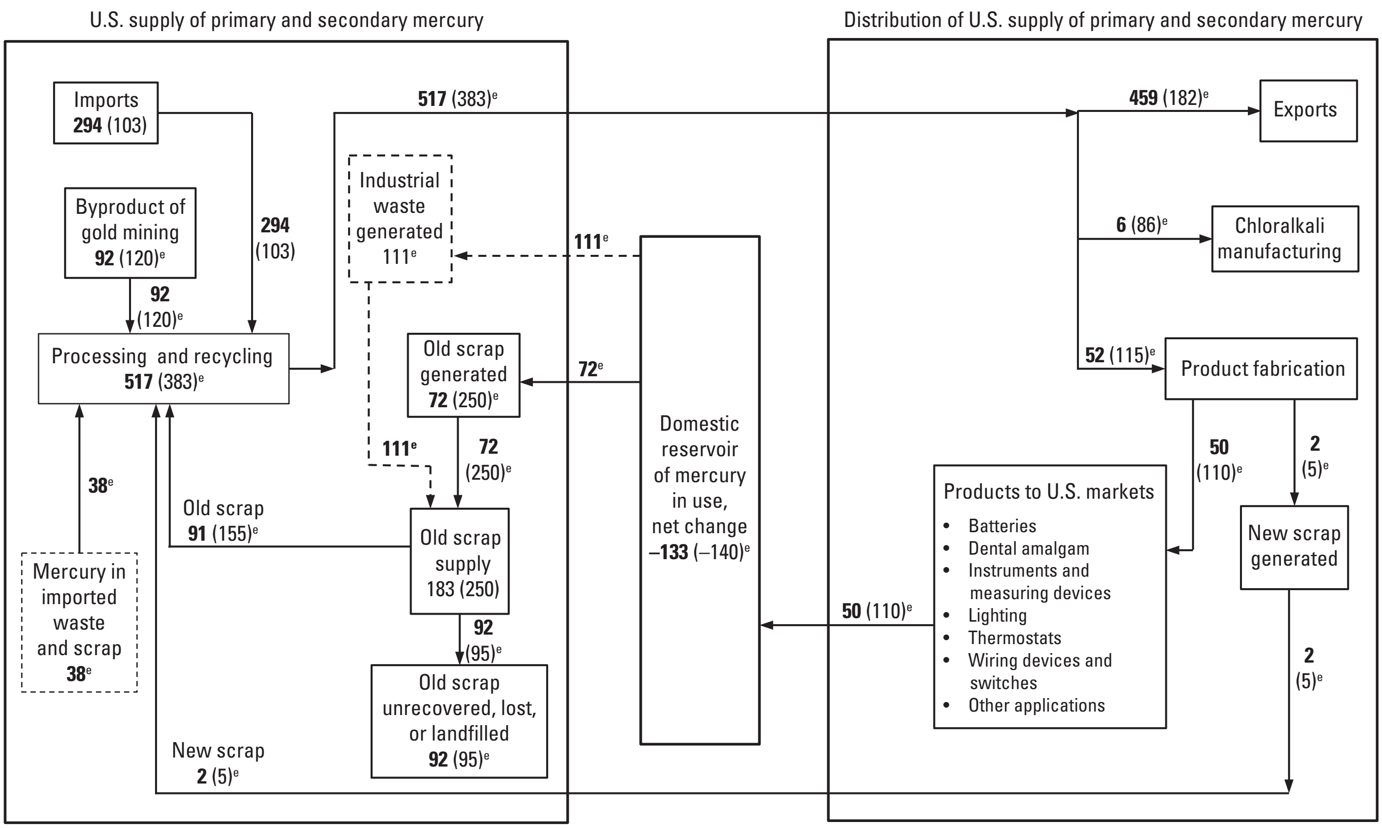

Figure 4. The flow of mercury in the United States in 2000 and 2010. Quantities are in metric tons of contained mercury. Values in bold reflect quantities in 2010; values in parenthesis reflect quantities in 2000 as reported by Matos and Brooks (2005). Industrial waste derived from soils from chloralkali plants that have been closed, industrial process waste, and waste imported from Canada were not reported in 2000. Values exclude dissipative losses. e, estimated.

because the use of mercury has been in decline, mercury is a low-volume commodity, and tracking of mercury recycling and sales are not mandated.

Figure 4 shows data from Matos and Brooks (2005) and estimates generated for this report. Matos and Brooks (2005) reported data for 2000, and this report includes data for 2010; the two studies used similar methodologies. Figure 4 shows two added components (indicated by dashed lines) that were not reported separately by Matos and Brooks (2005). The amount of mercury contained in imported products and scrap was estimated to be 38 t, and the amount of mercury contained in industrial waste generated from gold mining and a mercury-cell chloralkali plant that was decommissioned in 2009 was estimated to be 111 t.

Because the mercury recycling sector is undergoing considerable change, flows of mercury in the United States have changed considerably from year to year as the U.S. manufacturing industry adjusts to the export ban of mercury from the European Union enacted in 2011 and prepares for the export ban of mercury from the United States that is scheduled to take effect in 2013. It is likely that the data for 2010 may be considerably different from mercury flows in 2011 and 2012 as mercury use in chloralkali manufacturing diminishes, material from mercury-cell plants is recovered and exported, and existing mercury stockpiles are depleted in anticipation of the U.S. mercury export ban. A summary of the details in figure 4 follows.

Elemental mercury import data (294 t) and export data (459 t) are published by Brooks (2011). Data do not include mercury contained in imported or exported products, but may include material imported for processing then exported for foreign consumption.

Mine byproduct mercury data (92 t) were estimated based on company-reported mine site gold production levels and historical mercury production statistics as reported by Miller (2007) and the Nevada Division of Environmental Protection (2012). Data on the production of mercury as a byproduct from gold mining in the United States from 1988 through 2004 and in 2006 were compiled and compared with gold production data for the same years. Byproduct mercury production data for 2005 and 2011 were estimated based on the observed relationships between gold and mercury production from producing mines in years where mercury production was reported. Estimates for 2006 through 2010 were developed based on company data reported to the Nevada Division of Environmental Protection. Data include mercury recovered from calomel (mercurous chloride, a mercury-bearing byproduct (about 85 percent mercury) formed during gold processing that is captured by pollution-control devices at smelters and retorted offsite to recovery mercury). About 517 t of mercury was recovered in 2010. Of the mercury processed in the United States, 57 percent was derived from imports, 25 percent came from old product scrap, 18 percent was recovered as a byproduct of gold mining, and less than 0.4 percent came from new scrap.

In 2000, about 115 t of mercury was used in the fabrication of various products, primarily switches and thermostats. Honeywell International, Inc., the largest producer of mercury-based thermostats and switches in the United States, stopped producing mercury-based products in the United States in 2006. In 2010, about 52 t of mercury was used in the fabrication of products. The 50 t shown as products to U.S. markets in the distribution section of figure 4 reflects the amount of mercury contained in products produced in the United States for domestic consumption or export. The estimated amount of mercury used in 2010 is lower than prior years because of the closure of mercury cells in the chloralkali manufacturing sector and declining use of mercury in other product sectors. Brooks (2011) reports mercury use to be "less than 100 t".

In 2010, about 38 t of mercury contained in imported products and scrap was estimated to have been processed and recycled in the United States. No data are available on the amount of such material processed in 2000.

The reservoir of mercury in use in the United States includes mercury contained in fabricated materials such as automobile convenience switches, dental amalgam, fluorescent lamps, and thermostats produced in prior years and still in use. It also contains mercury produced from domestic recycling, recovered from process equipment from recently decommissioned chloralkali plants for domestic use or export, recovered from contaminated soils, equipment, or structures associated with decommissioned chloralkali plants or gold processing, or recovered by recycling of imported waste products. Consequently, the reservoir of mercury in use can vary significantly from year to year.

The old scrap supply (183 t) for 2010 includes 72 t of postconsumer scrap generated by recycling of mercury-containing products in the mercury reservoir in the United States that were fabricated before or during the specified year. The old scrap supply also includes 111 t of mercury contained in industrial wastes from a chloralkali plant that closed in 2009, residues from dental facilities and the gold industry, and imported waste from Canada, materials that were not reported separately in the 2005 study. Although data on mercury from industrial sources is limited, the quantity that becomes available in any given year can vary significantly from year to year.

Estimates of the amount of old scrap generated from discontinued or discarded products has decreased from about 250 t in 2000 to about 72 t in 2010. Estimates of the amount of old scrap consumed (155 t in 2000 and 91 t in 2010) reflect the amount of mercury processed or recycled for export or reuse in the United States and derived from the recovery of industrial wastes and fabricated products.

Old scrap unrecovered, lost, or landfilled (95 t in 2000 and 92 t in 2010) is an estimate of the amount of mercury in discarded products containing mercury that is stored, lost during processing or incineration, discarded in landfills, discarded at dental facilities, or portions of dental amalgam lost during cremation or burial. It does not include dissipative losses to the air or water. In chloralkali manufacturing, mercury is purchased annually to replace mercury that is consumed during processing or lost to the environment. The Chlorine Institute reports that 6.5 t of replacement mercury was purchased in 2010 (Robyn Brooks, project engineer, The Chlorine Institute, Inc., written commun., August 8, 2012). Two mercury-cell chloralkali plants closed or were converted to nonmercury uses in 2012, leaving only two remaining plants in operation in the United States; the amount of mercury purchased for use in the remaining two chloralkali plants will likely be less than 1 t annually until these plants are decommissioned. New scrap (5 t in 2000 and 2 t in 2010) represents the amount of new mercury recovered in the United States during the product fabrication process and returned for recycling or reuse.

In 2000, 115 t of mercury was estimated to have been used in the United States in product fabrication; the corresponding consumption in 2010 was estimated to be 52 t based on data compiled by the USGS and supported by unpublished industry estimates (Bruce Lawrence, president, Bethlehem Apparatus Company, Inc., and Cynthia Manson, Industrial Economics, Inc., written commun., October 11, 2012). Specific amounts for each end use were not available. Estimates were derived from the total amount processed and recycled in the United States less the amount exported, used in the chloralkali industry, or placed in temporary storage for future use.

Chloralkali Manufacturing

The chloralkali industry was the leading consumer of mercury in the United States from 1988 to 2002 (Matos and Brooks, 2005). Since 1995, the amount of new mercury used by the chloralkali manufacturing industry in the United States has steadily declined by 98 percent from 136 t in 1996 to an estimated 0.3 t in 2010 because of increased efficiencies and closures or conversions to nonmercury technologies at mercury-cell plants; the industry continues to recycle mercury from its mercury-cell chloralkali plants. In 2005, the U.S. chloralkali industry reportedly recovered about 50 percent of the mercury waste generated in processing through onsite recycling; the balance was retained in processing equipment and soils until such time as the plant is decommissioned and additional mercury can be recovered (Maxson, 2006, p. 14).

The chloralkali manufacturing process is an electrolytic process that involves passing an electric current through a brine that contains either sodium chloride or potassium chloride to yield chlorine gas, a caustic solution of sodium hydroxide or potassium hydroxide, and hydrogen. Three types of electrolytic cells can host this reaction: the diaphragm cell, the membrane cell, and the mercury cell. Cells are differentiated in the way the chlorine is kept separate from the coproducts generated in the cathode. In the mercury cell, the mercury acts as a cathode and forms an amalgam with sodium that separates the sodium from the caustic and hydrogen production. Water is added to remove the sodium, and the majority of the mercury-bearing sludge is recycled onsite and reused in the electrolytic-cell process. Because mercury is recycled internally, this recycled mercury remains as part of the reservoir of mercury in use (fig. 4) and does not become available for part of the mercury flow as illustrated in figure 5 but becomes important when the plant is closed and the onsite mercury is sold. In 1992, the EPA banned disposal into the land of mercury-bearing sludge generated from the electrolytic production of chlorine-caustic soda (U.S. Bureau of Mines, 1993).

With the decline in the use of the mercury-cell, the diaphragm-cell, which involves an asbestos-based diaphragm (either asbestos or polymer-modified asbestos) that separates the cathodes from the anodes, has become the predominant chloralkali technology used in the United States. The membrane-cell technology is similar, but rather than using mercury or arsenic, it employs a plastic ion-exchange membrane to separate the anode and chlorine gas from the caustic product.

Increasing costs for energy associated with mercury-cell technology and increasing regulation of mercury and the industries that use it have resulted in increased costs for processing and maintenance of mercury-cell chloralkali plants, reducing the competitiveness of this technology on a global scale. As a result, chloralkali manufacturers have closed or are considering closing the mercury-cell plants or are converting mercury-cell plants to technologies that are less energy-intensive and mercury-free. In 1996, 14 mercury-cell plants with 762 cells were operating in the United States; by 2010, four plants with 244 cells were operating (The Chlorine Institute, Inc., 2009). Olin Corporation had two plants; the plant in Augusta, Georgia, closed in 2012, and the plant in Charleston, Tenn., was converted in 2012 to a membrane technology that does not require mercury (Olin Corporation, 2010). As of November 2012, the PPG Industries, Inc. 200-metric-ton-per-day mercury-cell production unit in New Martinsville, West Virginia continued to operate, and the company had applied for a variance to keep the plant in operation at least until January 2014 (PPG Industries, Inc., 2012). The Ashta Chemical plant in Ashtabula, Ohio, was expected to close by 2018 (Olin Corporation, 2010). In 2007, mercury-cell technology accounted for 10 percent of the total chloralkali capacity; in 2011, it was reported to account for 3 percent of chloralkali capacity (de Guzman, 2011).

Improvements in technology have reduced the mercury requirement for chloralkali production. In 1996, about 0.069 kilograms (kg) (0.153 pound) of mercury was required per metric ton of chlorine capacity; by 2008, only 0.005 kg (0.011 pound) of mercury was required per ton of capacity (The Chlorine Institute, Inc., 2009). Figure 5 shows estimates for the principal mercury flow steps as represented by the chloralkali manufacturing industry in 2008. The quantities of mercury flow in 2008 are significantly lower than corresponding estimates for 1996 (Sznopek and Goonan, 2000) because of plant closures and conversions and technological improvements driven by stringent regulatory limits on mercury emissions and disposal. In 1996, inventories in the chloralkali sector included 3,050 t of mercury, purchases were 136 t, and 27 t of mercury was landfilled or released into the environment. In 2008, however, inventories in the chloralkali sector had been

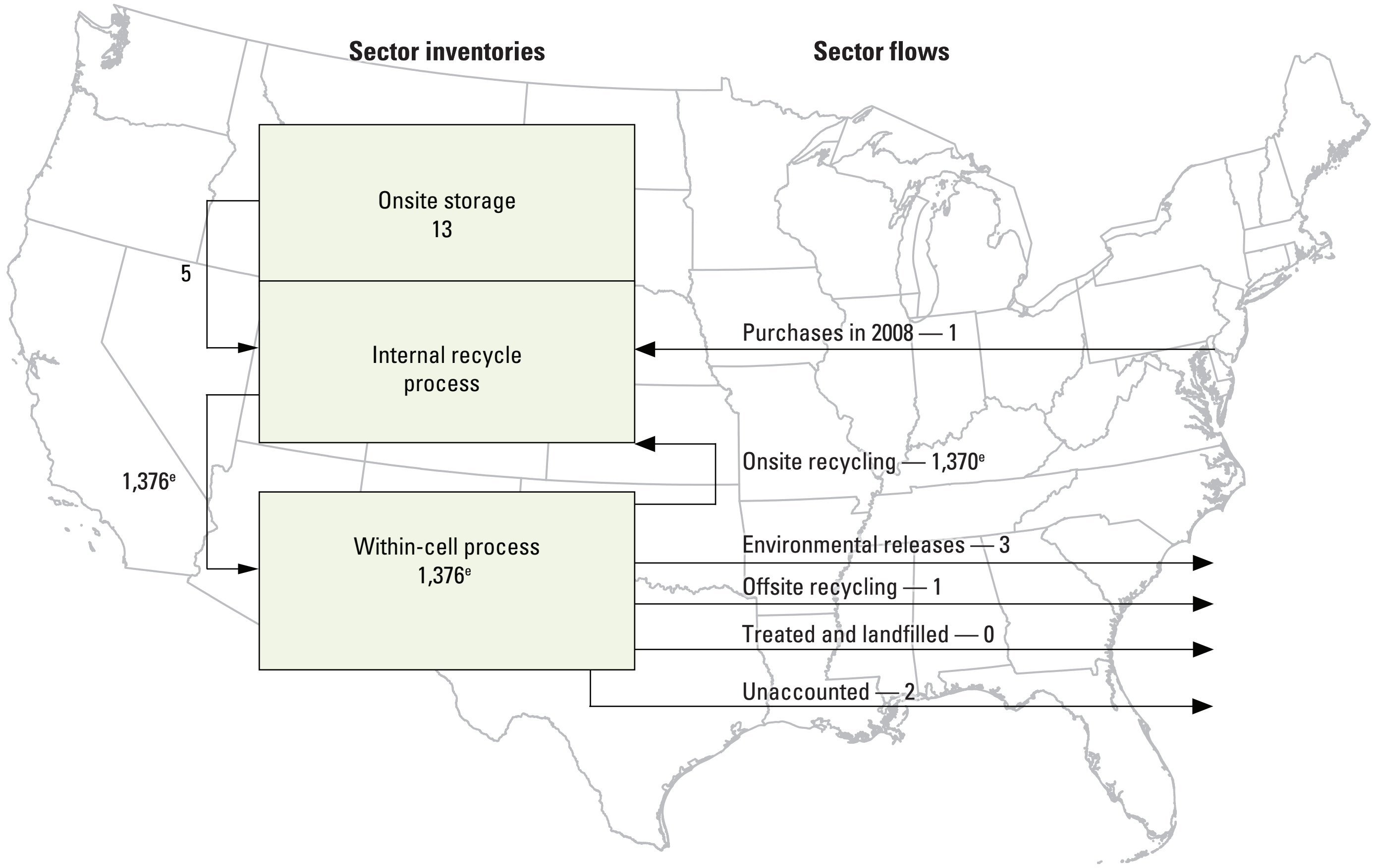

Figure 5. The flow of mercury from the mercury-cell process used in the chloralkali manufacturing industry in the United States in 2008. Data are derived from The Chlorine Institute, Inc. (2009) based on four plants in operation in 2008. Values are expressed in metric tons of mercury. e, estimated.

reduced to 1,389 t of mercury, onsite recycling of mercury had supplemented much of the purchased mercury, and 3 t of mercury was released into the environment (The Chlorine Institute, Inc., 2009). In 2010, the chloralkali sector in the United States purchased 6.5 t of mercury, used 0.3 t of mercury in chloralkali manufacturing, and released about 6 t of mercury to the environment (Robyn Brooks, project engineer, The Chlorine Institute, Inc., written commun., August 8, 2012).

From 1996 to 2010, six mercury-based chloralkali plants were closed, and four were converted (or scheduled to be converted) to membrane technology. Although many factors went into the decision whether to close or convert mercury-cell plants, the membrane process, which requires neither mercury nor asbestos, was chosen for all plants that were converted. In 2010, the chloralkali industry consumed 365 t of asbestos, or 35 percent of U.S. asbestos consumption, in 2010 (Virta, 2011).

A review of recent trends in the chloralkali industry can reveal how domestic and international regulation of the mercury industry can have unexpected global consequences. Increased regulation and voluntary plant closures have reduced mercury air and solid waste emissions from chloralkali manufacturing in the United States by about 85 percent from 2001 to 2008 (The Chlorine Institute, Inc., 2009); these changes to the structure of the industry have resulted in a significant amount of mercury released for sale on the international market from decommissioned mercury plants and from mercury recovered from recycled products. Although precise data on international trade are difficult to acquire, the United States has become a net exporter of mercury even though there has been no mining of mercury in the country since 1992. Regulations designed to reduce the amount of mercury available for global use can result in large, one-time releases of mercury into global markets with the recovery of mercury from decommissioned mercury-cell chloralkali plants. Implementation of the MEBA has accelerated this process.

Mercury (as elemental mercury and calomel) is recovered from stockpiles held by chloralkali manufacturers, electrolytic cells, and facility and soil decontamination efforts, but this material will no longer be available when all mercury-cell plants in the United States are decommissioned by 2018 and mercury contained in buildings and soils is recovered, sold, or stockpiled. A typical mercury cell contains an average of 4.7 t of process mercury (U.S. Environmental Protection Agency, 2010, p. 3–9). Thus, decommissioning 166 cells from the two plants expected to close in 2012 could yield about 780 t of mercury, not including onsite mercury stocks. The mercury content of contaminated buildings and soils could yield an additional 23 to 68 t of mercury per plant, depending on plant age, design, operating, maintenance, and waste disposal practices during the lifetime of the plant, and the amount of the mercury that could be recovered (Maxson, 2006). Mercury from closed plants is recycled by one of several large companies that recycle metals in the United States or is exported for recovery; data suggest that much of this mercury is sold through traders on the international market, and some of this mercury is ultimately purchased by numerous small-scale, unregulated artisanal gold mining operations in Africa, Asia, and Latin America. Stimulated by the increasing price of gold worldwide from 2005 to 2011, an increasing number of artisanal miners are producing gold using mercury, which is preferred by small miners rather than more complex processes than require materials such as cyanide. The production of gold using mercury is generally easier, faster, and cheaper and can produce a higher grade gold product than traditional panning methods (Lovitz, 2006).

Figure 6 compares exports of mercury from the United States from 1999 through 2011 with changes in mercury-cell chloralkali plant capacity, and table 3 lists the primary destinations of exports of mercury for years when large shipments of exported mercury took place relative to chloralkali plant closures. Large shipments to India, the Netherlands, Peru, and Vietnam seem to correlate with the closure of chloralkali plants in the preceding year. From 1999 through 2006, mercury was used for batteries, chlorine-caustic soda production, fungicides, lamps, and medical devices in India, and the country was one of the leading importers of mercury from the United States (Wankhade and Agarwal, 2003). Shipments to the Netherlands are also particularly notable; U.S. trade data show that, in total, 1,360 t of mercury was shipped to the Netherlands from 2006 through 2010, at a time when four chloralkali manufacturing plants were decommissioned. Shipments to the Netherlands accounted for 56 percent of total U.S. exports of elemental mercury in those 5 years. Simpson and Walsh (2012) suggest that much of this mercury is transported to warehouses of traders at the port of Rotterdam, and then is redistributed in smaller shipments to countries such as Colombia, where there is small-scale gold mining. India, Mexico, Peru, and Vietnam, countries that have also received large shipments of mercury from the United States, also have small-scale gold mining.

Table 3. Principal destinations of mercury exported from the United States from 1999 through 2011.

[Includes countries that received more than 50 metric tons (t) of mercury from the United States. NA, no countries received more than 50 t]

Year	Principal destinations and quantity, in metric tons
1999	India, 85
2000	India, 65
2001	NA
2002	Netherlands, 73
2003	Netherlands, 57; Peru, 51
2004	Vietnam, 79; Mexico, 64; India, 63
2005	Netherlands, 156
2006	Netherlands, 118; India, 80; Vietnam, 74
2007	NA
2008	Netherlands, 535; Vietnam, 121
2009	Netherlands, 414; Peru, 110; Vietnam, 107
2010	Netherlands, 295
2011	Canada, 96

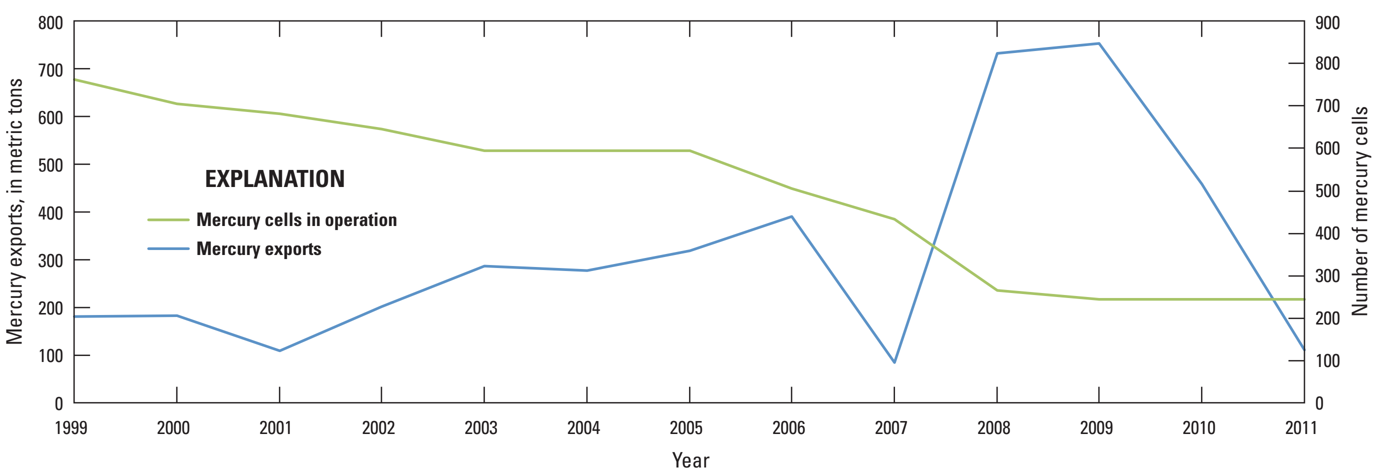

Figure 6. Relationship between mercury exports from the United States and the number of mercury cells in operation in the United States from 1999 through 2011. Export data from 1999 to 2010 are from U.S. Geological Survey (1997–2011). Data on mercury cells are from The Chlorine Institute, Inc., (2009). Estimated data for 2011 are derived from industry data and Brooks (2012).

In an international effort to reduce mercury sales for such use, a ban on mercury exports from the European Union took effect in 2011, and the MEBA would prohibit the sale and transfer of mercury outside the United States after January 2013. The MEBA would also place limits on the amount of mercury that could be imported if recyclers cannot export surplus mercury. Because chloralkali manufacturing plants have large amounts of mercury onsite, they have been affected by this legislation. Chloralkali plants in the United States that have not closed or been converted to nonmercury technology by 2013 would be required to store mercury at a site approved by the EPA for long-term mercury storage. Under the MEBA, the U.S. Department of Energy is required to designate one or more facilities for long-term management and storage of elemental mercury located within the United States. See the Effect of the Mercury Export Ban Act of 2008 on the U.S. Mercury Industry section for a further discussion.

Electrical and Electronic Instrumentation

Electrical and electronic applications accounted for 54 percent of the mercury used in the United States in 1980 (Matos and Brooks, 2005). Mercury use has subsequently decreased as a result of regulation, voluntary reduction in use, and the development of cost-effective non-mercury-containing alternative products.

Switches, Relays, and Sensors

Mercury has been used in electrical relays, sensors, and switches found in a variety of industrial and consumer products. Mercury switches include float switches, actuated by rising or falling liquid levels; tilt switches, actuated by a change in the switch position; pressure switches, actuated by a change in pressure; and temperature switches and flame sensors, actuated by a change in temperature. Mercury switches have been used in such devices as air conditioning equipment, appliances, automobiles and recreation vehicles, leveling devices, and security systems. Relays are devices that open or close electrical contacts. Mercury-containing relays have been used in cooking equipment and telecommunications circuit boards (Northeast Waste Management Officials' Association, 2008c, 2010d).

Some States and communities have placed restrictions on the sale and (or) distribution of mercury-containing switches and relays and have instituted reduction and collection programs for selected mercury-bearing products (Northeast Waste Management Officials' Association, 2010d). In response to these product bans and phase-outs, many companies have ceased manufacturing mercury switches and relays or stopped selling these devices in States that impose restrictions and in some cases curtailed sales nationwide. At least 11 States have ongoing collection programs for electrical or electronic products containing mercury; there are no ongoing nationwide collection programs for switches, except for switches used in vehicles as discussed in the Automobile Switches section.

Data collected by the IMERC for 2001, 2004, and 2007 provide an indication of the amount and industry trends of mercury use in sensors, switches, and relays. Mercury content varies with switch type, but most switches use about 1 gram (g) of mercury per switch. The data in table 4 show that the overall mercury content for switches, relays, and sensors decreased by 14 percent from 2001 to 2004 and a further 40 percent from 2004 to 2007, primarily as a result of mercury reduction efforts by manufacturers and States.

Automobile Switches

Mercury switches in automobiles accounted for about 50 percent of the mercury switches used in all applications in 2007. Mercury switches have been used in convenience lights and components of antilock brake systems (ABS) and ride control systems in many automobiles built from 1997 to 2006. In 2000, U.S. automakers used an estimated 4 million mercury switches each containing about 1 g of mercury (Brooks and Matos, 2006). Beginning in 1996, manufacturers of vehicles made outside the United States began phasing out mercury switches in new vehicles, and mercury switches were eliminated from vehicles manufactured in the United States after 2003. Even as mercury use in switches has

Table 4. Mercury use in switches, relays, and sensors.

[Data are modified from Ashe and others (2012). NA, not applicable; >, more than]

Product	Mercury content per unit, in grams	Applications	Total mercury content, in metric tons		
			2001	2004	2007
Tilt switches	0.05–5	Appliances, level controls, security alarms, thermostats	6.3	3.2	0.8
Float switches	0.1–67	Pumps	5.8	6.3	4.7
Flame sensors	>1	Stoves	2.3	1.1	0.9
Other switches	>1	Automobile convenience switches, antilock braking systems	19.1	18.9	12.8
Relays	0.005 – >1	Circuit boards, telecommunication systems	20.9	17.2	8.7
Total	NA		54.4	46.7	27.9

decreased, new automotive applications of mercury, including high-intensity discharge (HID) headlamps and cold-cathode fluorescent lamps used in backlit instrument panels, entertainment systems, and navigation systems, are being introduced in some vehicles. A typical dashboard light bulb contains 0 to 5 milligrams (mg) of mercury; a tube-style bulb typically contains 5 to 10 mg, but may contain up to 100 mg of mercury. A convenience light switch and an ABS sensor contains about 1 g of mercury (Northeast Waste Management Officials' Association, 2008c). About 90 percent of the mercury in vehicles is contained in convenience lighting assemblies, and 9 percent is found in ABS switches or sensors (Corbett, 2005).

In 2006, the NVMSRP was initiated as a cooperative effort by automobile manufacturers, the Environmental Council of States (ECOS), environmental organizations, the EPA, steelmakers, and vehicle dismantlers and shredders. Working with existing State mercury switch reduction and recycling efforts, the program set a goal to recover 80 to 90 percent of available mercury switches in the United States. Table 5 lists the results as of 2011. Between 2007 and 2011, the program had achieved an average estimated recovery rate of 21 percent. In 2011, the estimate for the amount of mercury in automotive switches in use in the United States was 31 t. An additional 2.7 t of mercury was contained in switches stockpiled or exported, and 0.7 t of mercury was recovered through recycling programs (End of Life Vehicle Solutions Corporation, 2012). These estimates exclude mercury contained in vehicles or vehicle components exported out of the United States.

Table 5. Mercury use in automotive switches.

[Data are from End of Life Vehicle Solutions Corporation (2012). NA, not available]

Year	Mercury in switches in use, in metric tons	Mercury in scrapped switches, in metric tons	Mercury in recovered switches, in metric tons	Mercury stockpiled, exported, or landfilled, in metric tons
1997	99	NA	NA	NA
1998	93	6	0	6
1999	87	6	0	6
2000	81	7	0	7
2001	74	7	0	7
2002	69	5	0	5
2003	63	5	0	5
2004	59	4	0	4
2005	54	4	0	4
2006	50	5	0.2	5
2007	45	5	0.7	4
2008	41	4	1	3
2009	38	4	0.9	3
2010	34	4	0.6	3
2011	31	3	0.7	3

Batteries

The use of mercury in consumer batteries has decreased significantly in the United States since the 1980s when battery manufacturing in the United States constituted the single leading use of mercury—1,000 t annually. By 1993, many battery manufacturers had begun selling mercury-free alkaline batteries, and the annual use of mercury in batteries by U.S. manufacturers decreased to about 10 t. Mercuric oxide button-cell batteries, containing 30 to 40 percent mercury by weight, were banned in the United States in 1996 under the Mercury Containing and Rechargeable Battery Management Act (MCRBMA). Mercuric oxide batteries larger than button-cell size are no longer available to the public but are still produced in limited quantities for military and medical applications where a stable current and longer service life is essential, as long as the manufacturer has established a procedure to collect, manage, and recycle end-of-life batteries. Button-cell batteries are still used in such applications as calculators, hearing aids, toys, and watches, but the MCRBMA limits the mercury content of button-cell batteries manufactured in the United States for these applications to 25 mg of mercury per button cell (National Electrical Manufacturers Association, 2002).

There are three different types of button-cell batteries that commonly contain mercury: alkaline manganese, silver-oxide, and zinc-air. Most alkaline manganese batteries are used in cameras, but they may be found in a variety of other devices. Silver-oxide button-cell batteries are used in calculators, cameras, games, medical devices, toys, and watches. Zinc-air button-cell batteries are used in hearing aids. In each of these types, a mercury coating is added to the cell to prevent the formation of hydrogen gas that can result in battery leakage and malfunction. Alkaline button-cell batteries produced in 2002 were estimated to have an average mercury content of 10.8 mg of mercury; silver-oxide button-cell batteries, 2.5 mg; and zinc-air button-cell batteries, 8.5 mg (Maine Department of Environmental Protection, 2005, p. 3). Since 2001, many States have enacted legislation restricting the sale of mercury button-cell batteries and (or) products that contain these batteries. U.S. battery manufacturers voluntarily committed to eliminate mercury in button-cell batteries by June 30, 2011, coinciding with the effective date of legislation in Connecticut, Maine, and Rhode Island that banned mercury-containing button-cell batteries in these States as of July 1, 2011 (Poon, 2011). The ban was extended for another 6 months because the supply of mercury-free button-cell batteries was disrupted as a result of the nuclear disaster in Fukushima, Japan, following the March 11, 2011, earthquake and tsunami (Fashion Jewelry and Accessories Trade Association, The, 2012).

Data on mercury-added button-cell production and use in the United States are not readily available. Reports by the IMERC estimate that all mercury batteries sold in the United States for 2001, 2004, and 2007 contained about 2.5 t, 2.2 t, and 1.9 t of mercury, respectively; these data generally reflect replacement batteries only and do not include batteries imported to the United States or batteries contained in imported products. (Northeast Waste Management Officials' Association, 2010a). The decreasing trend shown by these data appears to fit the industry pledge to reduce mercury use in batteries by 2011. Data compiled by the IMERC show that mercury contained in products sold in the United States accounted for more than 0.9 t in 2001, 1.3 t in 2004, and 0.9 t in 2007, but not all manufacturers of products containing mercury-added batteries disclosed their U.S. sales to the IMERC (James, 2009). Another estimate of the total mercury contained in button-cell batteries sold in the United States in 2007 suggested a range of 3.3 to 4.6 t of mercury (James, 2009, p. 4).

Import and export data reported by the U.S. International Trade Commission suggest that the United States imported many more manganese dioxide, silver oxide, and zinc-air button-cell batteries that it exported. In 2010, manganese oxide batteries were imported to the United States primarily from China (60 percent), Indonesia (19 percent), and Germany (9 percent); silver oxide batteries were imported primarily from Japan (55 percent), Switzerland (26 percent), and Germany (14 percent); and zinc-air batteries were imported primarily from Germany (44 percent), the United Kingdom (29 percent), and China (12 percent) (U.S. International Trade Commission, 2012). These statistics likely include mercury-containing and mercury-free batteries, and it is difficult to separate these two types, although a rough approximation can be made by assuming that 10 percent of the batteries from China are mercury-free (Zero Mercury Working Group, 2012) and 39 percent of the batteries from the European Union are mercury-free (Mudgal and others, 2012, p. 126). Batteries from Indonesia were assumed to be similar in distribution to batteries from the European Union, and batteries from Japan are totally mercury-free (United Nations Environment Programme, 2007). Based on these assumptions, the net imports of mercury-containing button-cell batteries of all types to the United States contained an estimated 7.6 t of mercury in 2010. This value does not include the amount of mercury included in batteries contained in imported products.

Recycling of mercuric oxide batteries in the United States in 2010 is believed to be limited to the recovery of mercury from the large batteries discarded by medical institutions and the military. Recycling of this material is required by the MCRBMA and is part of the material processed by the leading U.S. recyclers, such as Bethlehem Apparatus. Specific data on the amount of this material recycle are not reported.

There are no Federal restrictions on the disposal of button-cell batteries in the United States, nor are there State-sponsored programs to collect the batteries (Maine Department of Environmental Protection, 2005). Recycling of button-cell batteries is limited to local battery collection programs. A nationwide button-cell battery collection program has not been implemented because collection of button cells is not thought to be cost-effective, primarily because of the small amount of mercury in each button-cell battery and the need to keep button-cell batteries separate from other batteries being recycled because of potential mercury contamination. The estimated costs and potential safety hazards of collection, transportation, and recycling were found to outweigh the benefits gained by recycling (National Electrical Manufacturers Association, 2003). Silver-oxide button-cell batteries are often collected by jewelers and large retailers when they replace watch batteries and recycle them to recover the silver. In cases where mercury-containing button-cell batteries are recycled, they are collected and sent to the leading U.S. recycling companies for processing.

Lighting

Although mercury continues to be an essential component in the commercial and residential lighting industry, the contribution of mercury to lamps continues to decrease even as the energy efficiency of mercury-containing lamps increases. Because a small amount of mercury is contained in fluorescent lamps and high-intensity discharge lamps, concerns over possible mercury releases to the environment have led the industry to develop products using less mercury and government entities to implement stricter regulation related to mercury emissions, use, and disposal. The USGS conducted a study of mercury flow in the U.S. mercury-containing lamp sector as of 2001 (Goonan, 2006). Since that time, Federal and State regulations have become increasingly complex, new products have been introduced into the market, and a greater emphasis has been placed on improving mercury recycling rates and developing mercury-free alternatives. A review of mercury use and recycling activities as of 2010 follows. Annual mercury use in the U.S. lighting sector was estimated to be about 17 t (Gheysens, 2011), 70 percent greater than the 2007 value of about 10 t of mercury sold for lighting as reported by the IMERC (Northeast Waste Management Officials' Association, 2008b; Wienert, 2009).

A typical fluorescent lamp is made up of a phosphor-coated glass tube with electrodes located at either end. When voltage is applied, the electrodes energize the mercury vapor and cause it to emit ultraviolet energy. A phosphor coating absorbs the ultraviolet energy, which causes the phosphor to fluoresce and emit visible light. Mercury-containing lamps require three to four times less energy and have a longer life than traditional incandescent bulbs (National Electrical Manufacturers Association, 2005).

Since 1990, legislation has been enacted and several regulations have been promulgated that indirectly affect mercury use in fluorescent lamps. The Energy Policy and Conservation Act of 1992 set energy conservation standards for certain classes of general service fluorescent lamps (GSFLs) and established provisions for periodic review of these standards. In 2008, the DOE completed the first review of the standards and determined that the standards needed to be updated; amended standards were published on July 14, 2009 (U.S. Department of Energy, 2009). Fluorescent lamps of a standard 4-foot length are generally classified based on their diameter expressed in eights of an inch, thus a T12 lamp would have a diameter of 12/8 (1.5 inches) whereas a T8 lamp would have a diameter of 8/8 (1 inch) (Merritt, 2012). Based on an analysis by the DOE, most T12 fluorescent lamps are considered too inefficient to meet the new standards and can no longer be manufactured after July 14, 2012; fluorescent lamps not meeting the new standards must be replaced by that date. T12 lamps contain more mercury than the T5 and T8 lamps that are replacing them. The Energy Independence and Security Act of 2007 included provisions for phasing out mercury-free incandescent light bulbs in favor of more energy-efficient compact fluorescent light (CFL) bulbs, which contain an average of 4 mg of mercury (U.S. Environmental Protection Agency, 2012f). Regulations promulgated since 1990 to increase the energy efficiency of commercial and residential lighting have contributed to an average reduction of mercury use in general service fluorescent lamps by 77 percent since 1985, but have increased mercury use in general service fluorescent lamps by 6 t through encouraging the use of mercury-bearing CFLs as a replacement for incandescent light bulbs.

Mercury content in GSFLs has decreased from an average of 48.2 mg of mercury in 1985 to as low as 3.5 mg of mercury for a standard T8 48-inch-long fluorescent lamp (Northeast Waste Management Officials' Association, 2008c). Several U.S. manufacturers produce a low-mercury fluorescent lamp, containing 3.5 to 4 mg of mercury compared with 8 to 14 mg of mercury contained in a standard (T12) fluorescent lamp (U.S. Environmental Protection Agency, 2012a).

Estimates of mercury use in the lighting sector for 2010 are listed in table 6. The U.S. lighting industry had an inventory of 45.6 t of mercury in 2001 from 4.2 billion lamps that were in use (Goonan, 2006). In 2010, the estimated mercury inventory was 28.8 t from about 4 billion lamps in use, a 37 percent decrease on mercury inventory from 2001. Various types of linear fluorescent lamps are reported separately to show that the highest proportion of the mercury in use is derived from the T12 lamps that are being phased out compared with the T8 and T5 lamps that are replacing them. Mercury use from the lighting sector will continue to decrease as fewer T12 lamps are produced. CFL lamps, which contain up to 4 mg of mercury, were developed as a replacement for incandescent lamps. The use of CFL lamps is expected to be of relatively short duration. Light-emitting diode (LED) lamps, which contain no mercury, are expected to eventually replace CFL lamps in many applications (Wilburn, 2012).

Total mercury emissions in the United States are expected to decrease partially owing to the amended lighting standards that took effect in 2012 (U.S. Department of Energy, 2012). The use of energy-efficient lighting reduces the amount of fuel used in powerplants, the primary source of airborne mercury emissions in the United States. Full implementation of energy-efficient lighting programs nationwide was estimated to result in a reduction of close to 10 t per year of mercury primarily owing to reduced coal-generated electricity (U.S. Environmental Protection Agency, 2006, p. 45). Mercury emissions in 2001 were estimated to be about 2.9 t from the lamp sector (Goonan, 2006). Based on a reduced inventory of mercury available from the lighting sector in 2010 and available recycling estimates, a rough estimate of the mercury emission level in 2010 would be about 2 t from lamp disposal, recycling, and transport operations, using the methodology developed by Goonan (2006). Much of the mercury that is released into the air occurs in the period after the lamp is broken, most often during transport to disposal or recycling facilities. The estimate may be overstated because it does not take into account the mercury control methods implemented since 2001 to reduce mercury emissions at incinerators, landfills, or recycling facilities.

Table 6. Mercury-containing lamps used in 2010.

[CFL, compact fluorescent light; HID, high-intensity discharge; NA, not available]

Lamp type	Lighting service use sector									
	Commercial		Industrial		Outdoor		Residential		Total	
	Lamps, in million units	Mercury content, in metric tons	Lamps, in million units	Mercury content, in metric tons	Lamps, in million units	Mercury content, in metric tons	Lamps, in million units	Mercury content, in metric tons	Lamps, in million units	Mercury content, in metric tons
CFL	216	0.7	0.4	0.001	12	0.048	1,322	5.3	1,550	6
T5 fluorescent	108	0.25	9.2	0.021	NA	NA	3.6	0.008	121	0.3
T8 fluorescent	996	4.5	83	0.4	NA	NA	70	0.3	1,149	5.2
T12 fluorescent	538	5.4	36	0.4	NA	NA	368	3.6	942	9.4
HID[1]	35	1.5	14	0.6	93	3.3	1.4	0.05	143	5.5
Miscellaneous	13	0.2	0.5	0.006	29	0.4	132	1.8	175	2.4
Total	1,906	12.6	143	1.4	134	3.7	1,897	11.1	4,080	28.8

[1]Includes high-pressure sodium, low-pressure sodium, metal halide, and mercury vapor lamps. Adapted from U.S. Department of Energy (2012a).

Most mercury-containing lamps fail to pass the toxicity characteristic leaching procedure (TCLP) test mandated by the RCRA and thus must be treated as a hazardous waste. In 1999, the EPA enacted regulations that allow lamps to be regulated under the universal waste rule of modified hazardous waste regulations developed for other widely generated wastes such as batteries. Almost all States have adopted this EPA rule without amendment, and many have developed lamp handling guidelines and (or) recycling programs or procedures. In spite of these actions, nationwide data on recycling rates are not well known as most States do not require reporting by generators or recyclers for universal wastes. For 2003, a nationwide recycling rate estimate of 23.3 percent for fluorescent lamps was reported (Association of Lighting and Mercury Recyclers, 2004). According to this estimate, the commercial recycling rate was 29 percent, and the residential recycling rate was 2 percent (Association of Lighting and Mercury Recyclers, 2004). The low recycling rate can be attributed to the low value of recycled materials found in lamps, which reduces the economic incentive for lamp recycling, which is estimated to cost $0.50 to $2.00 per unit (National Electrical Manufacturers Association, 2008), and the lack of coordinated collection programs. The growing market penetration of CFLs has led to a number of CFL collection programs, but recycling remains expensive relative to the price of the lamp. It is likely that government-mandated replacement of T12 lamps with more energy efficient T8 or T5 lamps at government facilities and large corporate replacement programs could result in a temporary increase in the recycling rate of fluorescent bulbs, but the overall effect of such activities is not reported.

There are no comprehensive data on the number of lamps that have been recycled. A number of States and municipalities have set up programs to recycle CFLs but few programs exist for recycling linear fluorescent tubes (Northeast Waste Management Officials' Association, 2009). Some States and municipalities offer bulb recycling programs on a regular or occasional basis, and others mandate CFL lamp recycling. In many areas nationwide, CFL recycling programs are being offered by manufacturers, retailers, or utilities. Nationwide home improvement chain stores, for example, offer CFL recycling programs. Most of the material collected by these selective recycling programs is sent for processing to one of the six large recycling companies. Aggregated annual recycling data are not reported.

Replacement of T12 lamps by T8 lamps or substitution of incandescent bulbs by CFLs yields a small change in material requirements. Replacing 250 million incandescent bulbs with CFLs would require about 1 t of mercury. As LED technology displaces CFL technology in the lighting sector, less mercury would be required for the lighting sector. Production of large quantities of LEDs could potentially result in a more significant shift in the use of some metals or materials because LEDs require various metals such as arsenic, gallium, indium, and rare earth elements (Wilburn, 2012).

Instruments and Measuring Devices

Mercury has historically been used in a wide variety of instruments and measuring devices, which accounted for 8 percent of the mercury used in the United States in 1980. Such devices have been used in industrial and medical sectors because of the responsiveness of mercury to pressure and temperature. Minnesota was the first State to enact legislation in 1994 prohibiting the disposal of thermostats and other mercury-containing devices until the mercury had been removed. One outcome of this legislation was that Honeywell International, Inc., the leading manufacturer of thermostats in the United States at the time, started a thermostat recycling program in Minnesota. Since 2001, 13 States have enacted legislation banning the sale and use of mercury-containing measuring devices and thermometers (Northeast Waste Management Officials' Association, 2010c). In 2002, the EPA banned the sale of mercury-containing thermometers, and in 2010, issued a new rule under the Toxic Substances Control Act requiring that the EPA be notified at least 90 days before the beginning of production of mercury-containing devices (such as flow meters, natural gas manometers, and pyrometers) that come into service after September 11, 2009.

Measuring Devices

Mercury has been used in devices that measure liquid or gas flow (flow meters or strain gages), humidity (hygrometers or psychrometers), pressure (barometers, manometers, or sphygmomanometers), specific gravity (hydrometers), and temperature (pyrometers or thermometers). In 1990, about 110 t of mercury was used in the manufacture of such devices. In 1995, mercury content in such devices had decreased to 43 t; by 2000, mercury use in these devices had decreased to 30 t (Matos and Brooks, 2005). By 2001, environmental concerns related to mercury and Federal and State regulation had further reduced mercury use in these devices to 4.5 t (Northeast Waste Management Officials' Association, 2010c). In 2007, the latest date for which data are available, mercury use had decreased to about 1 t (Wienert, 2009). It is reasonable to assume that most of these devices are no longer manufactured or sold in the United States, except in cases where there is a specialty application and no suitable, cost-effective substitute for mercury is available.

Devices that are no longer sold in the United States are considered legacy products, which may still be used, resold as a used product, or stored before disposal occurs. As with other mercury-containing devices, recycling is done on a State-by-State or local basis. Recycled material is most often collected and sent to one of the six major U.S. recyclers.

Mercury-free alternatives to many of these devices have become available. Depending on the device, these alternatives may include a device that uses a substitute liquid that has appropriate characteristics and is readily available (such as alcohol in a fever thermometer or manometer), an aneroid (liquid-free) device, or a digital device that performs a similar function. Increasingly, digital devices are used in many applications. However, many of these digital devices require a battery, some of which contain mercury. A mercury-containing button-cell battery may be used, particularly if the device is produced in China and imported to the United States. If such a battery is used, then the end-of-life device must be treated under the EPA universal waste rules.

For selected applications, measuring devices used in laboratories use mercury-based instrumentation because accurate alternatives with the appropriate characteristics may not yet be available. Although a variety of analog and digital thermometers have become available for use, they may not meet the requirements of a laboratory device that requires very precise measurement. The National Institute of Standards and Technology (NIST) is participating in several efforts to identify alternative thermometers for a broad range of measurement applications and coordinate efforts to replace mercury-containing laboratory devices (National Institute of Standards and Technology, 2012).

Thermostats

For many years, mercury has been used in thermostats, both as stand-alone units in businesses and residences and as a component in heating and cooling equipment. Thermostats have historically contained mercury switches to automatically maintain building temperatures at a set level by triggering furnace or air conditioner operation when the desired temperature is reached. Mercury content for a single mercury-switch thermostat can range from 2.7 to 10.8 g of mercury, with an average content of about 4 g of mercury (James, 2005). During the past 15 years, the annual demand for mercury in thermostat manufacturing in the United States has been reduced from 13 to 18 t (15–20 tons) in 1995 to 0.9 t (less than 1 ton) in 2010 (Mercury Policy Project, 2010). This reduction can be attributed to States regulating sales of new mercury thermostats and the subsequent cessation of mercury thermostat production by the top U.S. manufacturers. In 2005, about 83 percent of all thermostats contained mercury (New England Zero Mercury Campaign, 2005). Electromechanical and electronic thermostats have been developed to replace mercury-switch thermostats, although mercury-containing thermostats are still being manufactured in other countries. The composition of these devices varies depending on type; evaluation of material substitution for these devices is beyond the scope of this report.

Data collected by the IMERC for 2001, 2004, and 2007 provide an indication of the amount of mercury used in this sector and the prevailing industry trend. In 2001, about 13.5 t of mercury was contained in thermostats sold in the United States. In 2004, about 13.1 t or mercury was contained in thermostats sold. Between 2001 and 2007, 17 States instituted restrictions on the sale of mercury-containing thermostats, and a number of companies have voluntarily phased out products using mercury-switch thermostats or switched to electromechanical or electronic thermostats that do not contain mercury. The IMERC reported that 3.5 t of mercury was contained in thermostats sold in 2007, a decrease of 73 percent from the amount found in thermostats in 2004 (Wienert, 2009; Northeast Waste Management Officials' Association, 2010e).

The Thermostat Recycling Corporation (TRC) was established in 1997 by the three leading U.S. thermostat manufacturers to collect and recycle mercury-switch thermostats removed from service. In 2004, the EPA estimated that mercury thermostats found in homes and businesses contained a reservoir of about 200 t of mercury in thermostats (James, 2005) and that about 2.5 million mercury-switch thermostats containing 9 to 14 t (10 to 15 tons) are removed from service each year in the United States (Mercury Policy Project, 2010). At 4 g of mercury per thermostat, the amount of mercury that could potentially become available annually is 10 t.

A study conducted for the State of California estimated that 237,000 to 490,000 mercury-switch thermostats would be removed from service in 2010 in California based on the average maximum assumed thermostat age of 30 years (Thermostat Recycling Corporation, 2012b). Using population estimates for California and the Nation as a guide, the California estimates could be extrapolated to the United States as a whole, yielding an estimate of 2 to 4 million mercury-switch thermostats containing 8 to 16 t of mercury that potentially could have been removed from use since 2008. This estimate seems reasonable given that there has been no new production of mercury switches and many thermostats have since been replaced with nonmercury types.

The number of thermostats recycled by TRC is low when compared with estimates of the number of thermostats removed from service annually (Thermostat Recycling Corporation, 2012a). From 1999 through 2008, TRC recovered 3.3 t of mercury. For that same period, an estimated 80 to 160 t of mercury was contained in thermostats that were removed from service. Thus, TRC has collected less than 5 percent of the thermostats that were removed from service during that decade (Mercury Policy Project, 2010). Recycling rates vary from State to State, ranging from 1.3 percent in New York to 12.7 percent in Maine. States without established procedures for thermostat recovery may not recycle any mercury thermostats, although TRC reportedly has collection sites in 48 States. As of May 2012, TRC has recovered more than 1.4 million thermostats containing 6 t (6.6 tons) of mercury since it began mercury recycling in 1999 (Thermostat Recycling Corporation, 2012a).

If the TRC data are accurate and account for all domestic recycling of thermostats, then there is a significant amount of mercury contained in thermostats in use and more in thermostats that have been stored or discarded. Assuming 8 to 16 t of mercury contained in thermostats is removed from service annually, and assuming a 5 percent recycling rate, then 7.6 to 15 t of mercury may be stored or discarded each year. Although mercury contained in thermostats is less likely to be released to the air than mercury in fluorescent tubes, it may be released into the air or groundwater over time, thus making a significant contribution to U.S. mercury emissions.

Dental Amalgam

Dental amalgam containing about 50 percent mercury has been used for more than 150 years in the United States for restoration of posterior teeth in children and adults. In 1980, 80 percent of all restorations used amalgam. Historically, dentists mixed amalgam onsite, using bulk liquid mercury and metal powders; in 2011, most dentists purchased amalgam imported in predosed capsules with a mercury content varying from 100 to 1,000 mg (Northeast Waste Management Officials' Association, 2010b). Dental amalgam is considered a medical device that is regulated by the U.S. Food and Drug Administration (FDA). In 2008, the FDA reviewed the best available evidence to determine whether the mercury vapor emitted by mercury amalgam fillings was a cause of concern. Based on the findings, the FDA issued a final regulation on dental amalgam in 2009 that classified dental amalgam as a class II or moderate risk to society, allowing the agency to apply controls on product labeling and disposal. This designation also applies to other alternative restorative materials, such as composites or gold (U.S. Food and Drug Administration, 2009, 2011).

Since 2003, 11 States have mandated requirements for best management practices for dental amalgam waste so that dental offices capture and recycle this waste. Requirements include installing amalgam separators, properly managing solid waste that contains amalgam, and recycling amalgam. In States where amalgam use is not regulated, use of amalgam separators and amalgam recycling rates are low. Use of these practices can eliminate 95 to 99 percent of dental mercury from entering municipal wastewater (Reindl, 2010).

Dental amalgam in teeth represents the leading source of mercury in use in the United States. There may be an inventory of up to 290 t of mercury residing in the teeth of U.S. residents (Concorde East/West Sprl, 2012). The number of new or replacement amalgam fillings in the United States appears to have been decreasing by 3.5 to 4 percent per year (Beazoglou and others, 2007). A single-surface amalgam filling requires about 400 mg of mercury; a filling with three or more surfaces can use about 800 mg of mercury (Concorde East/West Sprl, 2012, p. 8). In terms of the amount of mercury used in dental amalgam, dental mercury use decreased on average by about 2 percent annually from about 61 t in 1980 to about 30 t in 2000 (Matos and Brooks, 2005). Data collected by the IMERC suggest that this trend continued from 2001 through 2007 when the amount of mercury sold from five U.S. producers of dental amalgam decreased from about 28 t in 2001 to about 15 t of mercury in 2007 (Northeast Waste Management Officials' Association, 2010b). Although the general trend of mercury use in dental applications is decreasing, the IMERC mercury-added products database for 2010 reports statistics for four companies that suggest that about 18 t of mercury was sold in the United States for dental applications in 2010 (Northeast Waste Management Officials' Association, 2012).

With increasing awareness of the potential health hazards associated with mercury, improvements in quality of substitute materials in some applications, and a decrease in the incidence of dental decay, use of dental amalgam is decreasing (U.S. Environmental Protection Agency, 2012c). Mercury-free alternatives to dental amalgam include resin composites, resin and glass ionomers (a polymer containing an ion made of glass or resin and an organic acid), porcelain, or gold alloys. Although the cost of these alternative materials has decreased, the typical cost to the consumer selecting an alternative filling material is higher than the cost of using amalgam. A recent study suggests the basic cost for an amalgam filling is $144 compared with $185 for a composite filling (Concorde East/West Sprl, 2012, p. 2). These costs, however, do not include the costs associated with mercury collection, recycling, or mitigation of release of mercury emissions. In addition to cost, each type of restorative filling has certain advantages and disadvantages that must be evaluated by the consumer.

A study conducted by Concorde East/West Sprl (Concorde) suggests that he U.S. dental sector used about 30 t of mercury in 2009 (Concorde East/West Sprl, 2012, p. 21), a value considerably higher than that reported by the data collected by the IMERC. The NEWMOA recognizes that the data collected by the IMERC may underestimate the total amount of mercury sold in the United States because it does not include all sources of imported or exported material in its estimates (Northeast Waste Management Officials' Association, 2010b). The actual amount of mercury contained in dental amalgam used in the United States in 2010 likely is between the estimate of 18 t by the IMERC and the estimate of 30 t by Concorde (Adam Wienert, IMERC coordinator, Northeast Waste Management Officials' Association, oral commun., November 13, 2012). Assuming that domestic use in 2009 was similar to that in 2010, the available data suggest that as much as 12 t of mercury amalgam may have been imported to the United States to supplement the decreasing amount sold by domestic manufacturers. Figure 7 shows the mercury flow pattern for the dental sector in 2009 as developed by Concorde East/West Sprl. Mercury emissions data shown in figure 7 were developed based on data reported by Cain and others (2007).

Sources of mercury found in a dental office include new mercury amalgam purchased in predosed capsules, mercury amalgam removed from existing fillings, and mercury amalgam stocks in the dental office carried over from previous years. An additional source of mercury is amalgam recovered from lost teeth or teeth removed from deceased persons prior to burial or cremation.

The amount of mercury releases from dental amalgam to air, soil, and water as well as the effects of such releases on the environment and human health are being investigated by Government agencies and industry nongovernmental organizations. Of the 30 t of new mercury in dental amalgam reported to have been purchased by U.S. dental clinics in 2009 (Concorde East/West Sprl, 2012), 33 percent was discarded because it was not used during the procedure or it was removed from the tooth during the fitting of the filling (fig. 7). This relatively high discard rate can be attributed to the increasing use of

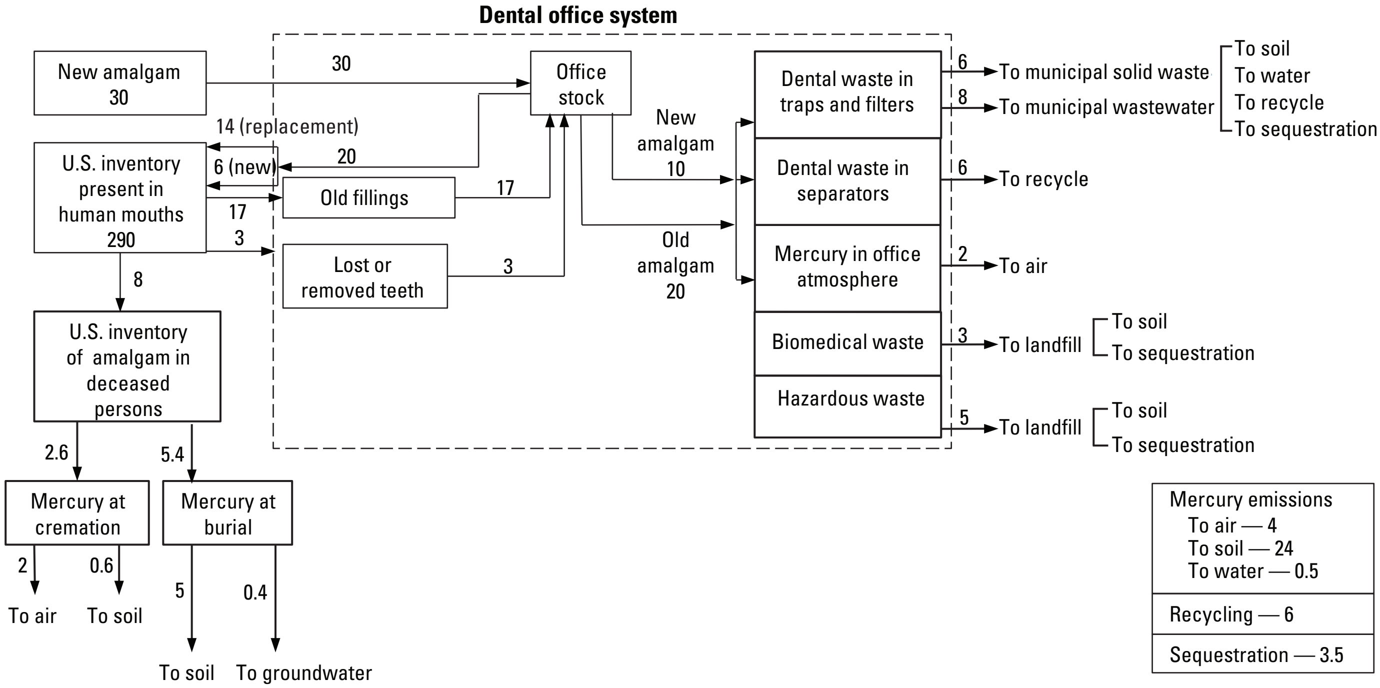

Figure 7. Material flow of mercury related to dental amalgam in 2009. Values are in metric tons. Adapted from Concorde East/West Sprl, (2012), except for emissions, which are from Cain and others (2007).

purchased, prepackaged amalgam ampoules; a filling may not require the amount of amalgam that is typically contained in the ampoule. Because 70 percent of all fillings are replacements of previous fillings, additional amalgam is lost by the removal of the old amalgam (Concorde East/West Sprl, 2012, p. 9).

Mercury waste related to amalgam is found in various forms. Wastewater containing mercury is collected in filters inserted in water lines, collected by amalgam separators, or sent directly to municipal facilities for further treatment. Solid biomedical waste or hazardous wastes generated by the office are collected and sent to hazardous waste landfills where the mercury is stored so that it is not emitted into the environment. Municipal waste facilities typically are able to remove about 90 percent of the mercury amalgam from wastewater (U.S. Environmental Protection Agency, 2012c). Based on available data, about 38 t of mercury was released into the environment, recycled, or stored annually (Cain and others, 2007). Mercury emissions generated in 2009 in the United States from the dental sector include 24 t of mercury emitted into the soil, 4 t emitted into the air, and 0.5 t entered into water systems. An additional 6 t of mercury was recycled, and 3.5 t was treated or stored in hazardous waste landfills.

An additional potential source of mercury contamination is dental amalgam found in the mouths of deceased persons. This source contributed to emissions of about 6 t of mercury to the soil and 2 t of mercury to the air in 2009 (Concorde East/West Sprl, 2012, p. 21). Mercury emissions from this source have been the subject of recent congressional hearings. Based on data from the Cremation Association of North America, the amount of mercury available from crematoria is expected to rise because of an increase in the number of cremations and an increase in the number of fillings per person cremated. One estimate suggests that mercury available from this source could increase from 3 t in 2009 to about 8 t in 2020 (Reindl, 2010).

Some dental amalgam settles out as a component of sewage sludge accumulated at municipal wastewater treatment plants. The EPA finalized rules in February 2011 that would reduce air emissions for mercury and eight other air pollutants from publically owned incinerators that burn sewage sludge to limit the release of dental mercury into the environment (U.S. Environmental Protection Agency, 2011). About 14 t of mercury generated at dental facilities was treated at municipal waste treatment facilities in 2009 (Concorde East/West Sprl, 2012).

Other Mercury-Containing Products

Mercury can be found in discarded electronic components, particularly computer batteries, backlit liquid-crystal display (LCD) screens, switches, and circuit boards. The amount of mercury in a computer may vary from 50 mg to 45 g (New England Zero Mercury Campaign, 2002); new computers are likely to contain less mercury. More than half of these electronic components are exported to Asia for recycling (O'Connell, 2004). Because mercury is often included in the "other metals" category of material recovered from computers and electronics when reported, information on the amount of mercury recovered from computers and electronics in the United States may not be accurate (National Safety Council, 1999).

A small amount of mercury is used in a variety of chemical products, including acids, alkalis, bleach, buffers, cleaning products, coating materials, dyes, fixatives, laboratory chemicals, preservatives, reagents, and stains. The content of mercury from mercury compounds, preservatives, and reagents is typically as much as 250 parts per million (ppm; Northeast Waste Management Officials' Association, 2008a).

About 0.9 t of mercury was sold in formulated compounds and products in 2001, 0.8 t in 2004, and 1.3 t in 2007 (Wienert, 2009). As of 2008, four States had in place restrictions on the sale and (or) distribution of formulated mercury-added products. A number of companies have begun phasing out the sale on some mercury-containing products. Use in this sector is expected to decrease as appropriate substitutes are developed. There is little likelihood of economic recovery of mercury from these sources because of the diffuse use and limited production numbers of mercury-containing formulated compounds and products.

Effect of the Mercury Export Ban Act of 2008 on the U.S. Mercury Industry

Much of the mercury that is being exported from the United States comes from mercury that has been recovered from recycled products, recovered from closed chloralkali facilities, or as a byproduct of gold and silver mining. Imported material from any of these sources may also be recycled and re-exported. The MEBA prohibits the sale or transfer of elemental mercury by Federal agencies to other government agencies or private entities after October 14, 2008, and prohibits the export of mercury from the United States after January 1, 2013. Mercury recovered through retorting must enter long-term storage as hazardous waste if it cannot be sold domestically. Mercury-containing products and waste and mercury compounds are not included under the ban and can continue to be manufactured and exported (U.S. Environmental Protection Agency, 2012d).

Banning mercury exports is expected to result in surplus elemental mercury inventories and reduce the amount of mercury-containing material imported for recycling. The DOE is developing options for long-term storage of elemental mercury and estimated that a storage capacity of 10,000 t of mercury would be necessary to handle the U.S. mercury storage requirement (U.S. Department of Energy, 2011, p. 3). Because no storage facility had been constructed as of January 2013, the DOE has allowed facilities to register to store mercury on site. As of 2013, two facilities had applied for storage permits from the DOE (Cynthia Manson, Industrial Economics, Inc., oral commun., February 12, 2013).

The long-term storage program for mercury is likely to affect mercury recycling by consumers, nonprofit recycling organizations, local recycling facilities, and the six leading mercury reprocessing companies. Much of the mercury recovered from chloralkali plants that closed before 2013 was exported; mercury recovered from chloralkali plants after the effective date of the MEBA in 2013 will likely be nominal (Bruce Lawrence, president, Bethlehem Apparatus Company, Inc., written commun., September 20, 2012). Potential sources of mercury that may require long-term storage include mercury stocks in the National Defense Stockpile and stocks held by the U.S. Department of Energy, mercury held by the two chloralkali plants closed in 2012, two remaining chloralkali plants in operation, mercury derived from gold mining in Nevada, and mercury held by reclamation and recycling facilities. Figure 8 summarizes the principal stockpiles of U.S. mercury as of 2010, along with estimates of the amount of mercury retained at each location.

Mercury users or recyclers no longer able to sell mercury on international commodity markets would likely lose revenue that would be gained by the sale of this mercury. In addition, they would be required to incur the costs for the storage of any mercury that could not be used domestically. Historically, the industry has not charged any fees for storing mercury from recycling consumer mercury products, but the DOE is required to assess fees for mercury storage. The MEBA may result in recyclers passing on the storage costs to customers in the form of increased charges for treating or reclaiming mercury, which may reduce the incentive for voluntary mercury recycling and therefore decrease the amount of recycling that takes place (Carpenter and others, 2011).

After the export ban takes effect, a possible alternative would be to export mercury byproducts and waste for conversion to elemental mercury outside the United States rather than continuing the current practice of retorting these materials in the United States and having to store the recovered mercury. Calomel recovered from the domestic gold industry and the chloralkali industry is the most likely material to be exported (U.S. Environmental Protection Agency, 2009, p. 36). For example, Bethlehem Apparatus Company, Inc. is considering moving its calomel recovery plant to Mexico to recover elemental mercury from gold ores mined in the United States and Latin America (Bruce Lawrence, president, Bethlehem Apparatus Company, Inc., written commun., September 20, 2012). Global recovery from the gold and chloralkali industries would likely be restricted to a few processors because the technology for recovery is highly specialized.

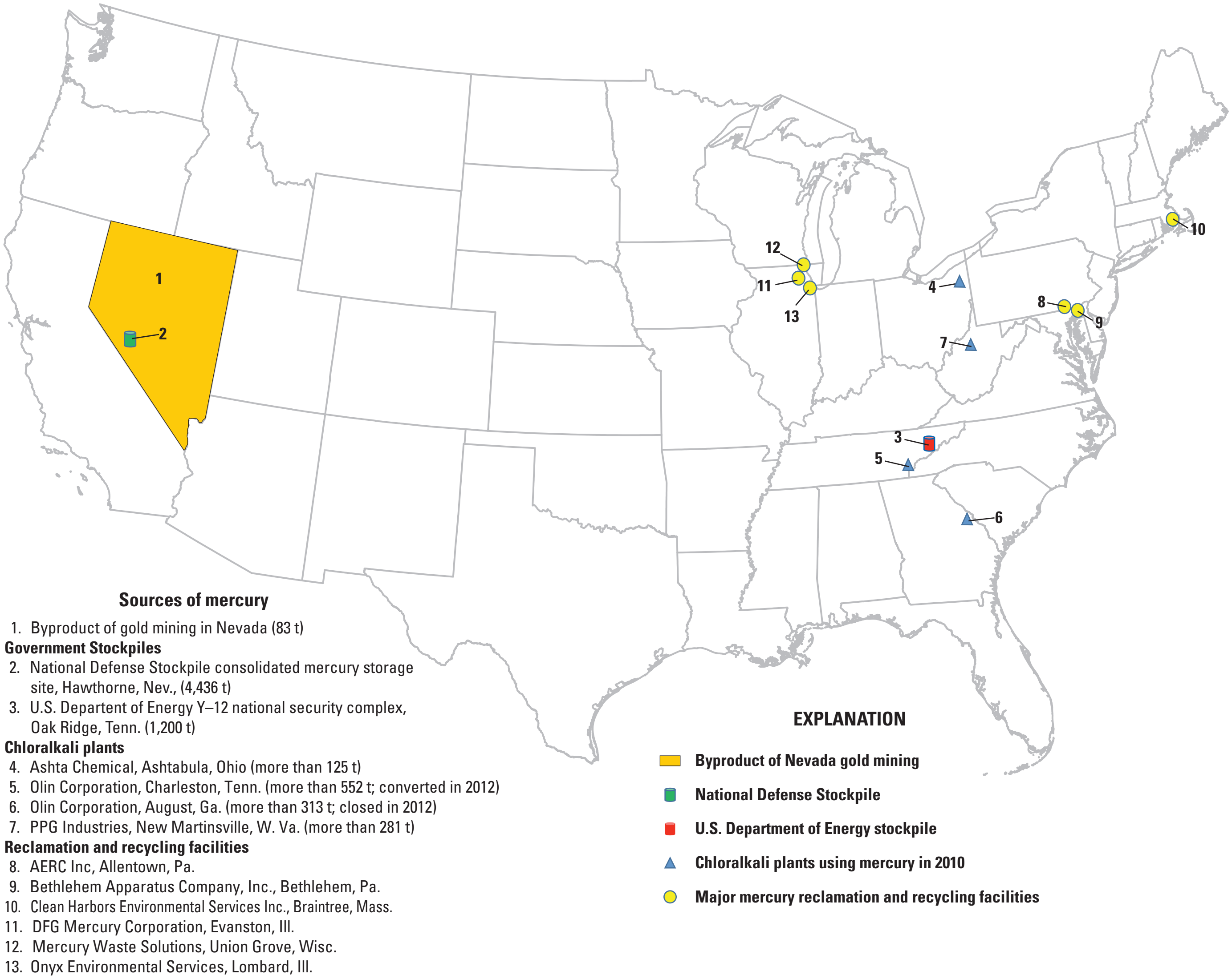

Figure 8. Location of leading production sources and inventories of mercury in the United States in 2010. Data represent production levels or inventory estimates reported (in metric tons (t)) and do not include mercury releases to air, land, or water. Data are from The Chlorine Institute, Inc. (2009), U.S. Environmental Protection Agency (2010), Brooks (2011), and U.S. Department of Energy (2011).

Summary and Conclusions

Consumption, production, and disposal of mercury in the United States have decreased as a direct result of increasing, stringent regulations and technological advancements related to mercury use. More than 20 Federal laws, rules, and regulations affecting mercury use have been enacted since 1970. The distribution of mercury use has changed significantly through regulation (paint and batteries), voluntary reduction by consumers (chloralkali manufacturing), and technological advances (dental, lighting, switches and relays). As global concern and regulation make it more difficult to import, use, sell, or dispose of mercury, consuming industries must increasingly rely on recycled mercury for needed supply or find acceptable substitutes for mercury.

Primary mercury in the United States is derived as a byproduct of processing gold and silver ore in Nevada. Data suggest that the amount of mercury recovered from gold processing operations in the United States has decreased by about 22 percent overall from 2001 through 2011; the average amount of mercury recovered annually is estimated to be 96 metric tons (t). In contrast, mercury emissions from the U.S. gold mining industry have decreased by 95 percent since 2001 as a result of increased regulation and improved collection and suppression technology (Elges, 2011).

The amount of new mercury used by the chloralkali industry, traditionally one of the leading industries that use mercury in the United States, has decreased by 98 percent from 136 t in 1996 (Sznopek and Goonan, 2000) to less than 3 t in 2010 because of increased processing and recycling efficiencies and plant closures or conversions; much of the mercury required for chloralkali production is derived from onsite recycling within the mercury-cell process. In 1996, 14 mercury-cell chloralkali plants were in production; in 2013, one or two mercury-cell chloralkali plants are expected to be in operation. Mercury air and solid waste emissions from chloralkali manufacturing have been reduced by about 85 percent from 2001 to 2008, but as plants are closed, mercury recovered from processing infrastructure of closed plants has been exported, making the United States a net exporter of mercury, even though no mercury has been mined in the United States since 1992. The Mercury Export Ban Act of 2008 (MEBA), prohibiting the sale, export, and transfer of elemental mercury in the United States after January 2013, is intended to limit mercury exports for unregulated uses such as artisanal gold mining in developing countries. Calomel produced from gold processing, often recovered by domestic mercury recyclers, may be exported for mercury recovery after the MEBA takes effect in 2013.

As the overall domestic use of mercury decreases and distribution in various products and devices has been reduced, the amount of mercury-containing old scrap generated from discontinued or discarded products has decreased from about 250 t in 2000 to about 72 t in 2010. In 2010, more than half the old scrap supply was derived from industrial waste generated from the treatment of remediated soils from a closed chloralkali plant, imported material, and mercury-containing waste generated from dental facilities. Available information suggests that, even though a significant percentage of this material is consumed, exported, or recycled, about 42 percent or 92 t of mercury scrap or waste was unrecovered, lost, or landfilled in 2010.

Regulations promulgated since 1990 to increase the energy efficiency of commercial and residential lighting have contributed to an average reduction of mercury use in general service fluorescent lamps by 77 percent since 1985, but have increased mercury use in general service fluorescent lamps by 6 t through encouraging the use of mercury-bearing compact fluorescent lights (CFLs) as a replacement for incandescent light bulbs. The growing market penetration of CFLs has increased the interest in recycling by the consumer, but recycling remains expensive relative to the price of the lamp. It is expected that light-emitting diodes (LEDs), which contain no mercury but are presently more expensive, will eventually replace CFLs in many applications.

The use of mercury in dental amalgam has been a source of growing concern and government investigation. Dental amalgam represents one of the leading uses of mercury in the United States at about 18 to 30 t annually and constitutes the largest amount of mercury in use in the United States. In 2009, an estimated 28.5 t of dental amalgam was released into the environment, 6 t was recycled, and 3.5 t was treated and stored in hazardous waste landfills (Cain and others, 2007; Concorde East/West Sprl, 2012). Principal sources of mercury-bearing dental waste include water sent to municipal waste treatment facilities, solid material collected in amalgam separators and recycled, and amalgam fillings contained in the bodies of deceased persons. Efforts are ongoing to research and promote the recovery of mercury from these sources.

Development of suitable alternatives for products and processes using mercury is ongoing. Mercury-free alternatives exist for most applications; costs are generally similar or higher than the mercury-containing product. In many cases, alternatives use less metal and more organic materials or electronics than their mercury-containing counterparts.

Much of the mercury contained in products that are recovered by municipal, State, or industry collection activities is recycled by one of six leading recycling companies that process this material and recycle the mercury for domestic use or export. Formal collection programs have been established to collect and recycle mercury from automotive switches, CFLs, dental amalgam, and thermostats. In spite of these programs, however, the overall recycling rate for mercury in products in the United States has remained low (at about 10 percent). Although reliable national statistics are not reported, the recycling rate for mercury worldwide is less than 10 percent. The DOE estimated that the average amount of mercury recovered annually from recycling operations in the United States at 62.5 t. Increasingly the U.S. recycling industry has been processing a significant amount of mercury-containing material derived from foreign gold mining operations or mercury-cell chloralkali plants that have been decommissioned. Since the European Union mercury export trade ban was enacted in 2011, some European companies have found it profitable to ship mercury-containing waste to the United States for elemental mercury recovery because they are unable to sell elemental mercury recovered within the European Union or on international markets.

Regulation of mercury export and storage is expected to result in surplus mercury inventories in the United States. Long-term storage of mercury from chloralkali plants, government stockpiles, and recycling industry stocks will be required after the MEBA goes into effect in 2013 unless mercury-containing products such as calomel are exported for foreign processing to elemental mercury rather than processing it in the United States. Costs attributed to long-term storage may affect the competitiveness of the recycling industry if consumers are unwilling to pay for increased charges for mercury treatment or reclamation. This in turn may reduce the incentive for voluntary mercury recycling and therefore reduce the amount of recycling that takes place.

Most mercury regulations relate to elemental mercury. There is still a considerable amount of mercury in use in the United States that is in the form of such chemical compounds as calomel or wastes, which are not covered by the MEBA. Therefore, exports of these materials may continue after 2012. Elemental mercury may be converted to nonregulated forms for export if markets for this material can be found and the cost to do so is less than the cost to store surplus elemental mercury. For example, Bethlehem Apparatus Company, Inc. is considering moving its calomel recovery plant to Mexico to recover elemental mercury from gold ores mined in the United States and Latin America (Bruce Lawrence, president, Bethlehem Apparatus Company, Inc., written commun., September 20, 2012).

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