REPORT TO CONGRESS

Potential Export of Mercury Compounds from the United States for Conversion to Elemental Mercury

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United States Environmental Protection Agency
Office of Pollution Prevention and Toxic Substances
Washington, DC 20460

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Acronyms and abbreviations

BDAT	Best Demonstrated Available Technology
BRS	Biennial Reporting System
COD	Chemical Oxygen Demand
DOD	United States Department of Defense
DOE	United States Department of Energy
EPA	United States Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
EU	European Union
HTS	Harmonized Tariff Schedule
IMERC	Interstate Mercury Education and Reduction Clearinghouse
U.S. ITC	United States International Trade Commission
IUR	Inventory Update Reporting
MEBA	Mercury Export Ban Act of 2008
kg	kilogram
mg/kg	milligrams per kilogram (= parts per million)
mg/l	milligrams per liter
mt	metric tons
NDEP	Nevada Division of Environmental Protection
NEWMOA	Northeast Waste Management Officials' Association
NMCP	Nevada Mercury Control Program
NvMACT	Nevada maximum achievable control technology
OPTC	Operating Permit to Construct
ppm	parts per million
RCRA	Resource Conservation and Recovery Act of 1976
SRS	Substance Registry Services
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
VMRP	Voluntary Mercury Reduction Program

Executive Summary

Introduction: Background and Purpose

Mercury is a naturally occurring element that is mobilized in the environment from natural sources (such as volcanoes) and human activities (such as industrial combustion and mining). Mercury is well-documented as a toxic chemical that is atmospherically transported on a local, regional, and global scale by cycling among air, land, and water. Because it is an element, mercury does not degrade.

Elemental mercury can be transformed in the environment into methyl mercury, which can be highly toxic depending on exposure and which biomagnifies in fish, including species consumed by humans. A number of adverse health effects associated with exposure to methyl mercury have been identified in humans and in animal studies. Most extensive are the data on neurotoxicity, particularly in developing organisms. The nervous system is considered to be the most sensitive target organ.

EPA is working on both domestic and international fronts to reduce mercury in the environment and to prevent human exposure to it. The Agency has issued regulations to reduce mercury releases to air, water, and land; and works with a variety of stakeholders, including the waste management and health care industries, to encourage voluntary efforts to reduce or eliminate mercury pollution.

The Mercury Export Ban Act of 2008 (MEBA), signed on October 14, 2008, prohibits the export of elemental mercury from the United States beginning in 2013. MEBA does not ban the export of mercury compounds. The prohibition on export of elemental mercury is intended to reduce the availability of elemental mercury on the global market. MEBA contains several other provisions and requires federal agencies to submit reports and other information to Congress.

This report is submitted to fulfill Section 4 of MEBA, which states:

> “REPORT TO CONGRESS ON MERCURY COMPOUNDS -
>
> (A) REPORT- Not later than one year after the date of enactment of the Mercury Export Ban Act of 2008, the Administrator shall publish and submit to Congress a report on mercuric chloride, mercurous chloride or calomel, mercuric oxide, and other mercury compounds, if any, that may currently be used in significant quantities in products or processes. Such report shall include an analysis of—
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> (i) the sources and amounts of each of the mercury compounds imported into the United States or manufactured in the United States annually;
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> (ii) the purposes for which each of these compounds are used domestically, the amount of these compounds currently consumed annually for each purpose, and the estimated amounts to be consumed for each purpose in 2010 and beyond;
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> (iii) the sources and amounts of each mercury compound exported from the United States annually in each of the last three years;

> (iv) the potential for these compounds to be processed into elemental mercury after export from the United States; and
>
> (v) other relevant information that Congress should consider in determining whether to extend the export prohibition to include one or more of these mercury compounds.."

Selection of Mercury Compounds for Assessment in this Report

EPA began with a list of approximately 200 mercury compounds and identified 12 which are currently produced and have some technological feasibility to be exported for elemental mercury generation. The group of twelve compounds includes the three identified by MEBA to be in this report. All but one of the selected compounds are manufactured (or imported) in very small quantities and used as specialty chemicals. In 2004, which is the most recent year that data are available, total sales of these chemicals were less than one metric ton.

Several of the selected mercury compounds also occur in industrial waste or byproducts. The only available quantity estimate is for byproduct mercury(I) chloride. Approximately 25 metric tons of elemental mercury is obtained annually from processing byproduct mercury(I) chloride. Mercury(I) chloride is one of the three compounds identified in MEBA, where it is referred to as "mercurous chloride or calomel."

Although there is a significant quantity of only one compound, mercury (I)chloride, EPA assessed all 12 for their potential to be produced in larger quantities for export. An incentive for such production might result from the surplus of elemental mercury caused by the MEBA ban on exports of elemental mercury beginning January 1, 2013. The excess mercury will need to be placed in permitted, long-term storage if it is not used. Costs of storage could be avoided for elemental mercury that is converted into mercury compounds for export and subsequent reconversion to elemental mercury in other countries. This scenario is the reason EPA assessed mercury compounds that are currently marketed in the United States in very small quantities.

Some of the 12 mercury compounds manufactured as specialty chemicals, and identified for closer assessment in this report, also occur as industrial byproducts or waste. The assessment took into account these additional volumes because after the export ban takes effect, it may be more economical to export byproducts and waste for conversion to elemental mercury outside the United States than to continue the current practice of retorting them in the United States and having to store the resulting elemental mercury. EPA did not find any mercury compounds contained in byproducts or waste that are not also in the group of 12 already identified.

EPA did not include in its assessment wastes with *de minims*[1] amounts of mercury compounds. Also excluded from this report are any mercury compounds in coal or resulting from coal combustion or found in manufactured consumer products. EPA did not assess these sources because of language in the legislative history of MEBA: "the Committee does not intend that this prohibition [ban on export of elemental mercury] prevent exportation of coal or fly ash, a

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[1] The term de minimis is used in this report to mean "insignificantly small."

by-product of coal combustion, or manufactured consumer products containing elemental mercury."[2] EPA reasoned that if Congress did not prohibit export of mercury occurring in manufactured consumer products or materials from coal combustion, then it was not important to assess the export of compounds in those items at this time.

Data Limitations

Information is not available at the level of specificity for all report topics required by MEBA. The act directs EPA to report on the sources and annual amounts of each mercury compound manufactured, imported, and exported; the uses of each compound; the annual amounts of each use; and estimates of each future use. There is limited public data on amounts of mercury compounds sold as specialty chemicals and on the uses of those chemicals that is collected by 14 states. The information is available for the years 2001 and 2004. There is not enough time-series sales data to provide a basis for accurately estimating future use.

More significant quantities of mercury compounds are produced in byproducts and waste, but quantity information is not collected. Import and export quantities and countries are reported only for mercury compounds as a group, and these aggregate amounts are not consistent enough to be useful.

Mercury Compound Sources, Amounts, Purposes, and International Trade

Mercury(I) chloride is the highest volume mercury compound generated in the United States. While it is manufactured in small amounts for specialty uses such as chemical and pharmaceutical applications, the large quantities generated and traded in the United States (roughly 25 metric tons of elemental mercury) are contained in byproducts from pollution control activities at gold mines. Elemental mercury is processed from byproduct mercury(I) chloride. An unknown quantity of mercury(I) chloride is imported into the United States, also for conversion to elemental mercury.

Four other mercury compounds (mercury(II) oxide, mercury (II) selenide, mercury(II) sulfide, and mercury(II) sulfate) can occur as byproducts or in waste; quantities are not known. All twelve mercury compounds are made as specialty chemicals that are sold for pharmaceutical and laboratory uses in quantities ranging from 0.2 kilograms to 261 kilograms. The quantities of imports and exports of these compounds are not known.

EPA was unable to find any evidence that compounds are currently exported from the United States for processing into elemental mercury in other countries.

Potential for Export of Mercury Compounds to be Used as a Source for Elemental Mercury

For each selected individual mercury compound, EPA evaluated both the technological feasibility and the economic feasibility of creating, shipping, and processing the compound into elemental mercury.

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[2] S. Rep. No. 110-477. 2008. Senate Report 110-477 – Mercury Market Minimization Act of 2007. Available online at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_reports&docid=f:sr477.110.pdf

Technological Feasibility

Mercury compounds that could be exported for the purpose of regenerating elemental mercury must be readily available (or easily generated), chemically stable, transportable, and easily converted to elemental mercury. Chemical processes ideally suited to this end will use inexpensive, readily available reagents, and simple procedures and equipment.

Economic Feasibility

In addition to being technologically feasible, it must be economically feasible to export compounds as a substitute supply for elemental mercury. For manufactured mercury compounds, economic feasibility requires that the costs of creating and exporting mercury compounds, combined with the cost of regenerating the elemental mercury in other countries, will be lower than the cost of producing elemental mercury from sources outside of the United States. If the mercury compound is produced as a byproduct or as part of a waste stream, then there is no "production" cost. After the export ban, there will be a cost to store the surplus elemental mercury that is produced from byproducts and waste. It will be economically feasible to export byproducts and waste containing mercury compounds for conversion to elemental mercury abroad only if the avoided costs of storage (or other disposition of the mercury in the United States), added to the revenue from selling elemental mercury abroad, are greater than the costs of shipment and overseas processing.

EPA qualitatively characterized the costs, cost savings, and revenue expected to result if mercury compounds are exported for conversion to elemental mercury. These findings were considered in light of certain characteristics of the global market for elemental mercury. For example, if a firm considered scaling up production of a mercury compound because of the abundance of elemental mercury in the United States after the ban, it would need to take into account the fact that world mercury prices are likely to remain stable in the long-run ,world demand is uncertain (due to declining use in many countries and rising use in artisanal gold mining), and large secondary sources of mercury may be available from tailings from mining, smelting, and natural gas, and from stockpiles in various countries.

Other Relevant Information

An understanding of the European Union's export ban is relevant to consideration by the U.S. Congress of expanding the U.S. ban to include mercury compounds. On October 22, 2008, the European Union expanded its future ban on the export of metallic (i.e., elemental) mercury to include:

- cinnabar ore[3]
- mercury(I) chloride
- mercury(II) oxide, and

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[3] Cinnabar ore is mercury(II) sulfide and is abundant in the European Union.

- mixtures of metallic mercury with other substances, including alloys of mercury, with a mercury concentration of at least 95 percent by weight.

The amended EU export ban provides exceptions for research and development, medical, or analysis purposes. Also, the EU regulation prohibits mixing metallic mercury with a substance for the sole purpose of export of metallic mercury. The effective date of the ban on exports (including metallic mercury) is March 15, 2011.

Summary of Information Required for this Report

This table presents in brief form EPA's research and analysis on each topic required in Section 4 of MEBA. Findings in the last column (potential for export) are developed more fully in the Conclusions section immediately following the table.

Table ES-1: Summary of Information on Mercury Compounds Required in the Mercury Export Ban Act of 2008

	Produced in U.S.		Imported						
Compound Name	Source Sector	Quantity in 2004 (kg)	Source	Quantity (annual)	Purposes and Uses	Quantity used annually in U.S.	Quantity used 2010 & after	Sources and quantities exported in last three years (2006, 2007, 2008)	Potential for export for regeneration of elemental mercury
Mercury(I) chloride	Air pollution byproduct at mines	~25,000Hg	Data for individual compounds not currently available	Data for individual compounds not currently available	1. Processed for elemental mercury regeneration	Data for individual compounds not currently available	Data on which to base projections are not currently available	Data for individual compounds not currently available	Likely
	Chemical manufacturing	1.3			2. Calomel (mercury(I) chloride) electrodes				Unlikely
Mercury(II) nitrate	Chemical manufacturing	88.7			1. Preparation of other mercuric products 2. Analytic reagent (test kits)				somewhat likely
Mercury(II) oxide	Chemical manufacturing; Battery recycling	32.5			1. Batteries 2. Synthesis of other mercury compounds 3. Analytical reagent				somewhat likely
Mercury(II) sulfate	Chemical manufacturing; Waste treatment	260.8 (amount from waste treatment unknown)			1. Gold and silver extraction 2. Reagent				somewhat likely
Mercury(II) sulfide	Naturally occurring; Chemical manufacturing; Waste treatment	0.6 (amount from waste treatment unknown)			1. Extraction of elemental mercury 2. Pigment				somewhat – Unlikely
Mercury(II) acetate	Chemical manufacturing	41.3			1. Manufacture of organomercuric compounds 2. Catalyst or reagent				Unlikely

Table ES-1: Summary of Information on Mercury Compounds Required in the Mercury Export Ban Act of 2008

	Produced in U.S.		Imported						
Compound Name	Source Sector	Quantity in 2004 (kg)	Source	Quantity (annual)	Purposes and Uses	Quantity used annually in U.S.	Quantity used 2010 & after	Sources and quantities exported in last three years (2006, 2007, 2008)	Potential for export for regeneration of elemental mercury
Mercury(II) chloride	Chemical manufacturing	76.8	Data for individual compounds not currently available	Data for individual compounds not currently available	1. Catalyst or reagent 2. Mercury capture waste procedures	Data for individual compounds not currently available	Data for individual compounds not currently available	Data for individual compounds not currently available	Unlikely
Mercury(II) iodide	Chemical manufacturing	11.3			1. Mayer's or Nessler's reagent 2. Nuclear particle detection instruments				Unlikely
Phenyl mercury(II) acetate	Chemical manufacturing	0.2			1. Preservative 2. Preparation of other phenylmercury compounds				Unlikely
Mercury(II) selenide	Mining waste; Waste treatment	Unknown.			1. Mining waste 2. Mercury capture waste procedures 3. Semiconductor				Very Unlikely
Mercury(II) thiocyanate	Chemical manufacturing	6.4			1. Analytical reagent 2. Photography (intensifier)				Very Unlikely
Thimerosal	Chemical manufacturing	Unknown			1. Preservative				Very Unlikely

* Estimate based on discussions with Melissa Barbanell, Barrick Gold Corporation (personal communication June 18, 2009) and refers to mercury content only.

Conclusions of Assessment of Potential for Export of Mercury Compounds

- One mercury compound, mercury(I) chloride, is likely to be exported and processed into elemental mercury after export. This compound is currently produced in significant quantities as a byproduct of U.S. gold mining, then converted to elemental mercury. After the export ban, producers will have incentives to avoid the cost of retort (conversion to elemental mercury using heat) and long-term storage of the elemental mercury. Mercury(I) chloride is easily reduced to elemental mercury and the yield is high (85% by weight). It is not clear, however, that global recovery of elemental mercury from mercury(I) chloride would spread beyond a handful of sophisticated processors, because the technology for recovery is highly specialized.

- Three other mercury compounds could possibly be exported and processed into elemental mercury after export. Mercury(II) oxide, mercury(II) sulfate, and mercury(II) nitrate are readily available as a byproduct or produced easily from surplus elemental mercury. They are easily reduced to elemental mercury and the yield is high (ranging from 62% to 93%). These compounds are produced in the United States, so some capacity exists, although quantities are small. However, significant capital investment would be required to produce larger quantities in the United States, and it is not clear that anticipated elemental mercury prices are high enough to justify the investment at this time. Mercury(II) sulfate is also currently generated as waste, which could possibly be purified for sale or exported.

  Production of mercury(II) nitrate and mercury(II) sulfate involves the handling of toxic substances such as sulfuric acid and generates mercury-containing wastes, which can increase expenses. Mercury(II) oxide is an interim product of several recovery processes and is relatively simple to manufacture, though it generally is produced from other compounds, including mercury(II) sulfate and mercury(I) chloride, and is more inefficient to produce from elemental mercury.

  If mercury(I) chloride export is banned, it is possible that production of mercury(II) oxide could become more cost-competitive. Because mercury(II) oxide is currently produced as an interim product in processing mercury(I) chloride, an increase in domestic mercury(I) chloride supplies would likely reduce the cost of producing mercury(II) oxide.

- It is not likely that the other eight mercury compounds assessed in this report will be exported and processed into elemental mercury. These compounds are currently produced only in small quantities for specialized laboratory or industrial uses. These eight compounds either cannot be converted to elemental mercury by heating or require manufacturing from other chemicals and thus require an extra production step. Producing, exporting, and converting these compounds into elemental mercury is likely to be too costly compared with costs of supplying mercury to the global market from other sources.

1. Introduction

1.1 Background

1.1.1 Concern about Mercury in the Environment

Mercury is a naturally occurring element. Mercury is mobilized from natural sources (such as volcanoes) and human activities (such as industrial combustion and mining) and mercury contamination is widespread in the United States and global environment. Human activities have increased the amount of mercury that is mobilized in the atmosphere; in soils and sediments; and in lakes, streams, and oceans (U.S. EPA, 2006, EPA's Roadmap for Mercury). Mercury can then be transported, depending on the form emitted and other factors, on local, regional and global scales before depositing in water. In aquatic ecosystems, mercury can be environmentally transformed into the organic form of mercury, methyl mercury, which can bioaccumulate and biomagnify through food webs, and is highly toxic.

Mercury exposure can cause a number of adverse effects on human health. These effects vary depending on the form of mercury to which a person is exposed and the level and length of exposure. The primary way humans are exposed to mercury is through eating fish containing methyl mercury. Methyl mercury exposure can cause neurological impairment, though research shows that most people's fish consumption does not cause a health concern (U.S. EPA, 2006). Fetuses and very young children are more sensitive to methyl mercury than adults. Methyl mercury in the mother's body passes to the fetus and may accumulate there. There is evidence in adults that methyl mercury also affects other systems. Specifically, some studies suggest that prolonged exposure to methyl mercury, especially at higher levels, can harm the heart, kidneys, and immune system. However, additional studies are needed to better categorize the effect of methyl mercury on these health endpoints (U.S. EPA, 2006). In addition to methyl mercury, individuals may also become exposed to harmful levels of elemental mercury found indoors in work places and in homes. When exposed to air, elemental mercury volatilizes and can be inhaled (U.S. EPA, 2006).

EPA is working to reduce mercury in the environment and to prevent exposure to humans. EPA and the Food and Drug Administration issued joint fish consumption advisories in 2004 and updated the national listing of fish advisories in 2007 which is an advisories database that includes advisories issued by state authorities. On an ongoing basis, EPA issues regulations to reduce mercury releases to air, water, and land, and works with many others, including several industries, such as waste management and health care, to encourage voluntary efforts to reduce or eliminate mercury pollution. In addition, EPA works with other countries to reduce mercury pollution (U.S. EPA 2009a). One EPA initiative concerned the problem of surplus quantities of commodity-grade mercury in the United States. In 2007, EPA brought together stakeholders to receive information and suggestions on options for managing this privately-held mercury.

1.1.2 Elemental Mercury: Chemistry, Uses, and DOD and DOE Surpluses

Elemental mercury (Hg^0) is unique among metals because it is a liquid at room temperature, it has a low boiling point, and it has high vapor pressure. Elemental mercury's high vapor pressure facilitates its removal from mixtures by volatilization, and thermal decomposition of mercury compounds at elevated temperatures often generates elemental mercury vapor, which can be condensed and collected (i.e., "retorted"). Elemental mercury can also react to form compounds in either the (Hg^{1+}) or (Hg^{2+}) oxidation state. Many of these mercury compounds, such as the halide salts, oxides, and nitrates, can be readily interconverted or transformed back into elemental mercury. In addition, mercury forms stable, covalent bonds with carbon or can form metallic bonds in metal alloy mixtures commonly called amalgams (Patnaik, 2003).

Because of these properties, humans have used mercury for a variety of purposes beginning thousands of years ago. In modern times, mercury has been used as a processing agent in the mining of gold, as a cathode in the manufacture of chlorine and caustic soda, and as a component in several types of industrial and consumer products, including measurement, switch, and lighting applications.

The U.S. Department of Defense and the U.S. Department of Energy (DOE) formerly stockpiled elemental mercury for use in a range of applications. Prior to 2008, both agencies voluntarily committed to storing, rather than selling, their mercury stockpiles. The Mercury Export Ban Act of 2008 (MEBA) specifically prohibits federal agencies from selling, distributing, or transferring elemental mercury except to facilitate storage.

In private markets in the United States, the European Union, and other industrialized countries, use of mercury has declined as substitutes have become available. Mining of mercury ore in the United States essentially stopped in the mid-1990s, though production of elemental mercury as a byproduct at gold mines continues where ores of gold also have substantial quantities of naturally-occurring mercury. At the same time, elemental mercury is also regenerated from industrial processes and made available for reuse. Concern exists that this regenerated elemental mercury can be used in ways that result in human exposure and environmental release. Of particular concern is the increasing use of elemental mercury (in developing countries) as a processing agent to extract gold from rock and soil by poor, small-scale gold miners, including women and children. These artisanal miners are often exposed to mercury through inhalation, and elemental mercury that is not recaptured for reuse is released to air, water, and land during this use.

1.1.3 Summary of U.S. Mercury Export Ban

The MEBA, enacted on October 14, 2008, includes the following provisions:

- The export of elemental mercury from the United States is prohibited, effective January 1, 2013
- Effective immediately upon enactment, Federal agencies are prohibited from conveying, selling or distributing elemental mercury under Federal control or jurisdiction to any other Federal agency , any State or local government agency, or any private individual or entity except for transfers to facilitate storage or transfers of coal
- The Federal government must provide long-term management and storage of any elemental mercury generated within the United States
- EPA and DOE are responsible for submitting the following to Congress:

  - A report on mercury compounds (to be submitted by EPA no later than October 14, 2009);
  - Annual reports on the previous year's incurred costs associated with the long-term storage and management of elemental mercury (to be submitted by DOE no later than 60 days after the end of each fiscal year);
  - A study on the impact of the long-term storage program on mercury recycling (to be submitted by DOE no later than July 1, 2014); and
  - A report on global supply and trade of elemental mercury (to be submitted by EPA at least three years after the effective date of the export prohibition but no later than January 1, 2017).
- DOE is to make available guidance related to the procedures and standards for receipt, management, and long-term storage of elemental mercury (no later than October 1, 2009 by DOE)

MEBA bans the export of elemental mercury from the United States, but does not ban the export of mercury compounds.

1.1.4 Summary of EU Export Ban on Mercury and Mercury Compounds

In 2007, the European Union passed a regulation banning the export of elemental mercury. On October 22, 2008, the European Union expanded the mercury export ban to include certain mercury compounds and mixtures. This ban applies to exports after March 15, 2011. The expanded ban prohibits the export of metallic mercury (elemental mercury), mercury(I) chloride; mercury(II) oxide; cinnabar ore; and mixtures of metallic mercury with other substances, including alloys of mercury, with a mercury concentration of at least 95 percent by weight.[4] There are exceptions to the ban for elemental mercury or mercury compounds used for research and development, medical, or analysis purposes. For further information on the EU ban, see Section 5.1, European Union Ban on Export of Mercury and Mercury Compounds.

1.1.5 Relationship Among Mercury Compounds, International Mercury Demand, and the U.S. Mercury Export Ban

Elemental mercury is currently a commodity that is bought and sold worldwide. The U.S. export ban will not change the fact that excess mercury will continue to be produced in the United States and that mercury trade will continue in the international market. The situation raises the question of whether mercury compounds could be exported from the United States for subsequent processing into elemental mercury in other countries.

There are two possible sources of material in the United States for development of compounds that can be exported to make elemental mercury available abroad:

1. Compounds that already exist in the U.S. market, either as manufactured products, byproducts of mining and industrial processes, or in industrial waste, could potentially be exported and then converted to elemental mercury.

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[4] Mercury(II) sulfide as cinnabar ore is abundant in the European Union. In the U.S., however, mercury(II) sulfide is primarily a manufactured compound.

2. Under certain economic conditions, surplus elemental mercury could potentially be used to manufacture large volumes of mercury compounds in the United States, which could then be exported and reprocessed outside the United States to regenerate the elemental mercury.

Manufacture and export of mercury compounds in volumes sufficient to provide a supplemental source of elemental mercury would most likely focus on compounds that are readily available or easily generated, stable, transportable, and readily converted back into elemental mercury. Chemical processes ideally suited to this end will utilize inexpensive, readily available reagents, and simple procedures and equipment. In short, to be economically feasible, the total process of manufacture, export, and reprocessing of compounds to regenerate elemental mercury must be competitive with the price of elemental mercury.

1.1.6 Statutory Requirements of the Report to Congress on Mercury Compounds

The requirement to submit the Report to Congress on Mercury Compounds, as contained in Section 4 of MEBA, reads as follows (with bold and underlining added to identify key elements of the report):

> REPORT TO CONGRESS ON MERCURY COMPOUNDS -
>
> (A) REPORT- Not later than one year after the date of enactment of the Mercury Export Ban Act of 2008, the Administrator shall publish and submit to Congress a report on mercuric chloride [i.e., mercury(II) chloride], mercurous chloride or calomel, [i.e., mercury(I) chloride], mercuric oxide, [i.e., mercury(II) oxide] and other mercury compounds, if any, that may currently be used in significant quantities in products or processes. Such report shall include an analysis of—
>
> (i) the **sources and amounts** of each of the mercury compounds **imported** into the United States or **manufactured** in the United States annually;
>
> (ii) the **purposes** for which each of these compounds are used domestically, the **amount** of these compounds currently consumed annually for each purpose, and the estimated **amounts to be consumed for each purpose in 2010 and beyond**;
>
> (iii) the **sources and amounts** of each mercury compound **exported** from the United States annually in each of the last three years;
>
> (iv) the **potential for these compounds to be processed into elemental mercury after export** from the United States; and
>
> (v) **other relevant information** that Congress should consider in determining whether to extend the export prohibition to include one or more of these mercury compounds.
>
> (B) PROCEDURE- For the purpose of preparing the report under this paragraph, the Administrator may utilize the information gathering authorities of this title, including sections 10 and 11.

1.2 Purpose of the Report

This report fulfills the requirement for the Report to Congress on Mercury Compounds under Section 4 of MEBA. It:

- provides the information available on sources, amounts, and uses of mercury compounds;
- assesses the potential for these compounds to be processed into elemental mercury after export from the United States; and
- as required, conveys information for Congress to consider in determining whether to extend the export ban to include one or more mercury compounds.

1.3 Report Organization

This report is organized by the sequence of topics in MEBA (see Section 1.1.6). A text box that maps to the requirements in the Act accompanies each relevant section of this report. There are five chapters in addition to the introduction: Chapter 2, Selection of Mercury Compounds and Discussion of Data Availability ; Chapter 3, Sources, Uses, and International Trade; Chapter 4, Potential for Export of Mercury Compounds To Be Used as a Source for Elemental Mercury; Chapter 5, Other Relevant Information to Assist Congress in Determining Whether to Extend the Export Ban ; and Chapter 6, Report Conclusions These chapters are followed by four appendices: Appendix A presents summary information about the mercury compounds addressed in this report, Appendix B describes how EPA's Inventory Update Reporting (IUR) database was used to identify mercury compounds for in-depth review, Appendix C presents more detailed information on the individual compounds addressed in this report, and Appendix D presents more detailed information on the chemistry of mercury compounds.

2. Selection of Mercury Compounds and Discussion of Data Availability

2.1 Method of Selecting Mercury Compounds Included in This Report

The compounds examined in this report include all mercury compounds that are produced or used in the United States in significant quantities. The report focuses in more detail on compounds that EPA considers to have some potential to be processed into elemental mercury after export. Over 200 mercury compounds exist in the United States, originating from the following three sources:

- **Manufactured mercury compounds.** These include compounds that are specifically developed as chemical products for use in laboratory settings or in the development of other products.
- **Byproducts.** Some mercury compounds are produced during the process of making other products of value. The primary example is mercury(I) chloride (commonly known as calomel), which is produced in significant quantities as part of the process of mining and refining gold at mines, and is used as a raw material for processing to regenerate elemental mercury. Byproduct compounds can be produced in significant quantities and are readily available to the market at low or no cost.
- **Industrial waste.** Several compounds are produced in waste streams generated in the United States in varying quantities. These wastes may contain only *de minimis* concentrations of mercury compounds in which case they would not be likely to be exported to supply elemental mercury. However, it is theoretically possible that in some circumstances, wastes with mercury compounds might be exported for conversion to elemental mercury.

For completeness, EPA also considered naturally occurring mercury compounds in the earth's crust as well as stockpiled mercury compounds**.** The ban on exports of elemental mercury could create an economic incentive to export compounds from these origins.

Excluded from this report are any mercury compounds resulting from coal combustion or found in manufactured consumer products. EPA did not assess these sources because of language in the legislative history of MEBA: "the Committee does not intend that this prohibition [ban on export of elemental mercury] prevent exportation of coal or fly ash, a by-product of coal combustion, or manufactured consumer products containing elemental mercury." [5] EPA reasoned that if Congress did not prohibit export of elemental mercury occurring in manufactured consumer products or materials from coal combustion, then it was not important to assess the export of mercury compounds in those items at this time. Furthermore, EPA knows of no use of mercury compounds contained in manufactured consumer products.

This section explains EPA's process for identifying and evaluating the compounds in this report. While a range of mercury compounds are manufactured for specific uses, EPA has

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[5] S.Rep. No. 110-477. 2008. Senate Report 110-477 – Mercury Market Minimization Act of 2007. Available online at: http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=110_cong_reports&docid=f:sr477.110.pdf

determined that the most significant quantities of mercury compounds in the United States occur as byproducts or in waste. In some cases these compounds are currently used as raw material and converted to elemental mercury. Because MEBA will restrict U.S. elemental mercury exports, it may become more economically feasible to process and export these byproduct compounds and regenerate elemental mercury after export. For these reasons, EPA includes these byproduct or waste compounds in the scope of this report, regardless of the extent to which they are currently used as compounds. However, wastes containing *de minimis* amounts of mercury compounds are unlikely to be candidates for export and conversion to elemental mercury.

2.1.1 Note on Dental Amalgam

EPA does not address dental amalgam in this report because it is not a compound. Dental amalgam is a mercury-containing product in which small, individual-use quantities of elemental mercury are packaged in separate containers from other ingredients and delivered as a "kit" of separate ingredients to dental offices. The elemental mercury remains separate until application, at which point it is mixed into an individual application of alloy.

2.1.2 Criteria for Inclusion

EPA used the following criteria to identify mercury compounds for this report:

- MEBA specifically requires the compound to be in the report (mercuric chloride (identified in the report as Mercury(II) chloride), mercurous chloride (Mercury(I) chloride), and mercuric oxide);
- At least 25,000 pounds (11,340 kilograms) of the compound was manufactured at a single site in at least one of the years since 1986, according to the Inventory Update Rule (IUR) reporting database;
- It was sold in the United States in 2001 and 2004, the two years for which data were collected for the Interstate Mercury Education and Reduction Clearinghouse database (IMERC) of the Northeast Waste Management Officials' Association (NEWMOA);
- The compound has potential for export in order to provide a source of elemental mercury, due to technical ease of production and conversion back to elemental mercury; or
- The mercury compound is produced in significant quantities as an industrial or mining byproduct or waste.

Table 2-1 lists the mercury compounds addressed in this report and the criteria for their inclusion.

Table 2-1: Mercury Compounds by Criteria for Inclusion in the Report

Compound	CAS Number	Criteria for Inclusion
Mercury(I) chloride	10112-91-1	1, 2, 3, 4, 5
Mercury(II) acetate	600-27-7	2, 3
Mercury(II) chloride	7487-94-7	1, 2, 3
Mercury(II) iodide	7774-29-0	3
Mercury(II) nitrate	10045-94-0	3, 4
Mercury(II) oxide	21908-53-2	1, 3, 4
Mercury(II) selenide	20601-83-6	5
Mercury(II) sulfate	7783-35-9	3, 4, 5
Mercury(II) sulfide	1344-48-5	3, 5
Mercury(II) thiocyanate	592-85-8	3
Phenylmercury(II) acetate	62-38-4	2
Thimerosal	54-64-8	3

Legend:
1. Specifically required for this report by MEBA
2. More than 25,000 pounds (11,340 kilograms) were produced at single site in any single reporting year since 1986
3. Manufactured or imported as a specialty chemical
4. Technologically feasible to export and convert to elemental mercury abroad
5. Produced in potentially significant quantities, including as a waste or byproduct

2.2 Data Sources and Limitations

EPA used a variety of sources to collect data on the domestic manufacture, imports, exports, byproduct production, and occurrence in waste streams of mercury compounds. Most of these databases have one or more important limitations when used for information on mercury compounds. In most cases, the limitations are due to the data source having been designed for other purposes.

2.2.1 Substance Registry Services Database

The Substance Registry Services (SRS) is EPA's central registry for information about regulated and monitored substances. The SRS identifies any EPA data systems, environmental statutes, or other sources that contain information about a particular substance. Substances include chemicals, biological organisms, physical properties, and miscellaneous objects. The SRS Database was used to identify mercury compounds for inclusion in this report.

2.2.2 Inventory Update Reporting Database

EPA regulations require manufacturers and importers of certain chemical substances included in the Toxic Substances Control Act (TSCA) Chemical Substance Inventory to report site and manufacturing information for chemicals (including imported chemicals) manufactured in amounts of 25,000 pounds (11,340 kilograms) or greater at a single site. The information reported to EPA is used to support risk screening, assessment, priority setting and management activities and constitute the most comprehensive source of basic screening-level, exposure-related information on chemicals available to EPA. There are limitations to using IUR data. The main limitation is that the IUR database includes only a one-year snapshot of data on chemicals manufactured, and the reported information relates only to the chemicals manufactured during that specific year. The database does not contain data on the quantity used in a year or the specific uses of each chemical. That is, a chemical that is not manufactured in a particular reporting year may still be in use, if there are leftover inventories from a previous year. Note that manufacture of mercury(II) oxide in 2006, the most recent year for which data were reported, was not sufficient to trigger the need for reporting, but the compound is a potential intermediate to several chemicals that were reported in the 2006 IUR.

2.2.3 Toxics Release Inventory

The 1986 Emergency Planning and Community Right-to-Know Act (EPCRA) and the 1990 Pollution Prevention Act require facilities to report data on the release and other waste management quantities of certain chemicals manufactured, processed or used in greater than certain quantities. These data are made available to the public in the Toxics Release Inventory (TRI). The current TRI toxic chemical list includes 581 individually listed chemicals and 30 chemical categories. The relevant chemical category for this report is Mercury Compounds, which "includes any unique chemical substance that contains mercury as part of that chemical's infrastructure" (U.S. EPA, 2008a). Information reported to the TRI does not distinguish among individual mercury compounds.

2.2.4 Biennial Reporting System

EPA, in partnership with the states, biennially collects information regarding the generation, management, and final disposition of hazardous wastes regulated under the Resource Conservation and Recovery Act of 1976 (RCRA), as amended. RCRA hazardous waste generation information is obtained from data reported by large quantity generators of RCRA wastes. EPA obtained data on relevant mercury compounds from the Biennial Reporting System (BRS) by identifying the waste streams with hazardous waste codes that are classified as mercury-bearing wastes. Like TRI data, BRS information cannot be broken down into data pertaining to individual compounds, and BRS does not provide information about the concentration of elemental mercury or mercury compounds in the reported waste streams. The most recent BRS data available for this report were the 2005 data.

2.2.5 NEWMOA, IMERC, and the EPA Mercury-Containing Products and Alternatives Database

IMERC was established in 2001 by NEWMOA to support legislative mercury reduction efforts and provide a central information source about products that contain mercury. IMERC maintains a Mercury-Added Products Database of national sales data submitted by manufacturers and distributors on mercury-added products sold (not produced) in the 14 states that require such reporting.[6] Regulations in these states require manufacturers or distributors to submit data on the national mercury use in their products, and to provide data updates every three years, starting in 2001. The most recent data available for this report were the 2004 data.

For this report, EPA used information in the IMERC database on the sales amounts and uses of mercury compounds in the United States. The reported quantities may be somewhat smaller than the national total. However, EPA does not consider this to be a serious limitation of the

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[6] California, Connecticut, Illinois, Louisiana, Maine, Massachusetts, Minnesota, New Hampshire, New Jersey, New York, North Carolina, Rhode Island, Vermont, and Washington.

data because it is unlikely that many, if any, mercury compounds are sold only in the 36 states that are not IMERC members.

IMERC also publishes fact sheets and reports based on the reported data. IMERC's database, fact sheets, and reports, as well as personal communication with NEWMOA officials, have contributed to the quantification of domestic mercury compound production and identification of manufacturers.

IMERC's Mercury-Added Products Database is the primary data source of EPA's Database on Mercury-Containing Products and Alternatives. IMERC's data are supplemented with other publicly available information on additional products and non-mercury alternatives. EPA used its database in conjunction with IMERC's data and reports in determining the domestic market for mercury compounds.

2.2.6 Data on U.S. Imports and Exports of Mercury Compounds

Data are available on quantities of mercury compounds in the aggregate, but not on individual compounds. The most comprehensive source of U.S. trade data is the United States International Trade Commission (U.S. ITC) database called the Interactive Tariff and Trade Dataweb. It is based on the Harmonized Tariff Schedule (HTS) codes developed by the World Trade Organization (Table 2-2). The newest HTS codes group all mercury compounds together for the purpose of tariff identification, and as a result they cannot be used to track trade in specific mercury compounds, but they can provide limited insights into the total volume of mercury compounds in trade.

Another source of trade data is the Comtrade database maintained by the United Nations. This data set contains trade data reported by the statistical authorities of approximately 200 countries or areas, including the United States The Comtrade data set also reports trade data based on HTS codes, but not at the same level of resolution. The U.S. ITC can report at the 10 digit HTS code level, and Comtrade groups data at the more aggregated six-digit HTS code level. Recent U.S.-reported data on U.S. trade in mercury compounds are identical in the Comtrade database and the U.S. ITC database. However, other countries' import and export data to and from the United States in the Comtrade database differ from data in the U.S. ITC database.

U.S. ITC data on mercury compound trade are currently included in one HTS code that encompasses all mercury compounds. Prior to 2007, separate codes were used for a limited number of specific mercury compound imports, including mercury oxides and mercury chlorides (including both the mercury(I)- and mercury(II)- forms). Other mercury compounds were grouped with general chemical compounds that did not include mercury. Due to inconsistencies in mercury compound trade data reported by the United States and its trading partners, as well as the lack of detail provided by the current HTS coding scheme (used in both Comtrade and U.S. ITC databases), accurate tracking of trade in individual mercury compounds is not possible. This limits the assessment of mercury compound markets and trade. Available import and export data for mercury compounds are discussed in more detail in Chapter 3.

EPA also examined other trade data sources, including the Eurostat database, waste import and export data in the BRS, and waste export reporting required by RCRA regulations. Each of these sources has limited data related to mercury compounds. For example, Eurostat data do not specify individual compounds.[7] BRS data report bulk quantities of waste by waste streams and do not provide data on constituent (chemical) concentrations or quantities. Finally, EPA conducted discussions with individuals involved in international elemental mercury trade, but these experts were unable to characterize global or U.S. trade in specific compounds.

Table 2-2: HTS Headings Dealing with Mercury and Its Compounds, Preparations, and Products

HTS Headings and Sub-Headings	Description
2805.40.0000	Mercury
2852.00	Compounds, inorganic or organic, of mercury, excluding amalgams:
2852.00.1000	mercuric oxide [mercury(II) oxide], mercuric cyanide [mercury(II) cyanide], mercuric oxycyanide [mercury(II) oxycyanide] and mercuric potassium cyanide [mercury(II) potassium cyanide]
2852.00.9000	Other
3815.90	Reaction initiators, reaction accelerators and catalytic preparations, consisting wholly of inorganic substances:
3815.90.2000	Of mercury or of molybdenum
3824.90	Chemical products and preparations of the chemical or allied industries, mixtures of two or more inorganic compounds:
3824.90.3300	Of mercury

2.2.7 1997 Report to Congress

In 1997, EPA produced the Mercury Study Report to Congress, fulfilling requirements of the Clean Air Act, as amended in 1990. The Report provided background information for this report, and was used to help identify the mercury compounds on which this report focuses.

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[7] Eurostat's mission is to provide the EU with statistics at a European level so as to enable comparisons between countries and regions. Eurostat collects data from member states and compiles statistics on a wide array of topics including structural indicators, employment and social policy indicators, and others.

3. Sources, Uses, and International Trade in Mercury Compounds

This chapter profiles the market for mercury compounds in the United States. Limited compound-specific information exists with respect to the quantities manufactured, imported, exported, or used. Therefore, aggregated data and information on mercury compounds are presented when disaggregated data (as requested in MEBA) are not available.

3.1 Sources and Amounts of Mercury Compounds Imported or Manufactured

Sources (supply) of mercury compounds include imports, production for commerce, byproducts and waste, existing stockpiles, and naturally occurring deposits. This section of the report identifies the sources of mercury compounds in the United States and, where available, the quantities of mercury compounds that come from these sources.

Crosswalk to Requirements in the Mercury Export Ban Act

- **i. Sources and amounts imported or manufactured**
- ii. Purposes and amounts consumed by use: current and future
- iii. Sources and amounts exported
- iv. Potential for processing into elemental mercury
- v. Other relevant information

3.1.1 Mercury Compounds Imported Into the United States

Import data on mercury compounds are of limited use for this report for two reasons. First, data currently address only aggregated quantities of all mercury compounds, and do not track individual compound quantities; though disaggregated import data for some classes of mercury compounds (“mercury chloride” and “mercury oxide”) are available prior to 2007.[8] Second, even total quantities of mercury compounds are uncertain due to conflicting estimates reported by (1) the U.S. International Trade Commission (U.S. ITC) Interactive Tariff and Trade Dataweb, and (2) U.S. trade partners reporting to the United Nations Commodity Trade Statistics Database (Comtrade). The quantity and value of U.S. imports for 2007 and 2008, as reported on February 15, 2009, are shown in Table 3-1. Quantities reported from the two sources are shown side-by-side for ease of comparison.

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[8] These data did not distinguish between mercury(II) chloride and mercury(I) chloride.

Table 3-1: Quantity and Value of U.S. Imports of Inorganic and Organic Mercury Compounds, by Trade Database Source, 2007-2008

Country	Year	U.S. ITC		Comtrade (U.S. imports as reported as exports by U.S. trading partners)	
		Metric Tons	Thousands of Dollars	Metric Tons	Thousands of Dollars
Germany	2007	124	$441	2	$160
	2008	118	$520	2	$174
Canada	2007	384	$163	555	$406
	2008	339	$92	339	$91
United Kingdom	2007	72	$463	47	$571
	2008	less than 1	$80	less than 1	$5
China	2007	97	$220	a	a
	2008	20	$70	a	a
France	2007	less than 1	$6	a	a
	2008	less than 1	$64	a	a
Spain	2007	11	$215	a	a
	2008	2	$61	a	a
Malaysia	2007	164	$161	a	a
	2008	22	$50	a	a
India	2007	1	$32	a	a
	2008	1	$39	a	a
Mexico	2007	less than 1	$2	a	a
	2008	2	$36	a	a
Belgium	2007	less than 1	$76	171	$242
	2008	less than 1	$24	less than 1	$1
Others	2007	26	$474	379	$4,751
	2008	less than 1	$21	8	$213
Total	2007	880	$2,254	1154	$6,130
	2008	504	$1,058	348	$485

a. Data were not available for the given year and country.
Data extracted from U.S. ITC and Comtrade on May 11, 2009.

It is not known why recent reported quantities of imported mercury compounds are an order of magnitude larger than what appears necessary to satisfy domestic U.S. demand (see section 3.2). One possibility supported by older U.S. ITC data is that imported mercury compounds are, in fact, byproduct materials imported solely for the retort of elemental mercury for re-sale on the global market. Alternatively, observed increases in the quantity of mercury compounds could reflect changes in reporting due to changes made to HTS codes in 2007.[9]

Prior to 2007, the U.S. ITC harmonized tariff system specifically tracked a subset of mercury compounds: mercury oxides (HTS 2825904500) and mercury chlorides (HTS 2827392000).[10] Other mercury compounds were included in broader metals categories, and data for imports of these compounds are not available. After 2006 mercury(II) oxides and mercury cyanide

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[9] Observed increases could also reflect imports of mercury compounds that are subsequently re-exported for sale abroad, either as raw compounds or as value-added products.

[10] These data did not distinguish between mercury(II) chloride and mercury(I) chloride.

compounds are aggregated into one code (HTS 2852001000) and all other mercury compounds are aggregated into another code (HTS 2852009000) (see Table 2-2, above). Import data for mercury oxides from 2002-2006 (as well as aggregated mercury(II) oxide and mercury cyanide compound data from 2007 and 2008) indicate that average annual imports are less than one metric ton, and do not show any significant trends. In contrast, mercury chloride imports from 2002-2006, including any chloride of mercury, (e.g., as mercury(II) chloride and mercury(I) chloride), averaged more than 250 metric tons per year, and showed significant increases after 2003. This pattern was dominated by imports from Chile of 410, 654, and 112 metric tons in 2004, 2005, and 2006, respectively.[11]

The U.S. ITC data from 2002 to 2006 suggest that mercury(I) chloride represented the bulk of mercury compound imports, though mercury(I) chloride imports from Chile have ceased since 2006. The data seem to show aggregate imports of mercury compounds from Canada, which had not exceeded 22 metric tons prior to 2007, increased dramatically in 2007 and 2008. It is not possible to determine whether recent imports from Canada are mercury(I) chloride, because newer U.S. ITC harmonized tariff codes do not specify mercury chlorides. If recent imports from Canada are of mercury(I) chloride, then the compound may originate from air pollution control processes at metals mines, or it may be imported to Canada from other regions before import to the United States Taken together, recent historical data suggest that mercury(I) chloride is likely the primary mercury compound imported into the United States, though data do not allow confirmation of this trend. Furthermore, observed increases in aggregated reported quantities could reflect changes in reporting.

3.1.2 Commercial Products Manufactured Domestically and Abroad

Only a small quantity of mercury compounds is produced for commercial use, which suggests that the producers of these mercury compound products are primarily specialty chemical producers producing small batches. It is not likely that these producers of high-value-added products currently have the production capacity to produce low-cost bulk mercury compounds, and it is therefore unlikely that these manufacturers would produce large-volume mercury compounds specifically to export them for the retort of elemental mercury.

Table 3-2 presents the quantity of mercury compounds sold commercially in the United States in 2001 and 2004, based on information reported to the IMERC database. Note that these data include mercury compounds sold commercially, including products manufactured abroad. The table shows national sales data reported by manufacturers that sell products in any of the 14 States that require reporting. The amounts may be less than actual national totals. (See section 2.2.5 for discussion of this data limitation.) The compounds sold are divided into three categories:

- *Mercury compound products* – mercury compounds sold as products, such as laboratory chemicals

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[11] Participants at the 2007 EPA stakeholder meetings on commodity mercury confirmed that these imports from Chile were mercury(I) chloride from gold mining operations, and were imported for recovery of elemental mercury (Lawrence, 2007; Pollara, 2007).

- *Products containing a mercury compound as a preservative* – products that contain a mercury compound such as thimerosal[12] that acts as a preservative or antifungal agent, but is not the main ingredient of the product
- *Mercury compounds in a value-added kit or product* – products that contain a mercury compound either as part of a chemical test kit or as an ingredient in another value-added chemical product, wherein the mercury compound is not the main ingredient.

Note that the manufacturers of products that contain mercury compounds may not be the original manufacturers of the mercury compounds themselves. Thus, the total quantities of mercury compounds shown in Table 3-2 may include some double counting.

Table 3-2: Quantities of Mercury Compounds Sold in the United States (kilograms)

Category	2001	2004
Mercury Compound Products	**500.4**	**563.3**
Mercury(I) chloride	8.1	1.3
Mercury(II) acetate	22.9	41.3
Mercury(II) chloride	101.9	76.8
Mercury(II) iodide	14.7	11.3
Mercury(II) nitrate	104.3	88.7
Mercury(II) oxide	26.7	32.5
Mercury(II) sulfate	133.8	260.8
Mercury(II) sulfide	1.0	0.6
Mercury(II) thiocyanate	4.5	6.4
Phenylmercury(II) acetate	0.2	0.2
Mercury(II) selenide	unknown	unknown
Thimerosal	unknown	unknown
All other compounds	82.3	43.4
Products Containing a Mercury Compound as a Preservative	**5.5**	**56.4**
Mercury Compounds in a Value-Added Kit or Product	**202.4**	**276.8**
Total	***708.3***	***896.5***

Note: Values include only the amounts of mercury compounds reported to NEWMOA by manufacturers and member states. The data may not include the entire universe of mercury-added products.
Source: NEWMOA

Table 3-2 shows larger quantities of mercury compounds reported as sold in 2004 compared with 2001. However, this does not necessarily imply that the use of mercury compounds is increasing. The larger numbers in 2004 could be a result of better reporting rates and/or additional NEWMOA member states in 2004. In addition, the listing of individual mercury compound products shows that the overall increase in individual compounds sold was driven by an increase in the reported amount of mercury(II) sulfate sold. The increase in the amount of mercury(II) sulfate sold was primarily driven by larger sales of chemical oxygen demand (COD) test kits that contain the compound. The reported quantities for most other mercury compounds were lower in 2004 compared to 2001.

Table 3-3 presents a list of manufacturers that reported the manufacture of mercury compounds or products containing mercury compounds to NEWMOA in 2004. Manufacturers are divided

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[12] Thimerosal is the common name for sodium ethylmercurithiosalicylate. For simplicity, this document uses the common name for this compound.

into the same three categories as mercury compounds; note that the manufacturers of "products containing a mercury compound as a preservative" and "mercury compounds in a value-added kit or product" may not be the original manufacturers of the mercury compounds themselves.

Table 3-3: Firms Reporting Manufacture of Mercury Compounds in the United States, 2004

Manufacturer	Mercury Compound Products	Products Containing a Mercury Compound as a Preservative	Mercury Compounds in a Value-Added Kit or Product
Abbott Laboratories		✓	
AccuStandard, Inc.			✓
Alfa Aesar, A Johnson Matthey Company	✓		
Aquarium Pharmaceuticals, Inc.			✓
Arlington Scientific		✓	
BD Biosciences		✓	
BD Diagnostic Systems		✓	
BioGenex Laboratories, Inc.		✓	
Biokit USA, Inc.		✓	
BioMerieux, Inc.		✓	
Bio-Rad Laboratories, Inc.		✓	✓
CHEMetrics, Inc.			✓
Chemicon International		✓	
Dade Behring, Inc.		✓	
Dexsil Corp.			✓
Diagnostic Products Corp.		✓	
EMD Chemicals, Inc.	✓	✓	✓
Hach Company	✓	✓	✓
Instrumentation Laboratory Co.		✓	
Inverness Medical Innovation (Binax, Inc.)		✓	
Jackson ImmunoResearch Laboratories, Inc.		✓	
Mallinckrodt Baker, Inc.	✓		
Palintest Limited			✓
Poly Scientific R&D Corp.			✓
R&D Systems, Inc.		✓	✓
Remel Incorporated		✓	✓
Rowley Biochemical Inc.			✓
Santa Cruz Biotechnology, Inc.		✓	
Stearns, Inc.			✓
TechLab, Inc.		✓	

Note: Table includes only mercury compound manufacture reported to NEWMOA by manufacturers and member states. The data may not include the entire universe of mercury-added products.

Source: NEWMOA

Four manufacturers reported sale of "mercury compound products" to IMERC: Alfa Aesar, EMD Chemicals, Hach Company, and Mallinckrodt Baker. Table 3-4 presents the compounds identified as produced by each of these manufacturers in 2001 and 2004.

Table 3-4: Mercury Compounds Manufactured in the United States in 2001, 2004

Compound	Alfa Aesar		EMD Chemicals		Hach Company		Mallinckrodt Baker	
	2001	2004	2001	2004	2001	2004	2001	2004
Mercury(I) chloride	✓	✓					✓	✓
Mercury(II) acetate	✓	✓		✓			✓	✓
Mercury(II) chloride	✓	✓		✓			✓	✓
Mercury(II) iodide	✓	✓		✓			✓	✓
Mercury(II) nitrate	✓	✓		✓	✓	✓	✓	✓
Mercury(II) oxide	✓	✓		✓			✓	✓
Mercury(II) selenide	✓	✓						
Mercury(II) sulfate	✓	✓		✓	✓	✓	✓	✓
Mercury(II) sulfide	✓	✓						
Mercury(II) thiocyanate	✓	✓		✓	✓	✓	✓	✓
Phenylmercury(II) acetate	✓	✓						
Thimerosal								
Other mercury compounds [a]	✓	✓	✓	✓				

Note: Table includes only mercury compound manufacture reported to NEWMOA by manufacturers and member states. The data may not include the entire universe of mercury-added products.

[a] Other Mercury Compounds (as of 2004): *Alfa Aesar*— mercury(II) cyanide, mercury(II) fluoride, mercury (I) nitrate, mercury(II) perchlorate, mercury(II) telluride, mercury(II) trifluoroacetate, mercury(II) trifluoromethanesulfonate, mercury potassium iodide, mercury tetrathiocyanatocobaltate, methylmercury(II) chloride, methylmercury(II) hydroxide, phenylmercury chloride, phenylmercury nitrate, dibenzyl mercury, diphenyl mercury, ethylmercury chloride; *EMD Chemicals*—P-Aminophenylmercuric Acetate

Source: NEWMOA

3.1.3 Byproducts

Several mercury compounds can be produced as byproducts of industrial processes, including gold mining and sulfide ore roasting. Production of mercury compound byproducts is frequently due to processes designed to remove mercury from other substances, such as mining ores, natural gas, or flue or smelter gases to prevent air pollution. To the extent that these compounds are processed to regenerate elemental mercury, the value of these materials is likely to be affected by the export ban. In other industrial processes where elemental mercury is a component of (and sometimes regenerated from) industrial waste streams, the mercury compounds generated are typically referred to as wastes.

Mercury(I) chloride and elemental mercury are produced in relatively large quantities as a byproduct of gold mining. Chapter 4 addresses mercury(I) chloride in the context of the export ban, when the elemental mercury converted from the mercury(I) chloride can no longer be sold abroad.

Mercury(I) chloride, mercury(II) sulfate, mercury(II) sulfide, and mercury(II) selenide are all produced during sulfide ore roasting, as discussed in Section 3.1.3.2. However, the specific quantities of byproduct mercury compounds generated from sulfide ore roasting and the mining of other metals are not readily available.

3.1.3.1 Gold Mining and Mercury Compound Generation (Mercury(I) Chloride)

In the processing of refractory and low-grade ores, gold extraction is accomplished by treating the ore with cyanide under alkaline conditions. The gold cyanide that leaches out is then sorbed onto activated carbon. Soluble mercury(II) cyanides ($Hg(CN)_2$, $Hg(CN)_3^-$, and $Hg(CN)_4^{2-}$) are also formed in the leachate and are captured by the activated carbon. Typically, the mercury on the filter material is retorted to regenerate elemental mercury. Alternatively, these soluble mercury(II) cyanide compounds can be converted into insoluble compounds, such as mercury(II) sulfide, by the addition of calcium sulfide or sodium sulfide to the leachate. The insoluble mercury compounds precipitate out prior to the sorption step. Other precipitating agents include the dialkyldithiocarbamates (typically potassium dimethyldithiocarbamate), which form mercury carbamate precipitates. The carbamates tend to be more stable than mercury(II) sulfide under the alkaline conditions required for cyanide leaching (Tessele et al., 1998). At least one gold mine in Nevada has reported using the carbamate technology (Jones and Miller, 2005). A bioremediation process (the Biocyanide process) for the conversion of mercury cyanides to mercury(II) sulfide in gold cyanide leachates has also been demonstrated on a pilot scale. Mercury cyanide solution is passed over a reactor bed made of a porous ceramic medium that is coated with a proprietary biofilm (U.S. EPA, 2007a).

Mercury is also regenerated from the gold processing roasters through air pollution control mechanisms. The most common procedure utilizes mercury(II) chloride in a scrubber, where the mercury(II) chloride reacts with volatilized elemental mercury to form mercury(I) chloride. In Nevada, the greatest amount of byproduct mercury recovered for sale pre-2005 in the United States came from the Barrick mines in Nevada.

Current regulations do not prohibit the export of mercury(I) chloride. Import data suggests that mercury recyclers are willing to purchase mercury(I) chloride, and one mercury recycler advertises services for converting mercury(I) chloride to elemental mercury, suggesting that this is an economically viable business. Therefore, it may also be economically feasible to export mercury(I) chloride for the purpose of converting it into elemental mercury in countries outside the United States.

Nevada Gold Mining

Approximately 80 percent of the gold produced in the United States comes from gold mines in Nevada. In 2002, Nevada instituted the Voluntary Mercury Reduction Program (VMRP), which sought to reduce mercury air emissions through voluntary addition of emission controls. The four Nevada gold mining companies with the greatest mercury emissions participated in the VMRP:

- Barrick Gold Corporation: Goldstrike Mining Operations
- Newmont Mining Corporation: Gold Quarry Operations Area; Twin Creeks Mine
- Placer Dome: Cortez Gold Mine Pipeline Mining Operation
- Queenstake Resources, Ltd.: Jerritt Canyon Mine

The participants in the VMRP are thought to comprise more than 90 percent of the mercury air emissions reported in EPA Region 9 in 2000. Through the VMRP, the participants reduced their mercury emissions by over 80 percent, leading to greater amounts of mercury byproduct captured (State of Nevada, 2006; NAC 445B.3653, 2006).

The four major Nevada gold mining companies voluntarily reported their total mercury byproduct for the years 1999–2003 (partial). Table 3-5 presents the mercury byproduct of the four major companies; the data include both elemental mercury and mercury(I) chloride combined; the amount of mercury(I) chloride cannot be determined except in the case of the Barrick Goldstrike mine, but this is the largest of the two gold mines in the United States producing mercury(I) chloride using the Boliden-Norzink process. Barrick staff provided Jones and Miller with a breakdown of their byproduct production, which is presented in Table 3-6.

Table 3-5: Total Mercury Byproduct Recovered for Sale (metric tons elemental mercury)

	1999	2000	2001	2002	2003 (partial)
Queenstake (Jerritt Canyon)	1.8	2.0	1.7	2.3	--
Placer Dome (Cortez)	0.9	0.5	0.5	0.4	0.4
Barrick (Goldstrike)	6.2	26.1	55.4	82.6	--
Newmont (Gold Quarry and Twin Creeks)	n/a	6.4	12.5	11.5	13.1
Total		**35.0**	**70.0**	**96.8**	--

Source: Jones and Miller, 2005

Table 3-6: Mercury Recovered at the Barrick Goldstrike Mine (metric tons elemental mercury)

	1999	2000	2001	2002
Elemental Hg, Refinery	6.2	9.8	11.6	9.2
Elemental Hg, Roaster		0.6	13.5	13.1
Mercury(I) chloride, Roaster		15.8	30.2	60.3

Source: Jones and Miller, 2005

As Table 3-6 shows, the quantity of elemental mercury recovered in mercury(I) chloride in the early 2000s exceeded the quantity of elemental mercury recovered, and in 2002 was produced in excess of 60 metric tons.

The Nevada gold mining companies generally sell their byproducts (elemental mercury and mercury(I) chloride) to recycling companies (Jones and Miller, 2005). These byproducts are not considered a waste, and therefore are not reported to the BRS or TRI databases. Table 3-7 lists the recycling companies to which three of the four major mining companies have sold their byproduct mercury.

Table 3-7: Nevada Gold Mine Mercury Byproduct Sales to Recycling Companies

Mining Company	Recycling Company	Recycling Company Location
Barrick (Goldstrike)	Bethlehem Apparatus	Bethlehem, PA
Cortez (Placer Dome)	Mercury Waste Solutions	Union Grove, WI
Newmont	D.F. Goldsmith Chemical and Medical Corp.	Evanston, IL

Source: Jones and Miller, 2005

Reporting of air emissions of mercury and mercury byproduct from gold mines in Nevada changed after 2005. In March of 2006, the State of Nevada passed the Nevada Mercury Control Program (NMCP), which superseded and replaced the VMRP. Effective May 4, 2006, the NMCP stipulates that "owners or operators that operate, construct or modify a thermal unit that emits mercury must apply for, and obtain, a Mercury Operating Permit to Construct (Mercury OPTC) to apply the NvMACT (Nevada maximum achievable control technology)" (State of Nevada, 2006, p. 2). The NMCP also includes a requirement to report any mercury co-product on an annual basis (NAC 445B.3611-3689); mercury co-product is defined as "any mercury which is collected from the site of a stationary source that conducts precious metals mining for shipment to another location to be sold or recycled" (NAC 445B.3619). The Nevada Division of Environmental Protection (NDEP) indicates that "co-product" includes elemental mercury as well as mercury contained in any other substrate, such as mercury(I) chloride (NDEP, 2009). Table 3-8 lists the annual quantities of mercury co-product reported in 2006 and 2007. Reported quantities of mercury byproducts cannot be broken out by elemental mercury and mercury compounds.

Table 3-8: Annual Mercury and Mercury Compound Byproduct Reported under the Nevada Mercury Control Program (metric tons)

Source	Permit	2006	2007
Newmont Mining Corporation – Twin Creeks Mine	AP1041-0723.01	8.1	12.0
Queenstake Resources USA, Inc - Jerritt Canyon Mine	AP1041-0778	2.7	0.9
Newmont Mining Corporation – Gold Quarry	AP1041-0793	2.5	3.1
Barrick, Bald Mountain Mine – Huntington Valley	AP1041-1362	2.7	2.1
Kennecott Rawhide Mining Company - Denton-Rawhide Mine	AP1041-1116.02	0.1	0.0
Cœur D'Alene Mining Corporation - Coeur Rochester Mine	AP1044-0063.02	14.6	14.0
Barrick Gold Corporation, Cortez Gold Mines	AP1041-2141 (Consolidated Title V Permit)	0.1	0.3
Florida Canyon Mining, Inc. – Florida Canyon Mine	AP1041-0106.02	0.2	0.0
Round Mountain Gold Corporation - Smoky Valley Common Operation	AP1041-0444.01	0.0	0.0
Homestake Mining Company - Ruby Hill Project	AP1041-0713.01	0.5	0.3
Marigold Mining Company - Marigold Mine	AP1041-0158.02	0.2	0.2
Barrick Goldstrick [sic] Mines, Inc.	AP1041-0739.01	89.4	53.2
Total		**120.9**	**86.1**

Sources: Nevada Bureau of Air Pollution Control, 2006 and 2007

Table 3-8 illustrates the decrease in total mercury byproduct that Barrick representatives identified in the last few years, from more than 80 metric tons in 2006 to 53 metric tons in 2007. Though the overall decrease in mercury byproduct production is primarily attributable to a reduction at the Barrick Goldstrike Mines, mercury byproduct production in 2007 was in line with byproduct production in 2002 (see Table 3-6 above). Barrick representatives estimate that 2008 production of mercury(I) chloride at the Goldstrike mine contained roughly 25 metric tons of elemental mercury (Barbanell 2009).

Gold Mining TRI Data

The 1986 Emergency Planning and Community Right-to-Know Act (EPCRA) and the 1990 Pollution Prevention Act require facilities to report data on the quantities of chemicals released or otherwise managed as waste. These data are made available to the public in the Toxics Release Inventory (TRI). Table 3-9 presents 2007 TRI mercury compounds data for the gold ore mining industry. Gold Ore Mining, NAICS 212221, is comprised of establishments primarily engaged in developing the mine site, mining, and/or preparing ores valued chiefly for their gold content.

Facilities in the Gold Ore Mining industry reported more than two million kilograms of on-site land releases of mercury compounds in 2007. This large quantity appears to reflect mercury content in waste rock or tailings containing mercury compounds. In 2007, more than 20,000 kilograms of mercury compounds were reported as recycled on- and off-site; the guidelines for reporting on- and off-site recycling are somewhat different. On-site recycling includes only the quantities of mercury compounds actually regenerated for reuse, not the total amount of the toxic chemical in the waste stream entering recycling units on-site. The opposite is true for off-site recycling, which includes all amounts of the toxic chemical intended to be recycled and sent off-site for that purpose, not just the amount of the toxic chemical (i.e., mercury compound or elemental mercury) actually regenerated (U.S. EPA, 2009b). These definitions indicate that the 23,147 kilograms reported to have been recycled on-site is the actual amount of mercury compounds regenerated for reuse, which should not include any waste rock. Conversely, the 2,084 kilograms reported to have been recycled off-site is too small a number to account for mercury in mercury(I) chloride from gold mines. TRI reports show that gold mines did not report mercury(I) chloride sent to mercury recyclers over the last decade because this byproduct is not considered to be a waste for purposes of TRI.

Table 3-9: TRI Report of Mercury Compound Waste Quantities Reported by Gold Ore Mining Industry for 2007(kilograms mercury)

	212221 Gold Ore Mining
Facility Count	**20**
Total Releases	**2,758,149**
Total Air Releases	1,485
Surface Water Discharges	0
Underground Injection	0
Total Land Releases	2,756,727
Total Waste Managed	**2,783,445**
Recycled On-site	23,147
Recycled Off-site	2,084
Quantity Released On- and Off-site	2,758,146

Notes:

- Total Air Releases are the sum of fugitive air emissions and stack or point source air emissions. Fugitive air emissions are all releases to air that are not released through a confined air stream. Stack or point source air emissions occur through confined air streams such as stacks, vents, ducts, or pipes.
- Total Land Releases includes releases of toxics to RCRA Subtitle C landfills, other landfills, land treatment, RCRA Subtitle C Surface Impoundments, other surface impoundments, and other land disposal.
- Recycled On-site is the total amount of the toxic chemical recycled on-site; this includes only the amount of the toxic chemical actually regenerated for reuse, not the total amount of the toxic chemical in the waste stream entering recycling units on-site.
- Recycled Off-site is the total amount of the toxic chemical sent off-site for recycling; this includes all amounts of the toxic chemical intended to be recycled and sent off-site for that purpose, not just the amount of the toxic chemical actually regenerated.
- Quantity Released On- and Off-site includes 1). total on-site disposal to Class I Underground Injection Wells, RCRA Subtitle C landfills, and other landfills; 2). total other on-site disposal or other releases; 3). total off-site disposal to Class I Underground Injection Wells, RCRA Subtitle C landfills, and other landfills; and 4). total other off-site disposal or other releases.

Source: U.S. EPA 2009b., TRI.NET, http://www.epa.gov/triexplorer Orginal reporting in lbs

3.1.3.2 Sulfide Ore Roasting and Mercury Compound Generation (Mercury(I) Chloride, Mercury(II) Sulfate, Mercury(II) Sulfide, and Mercury(II) Selenide)

Mercury is found in sulfide ores that are processed to isolate other metals in addition to gold; notably, silver, lead, zinc, and copper. Mercury contained in sulfide ores can be separated from other materials in the form of mercury(I) chloride, mercury(II) sulfate, mercury(II) sulfide, and mercury(II) selenide during roasting and smelting, and may deposit on the fly ash, dust, and slag generated in these processes. Detailed information on the distribution or quantities of mercury in these wastes is not available (Jasinski, 1994). Roasting and smelting sulfide ores generates sulfur dioxide, which is captured and converted to sulfuric acid prior to venting the stack gases to the atmosphere. A significant amount of the mercury generated during roasting is also emitted to the stack gases and contaminates the refined metal ores with sulfuric acid unless the mercury is removed from the stream. Several processes for mercury control are in use, including the Boliden-Norzink process and the Outokumpu process (Louie, 2005).

3.1.4 Mercury Compounds in Waste

EPA investigated whether industrial wastes containing mercury compounds are possible sources for export and subsequent conversion to elemental mercury. The information gathered suggests that the low mercury concentrations in most wastes containing mercury compounds make their export for the purpose of producing elemental mercury unlikely.

Under RCRA, hazardous wastes are either "listed" as particular waste streams (e.g., brine purification muds from mercury cell chlor-alkali plants) or are classified as "characteristic" wastes based on toxicity of single constituents (e.g., mercury), ignitability, reactivity, or corrosivity.

The following hazardous, mercury-bearing wastes may contain mercury in a compound form:

- D009 Wastes: Characteristic mercury wastes
  - D009 wastes contain mercury in the leachate from the waste (using the Toxicity Characteristic Leaching Procedure) at a concentration in the extract greater than or equal to 0.20 mg/L (roughly 0.20 ppm). These wastes are variable in composition, and can include used fluorescent bulbs, batteries, switches, and thermometers, as well as wastes from production of organomercury compounds using mercury(II) chloride catalysts or miscellaneous wastes from chlor-alkali production facilities (U.S. EPA, 1990).
  - D009 wastes' mercury concentrations are generally below 2.7 percent, except for mercury(II) oxide waste generated from battery recycling, which may have mercury concentrations exceeding 90 percent (U.S. EPA, 1990). Note that mercury(II) oxide waste from battery recycling is an unlikely candidate for export as an alternative to elemental mercury, because mercury oxide batteries are no longer widely used and the waste is generated in small quantities (U.S. EPA, 2009c).
  - There are two subcategories of D009 waste: high concentration mercury subcategory and low-concentration subcategory. RCRA regulations require that D009 wastes in the first subcategory are roasted or retorted to recover the elemental mercury.
- K071 Wastes: Brine purification muds from the mercury cell process in chlorine production, where separately prepurified brine is not used (U.S. EPA, 1990).
  - K071 wastes generally contain less than 100 parts per million mercury content, which is typically metallic mercury or mercury(II) chloride. The best demonstrated available technology (BDAT) to regenerate mercury from K071 wastes is to use a wet process (U.S. EPA, 1990).
- K106 Wastes: Wastewater treatment sludge from the mercury cell process in chlorine production
  - K106 wastes typically contain mercury at a concentration greater than 260 mg/kg (260 parts per million, or 0.026 percent) for which roasting or retorting is required. Mercury is generally in elemental form or as mercury(II) sulfide. K106 wastes are not likely to have mercury concentrations above 16 percent (U.S. EPA, 1990).
- P065 Wastes: Mercury fulminate
  - P065 wastes contain discarded or off-specification mercury fulminate, as well as container or spill residue. P065 waste requires incineration, regardless of total mercury content.

- P092: Phenylmercury acetate
    - P092 wastes contain discarded or off-specification phenylmercury acetate product, as well as container or spill residue. P092 waste requires incineration, roasting or retorting.

Mercury compound wastes are generated from two main processes: (1) those in which elemental mercury and/or mercury compounds are utilized for large-scale chemical production processes, and (2) remediation of contaminated soils, effluents, ground water, and flue gases.

3.1.4.1 Mercury Compound Wastes from the Chlor-Alkali Manufacturing Process

Historically, three large-scale chemical production processes have employed elemental mercury or mercury compounds. These include the production of chlorine and caustic soda (the chlor-alkali process), the manufacture of vinyl chloride from acetylene, and the manufacture of acetaldehyde from acetylene. In the United States today, only the chlor-alkali industry uses elemental mercury and generates a mercury compound waste.

The mercury-cell chlor-alkali process is an electrochemical process for the generation of chlorine gas and sodium hydroxide. Elemental mercury is used as the cathode material, and chlorine is generated from the brine (sodium chloride) electrolyte/feedstock. During the process, elemental sodium is produced at the cathode and forms an amalgam with the elemental mercury. The mercury-sodium amalgam is decomposed with water, forming sodium hydroxide. The elemental mercury is then recycled back into the process. During the manufacturing process, some elemental mercury is oxidized and forms mercury chloride compounds and mercury sulfides. Caustic wastewater sludge from this process typically contains mercury(I) and mercury(II) chlorides, mercury(II) sulfide, elemental mercury, and mercury species on activated carbon (U.S. EPA, 2007a).

Typical waste treatment processes involve retorting the sludge to reclaim elemental mercury. Alternatively, the sludge can be treated with acid, followed by hypochlorite to convert all of the available mercury to mercury(II) chloride. The mercury(II) chloride can then be washed from the sludge and precipitated as mercury(II) sulfide (Weiss and Lechugs, 1983; Blanch et al., 1978; Balco et al., 1977). Removal of elemental mercury from the wastewater can be accomplished by precipitation with sulfide to produce mercury sulfide (U.S. EPA, 2007a).

The volume of chlor-alkali process waste generated continues to decrease as newer, mercury-free technology is adopted. The number of chlor-alkali plants in the United States that use the mercury-cell process decreased from 25 in 1980 to five in 2009 (Chlorine Institute, 2008).

Table 3-10 presents 2007 TRI mercury compounds data for the Alkalies and Chlorine Manufacturing industry.[13] Alkalies and Chlorine Manufacturing, NAICS 325181, is comprised of establishments primarily engaged in manufacturing chlorine, sodium hydroxide, and other alkalies, often using an electrolysis process.

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[13] EPCRA and the 1990 Pollution Prevention Act require facilities to report data on the quantities of chemicals stored on-site as well as data on waste management. These data are made available to the public in the Toxics Release Inventory (TRI).

Facilities in the Alkalies and Chlorine Manufacturing industry reported releases of more than 1,400 kilograms of mercury compounds in 2007, almost entirely to air. The total mercury compound waste managed, however, was approximately 20,257 kilograms. Of that, 18,119 kilograms of mercury compounds were recycled on-site, indicating that more than 90 percent of the total waste managed is recycled either on- or off-site. Most likely, the recycled mercury compounds are used to reclaim elemental mercury to be reused as the cathode in the manufacturing process.

Table 3-10: TRI Release and Waste Management Data for Mercury Compounds for the Alkalies and Chlorine Manufacturing Industry (kilograms)

	325181 Alkalies and Chlorine Manufacturing
Facility Count	**2**
Total Releases	**1,438**
Total Air Releases	1,025
Surface Water Discharges	7
Underground Injection	0
Total Land Releases	7330
Total Waste Managed	**20,257**
Recycled On-site	18,119
Recycled Off-site	696
Quantity Released On- and Off-site	1,442

Note: Although seven Alkalies and Chlorine Manufacturing facilities reported to TRI in 2007, only two reported mercury compounds data.

- Total Air Releases are the sum of fugitive air emissions and stack or point source air emissions. Fugitive air emissions are all releases to air that are not released through a confined air stream. Stack or point source air emissions occur through confined air streams such as stacks, vents, ducts, or pipes.
- Total Land Releases total releases of toxics to RCRA Subtitle C landfills, other landfills, land treatment, RCRA Subtitle C Surface Impoundments, other surface impoundments, and other land disposal.
- Recycled On-site is the total amount of the toxic chemical recycled on-site; this includes only the amount of the toxic chemical actually regenerated for reuse, not the total amount of the toxic chemical in the waste stream entering recycling units on-site.
- Recycled Off-site is the total amount of the toxic chemical sent off-site for recycling; this includes all amounts of the toxic chemical intended to be recycled and sent off-site for that purpose, not just the amount of the toxic chemical actually regenerated.
- Quantity Released On- and Off-site includes 1). total on-site disposal to Class I Underground Injection Wells, RCRA Subtitle C landfills, and other landfills; 2). total other on-site disposal or other releases; 3). total off-site disposal to Class I Underground Injection Wells, RCRA Subtitle C landfills, and other landfills; and 4). total other off-site disposal or other releases.

Source: U.S. EPA 2009b., TRI.NET, http://www.epa.gov/triexplorer

3.1.4.2 Remediation of Mercury from Contaminated Sites and Effluents

Polluted soils, effluents, ground water, and flue gases contain large volumes of material that may contain relatively low concentrations of elemental mercury and its compounds. Pollution remediation processes described in the sections below are designed to concentrate, segregate, and isolate elemental mercury as inorganic mercury compounds. The resulting materials, therefore, represent a potential source of elemental mercury or its compounds.

Contaminated Soil and Solids (Soil, Sediment, and Sludge)

Soils and solids contaminated with elemental mercury and mercury compounds can be chemically treated to convert the mercury to soluble compounds that can be extracted into an aqueous phase by washing.[14] An acid extraction technique has also been demonstrated for the treatment of chlor-alkali plant waste at both pilot scale and full scale (U.S. EPA, 2007a). Additionally, soils can be treated with iodine and potassium iodide to convert mercury to a soluble compound; elemental mercury can then be regenerated from the wash solution by electrolysis (Foust, 1993, 1994).

Contaminated Water and Aqueous Effluents

Treatment options for contaminated liquids include precipitation and sorption techniques. Precipitation methods convert soluble mercury compounds into insoluble compounds such as mercury(II) sulfide. Separation of the precipitated compound from suspension in the liquid can be facilitated by pH adjustment, the addition of flocculants, or the use of sorbents. Mercury removal by precipitation has been successfully demonstrated at full scale to treat contaminated ground water at three locations and to treat wastewater at eight locations (U.S. EPA, 2007a). Membrane filtration methods (microfiltration, ultrafiltration, nanofiltration, or reverse osmosis) are typically preceded by a precipitation step. Filtration alone will not remove soluble mercury compounds (U.S. EPA, 2007a).

Sorption methods can capture elemental mercury and mercury compounds from liquid and gaseous streams. Commonly used sorbents include activated carbon, ion-exchange resins, and functionalized resins. (U.S. EPA, 2007a). In another process, effluents containing thimerosal were treated with hypochlorite to convert all of the mercury to mercury(II) chloride, which was captured on thiol-functional ion exchange resin (Robinson 1992a, 1992b).

Vinyl Chloride Manufacture

Mercury(II) chloride on activated carbon was once used extensively as a catalyst for vinyl chloride manufacture from acetylene. Spent catalysts can be regenerated by thermal regeneration or steam desorption to remove mercury. Waste streams from this process are likely to contain mercury(II) chloride and possibly elemental mercury. This process is still in operation in some parts of the world, although it has been phased out in Western countries in favor of a newer technology that uses ethylene as the feedstock and does not require a mercury catalyst (Rossberg et al., 2006). Because at least one vinyl chloride manufacturer was listed as a source of mercury-bearing wastes in the United States in the RCRA 2005 Biennial Report, there may be an export market for mercury(II) chloride to support the process elsewhere, as vinyl chloride is an important industrial material for making PVC plastics. This was the largest source of mercury compounds reported in the 2005 Biennial Report.

3.1.4.3 Special Case: Mercury Sulfide Waste

Bethlehem Apparatus, a mercury recycling company in Hellertown, Pennsylvania is developing a process "that allows the retirement of elemental mercury from future use by stabilizing it into a form that can be safely land filled."[15] This process involves converting elemental mercury into

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[14] Aqueous oxidative extractants include nitric acid, hypochlorite, and halogens (such as iodine) (Wilhelm, 1999). Mercury may then be removed from solution by precipitation from the wash phase with the addition of a base or other precipitating reagent (e.g., sulfide) or the addition of a flocculant.

[15] See: http://www.bethlehemapparatus.com/mercury-retirement.html.

mercury(II) sulfide which stabilizes the mercury. It is thus unlikely that the mercury(II) sulfide produced by Bethlehem Apparatus would be used as an alternative to exporting elemental mercury, and EPA did not further assess this encapsulated form of mercury(II) sulfide for the report.

3.1.5 Stockpiles of Mercury Compounds among End-Use Consumers

Mercury compounds have historically been used in agriculture as fungicides, mildewcides and pesticides. In early 1995, all mercury compound-containing U.S. pesticide registrations were discontinued. The last four uses to be phased out were turf fungicide, mildewcide for fresh-cut wood, latex paint fungicide/preservative, and outdoor fabric treatment. As a result, mercury compound-containing chemicals may be present in stockpiles in farms, golf courses, or other areas where these uses were expected (Wisconsin Department of Natural Resources, 1997). These stockpiles are most likely to be scattered at locations where they were previously utilized. It is unlikely that these mercury compound-containing chemicals will be found in large quantities.

3.1.6 Naturally Occurring Mercury Compounds

Of the more than 30 minerals that contain mercury, relatively few have been commercially exploited for their mercury content. Those that have include mercury(II) sulfide (cinnabar, HgS), metacinnabar (black cinnabar, HgS), mercury sulfide chloride (corderiote $Hg_3S_2Cl_2$), native elemental mercury (Hg), and livingstonite ($HgSb_4S_7$) (Jasinski, 1994). Mercury(II) sulfide (cinnabar) is by far the most abundant and commercially important of the mercury-bearing ores. High-quality ore often contains droplets of elemental mercury. Elemental mercury is extracted from mercury(II) sulfide (cinnabar) by retorting the ore and condensing the elemental mercury vapor that is released. Other methods of extraction of elemental mercury from mercury(II) sulfide (cinnabar) have been reported, including electrolytic methods (e.g., Baxter, 1929), chemical leaching (DeVito and Brooks, 2005), and an ancient method for isolating elemental mercury by crushing native mercury(II) sulfide (cinnabar) with vinegar in a copper vessel (Takacs, 2000). Retorting the ore to regenerate elemental mercury has been the preferred method for centuries, however. Because commercial mercury mining in the United States ceased with the closure of the last domestic mine in 1992, however, these ores containing mercury compounds are not coming into the U.S. market in large quantities.

3.1.7 Summary Sources of Mercury Compounds

Table 3-11 summarizes the sources of mercury compounds entering the U.S. market.

Table 3-11: Domestic Sources of Mercury Compounds in the United States (kilograms)

Compound	CAS Number	Quantity Sold (2004)	Byproduct or Waste	Imported currently or recent past
Mercury(I) chloride	10112-91-1	1.3	>25,000Hg	Imported in recent years
Mercury(II) acetate	1600-27-7	41.3	-	-
Mercury(II) chloride	7487-94-7	76.8	-	-
Mercury(II) iodide	7774-29-0	11.3	-	-
Mercury(II) nitrate	10045-94-0	88.7	-	-
Mercury(II) oxide	21908-53-2	32.5	-	unknown
Mercury(II) selenide	20601-83-6	unknown	unknown	-
Mercury(II) sulfate	7783-35-9	260.8	unknown	unknown
Mercury(II) sulfide	1344-48-5	0.6	unknown	-
Mercury(II) thiocyanate	592-85-8	6.4	-	-
Phenylmercury(II) acetate	62-38-4	0.2	-	-
Thimerosal	54-64-8	unknown	-	unknown
Other compounds	-	43.4	unknown	unknown
Total	**-**	**563.3**	**unknown**	**504,265**

"-" indicates not a source

"unknown" indicates is a source but quantity is unknown.

3.2 Purposes and Amounts of Mercury Compounds used: Current and Future

3.2.1 Current Uses

Mercury compounds have been used historically, and are sometimes still used, in batteries, pigments, laboratory catalysts or reagents, explosives, pharmaceutical applications, and electrochemistry (Toxnet Hazardous Substances Database, 2008a). Table 3-12 summarizes the purposes for which mercury compounds are currently used in the United States. As the table shows, more of the compounds are used in laboratory chemistry than any other single use.

Crosswalk to Requirements in the Mercury Export Ban Act

i. Sources and amounts imported or manufactured
ii. Purposes and amounts consumed by use: current and future
iii. Sources and amounts exported
iv. Potential for processing into elemental mercury
v. Other relevant information

Table 3-12: Purposes for Which Mercury Compounds Are Used and Amounts Consumed by Use

Compound	CAS Number	Quantity Sold (kg, 2004)	Uses	Availability of Non-Mercury Alternatives
Mercury(I) chloride	10112-91-1	1.3	Electrochemistry	Alternatives to mercury(I) chloride electrodes are available, depending on the application
Mercury(II) acetate	1600-27-7	41.3	Laboratory chemistry; Production of organomercuric compounds	None for laboratory or other uses
Mercury(II) chloride	7487-94-7	76.8	Laboratory chemistry; Waste treatment	None for laboratory use; Alternative waste treatment methods are available, depending on the application
Mercury(II) iodide	7774-29-0	11.3	Laboratory chemistry; Veterinary medicine; Nuclear particle detection	None for laboratory use; Alternatives are widely available for veterinary medicine uses; Alternatives for nuclear particle detection use unknown
Mercury(II) nitrate	10045-94-0	88.7	Laboratory chemistry	None for laboratory use
Mercury(II) oxide	21908-53-2	32.5	Laboratory chemistry; Batteries	None for laboratory use; Alternatives are available for battery uses
Mercury(II) selenide	20601-83-6	unknown	Semiconductors	Unknown
Mercury(II) sulfate	7783-35-9	260.8	Laboratory chemistry; Gold and silver extraction	None for laboratory use; Alternatives are available for gold and silver extraction use
Mercury(II) sulfide	1344-48-5	.6	None	Semiconductor use banned
Mercury(II) thiocyanate	592-85-8	6.4	Laboratory chemistry; Photography	None for laboratory use; Alternatives are widely available for photography use
Phenylmercuric acetate	62-38-4	less than 0.2	Pharmaceutical; Production of phenylmercury compounds	Alternatives available for pharmaceutical use; None for production of other compounds
Thimerosal	54-64-8	unknown	Pharmaceutical	Alternatives available for pharmaceutical use

3.2.2 Estimated Amounts of Mercury Compounds To Be Used for Each Purpose in 2010 and Beyond

It is difficult to predict future use of individual mercury compounds for specific purposes because quantities of compounds are limited and not well tracked. However, some general trends in use can be identified.

There is some indication that demand for mercury compounds in the United States may decline. NEWMOA predicts that reductions in mercury compound use are likely in the near future, and identifies two reasons for possible future reductions: pharmaceutical manufacturers continuing to eliminate use of thimerosal as a preservative, and laboratory use of mercury compounds ceasing at educational institutions because of state restrictions on mercury in schools (NEWMOA, 2008).

Use of mercury compounds in analytical laboratory chemistry is likely to remain approximately at current levels or to decline. Several mercury compounds have uses as laboratory standards or analytical reagents for which there seem to exist few or no viable alternatives (Nordic Council of Ministers, 2007). However, general trends suggest an overall decline in the use of mercury-containing products in the United States, likely due at least in part to increased awareness of mercury hazards and increased state regulation of mercury and mercury-containing products.

Production of mercury compounds as byproducts and in wastes will continue in some industries. In addition, more stringent regulation of waste treatment or air emissions may increase the quantity of mercury compounds that are removed from power plant emissions, waste streams, or flue gases resulting from industrial processes. Gold mining will continue to produce elemental mercury and mercury(I) chloride byproducts and is expected to continue at its current level (approximately 100 metric tons on an elemental mercury content basis) for the next several years. Although some domestic mining operations may increase the amounts of mercury they are capturing, some mines already capturing elemental mercury and producing byproduct mercury compounds may close in the next ten years, and some mines may shift to seams with lower mercury content (Lawrence, 2007).

3.3 Sources and Amounts of Mercury Compounds Exported

Table 3-13 presents the quantity and value of U.S. exports of inorganic and organic mercury compounds in 2007 and 2008, as reported by the United States in the U.S. ITC Dataweb or by U.S. trading partners in the United Nations Comtrade database. The data were downloaded on February 15, 2009. As with the data on imports, only aggregated quantities of all mercury compounds are available, and the two sources’ estimates do not agree.

Crosswalk to Requirements in the Mercury Export Ban Act

i. Sources and amounts imported or manufactured
ii. Purposes and amounts consumed by use: current and future
iii. Sources and amounts exported
iv. Potential for processing into elemental mercury
v. Other relevant information

Table 3-13: Quantity and Value of U.S. Exports of Inorganic and Organic Mercury Compounds, by Trade Database Source, 2007-2008

		U.S. ITC		Comtrade (U.S. exports as reported as imports by U.S. trading partners)	
Country	Year	Metric Tons	Thousands of Dollars	Metric Tons	Thousands of Dollars
Canada	2007	7,626	$22,045	1,932	$3,071
	2008	275	$1,158	a	a
China	2007	5	$1,260	a	a
	2008	42	$1,721	a	a
Japan	2007	3	$657	a	a
	2008	2	$722	a	a
Mexico	2007	104	$638	a	a
	2008	20	$28	a	a
Taiwan	2007	less than 1	$267	a	a
	2008	8	$584	a	a
United Kingdom	2007	less than 1	$46	a	a
	2008	5	$152	a	a
Others	2007	85	$785	613	$3,835
	2008	28	$1,269	a	a
Total	2007	7,823	$25,698	2,545	$6,906
	2008	380	$5,634	a	a

a. Data were not available for the given year and country.

Notes:

1) Data exclude HTS codes encompassing compounds other than mercury (specifically, HTS 3815902000, reaction inhibitors, reaction accelerators and catalytic preparations, consisting wholly of inorganic substances; of mercury or molybdenum).

2) Countries receiving exports only in either 2007 or 2008, but not both years, are included in the "others" category, though individual countries in some cases received U.S. exports of significant size (e.g., Venezuela, 61 metric tons in 2007; Turkey, 12 metric tons in 2008).

2008 data incomplete

According to the U.S. ITC, in 2007, 7,626 metric tons of mercury compounds were exported from the United States to Canada and 104 metric tons to Mexico. Exports to all other countries totaled 93 metric tons. In 2008, mercury compound exports totaled 275 metric tons to Canada, 42 metric tons to China, and only 20 metric tons to Mexico, and exports to all other countries totaled 43 metric tons.

The large quantity of mercury compounds exported to Canada in 2007 raises the possibility that a significant part of this total could be waste or byproduct materials being shipped to Canada for disposal, or could otherwise represent a reporting anomaly. Canada reported a much smaller import from the United States of 1,932 metric tons in its 2007 data provided to Comtrade. In addition, U.S. ITC data indicate that the United States exported only 275 metric tons of mercury compounds to Canada in 2008, a substantially lower amount than was reported in 2007.

The source of the large quantity of mercury compounds exported to Canada in 2007 is unclear. An export quantity of 7,626 metric tons is extremely large in the context of total global trade in elemental mercury, which is estimated to be only 3,500 metric tons annually (UNEP, 2008). Due to confidentiality concerns and data limitations, U.S. ITC could not provide information on why the reported quantities of exported mercury compounds are several orders of magnitude larger than what might be expected to satisfy global demand for mercury compounds. However, U.S. ITC data do reveal a consistent pattern of exports of mercury compounds from the United States to Canada during each month in 2007.

Given the UN estimate of global trade in elemental mercury of roughly 3,500 metric tons, if 7,626 metric tons of mercury-containing materials were, in fact, exported to Canada in 2007, it is almost certain that these materials were not pure mercury compounds, and that the total concentration of mercury compounds is in fact much lower than the total quantity reported. However, mercury and mercury compound content is not specifically reported. One indication that the compounds were of low purity, however, is the value of the shipments. The value for these shipments (approximately $22 million) suggests a compound price of approximately $2.90 per kilogram. This is approximately an order of magnitude less expensive than mercury compounds available for purchase on the global market, suggesting that these shipments were materials with low mercury content or mercury compound-containing wastes.

The export of significant quantities of low-priced mercury compounds to Canada may indicate that materials being shipped to Canada for disposal are being identified as mercury compounds in trade documents, consistent with new, more general HTS codes for mercury compounds. The closure of several U.S. chlor-alkali plants in recent years may have resulted in significant quantities of mercury-containing waste that would previously have been reported under other tariff codes.

4. Potential for Export of Mercury Compounds To Be Used as a Source for Elemental Mercury

4.1 Chemistry and Technological Feasibility of Conversion

Crosswalk to Requirements in the Mercury Export Ban Act

i. Sources and amounts imported or manufactured
ii. Purposes and amounts consumed by use: current and future
iii. Sources and amounts exported
iv. Potential for processing into elemental mercury
v. Other relevant information

Mercury is a Group IIB metal and is in the same group as zinc and cadmium. Unlike the other members of this group, mercury has two stable oxidation states: mercury(I), which takes the form of a binary cation, $(Hg_2)^{2+}$, and mercury(II) (Hg^{2+}). Elemental mercury (Hg^0) can be oxidized to readily form compounds in either oxidation state. Many of these mercury compounds, such as the halide salts, oxides, and nitrates, undergo ligand exchange reactions under mild conditions. Therefore, the common mercury compounds can be readily interconverted. In addition, mercury is one of the few metals that form stable, covalent bonds with carbon. A variety of inorganic and organometallic mercury compounds can therefore be generated in one or two synthetic steps from elemental mercury. Unique among metals, elemental mercury is a liquid at room temperature and has a low boiling point (356.73°C) and high vapor pressure (0.015 torr at 50°C). Mercury's high vapor pressure facilitates its removal from mixtures by volatilization, and thermal decomposition of mercury compounds at elevated temperatures often generates elemental mercury vapor, which can be condensed and collected (Patnaik, 2003).

Mercury compounds that could be exported for the purpose of regenerating elemental mercury must be readily available (or easily generated), stable, transportable, and easily converted to elemental mercury. Compounds that do not meet these criteria would not be economically competitive with existing sources of elemental mercury. Chemical processes ideally suited to these criteria will utilize inexpensive, readily available reagents, and simple procedures and equipment. Examples of the common chemical reactions that may be used to convert elemental mercury to mercury compounds and are representative of those currently used or generated in large-scale processes in the manufacturing, mining, power generation, and petroleum industries, or in other commercial processes are provided in Appendix D. Also provided are reactions than can be used to convert one mercury compound to another and processes that can be used to decompose mercury compounds back into elemental mercury. Individual mercury compound dossiers that include an examination of their potential for use as a source of elemental mercury are presented in Appendix C. This section provides an overview of the chemical processes involved in converting elemental mercury into mercury compounds, and vice-versa, and evaluates the technical feasibility of exporting several mercury compounds.

4.1.1 Conversion of Elemental Mercury to Mercury Compounds

Elemental mercury can be easily converted in one or two steps to a variety of inorganic and organometallic mercury compounds using inexpensive, readily available materials (Simon et al., 2006; Patnaik, 2003; Nowak and Singer, 1995). Common conversion methods are explained below.

4.1.1.1 The Thermal Oxidation of Elemental Mercury into Mercury(II) Oxide

Elemental mercury is stable in dry air under ambient conditions and oxidizes slowly in the presence of moisture. Direct oxidation of elemental mercury to mercury(II) oxide can be accomplished at a synthetically useful rate by heating elemental mercury to a temperature of 350°C in air.

$$\mathrm{Hg} + 1/2\ \mathrm{O_2} \xrightarrow[\text{heat}]{\text{air}} \mathrm{HgO}$$

4.1.1.2 The Chemical Conversion of Elemental Mercury into Mercury Halides

The reaction of elemental mercury with chlorine yields mercury chlorides. Unless an excess of chlorine is used, the product obtained is a mixture of mercury(I) chloride and mercury(II) chloride. The use of excess chlorine or the chlorination of mercury(I) chloride produces mercury(II) chloride.

$$2\ \mathrm{Hg} + \mathrm{Cl_2} \longrightarrow \mathrm{Hg_2Cl_2}$$
$$\mathrm{Hg_2Cl_2} + \mathrm{Cl_2} \longrightarrow 2\ \mathrm{HgCl_2}$$

Analogous reactions with bromine and iodine yield the mercury bromides and iodides, respectively.

4.1.1.3 The Chemical Conversion of Elemental Mercury in Waste Streams into Mercury Halides

Mercury(I) chloride can, on heating, disproportionate to yield elemental mercury and mercury(II) chloride. This reaction is exploited in scrubber systems for capturing elemental mercury.

$$\mathrm{Hg_2Cl_2} \xleftrightarrow[\text{heat}]{} \mathrm{Hg} + \mathrm{HgCl_2}$$

When gases containing elemental mercury vapor are passed through an aqueous solution of mercury(II) chloride, the above reaction is reversed, and insoluble mercury(I) chloride precipitates out of solution and can be collected. This is the mercury conversion process used in Nevada gold mining, known as the Boliden-Norzink process.

$$\mathrm{Hg} + \mathrm{HgCl_2}\ (\text{soluble}) \longrightarrow \mathrm{Hg_2Cl_2}\ (\text{insoluble})$$

4.1.2 Conversion of Mercury Compounds to Other Mercury Compounds

The most practical synthesis of a particular mercury compound is often accomplished via the conversion of one compound to another, even if a direct synthesis from elemental mercury is possible. The soluble mercury(II) salts such as mercury(II) chloride, mercury(II) nitrate, and mercury(II) acetate are frequently used in the commercial preparation of other mercury compounds. For example, mercury(II) oxide is more economically produced by the reaction of mercury(II) nitrate and an alkali hydroxide than by the rudimentary heating of elemental mercury in air described earlier.

$$\mathrm{Hg(NO_3)_2} + 2\ \mathrm{NaOH} \longrightarrow \mathrm{HgO} + 2\ \mathrm{NaNO_3} + \mathrm{H_2O}$$

This reaction sequence ultimately produces mercury(II) oxide in two steps from elemental mercury using only nitric acid and sodium hydroxide as reagents.

4.1.3 Conversion of Mercury Compounds to Elemental Mercury

Mercury compounds can be readily converted to elemental mercury using techniques that range from the simple to the complex. The three processes commonly used to accomplish this transformation in order of increasing sophistication are thermal decomposition, chemical reduction, and electrochemical reduction.

4.1.3.1 Thermal Decomposition

Many mercury compounds are decomposed and reduced upon heating to release elemental mercury vapor. This process, also called retorting, is the simplest method for generating elemental mercury from mercury compounds. In its most basic form, a retort consists of a furnace and a suitable surface on which to condense the elemental mercury vapor for collection. Commonly located at ore processing and waste processing facilities, the equipment can be configured to accommodate the nature and volume of material processed. Modern operations also include pollution control equipment such as dust collectors and scrubbers (DeVito and Brooks, 2005).

4.1.3.2 Chemical Reduction

Another method for generating elemental mercury from mercury compounds is chemical reduction. In a typical process, a mercury compound is dissolved or suspended in an aqueous solution and treated with a reducing agent. The elemental mercury settles to the bottom of the reactor as the reaction progresses and can be easily separated from the water. This process is used extensively in some industrial applications, most notably the removal of elemental mercury in chlor-alkali wastewater streams. Reducing agents that have been demonstrated to generate elemental mercury in these waste streams include hydrazine, sodium hydride, and sodium borohydride (Falbesaner et al., 1980; Nguyen, 1979; DeAngelis et al., 1978). The reduction of mercury compounds with sodium borohydride under synthetic conditions is known as the Ventron process (Nowak and Singer, 1995).

Some metals can reduce mercury compounds to elemental mercury. Barreau and Eusebe (1991) report a method for preparing pure elemental mercury from mercury(I) chloride. Mercury(I) chloride is suspended in an aqueous solution containing sulfuric acid (pH 0.5) and agitated with a powdered reducing metal, typically iron. Other metals that have been reported to reduce mercury chlorides include zinc, bismuth, tin, nickel, magnesium, manganese, and copper (Gerow and Soule, 1974).

4.1.3.3 Electrochemical Reduction

The reduction of soluble mercury compounds can also be effected by means of electrochemical reduction. In this process, the mercury compound is dissolved in an electrolyte solution, electrodes made of suitable materials are inserted, and an electrical current is applied to the cell. Elemental mercury initially forms as droplets at the cathode and subsequently either forms an amalgam with the cathode metal or falls to the bottom of the cell, where it is collected. Large-scale electrochemical cells are used in the plating industry, in metals extraction (electrowinning) in the mining industry, and in electrochemical waste treatment processes. Cell configuration, electrolytes, anode and cathode compositions, and other conditions are optimized for each process. Electrochemical reduction processes have the advantage that they can be performed on both mercury(I) or (II) species. See Appendix D for illustrative examples of electrochemical reduction processes.

4.1.4 Organomercury Compounds

Most organomercury compounds have limited use in commerce, are highly toxic, and are not likely to be suitable for export. Organomercury(I) compounds are not stable and can be prepared only at low temperatures. Although organomercury(II) compounds are relatively stable to air and moisture, some of the reagents used to prepare them, such as organomagnesium reagents (known as Grignard reagents), are moisture sensitive, and the reactions must be carried out in dry solvents under an inert atmosphere, greatly complicating these processes. Certain organomercury compounds have seen recent use as preservatives and pharmaceuticals (e.g., Thimerosal). Reactions used to prepare some representative organomercury compounds are shown in Appendix D.

4.1.5 Candidate Compounds for Sources of Elemental Mercury Based on Technological Feasibility of Conversion

Based on the technological conversion characteristics of mercury compounds described above and the analysis of the individual chemicals presented in Appendix C and Appendix D, four chemicals seem to be the most likely choices to be exported and converted to elemental mercury abroad: mercury(I) chloride, mercury(II) oxide, mercury(II) nitrate, and mercury(II) sulfate. These compounds have a high elemental mercury yield from conversion, and, given the necessary equipment and technology, can be easily reduced to elemental mercury, and either are readily available as a byproduct (mercury(I) chloride) or can be produced relatively easily from surplus elemental mercury (see compounds with “High” potential for export as an alternative to elemental mercury in Table 4-1).

Four other chemicals are potential candidates for export followed by regeneration of elemental mercury based on technological feasibility of conversion: mercury(II) acetate, mercury(II) chloride, mercury(II) iodide, and mercury(II) sulfide. These candidates generally cannot be reduced to elemental mercury by heating and therefore are slightly more difficult to convert to elemental mercury (see “Medium” compounds in Table 4-1).

Two additional chemicals could possibly be exported and reconverted to elemental mercury abroad based on their technological feasibility of conversion; however, these chemicals require manufacturing from other chemicals that are more likely to be exported and thus would require an extra step, making them less likely to be chosen for export. These chemicals are phenylmercury acetate and thimerosal (see “Low” compounds in Table 4-1).

Finally, the following two chemicals are not likely to be exported as a source of elemental mercury due to low technological feasibility of conversion: mercury(II) selenide, and mercury(II) thiocyanate. The chemistry of these compounds makes them difficult to prepare or handle, and unlikely to be exported with the purpose of regenerating the elemental mercury abroad (see "Very Low" compounds in Table 4-1).

Greater detail on the characteristics of the individual mercury compounds that influence the feasibility of their export and conversion can be found in Appendix C.

Table 4-1: Candidate Compounds, Sources, Feasibility of Conversion, and Potential for Export Based on Technological Feasibility

Compound	Potential Sources	Processes That Would Be Used To Convert to Elemental Mercury Outside U.S.	Quantity of Elemental Mercury Yield (% Mercury by Weight)	Technological Feasibility of Producing for Export and Subsequent Processing into Elemental Mercury	Rationale for Determining Potential
Mercury(I) chloride	Product; Byproduct; Waste; Convert from surplus elemental mercury	Chemical or electrochemical reduction; Dissociation by light or heat	85%	High	High elemental mercury yield from conversion; easily reduced to elemental mercury; either readily available as a byproduct or produced easily from surplus elemental mercury
Mercury(II) oxide	Product; Convert from other common mercury compounds; Convert from surplus elemental mercury	Decomposition by light or heat; Electrolytic reduction	93%	High	
Mercury(II) sulfate	Product; Convert from surplus elemental mercury; Byproduct	Reduction by heating	68%	High	
Mercury(II) nitrate	Product; Convert from surplus elemental mercury	Reduction by heating	62%	High	
Mercury(II) acetate	Product	Decomposition by heat or light	63%	Medium	Generally cannot be reduced to elemental mercury by heating and therefore are slightly more difficult to convert to elemental mercury
Mercury(II) chloride	Product; Convert from surplus elemental mercury; Convert from other common mercury compounds	Chemical or electrochemical reduction; Conversion to other inorganic compounds by heating	74%	Medium	
Mercury(II) iodide	Product; Convert from surplus elemental mercury; Convert from other common mercury compounds	Conversion to other inorganic compounds by heating	44%	Medium	

Table 4-1: Candidate Compounds, Sources, Feasibility of Conversion, and Potential for Export Based on Technological Feasibility

Compound	Potential Sources	Processes That Would Be Used To Convert to Elemental Mercury Outside U.S.	Quantity of Elemental Mercury Yield (% Mercury by Weight)	Technological Feasibility of Producing for Export and Subsequent Processing into Elemental Mercury	Rationale for Determining Potential
Mercury(II) sulfide	Naturally occurring; Product; Convert from surplus elemental mercury; Byproduct; Convert from other common mercury compounds	Reduction by retorting	86%	Medium	
Phenyl mercury(II) acetate	Product; Convert from other common mercury compounds	Ventron process (convert to inorganic mercury compounds, reduce with sodium borohydride); Burning	60%	Low	Require manufacturing from other chemicals that are more likely to be exported and thus would require an extra step, making them less likely to be chosen for export.
Thimerosal	Product; Convert from other common mercury compounds	Ventron process (convert to inorganic mercury compounds, reduce with sodium borohydride); Burning	50%	Low	
Mercury(II) selenide	Waste; Convert from surplus elemental mercury	Reduction by retorting	72%	Very Low	
Mercury(II) thiocyanate	Product; Convert from other common mercury compounds	Decomposition by heating (exothermic, difficult to control)	63%	Very Low	

[a] Categories are defined as follows:

- High: Most likely candidates to be used for export and conversion to elemental mercury
- Medium: Potential candidates to be used for export and conversion to elemental mercury
- Low: Possible candidates, but too expensive because manufactured from other candidates that are more likely to be exported
- Very Low: Unlikely candidates because their chemistry makes them too difficult or expensive to prepare or handle

4.2 Economic Feasibility of Exporting Mercury Compounds to Regenerate Elemental Mercury

In addition to being technologically feasible, it must be economically feasible to trade compounds as a substitute supply for elemental mercury in order for markets to develop and function. Economic feasibility requires not only that manufacture of mercury compounds and regeneration of elemental mercury from those compounds be technically practical, but also that this process be cost-competitive with other global supplies of elemental mercury. Note that this section focuses on the economic feasibility of production and trade of mercury compounds as a source of elemental mercury, rather than for use as compounds. Data in Chapter 3 suggest that demand for mercury compounds is unlikely to increase enough to justify significant increases in production or trade. EPA considered the economic feasibility of two different types of compound production: direct regeneration and sale of compounds from byproduct and waste, and explicit manufacture of compounds using surplus elemental mercury.

The economic feasibility of using U.S.–developed mercury compounds as an alternative supply of elemental mercury depends on the following factors:

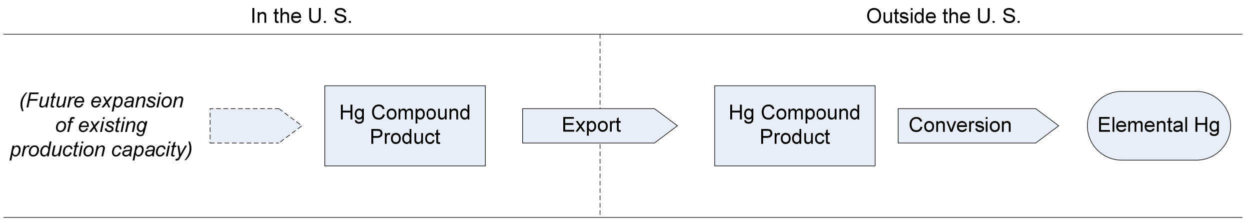
- The costs of obtaining domestic supplies of elemental mercury or mercury compounds, converting the elemental mercury into compounds (if necessary), shipping and handling the compounds, and regenerating the elemental mercury after export must be lower than the cost of providing elemental mercury from non-U.S. sources;
- The quantity of the compound manufactured in the United States (or available in byproducts or wastes) must be sufficient to justify development of systems for regenerating elemental mercury in other countries;
- Industrial capacity and technology for large-scale compound production in the United States must either exist currently or be cost-effective to produce; and
- Sustained global demand for elemental mercury at a price high enough to offset the cost of producing the compound *and* regenerating the elemental mercury must be likely to justify any capital expenses needed to increase U.S. production.

The above factors illustrate that substantially increasing export of mercury compounds for regeneration of elemental mercury would involve business risk for both suppliers of mercury compounds and the importers who would regenerate the elemental mercury.

4.2.1 Overview of Options for Mercury Compound Export

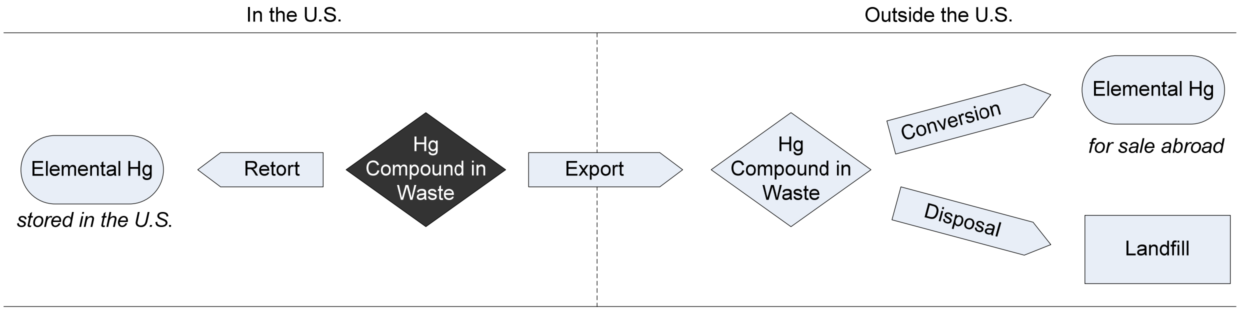
Compounds may be exported under one of three scenarios: as value-added manufactured products, as byproducts or recovered from wastes, and as high-volume compounds manufactured from elemental mercury and exported for the purpose of regenerating the elemental mercury outside the United States The economic viability of each of these export scenarios depends on whether it is cost-competitive with other options, including the market costs of competing products (e.g., other sources of compounds or elemental mercury) and the domestic cost of disposal or long-term storage. Figure 4-1, Figure 4-2, and Figure 4-3 illustrate the market dynamics for each export scenario.

Figure 4-1: Mercury Compound Products



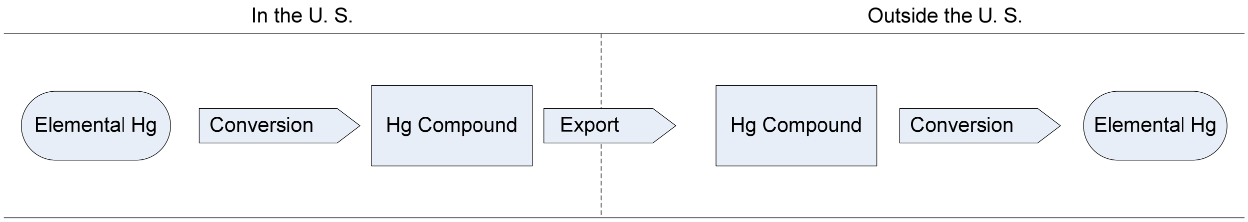
U.S. producers currently develop only small quantities of compounds as products, using less than two metric tons of elemental mercury, according to data reported to IMERC (NEWMOA, 2008). Production of these high-value specialty products in large-volumes would therefore require additional capacity, and it is possible that significant new production of these compounds would oversupply the market.

Figure 4-2: Mercury Compounds in Waste or as Byproduct



In considering export of mercury compounds in waste or byproducts, the cost of treatment/long-term storage/disposal of the recovered elemental mercury must be weighed against the costs of export.[16] Exported byproducts or waste streams can either be landfilled or converted to elemental mercury for sale abroad. Most mercury compound-containing waste streams have low enough concentrations of mercury that disposal abroad may be more cost effective than conversion abroad, even if global elemental mercury prices rise. However, for some mercury compound byproducts or wastes, the cost of export and conversion to elemental mercury may be lower than the cost of retorting and storage in the United States. Currently, only mercury(I) chloride can be economically exported as a cost-competitive source of elemental mercury.

Figure 4-3: Conversion of Elemental Mercury for Export as Mercury Compounds



The final export scenario for mercury compounds is production of compounds from elemental mercury within the United States into compounds for export and regeneration of elemental mercury. While this scenario is not currently cost-competitive with other supplies of elemental mercury, in the context of an export ban, it is possible that U.S. producers could develop and export compounds from elemental mercury as a cost-competitive alternative to long-term

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[16] For this analysis, EPA considered only the byproduct and waste containing more than *de minimis* amounts of mercury.

storage domestically, and as a competitive source of elemental mercury globally. To be viable, however, this scenario requires that both storage prices and elemental mercury market prices be high enough to offset any capital costs required with building additional compound production capacity.

4.2.2 Key Market Dynamics and Features Affecting Compound Manufacture

In a market without trade constraints, manufactured mercury compounds are not a competitive source of elemental mercury because they require elemental mercury as a raw material and involve additional production costs. Byproduct compounds such as mercury(I) chloride may be competitive if processing costs to regenerate elemental mercury from compounds are competitive with costs of elemental mercury production from other sources (e.g., mined mercury ore, recycling).

Enactment of a ban on the export of elemental mercury, however, creates both a barrier and a potential opportunity for U.S. compound producers. Under the export ban, owners of elemental mercury supplies in excess of domestic elemental mercury demand must bear the costs of long-term storage. As a result, a significant portion of the domestic supply of elemental mercury will have a *negative* value equal to the cost of long-term storage in the domestic market but a positive value in the global market. A mercury compound producer who can first charge a “supplier” (e.g., a gold mine) a fee for recycling surplus mercury, then use that mercury as a raw material to produce a mercury compound, and finally sell that compound internationally, could theoretically operate profitably if:

Market value of elemental mercury + avoided storage/treatment/disposal costs- (compound production cost + export costs + mercury regeneration cost) > 0

The limited supply of U.S. domestic mercury, however, limits the financial opportunities associated with this compound trade. A domestic U.S. compound producer would have two supply sources for raw materials: compounds directly produced (as byproducts or in waste), and elemental mercury otherwise slated for domestic storage (and, ultimately, treatment and disposal) that can be used to manufacture compounds. The supply of surplus elemental mercury and compounds coming to market is expected to be very small, with current domestic surplus of elemental mercury estimated at roughly 80 to 100 metric tons per year and the mercury content of byproduct compounds not likely to exceed 25 metric tons, annually. Although a compound producer could obtain revenues *both* by charging the producer for unwanted mercury (up to the cost of long-term storage/treatment/disposal) *and* by selling the mercury compounds (at a price competitive with elemental mercury when regeneration costs are considered), the total revenue associated with compounds manufactured from 125 metric tons of surplus domestic elemental mercury or surplus mercury compounds is limited.

If a producer of compounds does not require any capital investment to begin operations, then it may be possible to earn a profit by producing compounds that can compete as raw materials for elemental mercury. However, the limited potential for revenue from the sale of elemental mercury (due to the small quantity available in the United States) in turn limits the ability of a producer to make significant capital investments in capacity or technology to expand mercury compound production, particularly if operating costs associated with manufacturing a compound are also high (e.g., due to waste management requirements).

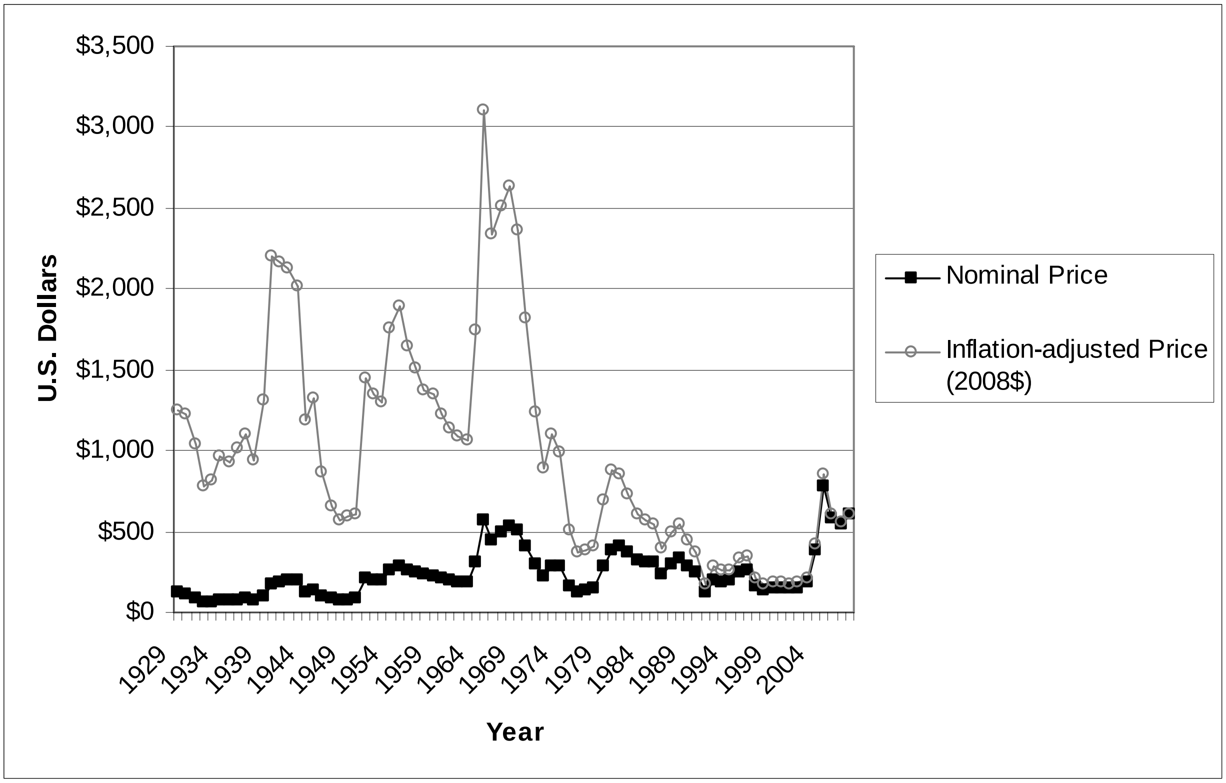
Given these constraints, manufacturers considering trade in compounds as a source for elemental mercury must consider the prices and supply and demand trends in the global elemental mercury market, as well as the direct costs associated with their operations, and competition from domestic storage/treatment/disposal alternatives.

4.2.3 General Economic Considerations: Current Prices of Elemental Mercury and Compounds

To ensure the economic feasibility of using compounds as an alternative source of elemental mercury, producers must be able to rely on consistent elemental mercury prices. Current spot prices (i.e., prices for immediate payment and delivery) for elemental mercury and mercury compounds provide an initial insight into the economic feasibility of trading mercury compounds as a substitute for elemental mercury.

Spot prices for elemental mercury appear to have remained in the range of $500–$700 per 76 pound (34.5 kilogram) flask since 2007 after decades of decline in prices coincident with a declining market for elemental mercury (see Figure 4-4). Historical elemental mercury prices were in the $2,000 per flask range in the 1940s (inflation-adjusted; 2008$, as are all price values in this paragraph), averaged $658 per flask in the post-war period until 1950 and $1,419 per flask from 1951 through 1964; and hit a peak price of $3,100 per flask in 1965 (USGS, 1998). Since the late 1960s, prices began to decline steadily to less than $200 per flask in 2003; though the price of elemental mercury briefly spiked to just over $1,000 per flask (approximately equal to $29,000 per metric ton) in 2005 in the face of perceived shortfalls due to a decline in primary mercury mining and strong elemental mercury demand due to the rising price of gold (USGS, 1998; Metal Bulletin, 2005). Prices declined from this brief relative price peak in 2005 within months, and as of 2008, the price for a flask of the metal had stabilized at approximately $600. This price is considered fairly strong compared with prices in the 1990s (elemental mercury averaged $230 per flask from 1991 through 2003), but has not shown any significant increase since the passage of MEBA (USGS, 2009). Price fluctuations of the type seen in the last 10 years can be expected to occur in small and declining markets such as the elemental mercury market because small changes in production (e.g., the retirement of a single chlor-alkali plant or a temporary mine closure) can have a significant short-term impact on total supply.

Figure 4-4: Historical Prices for Elemental Mercury: 1929 - 2009



Available information for mercury compounds sold as products reveals a wide range of prices. Bulk mercury compounds produced as byproducts from industrial processes or mining (e.g., mercury(I) chloride (calomel)) likely command minimal prices, and in some cases processors may charge a fee for acceptance of the byproducts. In contrast, mercury compounds produced for industrial or laboratory use range in price depending on whether or not they are purchased in bulk. This two-tiered cost structure exists for elemental mercury as well: bulk elemental mercury typically trades for hundreds of dollars per 76-pound flask (34.5 kilograms), but is sold by laboratory chemical providers in small quantities of similar quality at an average price of roughly $200 per pound ($440.92 per kilogram), a 3,000 percent mark-up.

Table 4-2: Market Prices of Elemental Mercury and Selected Mercury Compounds

Compound	Specialty Chemical Price (per Kilogram)	Bulk Chemical Price (per Kilogram, including shipping)	Ratio of Specialty Chemical to Bulk Price	Percent Mercury Content	Price per Kilogram of Mercury (bulk) (does not include processing)
Mercury(I) chloride (specialty chemical)	$236	Unknown	NA	85%	Likely equal to or higher than elemental mercury
Mercury(I) chloride (byproduct)	NA	Low	NA	<85%	Likely low
Mercury(II) chloride	$295	$27	11	74%	$36.49
Mercury(II) nitrate	$699	$32	22	62%	$51.61
Mercury(II) sulfate	$1473	$31	48	68%	$45.59
Mercury(II) sulfate (waste)	NA	Low	NA	<68%	Likely low
Elemental mercury	$432	$17.42	25	100%	$17.42

Sources: Fisher Scientific, 2009; Gurjar Chemicals, 2009

Bulk mercury compounds are produced and sold globally. Online retail price estimates for bulk compounds (minimum order of 500 kilograms) are in the $27 to $32 range including the base cost, insurance, and shipping (Gurjar Chemicals, 2009). As Table 4-2 illustrates, bulk mercury compound prices are higher than the price of elemental mercury, consistent with the value-added nature of manufactured mercury compounds, which typically use elemental mercury as an input.[17]

EPA initially considered the possibility that manufactured high-volume compounds could be sold into the market for compounds (i.e., for use as compounds, rather than for recovering elemental mercury), but data on quantities of compounds produced and sold in the United States suggest that the quantities of compounds necessary to ensure operational profitability would far exceed existing demand for specific compounds, even those sold in bulk. As a result, producers of high-volume compounds would most likely be unable to sell those compounds at current market prices.

4.2.4 U.S. Production Capacity for High-Volume, Low-Cost Compound Production

U.S. manufacturers currently produce mercury compounds for high-value manufacturing uses, but these firms have little economic incentive to expand this production significantly and risk oversupply in small markets, though they may take advantage of reduced U.S. elemental mercury prices resulting from an export ban and increase production incrementally.

Data from IMERC on 2004 U.S. sales of mercury compounds identify roughly 30 companies reporting production of chemical compounds containing mercury. The total quantity of mercury used in these compounds, which include the compounds considered for this report as well as some industrial fixatives and other mixtures, is less than two metric tons for 2004.[18] The

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[17] According to the United Nations Environment Programme, retorting costs from wastes with greater than 10 percent mercury content are "less than $50 per kg," and mercury recovery from mercury(I) chloride costs approximately $10 to $20 per kg (UNEP, 2008).

[18] NEWMOA 2008, supplemented with personal communication with Adam Wienert, April 9, 2009. Mr. Wienert noted that the July 2008 NEWMOA report predated receipt of submissions from roughly 10 companies, and therefore the roughly one metric ton of mercury reported in that document is a low estimate.

trend since 2001 appears to be one of slowly declining production, consistent with general trends in the use of mercury in manufacturing applications globally.

While the IMERC chemical compound quantity estimates include only manufacturers required to report to IMERC, the data suggest that U.S. industrial production of mercury compounds is highly specialized, and is probably not adequate for immediate high-volume production of compounds using many metric tons of elemental mercury. Therefore, U.S. mercury compound producers are not likely to be an immediate source of supply for significant new trade in mercury compounds for the purpose of retorting elemental mercury.

The only compounds that may see significant growth in production in the current market are those such as mercury(I) chloride that occur as byproducts or in waste. Generation of these compounds is driven by external factors such as gold prices and adoption of air pollution control processes and is disconnected from market demand for compounds as products. In contrast to mercury compound manufacturers, U.S. mercury waste management companies are well positioned to process large volumes of byproduct or waste compounds, either to regenerate elemental mercury or to refine the compounds to an industrial grade. To date, U.S. mercury recyclers have emphasized regeneration of elemental mercury from compounds or, in the case of mercury(II) sulfide, development of compounds in order to accomplish mercury disposal abroad (Bethlehem Apparatus, 2009). It is possible that companies in this sector could leverage and expand their existing elemental mercury purification capacity and technology to economically refine or develop compounds for trade as an alternative to storage domestically or disposal abroad, but only if they perceive sufficient market demand to justify the adoption of new technologies, processes, and permits. As a result, the feasibility of compounds as an alternative supply of elemental mercury requires consideration of strength of demand for elemental mercury, and the ability of current non-U.S. elemental mercury supplies to meet that demand at competitive prices.

4.2.5 Supply and Demand Information for Elemental Mercury

Elemental mercury is traded in a very small market characterized by well-established relationships among a limited number of traders and industrial customers. Recent estimates of the size of the global elemental mercury market estimate global demand for elemental mercury at roughly 3,500 metric tons annually (UNEP, 2008). However, this estimate reflects significant uncertainty regarding two key sources of demand: Chinese manufacturing and artisanal gold mining operations. The Chinese government estimates elemental mercury use in China at roughly 1,100 metric tons per year (China Chemicals Registration Center, 2005). Artisanal gold mining operations may account for up to 22 percent of the global demand for elemental mercury (UNEP, 2008). A key concern for policy makers is the extent to which demand in China and in artisanal gold mining areas may seek alternative sources of elemental mercury by processing compounds if the global elemental mercury supply decreases due to export bans.

4.2.5.1 Global Elemental Mercury Market

Consistent with trends observed over recent decades, global demand for mercury in products and manufacturing (e.g., paint, batteries) is expected to continue to decline in coming years in most sectors, with the exception of lighting. The quantities of mercury used as an agent, cathode, or catalyst in certain sectors such as in the production of vinyl chloride monomer and polyurethane in China is not well documented, and it is therefore difficult to predict future trends in demand for those uses.[19]

In recent years as the price of gold has increased, demand for elemental mercury by artisanal gold miners appears to have increased, though the total quantities used by artisanal miners are very difficult to estimate. Artisanal gold mining operations are generally illegal which adds to the difficulty estimating how much is used. Elemental mercury is typically supplied to these operations indirectly and in small quantities, often through black markets. The United Nations Environment Programme (UNEP) has estimated that artisanal gold miners use more than 600 and perhaps as much as 1,000 metric tons of elemental mercury annually (Maxson, 2006). This remains a rough estimate due to the difficulties in acquiring information.

Global supply of elemental mercury to meet industrial and artisanal mining demand includes primary mining for mercury in China and Kyrgyzstan, production of by-product mercury from other metals mines, and regeneration of secondary elemental mercury from industrial processes such as chlor-alkali facilities, and from waste. Primary elemental mercury production has decreased consistently in recent decades. Global primary mercury mining in recent decades has been dominated by three nations mining mercury for export (Spain, Kyrgyzstan and Algeria), and China, which has mostly provided for its own robust home market. Both Spain and Algeria have stopped mercury mining operations (Maxson, 2006). During the early to mid-2000s, China restricted mercury imports and increased domestic production of elemental mercury, as it determined that it could once again produce elemental mercury at its mines for less than it would cost to import the elemental mercury from elsewhere. China has a substantial internal market for elemental mercury, has not historically exported much elemental mercury, and is not expected to start now (Maxson, 2006). Kyrgyzstan has been producing close to its practical capacity of 600 metric tons of elemental mercury per year (Maxson, 2006). In 1990, global supply was approximately 7,000 metric tons; in 2005 it was estimated to be about 3,500 metric tons (Maxson, 2006). The government of Kyrgyzstan is working on a joint project with Switzerland and the UN to assess ways to phase out mercury mining in Kyrgyzstan.

Overall, the trend in primary mercury mining over recent years has been a significant decrease in production. The only large-scale primary mercury mine currently feeding global supply is in Kyrgyzstan and is a state-run facility that may not react predictably to future market trends. While increased market prices could create an incentive for additional mines to enter the market, the costs and time associated with preparing those mines for production might be prohibitive. Further, other factors such as the pledge by the International Council on Mining and Metals not to open new primary mercury mines decreases the likelihood that new mining will occur.

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[19] Although data for China are uncertain, one estimate of demand for mercury for use in vinyl chloride monomer was approximately 550 metric tons annually in 2004, with an estimated increase to 900 metric tons by 2010 (NRDC, 2007).

Secondary sources of elemental mercury such as old mine tailings may also begin to provide elemental mercury to market if prices increase; for example, the Commission for Environmental Cooperation estimates that tailings from silver mines in the Zacatecas region of Mexico contain approximately 13,000 metric tons of mercury reserves (Mexican Mercury Market Report, 2008). Byproduct mercury production from mines (such as gold) is likely to remain relatively constant at approximately 500 metric tons annually (UNEP, 2008).

Elemental mercury from chlor-alkali plants and from the recycling of mercury-containing products also continues to enter the market. Chlor-alkali plants in regions unaffected by the EU and U.S. export bans currently store approximately 11,000 metric tons of elemental mercury that may be delivered to the global market over the next 40 years as these plants are retired, and demand for elemental mercury from this sector will simultaneously decline.[20] In the long term, the quantity of elemental mercury coming to market from products will likely decrease reflecting the decrease in mercury used in manufactured products, though mercury regenerated from air pollution control systems is likely to continue and may increase. Note that additional constraints on trade of secondary mercury (e.g., chlor-alkali mercury) through treaty or legislation in other countries could result in reductions in elemental mercury supply (and potentially higher elemental mercury prices) for some time, but it is not possible to assess the specific market impacts of supply constraints because other sources of supply (e.g., regeneration of elemental mercury from historic mine tailings) may increase to meet demand.

As the regeneration of elemental mercury from chlor-alkali plants and from products continues and demand declines in the next several decades, it is possible that a state of occasional or even chronic global oversupply of elemental mercury could occur, even if the market in the near term is characterized by periods of supply shortage. Moreover, efforts to reduce mercury content in products may also reduce demand for certain mercury compounds. For example, as mercury use in batteries continues to be reduced, demand for mercury(II) oxide, a compound of mercury used in battery manufacturing, may also decrease. Although supply of elemental mercury is difficult to predict with accuracy, it is likely that elemental mercury will continue to be available to meet global demand, even when export bans in the European Union and United States take effect. As a result, it is difficult to envision a market in which scarcity of elemental mercury results in sustained market prices for elemental mercury that are much higher than they are currently.

Potential Impact of Mercury Global Treaty

According to Decision 25/5 “Chemicals management, including mercury” of the 25th session of the United Nations Environment Programme Governing Council / Global Ministerial Environmental Forum held in February of 2009 in Nairobi, Kenya, members agreed to “further international action consisting of the elaboration of a legally binding instrument on mercury,

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[20] This estimate assumes that approximately 8,000 of the 9,000 metric tons of mercury still held in European mercury cells and approximately 1,000 tons of mercury held in U.S. mercury cells will be diverted to storage as a result of the bans (Eurochlor, 2008; Chlorine Institute, 2008).This estimate also is based on the assumption that each of the four remaining mercury cell chlor-alkali facilities in the United States that are anticipated to continue to operate after 2013 contains 250 metric tons of elemental mercury.

which could include both binding and voluntary approaches, together with interim activities, to reduce risks to human health and the environment" (UNEP 2009). A future treaty may result in decreased global demand, supply, and trade in elemental mercury, which would in turn affect the incentives for exporting mercury compounds from the United States for processing into elemental mercury for the international market. Such potential changes are uncertain at this time.

Potential Impact of Mercury Export Ban Act

The possibility exists that the decrease in global supply of mercury due to the U.S. ban on elemental mercury could have unintended effects that work against the goal of the act, which is to reduce release of mercury to the environment. One of these unintended effects, although unlikely, could be to increase primary mercury mining in other countries. However, based on the long-term trend of decreasing primary mining, the cost of opening a new mine, and the commitment of the members of the International Council on Mining and Metals not to produce mercury as a primary product, it is unlikely that any new mines will open.[21] Another potential impact could theoretically be a reduction in voluntary mercury recycling in the United States, including recovery of mercury from consumer products. At this time, EPA has no evidence that negative effects of the export ban are likely. However, if they occur, expansion of the ban to mercury compounds could add to the effects because of the further decrease in U.S. contribution to global supply.

4.2.5.2 U.S. Elemental Mercury Market

The U.S. domestic elemental mercury market represents a limited and decreasing portion of the global elemental mercury market. U.S. domestic demand for elemental mercury for industrial use continues to decline, and is currently estimated to be approximately 100 metric tons – less than 5 percent of the global market (Balistreri, 2007; Chlorine Institute, 2008). Total U.S. domestic supply has been in the range of 180-200 metric tons from U.S. gold mines and waste, product regeneration, and the frequent closure of mercury-cell chlor-alkali plants over the past decade (Balistreri, 2007). In recent years U.S. domestic production of secondary elemental mercury has been sufficient to meet domestic demand, and supply an additional 80-100 metric tons per year to the global market (Lawrence, 2007). Domestic demand for mercury is likely to decline as manufacturing shifts away from mercury-containing products and chlor-alkali plants continue to close, and the reduced use of mercury-containing products will likely result in a long-term decline in secondary mercury recovery from products (Lawrence, 2007). Other sources of secondary and byproduct mercury, such as gold mining and regeneration of elemental mercury from air pollution equipment, are likely to continue and may increase, particularly if gold prices remain strong and mining expands to lower-quality seams. These sources, however, are also driven in part by air emissions control requirements, advances in technology, and mercury content in mine reserves.

Independent of U.S. domestic production and regeneration of elemental mercury, U.S. waste recovery operations and brokers have imported and exported several hundred metric tons of

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[21] See www.icmm.com

elemental mercury per year. Currently, trade in elemental mercury and trade in compounds is primarily limited to the import of significant quantities of mercury(I) chloride, probably for the purpose of extracting and selling elemental mercury. In the context of MEBA, operations to regenerate elemental mercury from mercury(I) chloride are likely to move outside of the United States and continue.

4.2.5.3 Implications of Global Mercury Market for Compound Trade

Recent trends in elemental mercury trade do not suggest that a significant, long-term shortage of elemental mercury will emerge in the near future, absent significant new agreements to further restrict supply. Recent market trends include decline in industrial use, consistent or potentially growing secondary production, and relatively stable prices for several years. Price swings are likely in the future as the market contracts, and prices could potentially rise for a time following the implementation of the EU export ban in 2011. In the long term, however, elemental mercury prices are likely to be moderated by increases in secondary supplies such as chlor-alkali plant retirements outside of the European Union and, possibly, by release of private stockpiles of elemental mercury held by recyclers and traders. It is unlikely that an elemental mercury shortage or price shock would be severe or persistent enough to encourage demand for compounds as an alternative source of elemental mercury, particularly because compound prices would also be affected by any severe elemental mercury shortage.

These price and demand trends limit the potential for significant demand for compounds as a source of elemental mercury. However, in limited circumstances it is possible that trade in compounds as sources of elemental mercury could be feasible if domestic long-term storage/treatment/disposal costs, as well as foreign disposal costs, are relatively high and generators seek a less costly option than regeneration and storage of elemental mercury. Due to the large size of the companies that produce mercury compounds, the total costs associated with long-term storage and disposal of mercury may not be a significant factor in their management decisions. In some cases, these companies may choose disposal or storage in spite of higher costs, if, for example, they are concerned about long-term liability or adverse publicity associated with future uses of mercury from their facilities.

4.2.6 Consideration of Specific Compounds with Potential to Supply Elemental Mercury

As presented in Sections 3.1.3 and 3.1.4, five compounds are currently generated as byproducts or in waste from industrial processes: mercury(I) chloride, mercury(II) oxide, mercury(II) sulfide, mercury(II) sulfate, and mercury(II) selenide. Of these five, only mercury(I) chloride is generated in a significant quantity. Generators of these byproduct or waste compounds, along with generators of excess elemental mercury and some mercury compound-containing wastes, have an incentive to weigh the costs of disposition path alternatives.

Of these, the largest quantity is mercury(I) chloride that is produced annually by domestic gold mines; primarily in Nevada (see Table 3-11). Quantities of mercury(II) sulfate, mercury (II) sulfide, and mercury(II) selenide waste are more difficult to estimate, as discussed in Section

3.1.3 and Section 3.1.4. Total quantities produced, however, are likely to be significantly smaller than quantities of mercury(I) chloride produced (Bethlehem Apparatus, 2009; EPA, 2007a).[22]

Management options for these compounds, and for surplus elemental mercury, include:

- Retorting and long-term storage of elemental mercury
- Other options for disposal (if available)
- Processing and sale (including export) of compounds.

A handful of U.S. mercury waste recovery companies (i.e., retorters), including Bethlehem Apparatus, Mercury Waste Solutions, and D.F. Goldsmith, have the capacity and technology to perform high-volume waste recovery for these compounds. These firms also have relationships with generators of byproduct mercury, mercury wastes and mercury compounds, and with purchasers of elemental mercury.

Mercury recyclers may have an economic incentive to expand operations to produce high-volume mercury compounds if they perceive adequate demand and determine that they are cost-competitive. As one example, mercury(II) oxide is currently produced as an interim product in processing mercury(I) chloride. Depending on the type of process used it could be possible to produce mercury(II) oxide in bulk by adjusting processes already in place. Production of compounds such as mercury(II) sulfate and mercury(II) nitrate, though also relatively simple, would require significant capital investment to add new production lines and obtain permitting to handle mercury-containing wastes and other hazardous materials (e.g., sulfuric acid). Given the small quantities of available domestic elemental mercury supplies and the difficulty predicting sustained high elemental mercury prices, it is not clear that these companies would assume this business risk.

In addition, it appears that at least one company (Bethlehem Apparatus) is pursuing disposal technologies rather than emphasizing opportunities to export compounds for elemental mercury recovery. It is possible that this disposal solution may represent a low-cost alternative to long-term elemental mercury storage that is also a relatively low-risk manufacturing venture for the recycler.

4.2.7 Capacity Outside of the United States To Convert Compounds to Elemental Mercury

In addition to manufacturing or recovering compounds, a producer must ensure that capacity exists outside the United States for recovery of elemental mercury. At this time, it appears that only byproduct compounds (e.g., mercury(I) chloride and mercury(II) sulfide) are currently traded as sources of elemental mercury. EPA was unable to find any evidence that any compounds are currently exported from the United States for processing into elemental mercury in other countries.

In the event that global supply of elemental mercury is severely constrained, increased demand for compounds as alternative sources of elemental mercury would focus on compounds that can be easily treated to regenerate elemental mercury. As noted in Section 4.1, several compounds

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[22] Mercury (II) sulfate is typically produced by smelters.

(e.g., mercury(I) chloride, mercury(II) oxide, mercury(II) sulfate, or mercury(II) nitrate) can provide elemental mercury through simple roasting and condensing. Regeneration of elemental mercury from many other mercury compounds requires chemical conversion (reduction of mercury to elemental mercury).

The technology to recover elemental mercury from mercury(II) oxide, mercury(II)sulfate, and mercury(II) nitrate is widely available globally. However, unless a U.S. producer operates its own off-shore recovery facility, it may be difficult to ensure that demand would remain constant. While the financial commitment associated with basic retorting technology is not prohibitively expensive, a purchaser will invest in it only if he believes that recovery of elemental mercury from compounds is, and will remain, less expensive than the direct purchase of elemental mercury. The markets of most concern, such as artisanal mining, are in many ways least likely to invest in capital equipment for processing mercury, given that their operations require that elemental mercury be widely distributed in small quantities throughout remote geographical areas.

Even if elemental mercury prices were to rise in the future, it is likely that (a) mercury compound prices would also increase, and (b) mercury from byproduct from existing non-mercury mines or from secondary sources such as historic mine tailings, would increase to provide additional elemental mercury.[23] Given this economic dynamic, it is difficult to identify market conditions that would favor the development of significant demand for compounds as alternative sources of elemental mercury.

4.3 Assessment of Potential for Export of Compounds Based on Technological and Economic Factors

Table 4-3 shows the results of EPA's assessment of the potential for export of the compounds studied in this report. The table is organized hierarchically to first show the most likely candidates for potential export and conversion to elemental mercury. For their overall assessment, EPA considered technical feasibility in conjunction with economic feasibility for each compound for each source (i.e. specialty chemical manufacture, waste, byproduct). The resultant characterizations are as follows:

Assessment	Technical Feasibility	Economic Feasibility
Likely	High	Currently produced in significant quantities Low cost for conversion

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[23] It is difficult to obtain specific information about primary mercury mines, particularly in China, but recent formal cutbacks (approximately a decade ago) in production appeared to be correlated with either low prices or significant secondary supply (e.g., from chlor-alkali plant closures) (NRDC, 2007). Moreover, the China mining association web site reports that Chinese mines have a capacity of over 900 tons with at least three large mines producing 100 tons per year. A market with longer-term supply constraints and higher prices would provide the basis for expansion of these operations. Furthermore, small scale mercury mining, along with recovery of mercury from historic mine tailings, is already occurring in Mexico at current prices and may expand if prices increase (Mexican Mercury Market Report, 2008). Finally, larger-scale gold mines in areas with high mercury concentrations may improve recovery efforts if these become more economical in a high-priced mercury market.

		Little if any new capital investment Evidence of current international trade
Somewhat Likely	High	Low cost for conversion Capital Investment needed to expand production capacity No current trade
Unlikely	Medium to Low	Significant cost for conversion
Very Unlikely	Low	Currently produced in limited quantities High cost for conversion

An important factor in determining the economic feasibility of exporting a mercury compound as a substitute for elemental mercury is whether trade in the compound would allow the holders of mercury supplies to avoid storage/treatment/disposal costs. For compounds that are currently available as byproducts or waste, the principal disposition path is recovery (retorting) and long-term storage of elemental mercury. For some compound-bearing wastes with low mercury content, other disposal options may be feasible, but Table 4-3 assumes that compounds include high mercury content and must be retorted. For compounds produced from surplus domestic elemental mercury supplies, disposition costs for elemental mercury would still be a relevant consideration, though retort costs would be minimal.

Table 4-3: Summary of Technological Feasibility, Economic Feasibility, and Overall Potential for Export of Candidate Compounds

	Technological Feasibility of Conversion			**Economic Feasibility**				
Compound	Processes Used to Convert to Elemental Mercury	Percent Mercury by Weight	Potential for Export Based on Technical Feasibility [a]	Potential source	Quantity Reported by Producers[b]	Avoided Retort and Long-Term Storage Costs [g]	Processing Costs for Sale	**Overall Potential for Export**
Mercury(I) chloride	Chemical or electrochemical reduction; Dissociation by light or heat	85%	High	Mining and air pollution control byproduct	~25 metric tons of Hg/year[c]	Significant	Low technical requirements; Requires processing to remove impurities; offset by significant retort and long term storage costs (retort + long-term storage/ treatment/ disposal costs)	**Likely (for byproduct): large volume currently traded internationally and imported by the U.S. for regenerating of elemental mercury.**
				Convert surplus elemental mercury to bulk compound; Increase specialty chemical production;	1.3 kg	Moderate	Higher cost inputs required; equal to manufacturing costs.	Unlikely
Mercury(II) oxide	Decomposition by light or heat; Electrolytic reduction	93%	High	Byproduct; Convert surplus elemental mercury to bulk compound; Convert from other common mercury compounds	32.5 kg	Moderate to significant	Low technical requirements; equal to manufacturing costs. Could be produced in bulk as an interim product in mercury(I) chloride processing.	**Somewhat likely; requires new capacity.**

Table 4-3: Summary of Technological Feasibility, Economic Feasibility, and Overall Potential for Export of Candidate Compounds

	Technological Feasibility of Conversion			Economic Feasibility				
Compound	Processes Used to Convert to Elemental Mercury	Percent Mercury by Weight	Potential for Export Based on Technical Feasibility [a]	Potential source	Quantity Reported by Producers[b]	Avoided Retort and Long-Term Storage Costs [g]	Processing Costs for Sale	**Overall Potential for Export**
Mercury(II) sulfate	Reduction by heating	68%	High	Waste from smelters: Convert surplus elemental mercury to bulk compound;	Not Available	Moderate to significant	Cost unclear: requires purification; Significant retort and long term storage costs (retort + long-term storage/ treatment/ disposal costs)	**Somewhat likely (for waste); requires new capacity.**
				Convert surplus elemental mercury to bulk compound; Increase specialty chemical production;	260.8 kg		Low technical requirements; equal to manufacturing costs. Bulk production would require RCRA Subtitle C Permitting for disposal of mercury-containing wastes.	Unlikely
Mercury(II) nitrate	Reduction by heating	62%	High	Convert surplus elemental mercury to bulk compound; Increase specialty chemical production	88.7 kg	Moderate	Low technical requirements; equal to manufacturing costs. Bulk production would require RCRA Subtitle C Permitting for disposal of mercury-containing wastes.	**Somewhat Likely; little existing capacity.**

Table 4-3: Summary of Technological Feasibility, Economic Feasibility, and Overall Potential for Export of Candidate Compounds

	Technological Feasibility of Conversion			**Economic Feasibility**				
Compound	Processes Used to Convert to Elemental Mercury	Percent Mercury by Weight	Potential for Export Based on Technical Feasibility [a]	Potential source	Quantity Reported by Producers[b]	Avoided Retort and Long-Term Storage Costs [g]	Processing Costs for Sale	**Overall Potential for Export**
Mercury(II) acetate	Decomposition by heat or light	63%	Medium	Increase specialty chemical production	41.3 kg	Not applicable	Equal to manufacturing costs.	Unlikely; requires new capacity.
Mercury(II) chloride	Chemical or electrochemical reduction; Conversion to other inorganic compounds to be converted by heating	74%	Medium	Increase specialty chemical production;; Convert from surplus elemental mercury; Convert from other common mercury compounds	76.8 kg	Not applicable	Equal to manufacturing costs.	Unlikely; requires new capacity.
Mercury(II) iodide	Conversion to other inorganic compounds to be converted by heating	44%	Medium	Increase specialty chemical production; Convert from surplus elemental mercury; Convert from other common mercury compounds	11.3 kg	Not applicable	Equal to manufacturing costs.	Unlikely; requires new capacity.
Mercury(II) sulfide	Reduction by retorting	86%	Medium	Increase specialty chemical production; Naturally occurring; Convert from surplus elemental mercury; Byproduct; Convert from other common mercury compounds,	0.6 kg	Not applicable	Equal to manufacturing costs.	Somewhat likely/unlikely; manufactured product unlikely to be cost-competitive with a naturally occurring source of mercury(II) sulfide (cinnabar ore).

Table 4-3: Summary of Technological Feasibility, Economic Feasibility, and Overall Potential for Export of Candidate Compounds								
	Technological Feasibility of Conversion			**Economic Feasibility**				
Compound	Processes Used to Convert to Elemental Mercury	Percent Mercury by Weight	Potential for Export Based on Technical Feasibility [a]	Potential source	Quantity Reported by Producers[b]	Avoided Retort and Long-Term Storage Costs [g]	Processing Costs for Sale	**Overall Potential for Export**
				Waste	Not Available, but possibly significant	Significant; stabilization and export currently disposal option[c]	Low technical requirements; Requires processing to remove impurities.	
				Naturally occurring (Cinnabar)	No active mines in the U.S. but found in abandoned Hg mines	Not applicable	Not applicable	
Phenyl mercury(II) acetate	Ventron process (convert to inorganic mercury compounds, reduce with sodium borohydride) ; Burning	60%	Low	Convert from other common mercury compounds; Increase specialty chemical production	0.2 kg	Not applicable	Equal to manufacturing costs.	Unlikely
Mercury(II) selenide	Reduction by retorting	72%	Very Low	Waste; Convert from other common mercury compounds	Small quantities	Significant avoided retort and long-term storage / treatment / disposal costs	Requires expensive input material – selenium; Significant retort and long term storage costs/ treatment/ disposal costs.	Very Unlikely

Table 4-3: Summary of Technological Feasibility, Economic Feasibility, and Overall Potential for Export of Candidate Compounds

	Technological Feasibility of Conversion			**Economic Feasibility**				
Compound	Processes Used to Convert to Elemental Mercury	Percent Mercury by Weight	Potential for Export Based on Technical Feasibility [a]	Potential source	Quantity Reported by Producers[b]	Avoided Retort and Long-Term Storage Costs [g]	Processing Costs for Sale	**Overall Potential for Export**
Mercury(II) thiocyanate	Decomposition by heating (exothermic, difficult to control)	63%	Very Low	Convert from other common mercury compounds; Increase specialty chemical production	6.4 kg[f]	Not applicable	Equal to manufacturing costs.	Very Unlikely
Thimerosal	Ventron process (convert to inorganic mercury compounds, reduce with sodium borohydride) ; Burning	50%	Low	Increase specialty chemical production	unknown	Not applicable	High-cost inputs and process; Equal to manufacturing costs.	Very Unlikely

Notes:

a. Categories are defined as follows:
- High: Likely candidates to be used for export and conversion to elemental mercury
- Medium: Potential candidates to be used for export and conversion to elemental mercury
- Low: Possible candidates, but too expensive because manufactured from other candidates that are more likely to be exported
- Very Low: Unlikely candidates because their chemistry makes them too difficult or expensive to prepare or handle

b. Quantities of manufactured products from IMERC 2004 data unless otherwise noted.

c. Quantities of mercury(I) chloride are produced as mercury(I) chloride waste by domestic gold mines; primarily in Nevada (Jones and Miller, 2005; see Table IV-5, above). Barrick representatives estimate that the current production of mercury(I) chloride at the Goldstrike mine is roughly 25 metric tons, and represents the majority of mercury(I) chloride produced by gold mines in the United States

d. Some mercury(II) sulfide is produced as a stabilized waste for landfilling. (Bethlehem Apparatus, 2009).

e. NEWMOA "IMERC Mercury Added Products Database," accessed at: http://www.newmoa.org/prevention/mercury/imerc/notification/index.cfm

f. Long-term storage costs and overall disposition pathway costs for mercury are highly uncertain; DOE will be examining costs of long-term management and storage of elemental mercury

g. As currently manufactured, retort and long-term storage costs are not applicable to these compounds. If these compounds were manufactured from surplus domestic elemental mercury, the long-term storage/treatment/disposal fee would become relevant, though retort costs would remain inapplicable.

Source: NEWMOA

As shown in Table 4-3, mercury compounds in the United States vary in their potential for use as exports for the purpose of retorting elemental mercury based on supply costs. The economic rationale for supply of these compounds for export is summarized below.

- The one compound that is likely to be used as an alternative supply of elemental mercury is mercury(I) chloride. This compound is currently produced as a waste in significant quantities, and producers have incentives to avoid retort and storage costs. In addition, waste mercury(I) chloride is internationally traded, and mercury recyclers in the United States have purchased waste mercury(I) chloride for the purpose of recovering elemental mercury for sale.[24] It is not clear, however, that global recovery of elemental mercury from mercury(I) chloride would spread beyond a handful of sophisticated processors, because the technology for recovery is highly specialized.[25]
- The other mercury compounds that are possible candidates for production for export to supplement elemental mercury trade are mercury(II) oxide, mercury(II) sulfate, and mercury(II) nitrate. Significant capital investment would be required to produce larger quantities in the United States, and it is not clear that expected quantities of surplus elemental mercury and anticipated elemental mercury prices are high enough to justify the investment at this time. However, all of these compounds are commonly produced and traded for industrial uses in relatively small quantities. Mercury(II) sulfate is also currently generated as waste, which could possibly be purified for sale or exported. It does not appear that significant quantities of mercury(II) sulfate are currently processed to regenerate elemental mercury. Production of mercury(II) nitrate and mercury(II) sulfate involves the handling of toxic substances such as sulfuric acid and results in quantities of mercury-containing wastes, which can increase expenses. Mercury(II) oxide is an interim product of several recovery processes and is relatively simple to manufacture, though it generally is produced from other compounds, including mercury(II) sulfate and mercury(I) chloride, and is more inefficient to produce from elemental mercury. If mercury(I) chloride export is banned, it is possible that production of mercury(II) oxide could become more cost-competitive. Because mercury(II) oxide is currently produced as an interim product in processing mercury(I) chloride, an increase in domestic mercury(I) chloride supplies would likely reduce the cost of producing mercury(II) oxide.
- Production of other mercury compounds is typically too costly to provide competitive alternative sources of elemental mercury. Compounds as a source of elemental mercury for export (e.g., mercury(II) selenide, thimerosal, and mercury(II) thiocyanate) are currently produced in small quantities for targeted industrial purposes, and require significant processing and expensive ingredients. Cost-effective bulk production of these compounds does not appear feasible.

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[24] While mercury(I) chloride is also manufactured for specific purposes, it does not appear that byproduct mercury(I) chloride is used as a source for manufactured mercury(I) chloride, or that manufactured mercury(I) chloride would be a likely substitute source for elemental mercury because, like other manufactured compounds, it would be more costly than other sources of mercury.

[25] In addition, it appears that one stage in this process results in mercury(II) oxide, but it is not clear whether the quality of mercury(II) oxide is high enough to represent a tradable commodity. The ultimate product of the process is elemental mercury. See http://www.bethlehemapparatus.com/calomel-conversion.html.

4.4 Summary of Technical and Economic Feasibility of Potential for Export

The current, relatively stable prices and supply of elemental mercury globally, coupled with the limited capacity of U.S. producers to provide high-volume, low-cost mercury compound products without investing in new capital equipment, limit the economic opportunity to manufacture compounds for export as an alternative source of elemental mercury. Unless mercury compounds are currently traded to provide elemental mercury (as appears to be the case with recovery of elemental mercury from mercury(I) chloride), it is unlikely that economic circumstances will favor the development of these markets, even for compounds that are relatively easy to make and process for regeneration of elemental mercury.

With the exception of capacity for managing mercury (I) chloride and other compounds produced as byproducts or waste, current compound production capacity in the United States does not appear sufficient to produce high enough volumes of compounds to compete with other sources of elemental mercury on the global market. Specialty chemical firms are not ideally positioned to invest in capital equipment for production of high-volume products, particularly in a small market. Moreover, most mercury compounds produced by these firms are fairly complex and have expensive manufacturing processes.

U.S. mercury recyclers, in contrast, have the capacity to process larger volumes of mercury in waste, and could be positioned to expand operations to produce compounds, but it is not clear that the limited quantities of elemental mercury likely to be available to these producers would justify the investment at current elemental mercury prices.

The small quantities of surplus elemental mercury and byproduct compounds available to the U.S. market limit the financial potential of any effort to develop and trade new compounds. At recent elemental mercury prices of roughly $600 per flask ($7.90 per pound, $17.42 per kilogram), the total potential for revenue from an annual surplus production of 125 metric tons of elemental mercury and mercury compounds is roughly $2.2 million, before subtracting production costs. While in some cases producers may also be able to charge fees for taking possession of the elemental mercury or mercury compounds, the potential revenues associated with this option are highly uncertain.

Absent significant and *sustained* price increases, this financial potential is not likely to be sufficient to justify significant investment in new capital equipment, materials, and permits required to manufacture compounds, export them, and recover elemental mercury.[26] While sustained mercury price increases are possible (e.g., after the EU export ban takes effect in 2011 or in the context of additional treaties restricting supply of elemental mercury), it is difficult to predict persistent shortfalls in elemental mercury supply given capacity at primary mines and the range of secondary supply sources. In this context, it is unlikely that mercury compounds will emerge as a viable alternative source of elemental mercury over the long term.

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[26] Note that in the case of regeneration of elemental mercury from mercury(I) chloride, the equipment and capacity for this operation is already in place.

Table 4-4 summarizes the technological and economic feasibility assessment for the four compounds deemed most likely to be supplied in significant quantities by U.S. producers. In all cases except mercury(I) chloride, potential for expansion of operations beyond what is currently in place is limited by the need to invest in capital equipment and industrial capacity in the context of uncertain market demand.

Table 4-4: Summary of Assessment of Technical and Economic Feasiblity of Potential for Export

Compound	Description	Quantity Recorded as Produced or Sold in the U.S. by Reporting Companies	Technical and Economic Feasibility Summary	Conclusions
Mercury(I) chloride	Air pollution byproduct;	~25,000 kg (Hg)*	Currently traded in large volumes for regeneration of elemental mercury using available technology. *Cost-competitive and technologically feasible source of elemental Hg*	Likely
	Chemically manufactured product	1.3 Kg produced		
Mercury(II) sulfate	Chemically manufactured product;	259 kg product; waste		
	Waste treatment byproduct	na	Recovered as waste, but requires adoption of new U.S. production capacity and technology to process product to regenerate elemental mercury. *Not currently cost competitive or technologically feasible given existing capacity*	Possible
Mercury(II) nitrate	Chemically manufactured product	88.7 kg product	Requires adoption of new U.S. production capacity and technology to process product to regenerate elemental mercury. *Not currently cost competitive or technologically feasible given existing capacity*	Possible
Mercury(II) oxide	Byproduct	unknown	Occurs as process byproduct including interim product in regeneration of mercury from mercury(I) chloride, but requires adoption of new U.S. production capacity and technology to process product to regenerate elemental mercury. *Could become cost competitive if export of mercury(I) chloride is banned ; however, existing technological capacity limits feasibility*	Possible
	Chemically manufactured product;	32.5 kg product		

*Quantity of mercury in byproduct mercury(I) chloride; estimate based on discussions with Melissa Barbanell, Barrick Gold Corporation (personal communication June 18, 2009).

Mercury(I) chloride is likely to continue to represent an economical source of elemental mercury, since it is currently traded for this purpose. While three other compounds – mercury(II) sulfate, mercury(II) nitrate, and mercury(II) oxide – represent possible candidates for export as alternative sources of elemental mercury, production of these compounds is not currently cost-competitive with other sources of elemental mercury and production of high volumes would require additional capital investment.

5. Other Relevant Information to Assist Congress in Determining Whether to Extend the Export Ban

5.1 European Union Ban on Export of Mercury and Mercury Compounds

On October 22, 2008, the European Union expanded its original ban on elemental mercury exports, introduced in 2007, to include several mercury compounds. The expanded ban prohibits the export from the European Union of "metallic mercury (elemental mercury), cinnabar ore, mercury(I) chloride, mercury(II) oxide, and mixtures of metallic mercury with other substances, including alloys of mercury, with a mercury concentration of at least 95 percent by weight."[27] In addition, the EU law prohibits the "mixing of metallic mercury with a substance for the sole purpose of export of metallic mercury." The implementation date of the expanded ban is March 15, 2011. The amended export ban excludes elemental mercury or mercury compounds used for research and development, medical, or analysis purposes.

In general terms, the European Union expressed the opinion that because mercury compounds are classified as toxic, curbing trade in these compounds would reduce exposure to mercury, particularly if the compounds are used to recover elemental mercury for further use.[28]

Cinnebar ore (i.e. mercury (II) sulfide), mercury(I) chloride, and mercury(II) oxide were included in the export ban because they constitute key ongoing uses of mercury in the European Union. For example, mercury oxide is currently found and recovered in the European Union in anodes and in batteries. While mercury oxide batteries are not produced in the European Union, some production is still ongoing in China and mercury oxide batteries are still imported into the European Union (Commission of the European Communities, 2006).

Cinnabar ore is no longer mined in the European Union since the last mercury mine closed in Almadén, Spain, but the European Union perceived an incentive to export cinnabar for conversion to elemental mercury. Cinnabar ore from Almadén has an exceptionally high mercury content, and retrieving the elemental mercury is technically simple and inexpensive. At current elemental mercury prices, the European Union determined that the export of cinnabar ore and certain other mercury compounds mentioned in EU regulation would still be profitable after the introduction of the 2011 export ban (Commission of the European Communities, 2006).

Mercury(I) chloride is used in the European Union in electrochemistry, pesticides, and cosmetics such as soaps and skin-lightening creams, and is also a byproduct of production of other non-ferrous metals in Europe (e.g., zinc). The European Union included mercury(I) chloride in its ban due to concerns that mercury(I) chloride byproduct generated within the European Union could be exported as a compound for recovery of elemental mercury by a

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[27] Mercury(II) sulfide as cinnabar ore is abundant in the European Union. In the U.S., however, mercury(II) sulfide primarily exists as a manufactured product.

[28] Draft Report on the proposal for a regulation of the European Parliament and of the Council on the banning of exports and the safe storage of metallic mercury (COM(2006)0636 – C6-0363/2006 – 2006/0206(COD)) Committee on the Environment, Public Health and Food, 27 Feb 2007.

third-country processor at little cost, though the recovery process is sophisticated and requires several chemical inputs. (Commission of the European Communities, 2006).

5.2 Evidence That Mercury Compounds Are Exported for Processing into Elemental Mercury

EPA was unable to find any conclusive evidence that compounds are currently exported from the United States for processing into elemental mercury. The only reference to international partnerships is the Bethlehem Apparatus reference to its proprietary process for recovering mercury from mercury(I) chloride : "After consultation with Universal Dynamics of Vancouver, B.C., Bethlehem Apparatus developed and built a proprietary mercury(I) chloride processing system."[29] This comment implies that at this time, Bethlehem Apparatus is recovering elemental mercury from mercury(I) chloride domestically, but it also seems feasible that mercury(I) chloride could potentially be exported in partnership with Universal Dynamics for processing.

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[29] http://www.bethlehemapparatus.com/calomel-conversion.html.

6. Report Conclusions

Over a dozen mercury compounds are currently manufactured in significant quantities in the United States, though most of these compounds are manufactured as part of the specialty chemical industry as value-added products sold in small quantities. In addition, larger volumes of mercury compounds are produced as byproducts or in mercury-containing waste. The most significant of these is mercury(I) chloride which is produced by air pollution processes in several gold mines in quantities exceeding 25 metric tons of elemental mercury per year.

Uses for mercury compounds are typically limited to chemical uses (e.g., preservatives or process agents) or in other highly specialized industrial applications, and in a limited number of consumer products such as batteries. At present, the chief mercury compound that is used as a source of elemental mercury in the United States is mercury(I) chloride.

In addition to domestic production, quantities of mercury compounds are imported to and exported from the United States. Though data do not identify quantities of individual compounds traded internationally in recent years, in the early part of the decade, data for specific compound imports suggested that mercury chlorides (including mercury (I) chloride) accounted for the majority of imports; mercury traders in the United States have verified that they have imported mercury(I) chloride and used it as a raw material to regenerate elemental mercury.

Export data are less informative, in part because recent large reported quantities (exceeding 7,000 tons) are difficult to reconcile with the small size of the global elemental mercury market, which is estimated at roughly 3,500 metric tons. Currently available data are not sufficient to describe uses, imports, or exports of specific mercury compounds in detail.

EPA has examined the technological and economical feasibility of the export of 12 mercury compounds, and found that only mercury compounds produced as byproducts or as part of waste streams, such as mercury (I) chloride have potential to be cost-competitive if exported as alternatives for elemental mercury. Mercury (I) chloride is likely to continue to represent an economical source of elemental mercury, since it is currently traded for this purpose. While three other compounds – mercury (II) sulfate, mercury (II) nitrate, and mercury (II) oxide – represent possible candidates for export as alternative sources of elemental mercury, production of these compounds is not currently cost-competitive with other sources of elemental mercury. Export on a larger scale would require expansion of U.S. production capacity and would only be cost-competitive given a much higher global price of elemental mercury.

Although global supply of elemental mercury is difficult to predict with accuracy, a range of sources of mercury exist outside the United States., and current market information (e.g., the stability of prices in the last 12 months and continuing downward trends in overall industrial demand) suggests that elemental mercury will continue to be available in response to demand, particularly as demand from chlor-alkali plants and other industrial sectors continues to decline and secondary mercury from some of these facilities also becomes available. As a result, while supply and price fluctuations are likely, it is difficult to predict a scenario with the sustained scarcity of and high prices for elemental mercury that would be sufficient to support the development of the infrastructure necessary to develop and export compounds in order to provide an alternative supply of elemental mercury.

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Appendix A – Mercury Compound Identifying Information

Table A-1: Identifying Information for Mercury Compounds in This Report

Compound	CAS Number	Alternate Names	Description	Mercury by Molecular Weight	Uses	Production Status
Mercury(I) chloride	10112-91-1	Mercurous chloride	Heavy white powder or colorless crystals	85%	Electrochemistry; Mining by-product	Currently manufactured[a,b]; Mining byproduct
Mercury(II) acetate	1600-27-7	Mercuric acetate, Diacetoxymercury, Mercuric diacetate,	Colorless crystalline solid	63%	Production of organomercuric compounds.	Currently manufactured[d]
Mercury(II) chloride	7487-94-7	Mercuric chloride	Toxic and corrosive white powder	74%	Laboratory chemistry; Waste treatment	Currently manufactured[a,b]
Mercury(II) iodide	7774-29-0	Mercuric iodide	Red or yellow powder	44%	Laboratory chemistry; Veterinary medicine; Nuclear particle detection	Currently manufactured[a,b]
Mercury(II) nitrate	10045-94-0	Mercuric nitrate	White or slightly yellow powder	62%	Laboratory chemistry	Currently manufactured[a,b]
Mercury(II) oxide	21908-53-2	Mercuric oxide	Red, orange, or yellow powder	93%	Laboratory chemistry; Batteries	Currently manufactured[a,b]
Mercury(II) selenide	20601-83-6	None	ultrapure 100 mesh powder		Electrochemistry	Waste from production of semiconductors and integrated circuitry
Mercury(II) sulfate	7783-35-9	Mercuric sulfate	White granules or crystalline powder	68%	Laboratory chemistry; Gold and silver extraction	Currently manufactured[a]
Mercury(II) sulfide	1344-48-5	Mercuric sulfide, cinnabar	Red hexagonal crystals or black cubic crystals	86%	Mercury extraction; Waste; Pigment	Currently manufactured[c]; Waste; Naturally occurring
Mercury(II) thiocyanate	592-85-8	Mercuric thiocyanate	White to tan powder	63%	Laboratory chemistry; Photography	Currently manufactured[a,b]
Phenylmercury (II) acetate	62-38-4	PMA	White crystalline powder or white prisms	60%	Pharmaceutical; Production of phenylmercury compounds	Currently manufactured[c]
Thimerosal	54-64-8	Sodium Ethylmercurithio-salicylate, Merthiolate, Thiomersal	Cream colored crystalline powder	49%	Pharmaceutical	Currently manufactured[a,b]

[a] Based on 2004 NEWMOA data.
[b] According to EPA's 1997 report to Congress.
[c] Based on chemical supplier websites.
[d] According to Simon et al. (2006)

Appendix B – Mercury Compounds in the IUR Database

The six chemicals identified as those with the production levels of greater than 25,000 pounds (11,340 kilograms) or greater at a single site according to the IUR database were selected for in-depth review. The purpose of the IUR program is to collect quality screening-level, exposure-related information on chemical substances and to make that information available for use by EPA and, to the extent possible while still protecting confidential business information, to the public. The IUR regulation requires manufacturers and importers of certain chemical substances included in the TSCA Chemical Substance Inventory to report site and manufacturing information for chemicals (including imported chemicals) manufactured in amounts of 25,000 pounds (11,340 kilograms) or greater at a single site. Additional information on domestic processing and use must be reported for chemicals manufactured in amounts of 300,000 pounds (136,078 kilograms) or more at a single site. The IUR data are used to support risk screening, assessment, priority setting and management activities and constitute the most comprehensive source of basic screening-level, exposure-related information on chemicals available to EPA.

EPA searched the databases from 1986 through 2006 for any mercury compound or elemental mercury (not included in this Report to Congress) that met the listing criteria stated above.

Table A2-1: Identifying information for mercury compounds in this report

CAS No.	1986	1990	1994	1998	2002	2006	Chemical Name
62384	10K - 500K	10K - 500K	No Reports	No Reports	>1M - 10M	No Reports	Mercury, (acetato-.kappa.O)phenyl-
1600277	>1M - 10M	No Reports	No Reports	No Reports	No Reports	No Reports	Acetic acid, mercury(2+) salt
7487947	No Reports	10K - 500K	No Reports	No Reports	No Reports	< 500,000	Mercury chloride ($HgCl_2$)
10112911	No Reports	No Reports	No Reports	10K - 500K	No Reports	No Reports	Mercury chloride (Hg_2Cl_2)
26545493	No Reports	10K - 500K	No Reports	No Reports	No Reports	No Reports	Mercury, (neodecanoato-.kappa.O)phenyl-

There are limitations to using IUR data. The main limitation is that if no chemical was manufactured in the year reporting was done then that chemical could go completely unnoticed if only IUR data were used. Note that mercury(II) oxide is not on the list but is an intermediate to several of the listed chemicals.

Appendix C – Individual Mercury Compound Summaries

C.1 Mercury(II) acetate

Formula: $Hg(C_2H_3O_2)_2$
Percent mercury by weight: 63
CAS Index Name : Acetic acid, mercury(2+) salt (2:1)
CASRN: 1600-27-7
Synonyms: Mercuric acetate, Diacetoxymercury, Mercuric diacetate, Mercury diacetate (HSDB, 2009)

C.1.1 Product description

Mercury(II) acetate is a colorless crystalline solid that melts at about 178°C. It will decompose at higher temperatures or when heated rapidly. Mercury(II) acetate is soluble in water, but the solution decomposes on standing to produce a yellow precipitate. Mercury(II) acetate is soluble in alcohol (Patnaik, 2003).

C.1.2 Product uses

Mercury(II) acetate is primarily used as a starting material for the manufacture of organomercuric compounds, including phenylmercury(II) acetate. Mercury(II) acetate is also used as a catalyst in organic polymerization reactions and as a reagent in analytical chemistry (Simon et al., 2006).

C.1.3 Synthesis from mercury

Mercury(II) acetate is typically prepared from other common mercury compounds. For example, heating mercury(II) oxide in a slight excess of warm 20% acetic acid will produce mercury(II) acetate. Mercury(II) oxide feedstock for this process can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) oxide is presented in its chemical summary.

Mercury(II) acetate can also be prepared directly from elemental mercury by reaction with peracetic acid dissolved in acetic acid. This reaction is quite exothermic and needs to be carefully controlled. A more economical method is to use 50% hydrogen peroxide instead of peracetic acid, but the reaction does not go quite as smoothly (Nowak and Singer, 1995).

C.1.4 Reduction to elemental mercury

Mercury(II) acetate will decompose when heated or when exposed to light (O'Neil et al., 2001). It is unclear whether this decomposition leads directly to elemental mercury or to mercury(II) oxide. Either reaction can lead to the eventual release of elemental mercury. Mercury(II) oxide is reduced to elemental mercury and oxygen when heated. More information on the reduction of mercury(II) oxide is presented in its chemical summary.

In aqueous solution, mercury(II) acetate slowly hydrolyzes to form acetic acid and mercury(II) oxide (CrossFire Gmelin Database, 2009). As noted above, this can lead to the eventual release of elemental mercury from mercury(II) oxide decomposition (O'Neil et al., 2001).

C.1.5 Potential sources

Sources of mercury(II) acetate include manufacturing facilities or sites where it is used as an intermediate in the manufacture of other organomercuric compounds.

C.1.6 Potential for export as an alternative to mercury

Mercury(II) acetate can be prepared directly from elemental mercury in a single step requiring inexpensive reagents. Mercury(II) acetate can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by heating mercury(II) acetate and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) acetate is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) acetate is a potential candidate for export as a mercury source because of its following attributes:

- It is available in commercial quantities or can be readily prepared from commercially available materials;
- It can be transported easily; and
- It produces elemental mercury simply by heating and condensing the resulting vapor.

C.2 Mercury(I) chloride

Formula: Hg_2Cl_2
Percent mercury by weight: 85
CAS Index Name: Mercury chloride (Hg2Cl2)
CASRN: 10112-91-1
Synonyms: Mercurous chloride, Calomel, Calogreen, Calotab, Dimercury dichloride, Mercury protochloride (Linstrom and Mallard, 2009)

C.2.1 Product description

Mercury(I) chloride, also known as calomel, is a white powder and has a low aqueous solubility of 2 mg/L. It sublimes without melting when heated to 400–500°C, but this occurs at least in part as a result of dissociation to elemental mercury and mercury(II) chloride (Nowak and Singer, 1995). Dissociation of mercury(I) chloride is also promoted by sunlight and by reaction with solutions of alkali iodides, bromides, or cyanides (O'Neil et al., 2001).

Mercury(I) chloride is available as a powder in quantities from 25 g to 2.5 kg (EPA Mercury Containing Products Database, 2008).

C.2.2 Product uses

Mercury(I) chloride is primarily used in calomel (mercury(I) chloride) electrodes, which act as standard electrodes for measuring electrochemical potential. Mercury(I) chloride can also be used in pyrotechnics to produce a dark green light, although mercury salts are prohibited in consumer fireworks in the United States. by Federal law (CPSC, 1997).

Mercury(I) chloride was formerly used as an antiseptic and as a treatment for syphilis before the advent of penicillin (Patnaik, 2003). It was also formerly used as a fungicide and in agriculture for controlling root maggots. In the late 1970s, the United States restricted the acceptable pesticide uses of mercury to the treatment of outdoor textiles and to the control of fungal pests, particularly brown mold on freshly sawn lumber, Dutch elm disease, and snow mold. In 1991, the EPA announced the cancellation of mercury biocide registrations (DeVito and Brooks, 2005) eliminating this use for mercury(I) chloride.

C.2.3 Synthesis from mercury

Mercury(I) chloride is typically prepared by passing a limited amount of chlorine gas over mercury in a heated silica retort. The use of excess chlorine will result in oxidation of mercury(I) chloride to mercury(II) chloride ($HgCl_2$) (Patnaik, 2003). The use of the highly toxic and corrosive chlorine limits this synthetic procedure to appropriately equipped facilities.

Mercury(I) chloride can also be prepared from other mercury compounds using basic laboratory transformations. For example, mercury(I) chloride is obtained as a white precipitate by adding a cold acidic solution of sodium chloride to a solution of mercury(I) nitrate. Mercury(I) nitrate is, in turn, prepared by the action of moderately dilute nitric acid on elemental mercury (Patnaik, 2003). Mercury(I) chloride can also be prepared by heating mercury(II) chloride with elemental mercury (Bebout, 2006). Mercury(II) chloride can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) chloride is presented in its chemical summary.

C.2.4 Reduction to elemental mercury

Elemental mercury can be obtained from mercury(I) chloride by electrochemical reduction using an electrolyte solution comprised of aqueous hydrochloric acid and collecting the resulting liquid metal (Grossman and George, 1991, 1989).

Chemical reduction of mercury(I) chloride can be accomplished by reaction with non-amalgamating metals, such as iron. In a typical process, mercury(I) chloride in a suspension can be reduced by addition of iron powder with agitation. The product, elemental mercury, falls out and is cleaned with aqueous nitric acid (Barreau, 1991).

Mercury(I) chloride can also be converted to other mercury compounds, which can then subsequently be reduced to elemental mercury. For example, when heated with additional chlorine, mercury(I) chloride is oxidized to mercury(II) chloride. Mercury(II) chloride can be converted to mercury(II) oxide, which is reduced to elemental mercury and oxygen by heating. More information on the synthesis and reactions of mercury(II) chloride and mercury (II) oxide is presented in their chemical summaries.

Mercury(I) chloride is dissociated by sunlight or by heating in an open container. Both of these processes can be used to produce elemental mercury using simple equipment. Reaction of mercury(I) chloride with solutions of alkali iodides, bromides, or cyanides produces mercury(II) salt and elemental mercury (O'Neil et al., 2001). However, these reactions yield only half of the elemental mercury as other reactions as half of the metal ends up as the mercury(II) salt.

Mercury(I) chloride can be reduced to elemental mercury by reaction with 2-amino-ethanethiol hydrochloride in water (CrossFire Gmelin Database, 2009). Similarly, other conversions of mercury(I) chloride to elemental mercury have been reported in the literature. It is unclear if these methods are useful for producing large quantities of elemental mercury.

C.2.5 Potential sources

Mercury(I) chloride is a common product from waste treatment methods used in a variety of industries. One such method is the Boliden-Norzink process, which is used to remove mercury from flue gases resulting from the burning of natural gas or the refining of zinc, gold, copper, or other metals where elemental mercury is an impurity. In the Boliden-Norzink process, flue gasses containing elemental mercury are washed with an aqueous solution of mercury(II) chloride and the resulting water-insoluble mercury(I) chloride precipitates out of solution (Louie, 2005).

Mercury(I) chloride is also a waste from the chlor-alkali industry in which mercury metal is used as a cathode material in the electrochemical generation of chlorine gas from brine (U.S. EPA, 2007a).

Mercury(I) chloride could be obtained through the disassembly or destruction of calomel electrodes. However, this process would be labor intensive and only small quantities are present within each electrode.

C.2.6 Potential for Export as an Alternative to Mercury

Mercury(I) chloride is a waste from a wide variety of industrial processes. Mercury(I) chloride can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of chlorine. Mercury(I) chloride can also be prepared from other mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by either chemical or electrochemical reduction of mercury(I) chloride, and collecting the resulting liquid metal. These processes can be accomplished using basic equipment and inexpensive reagents. Mercury(I) chloride is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(I) chloride is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It is a common waste from a wide variety of industries;
- It can be prepared from commercially available materials using straight-forward methods;
- It can be transported easily; and
- It can be converted to elemental mercury using a number of techniques and process, some of which do not require complicated equipment or procedures.

Concern was raised in Europe that mercury(I) chloride waste from the Boliden-Norzink process could be exported from the European Union as a mercury waste or as a compound, and the mercury could be recovered inexpensively outside the European Union (European Commission Directorate General for Environment, 2006); the EU's mercury export ban was amended in October of 2008 to include mercury compounds.

C.3 Mercury(II) chloride

Formula: $HgCl_2$
Percent mercury by weight: 74
CAS Index Name : Mercury chloride (HgCl2)
CASRN: 7487-94-7
Synonyms: Mercuric chloride, Mercury perchloride, Mercury bichloride, Mercuric bichloride, Mercury dichloride, Corrosive sublimate (Linstrom and Mallard, 2009)

C.3.1 Product description

Mercury(II) chloride is a white crystalline solid that melts at 276°C. It sublimes without decomposition at 304°C. Mercury(II) chloride has a high vapor pressure of 5 torr at 166°C and 60 torr at 222°C; at which temperatures, it is still a solid. Mercury(II) chloride is water soluble (7.4 g/100 ml at 20°C). The solubility of mercury(II) chloride increases in aqueous hydrochloric acid or chloride ion solutions. Mercury(II) chloride is also soluble in alcohol, ether, acetone, and ethyl acetate (Patnaik, 2003).

Mercury(II) chloride is sold as a powder in 100 g, 125 g, 250 g, 500 g, 1.0 kg, 2.5 kg, and 50 kg containers. The compound also appears to have been offered by one company as a 5% solution, the sale of which was discontinued in 2005. (EPA Mercury Containing Products Database, 2008)

C.3.2 Product uses

Mercury(II) chloride is used as an intermediate for the preparation other mercury compounds including red and yellow mercury(II) oxide, ammoniated mercury, and mercury(II) iodide, and as an intermediate in organic synthesis (Nowak and Singer, 1995). Mercury(II) chloride is used in the Boliden-Norzink process to remove mercury from flue gases resulting from the burning of natural gas or the refining of zinc, gold, copper, or other metals where elemental mercury is an impurity. Other applications include processes for etching steel and electroplating aluminum (O'Neil et al., 2001).

Until about 1980, mercury(II) chloride was used extensively as a catalyst for the preparation of vinyl chloride from acetylene. Since the early 1980s, vinyl chloride and vinyl acetate have been prepared from ethylene instead of acetylene, and the use of mercury(II) chloride as a catalyst has practically disappeared (DeVito and Brooks, 2005).

Other former uses include using mercury(II) chloride as an intensifier in photography; for preserving wood and anatomical specimens, including embalming; for tanning leather; as a fungicide; as a depolarizer for dry batteries; and as an antiseptic (O'Neil et al., 2001). The 1996 U.S. Mercury-Containing Battery Management Act limited the use of mercury in batteries to mercury oxide batteries and small quantities of elemental mercury added to batteries to prevent the buildup of hydrogen gas. In the late 1970's, the United States restricted the acceptable pesticide uses of mercury to the treatment of outdoor textiles and to control of fungal pests, particularly brown mold on freshly sawn lumber, Dutch elm disease and snow mold (DeVito and Brooks, 2005).

C.3.3 Synthesis from mercury

Mercury(II) chloride is typically manufactured by heating mercury with excess chlorine. Purification of mercury(II) chloride in this process takes advantage of its low sublimation temperature as the resulting sublimate is collected (Patnaik, 2003). The use of the highly toxic and corrosive chlorine limits this synthetic procedure to appropriately equipped facilities.

Mercury(II) chloride can also be prepared from other commonly available mercury compounds. For example, the treatment of mercury(II) oxide with aqueous hydrochloric acid produces mercury(II) chloride which is separated by crystallization. An alternative method is to heat mercury(II) sulfate with sodium chloride to produce mercury(II) chloride, which vaporizes under these conditions; the sublimate is then condensed and collected (Patnaik, 2003). The mercury(II) oxide or sulfate feedstocks for these processes can be obtained in commercial quantities, or can themselves be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) oxide and mercury(II) sulfate is presented in their chemical summaries.

C.3.4 Reduction to elemental mercury

Mercury(II) chloride reacts with tin(II) chloride to give a white precipitate of mercury(I) chloride which then is further reduced by tin(II) chloride to give a black deposit of mercury (Patnaik, 2003). It can also be electrochemically reduced to elemental mercury and chlorine using a mercury metal cathode (Louie, 2005).

Mercury(II) chloride can be converted using standard solution chemistry to other mercury compounds, which can subsequently be reduced to elemental mercury (Patnaik, 2003). For example, mercury(II) chloride can be converted to red mercury(II) oxide by heating in a solution of sodium carbonate. Mercury(II) chloride can also be converted to yellow mercury(II) oxide by dissolving it in water and treating it with a strongly alkaline reagent, typically sodium hydroxide. An aqueous solution of mercury(II) chloride can be treated with an excess of hydrogen sulfide or sodium sulfide to produce mercury(II) sulfide as a precipitate. The mercury(II) oxide or mercury(II) sulfide produced in these processes can be reduced to elemental mercury by heating. More information on the reduction of mercury(II) oxide and mercury(II) sulfide is presented in their chemical summaries.

C.3.5 Potential sources

Potential sources of mercury(II) chloride are from the facilities where it is manufactured or used. Those laboratories that use mercury(II) chloride as a catalyst or reagent, and industries that use mercury(II) chloride to capture mercury as part of their waste control procedures, are likely to have the highest amounts of this compound present on-site.

C.3.6 Potential for export as an alternative to mercury

Mercury(II) chloride is commercially available. It can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of chlorine. Mercury(II) chloride can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents.
Elemental mercury can be obtained from mercury(II) chloride by either chemical or electrochemical reduction of mercury(II) chloride and collecting the resulting liquid metal. These processes can be accomplished using basic equipment and inexpensive reagents.

Mercury(II) chloride can also be readily converted to other common inorganic mercury compounds using basic equipment and inexpensive reagents which can then, in turn, be converted to elemental mercury by heating.

Mercury(II) chloride is a stable solid. It sublimes at high temperatures facilitating its separation and purification. It is used in a number of commercial applications and can be transported using standard methods.

Mercury(II) chloride is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily;
- It can be converted to elemental mercury simply by either chemical or electrochemical methods; and
- It can be used to produce elemental mercury by first converting it to other common mercury compounds which are then heated.

C.4 Mercury(II) iodide

Formula: HgI_2
Percent mercury by weight: 44
CAS Index Name: Mercury iodide (HgI2)
CASRN: 7774-29-0
Synonyms: Mercuric iodide, Mercury diiodide, Mercury biniodide, Red Mercuric iodide, Coccinite (Linstrom and Mallard, 2009)

C.4.1 Product Description

Mercury(II) iodide is either a red or yellow crystalline solid depending on its crystal structure. The red iodide turns yellow on heating to 130°C, but returns to red on cooling. Mercury(II) iodide has a melting point of 259°C and vaporizes without boiling at 354°C. Mercury(II) iodide has a water solubility of 60 mg/L and is light sensitive (O'Neil et al., 2001).

Mercuric iodide is sold as a powder in 50 g and 250 g containers, as well as in solution as Nessler's reagent (EPA Mercury Containing Products Database, 2008).

C.4.2 Product Uses

Mercury(II) iodide is reacted with potassium hydroxide or potassium iodide to form complex halide K_2HgI_4 (CAS No. 7783-33-7), which is known as either Mayer's reagent when in solid form or as Nessler's reagent when in alkaline solution. This complex is used to detect low levels of ammonia. The sodium complex (Na_2HgI_4) can also be formed by reaction with sodium hydroxide (Patnaik, 2003).

Mercury(II) iodide is used in instruments that detect nuclear particles. Various metals including palladium, copper, aluminum, tin, silver, and tantalum affect the photoluminescence of mercury(II) iodide, which is of importance in the preparation of high quality photodetectors (Nowak and Singer, 1995).

Additional uses of mercury(II) iodide include that of an image enhancer in photography and uses in medicine and veterinary medicine for the treatment of skin (HSDB, 2009). Mercury(II) iodide has also been mentioned as a catalyst in group transfer polymerization of methacrylates or acrylates (Nowak and Singer, 1995). It is not clear if these are current uses of mercury(II) iodide.

C.4.3 Synthesis from mercury

Mercury (II) iodide is typically produced from the reaction of elemental mercury with iodine in ethanol (Patnaik, 2003).

Mercury(II) iodide can also be prepared from other commonly available mercury compounds. For example, mercury(II) iodide can be made by precipitation from a solution of a mercury(II) salt and potassium iodide. Examples of mercury(II) salts used for this reaction are mercury(II) chloride, mercury(II) nitrate, and mercury(II) acetate (Patnaik, 2003). Mercury(II) chloride, nitrate, and acetate feedstocks for these processes can be obtained in commercial quantities, or can themselves be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of these compounds is presented in their chemical summaries.

C.4.4 Reduction to elemental mercury

Mercury(II) iodide can be reduced to elemental mercury by first converting it to other mercury compounds, which are then reduced to elemental mercury. For example, mercury(II) iodide is converted to mercury(II) oxide by reaction with an alkali such as sodium, lithium, or potassium hydroxide (CrossFire Gmelin Database, 2009). Mercury(II) oxide is reduced to elemental mercury and oxygen when heated. More information on the reduction of mercury(II) oxide is presented in its chemical summary.

C.4.5 Potential sources

Manufacturing and use facilities are potential sources of mercury(II) iodide as well as kits for making Mayer's or Nessler's reagent.

C.4.6 Potential for export as an alternative to mercury

Mercury(II) iodide can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of iodine. Mercury(II) iodide can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained from mercury(II) iodide after chemical conversion to more readily reduced mercury(II) oxide. This process can be accomplished using basic equipment. Mercury(II) iodide is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) iodide is a potential candidate for export as a mercury source because of its following attributes:

- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily; and
- It produces elemental mercury first by chemical conversion to mercury(II) oxide, followed by the heating and condensing of the resulting vapor.

C.5 Mercury(II) nitrate

Formula: $Hg(NO_3)_2$
Percent mercury by weight: 62
CAS Index Name: Nitric acid, mercury(2+) salt (2:1)
CASRN: 10045-94-0
Synonyms: Mercuric nitrate, Mercury dinitrate, Mercury pernitrate (HSDB, 2009)

C.5.1 Product description

Mercury(II) nitrate is commonly found as the monohydrate, $Hg(NO_3)_2 \bullet H_2O$. This compound is a white crystalline or powdery substance with a melting point of 79°C (Lewis, 1997). Mercury(II) nitrate decomposes on heating and is soluble in water and aqueous nitric acid. Mercury(II) nitrate is insoluble in alcohol (Patnaik, 2003).

Mercury(II) nitrate is sold as a powder in various quantities, as well as in solution at 0.0141N, 0.0171N, 0.025N, and 0.2256N in 1.0 L or 500 ml volumes (EPA Mercury Containing Products Database, 2008).

C.5.2 Product uses

Mercury(II) nitrate is used as the starting material and for the preparation of a great many other mercuric products. It is a nitrating agent for aromatic organic compounds. It can also be used as an analytical reagent for the determination of chloride ions in water (Nowak and Singer, 1995).

Mercury(II) nitrate was formerly used as an insecticide against *Phylloxera* (O'Neil et al., 2001). In the late 1970's, the United States restricted the acceptable pesticide uses of mercury to the treatment of outdoor textiles and to the control of fungal pests, particularly brown mold on freshly sawn lumber, Dutch elm disease, and snow mold, eliminating this use for mercury(II) nitrate.

Mercury(II) nitrate was formerly used to manufacture fur felt hats (O'Neil et al., 2001) before this use was banned by the U.S. Public Health Service in 1941.

C.5.3 Synthesis from Mercury

Mercury(II) nitrate is typically prepared by dissolving elemental mercury in excess, hot, concentrated nitric acid. Upon evaporation of the solution, large colorless deliquescent crystals of the monohydrate, $Hg(NO_3)_2 \bullet H_2O$, form (Patnaik, 2003).

Mercury(II) nitrate can also be obtained by boiling a solution of mercury(I) nitrate or by the action of light on mercury(I) nitrate (Patnaik, 2003).

C.5.4 Reduction to elemental mercury

Gentle heating of mercury(II) nitrate generates mercury(II) oxide, evolving nitrogen dioxide and oxygen. With strong heating, mercury(II) nitrate reduces to elemental mercury, nitrogen oxides, and oxygen (Patnaik, 2003).
Mercury(II) nitrate can also be converted to other mercury compounds which can subsequently be reduced to elemental mercury. For example, mercury(II) nitrate can be dissolved in water

and treated with a strongly alkaline reagent, typically sodium hydroxide, to yield yellow mercury(II) oxide. Mercury(II) oxide is reduced to elemental mercury and oxygen when heated. More information on the reduction of mercury(II) oxide is presented in its chemical summary.

C.5.5 Potential sources

Potential sources of mercury(II) nitrate are the facilities where it is manufactured or used. Those laboratories that use mercury(II) nitrate as an intermediate to form other mercury compounds are likely to have the highest amounts of this compound present on-site.
Mercury(II)nitrate could be obtained through the disassembly or destruction of small-scale kits designed to detect chlorine. However, this process would be labor intensive and only small quantities are present within each kit.

C.5.6 Potential for export as an alternative to mercury

Mercury(II) nitrate is commercially available. Mercury(II) nitrate can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of nitric acid. Elemental mercury can be obtained by strongly heating mercury(II) nitrate and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) nitrate is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) nitrate is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily; and
- It produces elemental mercury simply by heating and condensing the resulting vapor.

C.6 Mercury(II) oxide

Formula: HgO
Percent mercury by weight: 93
CAS Index Name: Mercury oxide (HgO)
CASRN: 21908-53-2
Synonyms: Mercuric oxide, Mercuric oxide red, Mercuric oxide yellow (Linstrom and Mallard, 2009)

C.6.1 Product description

Mercury(II) oxide is a red/red-orange or yellow/orange-yellow powder. Red mercury(II) oxide has a coarser particle size than yellow mercury(II) oxide. Mercury(II) oxide has a water solubility of 58 mg/L (Weast, 1983–1984) and decomposes on exposure to light (O'Neil et al., 2001). The decomposition temperature of mercury (II) oxide is 332°C (Nowak and Singer, 1995).

Mercury(II) oxide is sold in red or yellow powder, in quantities from 125 g to 50 kg (EPA Mercury Containing Products Database, 2008).

C.6.2 Product uses

Mercury(II) oxide's primary uses are in batteries and as a reagent for the synthesis of other mercury compounds, including Millon's base (Hg_2NOH). Other uses include as a reagent for analytical detection, as a chemical reagent in synthesis of organic compounds, as a depolarizer in dry batteries, and as a catalyst in organic reactions. Former uses include use in antifouling paints, as a seed protectant, and as a fungicide (HSDB, 2009). In the late 1970's, the United States restricted the acceptable pesticide uses of mercury to the treatment of outdoor textiles and to control of fungal pests, particularly brown mold on freshly sawn lumber, Dutch elm disease, and snow mold. In 1972, the use of mercury in antifouling paint formulations was banned. In 1991, the EPA announced the cancellation of mercury biocide registrations (DeVito and Brooks, 2005) eliminating this use for mercury(II) oxide.

After the passage of the 1996 federal Mercury-Containing Battery Management Act, most batteries made in the United States do not contain mercury. Mercury(II) oxide has been used as the cathode material of dry cell batteries such as zinc-mercury, cadmium mercury, and indium-bismuth-mercury cells. Mercury(II) oxide button cell batteries, once widely used in hearing aids, are now prohibited under the Mercury-Containing Battery Management Act. The use of larger mercury(II) oxide batteries is limited to the military and medical equipment where a stable current and long service life is essential. Elemental mercury may be added to batteries, including button cell batteries, in small quantities to prevent the buildup of hydrogen gas, which can cause the cells to bulge and leak (U.S. EPA, 2009).

C.6.3 Synthesis from mercury

Mercury(II) oxide is typically prepared from other common mercury compounds. For example, mercury(II) nitrate or mercury(II) chloride can be dissolved in water and treated with a strongly alkaline reagent, typically sodium hydroxide, to yield yellow mercury(II) oxide or a mildly alkaline reagent, such as sodium carbonate, to yield red mercury(II) oxide, which fall out of solution. Red mercury(II) oxide is also prepared by heat-induced decomposition of mercury(II) nitrate (Nowak and Singer, 1995). Mercury(II) nitrate and mercury(II) chloride feedstocks for these processes can be obtained in commercial quantities, or can themselves be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of these compounds is presented in their chemical summaries.

Elemental mercury is stable to dry air, but is slowly converted to mercury(II) oxide in the presence of moisture. The direct conversion of elemental mercury to mercury(II) oxide may be accomplished more readily by heating mercury in air or oxygen at a temperature of about 350°C (Patnaik, 2003).

Other direct conversions of mercury to mercury(II) oxide have been reported in the literature. Mercury(II) oxide can be made by reacting elemental mercury with hydrogen peroxide or aqueous hydrogen peroxide. It can also be made from reacting elemental mercury with potassium hydroxide in water or from the reaction of mercury with carbon dioxide. Additionally, mercury(II) oxide can be made from reacting elemental mercury with potassium chlorate (CrossFire Gmelin Database, 2009). It is unclear if these latter methods are useful for producing large quantities of mercury(II) oxide.

C.6.4 Reduction to elemental mercury

Mercury(II) oxide decomposes on exposure to light or when heated to temperatures above 500°C, releasing elemental mercury and oxygen (O'Neil et al., 2001).

Elemental mercury can also be recovered from mercury(II) oxide electrolytically using an electrolyte solution comprised of glacial acetic acid and water (Grossman and George, 1991, 1989).

C.6.5 Potential sources

Potential sources of mercury(II) oxide are from the facilities where it is manufactured or used. Those laboratories that use mercury(II) oxide as an intermediate to form other mercury compounds are likely to have the highest amounts of this compound present on-site.

Another potential source of mercury(II) oxide is from large mercury oxide batteries. U.S. federal law allows mercury oxide batteries to be sold only if the manufacturer has established a system to collect the waste batteries and ensure that the mercury is properly managed. The recycling of mercury from waste mercury oxide batteries involves the breaking and crushing of the batteries followed by the thermal conversion of mercury(II) oxide to elemental mercury and the condensation and collection of the liquid metal (Martin et al., 2004).

The use and disposal of button cell batteries containing metallic mercury are unregulated at the federal level (U.S. EPA, 2009c). However, the use of mercury(II) oxide in button cell batteries is prohibited under the Mercury-Containing Battery Management Act of 1996.

C.6.6 Potential for export as an alternative to mercury

Mercury(II) oxide is commercially available. It can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of air. Mercury(II) oxide can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by heating mercury(II) oxide and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) oxide is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) oxide is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily; and
- It produces elemental mercury simply by heating and condensing the resulting vapor.

C.7 Mercury(II) selenide

Formula: HgSe
Percent mercury by weight: 72
CAS Index Name: Mercury selenide (HgSe)
CASRN: 20601-83-6
Synonyms: Mercury-selenium complex, Mercuric selenide, Mercury monoselenide (ChemIDplus Database, 2009), Tiemannite (Simon et al., 2006)

C.7.1 Product description

Mercury(II) selenide is a solid that takes the form of grey or violet–black plates, melting point > 600 °C. Mercury(II) selenide is insoluble in water and will sublime in a vacuum (Weast, 1983–1984).

C.7.2 Product uses

Mercury(II) selenide has seen only limited use in commerce. Mercury(II) selenide is used as a semiconductor in solar cells, thin-film transistors, infrared detectors, and ultrasonic amplifiers (Lewis, 1997).

C.7.3 Synthesis from mercury

Mercury(II) selenide is prepared directly from its elements, mercury and selenium, to give a violet–black material (Bebout, 2006). This reaction forms the basis for gas purification systems controlling the emission of elemental mercury from the burning of coal and natural gas. In these systems, selenium is used as an absorbent for mercury, forming stable mercury(II) selenide (Simon et al., 2006).

C.7.4 Reduction to elemental mercury

Mercury(II) selenide can be retorted to release its elemental constituents, mercury and selenium. For example, mercury(II) selenide waste from refining ores, such as zinc and gold, is a slurry that has been reprocessed in a multiple-hearth furnace that evaporates the mercury fraction. Alternatively, this residue can be converted to metallic mercury in a rotary kiln by adding lime fluxes, with a relatively inert residue remaining behind (Simon et al., 2006).

Liquid treatment processes (hydrometallurgy) for mercury(II) selenide that result in the mercury being extracted in the form of mercury(II) oxide or mercury(II) sulfide have been reported. However, these processes do not appear to be economically practical at present because of the relative expense of the reactants involved (Simon et al., 2006).

C.7.5 Potential sources

Mercury(II) selenide may be a waste from the refining or smelting of ores, including zinc and gold, when the ore contains both mercury and selenium, or mercury-containing sulfidic ores (Simon et al., 2006). Mercury(II) selenide is also a byproduct from flue gases purification processes in which selenium is used as an absorbent to remove volatilized mercury from the burning of fuels such as coal and natural gas (Simon et al., 2006).

C.7.6 Potential for export as an alternative to mercury

Mercury(II) selenide can be a waste from the refining of ores, such as zinc and gold. Mercury(II) selenide may also be present in waste streams from the burning of coal and natural gas where selenium is used as an absorbent for mercury. Mercury(II) selenide can be prepared directly from elemental mercury in a single step by reaction with selenium. This process can be accomplished using basic equipment but requires relatively expensive selenium as a feedstock. Elemental mercury can be obtained by heating mercury(II) selenide and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) selenide is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) selenide is an unlikely candidate for export as a mercury source because of its following attributes:

- Its synthesis requires relatively expensive selenium;
- It likely has a higher monetary value as mercury(II) selenide than as elemental mercury; and
- Processes to recover mercury may produce toxic hydrogen selenide [H_2Se] gas.

The above factors are anticipated to far outweigh the following attributes which suggest that mercury(II) selenide could be a possible candidate for export as a mercury source because:

- It is available from waste streams from various industrial processes; and
- It produces elemental mercury simply by retorting and condensing the resulting vapor.

C.8 Mercury(II) sulfate

Formula: $HgSO_4$
Percent mercury by weight: 68
CAS Index Name: Sulfuric acid, mercury(2+) salt (1:1)
CASRN: 7783-35-9
Synonyms: Mercuric sulfate, Mercury bisulfate, Mercury persulfate (HSDB, 2009)

C.8.1 Product description

Mercury(II) sulfate forms white crystals that will absorb water from the air if not kept in a sealed container. It is soluble in hot, dilute sulfuric acid, hydrochloric acid, and concentrated solutions of sodium chloride. Decomposes before reaching 450°C. When dissolved in water, mercury(II) sulfate will decompose to form the water-insoluble basic sulfate $HgSO_4 \bullet 2HgO$ (Patnaik, 2003).

C.8.2 Product uses

Mercury(II) sulfate is used with sodium chloride in the extraction of gold and silver from roasted pyrites. It is also a reagent for wine coloring (Patnaik, 2003). Mercury(II) sulfate is used in analytical chemistry to bind chloride ions in the determination of the COD of wastewater and as a catalyst in organic reactions such as conversion of acetylene to acetaldehyde. Mercury(II) sulfate can be used as a depolarizer in galvanic cells (Simon et al., 2006). The 1996 U.S. Mercury-Containing Battery Management Act limited the use of mercury in batteries to mercury oxide batteries and small quantities of elemental mercury added to batteries to prevent the buildup of hydrogen gas.

C.8.3 Synthesis from mercury

Mercury(II) sulfate is typically prepared by heating mercury with an excess of concentrated sulfuric acid (Patnaik, 2003). Mercury(II) sulfate is also prepared by reaction of a freshly prepared and washed wet filter cake of yellow mercury(II) oxide with sulfuric acid in glass or glass-lined vessels (DeVito and Brooks, 2005). Mercury(II) oxide feedstock for this process can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) oxide is presented in its chemical summary.

C.8.4 Reduction to elemental mercury

Mercury(II) sulfate first turns yellow and then becomes red-brown when heated. When heated to red heat, it will reduce to elemental mercury, sulfur dioxide, and oxygen (Patnaik, 2003).

C.8.5 Potential sources

Potential sources of mercury(II) sulfate are from the facilities where it is manufactured or used in commercial processes. Mining facilities represent potential sources of this compound because of the use of mercury(II) sulfate in the extraction of gold and silver.

Industries that use mercury(II) sulfate to capture mercury as part of their waste control procedures represent an indirect source of this material and may have the most significant amounts of this compound present on-site. For example, smelter gas containing volatilized mercury can be passed through heated, concentrated sulfuric acid to produce mercury(II) sulfate, which precipitates out when the solution becomes saturated in the Outokumpu process (Louie, 2005).

C.8.6 Potential for export as an alternative to mercury

Mercury(II) sulfate is commercially available. It is also present in waste streams from industries that use the Outokumpu process to cleanse mercury from flue gases. Mercury(II) sulfate can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of concentrated sulfuric acid. Mercury(II) sulfate can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by heating mercury(II) sulfate and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) sulfate is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) sulfate is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It can be found in waste streams from mercury treatment processes;
- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily; and
- It produces elemental mercury simply by heating and condensing the resulting vapor.

C.9 Mercury(II) sulfide

Formula: HgS
Percent mercury by weight: 86
CAS Index Name: Mercury sulfide (HgS)
CASRN: 1344-48-5
Synonyms: Cinnabar, Metacinnabar, Mercury sulfide black, Mercury Sulfide red, Chinese red, Vermilion (Lewis, 1997)

C.9.1 Product description

Mercury(II) sulfide is a red or black solid depending on its crystal structure. Red mercury(II) sulfide occurs in nature as the mineral cinnabar, which is the principle source for mercury production worldwide. Black mercury(II) sulfide, known as metacinnabar, occurs only rarely in nature. It sometimes coexists with the red form and may be found as a black deposit over cinnabar (Patnaik, 2003). The red sulfide transitions to the black sulfide at 386°C, but reverts back to red form on cooling. Both forms are insoluble in water and will sublime at 583°C. Red mercury(II) sulfide is light sensitive (O'Neil et al., 2001).

C.9.2 Product uses

The most important use of this compound, the principal ore of mercury, is for the extraction of mercury metal. It was also used as an artificially prepared scarlet product, vermilion, which was used as artists' pigment and for coloring plastics. The red sulfide is also used as an antibacterial agent. The black sulfide is used for coloring horns, rubber, and other materials (Patnaik, 2003). Production of mercury-containing pigments in the United States was discontinued in 1988, but some mercury pigments may still be imported into the United States (DeVito and Brooks, 2005).

C.9.3 Synthesis from mercury

Red mercury(II) sulfide occurs natively and is mined in the form of the mineral cinnabar. It can also be prepared by heating elemental mercury with a solution of potassium pentasulfide, producing a scarlet compound. For use as the pigment vermilion, mercury(II) sulfide may be made by grinding sodium sulfide with sulfur and slowly adding mercury. The shades are not as bright when prepared at 0°C (Patnaik, 2003).

Black mercury(II) sulfide is prepared by treating mercury with molten or powdered sulfur (Patnaik, 2003). Black mercury(II) sulfide is also prepared from other common mercury compounds. For example, black mercury(II) sulfide can be made by precipitation from an aqueous solution of mercury(II) salt, such as mercury(II) chloride, with excess hydrogen sulfide or sodium sulfide (Patnaik, 2003). The mercury(II) chloride feedstock for this process can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) chloride is presented in its chemical summary.

C.9.4 Reduction to elemental mercury

The methods used to recover elemental mercury from mercury(II) sulfide(cinnabar ore) may also be applied to synthetic mercury(II) sulfide. A typical process is heating or retorting mercury(II) sulfide in a current of air or oxygen. The reduction reaction begins at about 300°C to release mercury vapor and sulfur dioxide. Alterations to the typical process include the addition of reducing metals or fluxes such as iron metal or lime (calcium oxide) so as to bind the sulfur in solid form (as iron sulfide or calcium sulfate). The liberated elemental mercury vapor is condensed and collected (Patnaik, 2003).

C.9.5 Potential sources

Potential sources of mercury(II) sulfide are from facilities where it is manufactured or used. Although there are currently no active cinnabar mines in the United States, mercury(II) sulfide can be found in waste dumps from abandoned mercury mines (Hojdova et al., 2008).

Industries that use mercury(II) sulfide as part of their waste treatment procedures, and industries that process these wastes, are likely to have significant amounts of this compound present on-site. An example of waste treatment processes that may form mercury(II) sulfide on-site include the treatment of aqueous waste streams from processing of petroleum or from the chlor-alkali process with excess sodium sulfide. The resulting water-insoluble mercury(II) sulfide precipitates out and is collected and sent for mercury recovery. Another example is the removal of mercury present in natural gas by the use of activated charcoal scrubbers impregnated with sulfur (Simon et al., 2006). Once saturated with mercury(II) sulfide, the used charcoal filter can be retorted, regenerating the charcoal and liberating elemental mercury (DeVito and Brooks, 2005).

C.9.6 Potential for export as an alternative to mercury

The naturally occurring form of mercury(II) sulfide, mercury(II) sulfide(cinnabar ore), is the world's principal source of mercury. Mercury(II) sulfide is also a byproduct of mercury waste treatment processes that take advantage of mercury's natural affinity for sulfur. Mercury(II) sulfide can be prepared directly from elemental mercury in a single step requiring only that it be heated in the presence of sulfur. Mercury(II) sulfide can also be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by heating mercury(II) sulfide and condensing the vapor. This process can be accomplished using basic equipment. Mercury(II) sulfide is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Mercury(II) sulfide is a potential candidate for export as a mercury source because of its following attributes:

- It is commercially available;
- It has alternative sources as it may be found in waste streams from a wide variety of mercury treatment processes;
- It can be readily prepared from a wide variety of commercially available materials;
- It can be transported easily; and
- It produces elemental mercury simply by heating and condensing the resulting vapor.

It is unlikely that mercury(II) sulfide(cinnabar ore) would be exported because there are no active mines in the United States Due to the costs associated with making purified vermilion, it is also unlikely that mercury(II) sulfide pigments would be used as a source for elemental mercury.

C.10 Mercury(II) thiocyanate

Formula: $Hg(SCN)_2$
Percent mercury by weight: 63
CAS Index Name: Thiocyanic acid, mercury(2+) salt (2:1)
CASRN: 592-85-8
Synonyms: Mercuric thiocyanate, Mercuric sulfocyanate, Mercury (HSDB, 2009)

C.10.1 Product description

Mercury(II) thiocyanate is a white powder that is thermally unstable. Decomposition begins at 110°C and becomes spontaneous at 165°C, with the compound increasing in volume and producing a blue flame (Simon et al., 2006).

Mercury(II) thiocyanate has a water solubility of 0.7 g/L at 20°C, but will decompose in hot water (Weast, 1983–1984). Mercury(II) thiocyanate is light sensitive (O'Neil et al., 2001).

Mercury(II) thiocyanate is sold as a powder in quantities from 25 g to 5 kg, and in a 1.0 g/L methanol solution (EPA Mercury Containing Products Database, 2008).

C.10.2 Product uses

Mercury(II) thiocyanate is used as an analytical reagent for chloride analysis of water and as an intensifier in photography (HSDB, 2009). Mercury(II) thiocyanate has been used in pyrotechnics in the manufacture of "pharaoh's serpent" fireworks (O'Neil et al., 2001). Mercury salts are currently prohibited in consumer fireworks in the United States by Federal law (CPSC, 1997).

C.10.3 Synthesis from mercury

Mercury(II) thiocyanate is typically produced from other common mercury compounds. Mercury(II) thiocyanate is made as a white precipitate by the addition of potassium thiocyanate solution to mercury(II) nitrate (Patnaik, 2003). Another method is to add ammonium sulfocyanate to a solution of mercury(II) nitrate, yielding mercury(II) thiocyanate as a precipitate (Lewis, 1997). Mercury(II) nitrate feedstock for these reactions can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) nitrate is presented in its chemical summary.

C.10.4 Reduction to elemental mercury

Mercury(II) thiocyanate swells up to many times its original volume when it is heated, decomposing finally at about 165°C into elemental mercury, nitrogen, and oxides of carbon and sulfur (O'Neil et al., 2001).

C.10.5 Potential sources

Mercury(II) thiocyanate can be acquired in small amounts from kits used to analyze for chlorine in water and from photography supplies. Mercury(II) thiocyanate is also a component of "pharaoh's serpent" type fireworks, although they have been prohibited in the United States (CPSC, 1997).

C.10.6 Potential for export as an alternative to mercury

Mercury(II) thiocyanate can be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by heating mercury(II) thiocyanate, though this reaction is exothermic and expands many times in volume making it difficult to control using basic equipment. Mercury(II) thiocyanate has a few current commercial applications where it is present in small quantities. Mercury(II) thiocyanate is an unstable solid, yet it only carries a DOT Hazard Label of 6.1: Irritating material which, upon contact with fire or air, gives off dangerous or intensely irritating fumes (U.S. DOT, 2009).

Mercury(II) thiocyanate is an unlikely candidate for export as a mercury source because of its following attributes:

- It is an unstable solid; and
- It produces elemental mercury in a manner that is difficult to control using basic equipment.

C.11 Phenyl mercury(II) acetate

Formula: $Hg(C_6H_5)(C_2H_3O_2)$
Percent mercury by weight: 60
CAS Index Name: Mercury, (acetato-κO)phenyl-
CASRN: 62-38-4
Synonyms: Phenylmercuric acetate, Acetoxyphenylmercury, PMA (HSDB, 2009)

C.11.1 Product description

Phenylmercury acetate forms small white lustrous crystals that melt at 148–150°C. It is only slightly soluble in water, but dissolves in glacial acetic acid and in various organic solvents. Phenylmercury acetate is slightly volatile at ordinary temperatures (Lewis, 1997).

C.11.2 Product uses

Phenylmercury acetate is used as a preservative in ophthalmological preparations and nasal sprays at concentrations around 0.0008 and 0.002%, respectively (U.S. FDA, 2009a). Phenylmercuric acetate is also used as the starting material in the preparation of many other phenylmercury compounds (Nowak and Singer, 1995). Many phenylmercury compounds are used as catalysts in the manufacturing of polyurethanes (Foulkes, 2001).

Phenylmercury compounds were also formerly employed as slimicides for seed dressing, as fungicides in paper and pulp, and as topical disinfectants and spermicides (Foulkes, 2001). In the late 1970's, the United States restricted the acceptable pesticide uses of mercury to the treatment of outdoor textiles and to control of fungal pests, particularly brown mold on freshly sawn lumber, Dutch elm disease, and snow mold (DeVito and Brooks, 2005), thereby limiting many of the uses of phenyl mercury(II) acetate.

Mercury-based biocides, such as phenylmercury acetate and phenylmercury oleate, were formerly registered as biocides in interior and exterior paints, and in antifouling paints. In 1972, the use of mercury in antifouling paint formulations was banned. In 1991, the EPA announced the cancellation of mercury biocide registrations (DeVito and Brooks, 2005).

C.11.3 Synthesis from mercury

Phenylmercury(II) acetate is synthesized from other mercury compounds. Mercury(II) acetate is reacted with benzene to form phenylmercury(II) acetate (Foulkes, 2001). Mercury(II) acetate feedstock for this process can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) acetate is presented in its chemical summary.

C.11.4 Reduction to elemental mercury

Organomercury compounds, such as phenylmercury acetate, are not as easily converted to elemental mercury as inorganic mercury compounds. One method used on waste streams containing organomercury compounds is to convert them to inorganic mercury compounds by treatment with chlorine. The inorganic mercury compounds thus formed can be reduced with sodium borohydride to liberate elemental mercury. This process is known as the Ventron process (Nowak and Singer, 1995) and was tested on phenylmercury acetate in U.S. Patent No. 3,764,528 by Ventron Corporation in 1973.

Another possible route to elemental mercury from phenylmercury(II) acetate is by burning to oxidize off the carbon followed by collecting the resulting vapor.

C.11.5 Potential sources

Manufacturing and use sites are potential sources of phenylmercury(II) acetate. To limit phenylmercury(II) acetate waste, it is often precipitated from its solution in acetic acid by addition of water. The filtrate is then collected and reused (Nowak and Singer, 1995).

Ophthalmological preparations and nasal sprays are possible sources of phenylmercury(II) acetate, although it is present in extremely low concentrations in these products.

C.11.6 Potential for export as an alternative to mercury

Phenylmercury(II) acetate can be prepared from other common mercury compounds in a single synthetic step that can be accomplished using basic equipment and inexpensive reagents. Elemental mercury can be obtained by converting phenylmercury(II) acetate to mercury(II) chloride, then either chemical or electrochemical reduction of the chloride, followed by collection of the resulting liquid metal. It is possible that elemental mercury may be obtained by burning phenylmercury(II) acetate to oxidize off the carbon and collecting the resulting vapor. These processes can be accomplished using basic equipment and inexpensive reagents Phenylmercury(II) acetate is a stable solid and is used in a number of commercial applications. It is easy to handle and can be transported using standard methods.

Phenylmercury(II) acetate is a possible candidate for export as a mercury source because of its following attributes:

- It can be prepared from commercially available materials;
- It can be transported easily; and
- It may produce elemental mercury by burning and condensing the resulting vapor.

However, phenylmercury(II) acetate is far less attractive as a candidate for export as a mercury source because it would require an additional step to make and export phenylmercury(II) acetate than to export feedstock mercury(II) acetate directly. Given that mercury(II) acetate is a better source of elemental mercury, its conversion to phenylmercury(II) acetate is counterproductive.

C.12 Thimerosal

Formula: $Hg(C_2H_5)(C_7H_4NaO_2S)$
Percent mercury by weight: 50
CAS Index Name: Mercurate(1-), ethyl[2-(mercapto-κS)benzoato(2-)-κO]-, sodium (1:1)
CASRN: 54-64-8
Synonyms: Thiomersal, Sodium ethylmercurithiosalicylate, Merthiolate (HSDB, 2009)

C.12.1 Product description

Thimerosal is a cream-colored crystalline powder with a water solubility of about 1.0 g/mL. It is stable in air, but is light sensitive (O'Neil et al., 2001). Melting point = 232 – 233°C and pH = 6.7 for a 1% w/v aqueous solution at 20°C.

C.12.2 Product uses

Thimerosal is primarily used as a preservative in pharmaceutical applications, such as ophthalmic solutions and vaccines (U.S. FDA, 2009a). Thimerosal is also used as an antimicrobial preservative in cosmetics (HSDB, 2009). Thimerosal is an organic mercury compound that is metabolized to ethylmercury and thiosalicylate. It has been primarily used as a preservative in pharmaceutical applications, such as ophthalmic solutions and vaccines (U.S. FDA, 2009a).

Thimerosal has been used as a preservative in biological products since the 1930s. Apart from some narrow regulatory exceptions (such as for some live vaccines), preservatives are required to be added to multi-dose vials of vaccines in the United States to prevent microbial growth. Thimerosal is no longer included, or has been reduced to trace amounts, in all vaccines routinely recommended for children 6 years and under, except in some formulations of the inactivated influenza vaccine (U.S. FDA, 2009b). This has been possible because the vaccines are formulated in single-dose presentations. Inactivated influenza vaccine is available in both thimerosal-preservative-containing and thimerosal-preservative-free formulations.

Thimerosal in concentrations of 0.001–0.01% are effective against a broad spectrum of pathogens; a vaccine containing 0.01% thimerosal contains 50 micrograms of thimerosal per 0.5 mL dose, or approximately 25 micrograms of mercury per 0.5 mL dose (U.S. FDA, 2009a).

In June 2000, the American Academy of Family Physicians (AAFP), the American Academy of Pediatrics (AAP), the Advisory Committee on Immunization Practices (ACIP), and the Public Health Service (PHS) released a joint statement recommending moving rapidly to vaccines free of thimerosal. They declared the use of thimerosal as a preservative acceptable until adequate supplies of thimerosal-free vaccines are available (Toxnet Hazardous Substances Database, 2008h). According to the FDA, the use of mercury-containing preservatives in vaccines has declined since 1999, primarily due to manufacturers transitioning from multi-dose vials which require a preservative to single-dose vials U.S. Food and Drug Administration, 2008).

C.12.3 Synthesis from mercury

Thimerosal is made by the reaction between ethyl mercuric chloride and thiosalicylic acid in alcoholic sodium hydroxide (Lewis, 1997). Ethyl mercuric chloride can be made from the reaction of mercury(II) chloride and an organometallic reagent such as tetraethyl lead or triethyl aluminum (Crossfire Gmelin Database, 2009). Mercury(II) chloride feedstock for this process can be obtained in commercial quantities, or can itself be readily prepared in one or two steps from elemental mercury and commercially available compounds. More information on the production of mercury(II) chloride is presented in its chemical summary.

C.12.4 Reduction to elemental mercury

Organomercury compounds are not as easily converted to elemental mercury as inorganic mercury compounds. One method used on waste streams containing organomercury compounds is to convert them to inorganic mercury compounds by treatment with chlorine. The inorganic mercury compounds thus formed can be reduced with sodium borohydride to liberate elemental mercury. This process is known as the Ventron process (Nowak and Singer, 1995).

It is possible that elemental mercury may be obtained by burning thimerosal to oxidize off the carbon and collecting the resulting mercury vapor.

C.12.5 Potential sources

Manufacturing and use sites are potential sources of this compound. Vaccines and ophthalmological preparations are possible sources of thimerosal as well, although it is present in extremely low concentrations in these products.

C.12.6 Potential for export as an alternative to mercury

Thimerosal can be prepared from elemental mercury in multiple steps, which require expensive reagents and specialized equipment. Elemental mercury can be obtained by converting thimerosal to mercury(II) chloride, then either chemical or electrochemical reduction of the chloride, followed by collection of the resulting liquid metal. It is possible that elemental mercury may be obtained by burning thimerosal to oxidize off the carbon and collecting the resulting mercury vapor. Thimerosal is a light sensitive solid and would require careful transport.

Thimerosal is an unlikely candidate for export as a mercury source because of its following attributes:

- It is difficult to prepare and requires expensive reagents and specialized equipment;
- It is light sensitive and requires careful transport; and
- It has a higher monetary value than elemental mercury.

Appendix D – Detailed Chemistry of Mercury Compounds

D.1 Conversion of elemental mercury to mercury compounds

Elemental mercury can be easily converted in one or two steps to a variety of inorganic and organometallic mercury compounds using inexpensive, readily available materials (Simon et al., 2006; Patnaik, 2003; Nowak and Singer, 1995). The following examples illustrate some common reactions of elemental mercury. The compounds shown in these examples are representative of those currently used and/or generated in large scale processes in the manufacturing, mining, power generation, and petroleum industries, or other commercial processes.

D.1.1 The chemical transformation of elemental mercury into mercury(II) sulfide

Elemental mercury can be converted to mercury(II) sulfide by reaction with molten sulfur, or with polysulfide salts, such as potassium pentasulfide. The reaction between mercury and potassium pentasulfide is used to produce pigment grade vermilion (red mercury(II) sulfide).

$$\mathrm{Hg} + \mathrm{S} \xrightarrow[\text{heat}]{} \mathrm{HgS}$$

$$\mathrm{Hg} + \mathrm{K_2S_5} \xrightarrow[\text{heat}]{} \mathrm{HgS} + \mathrm{K_2S_4}$$

D.1.2 The chemical transformation of mining byproducts into mercury(II) sulfide

The Merrill-Crowe process is the reaction of polysulfide or dithiocarbamate salts with soluble mercury-containing waste in gold mining cyanide leachate streams which makes insoluble, isolable mercury sulfide compounds.

$$\mathrm{Hg} + \mathrm{CN^-} \longrightarrow [\mathrm{Hg(CN)_4}]^{2-}$$

$$[\mathrm{Hg(CN)_4}]^{2-} + \mathrm{S^{2-}} \longrightarrow \mathrm{HgS} + 4\mathrm{CN^-}$$

D.1.3 The chemical reaction of elemental mercury with acids to form mercury nitrates and sulfates

Mercury will react with concentrated nitric and sulfuric acids to produce mercury(II) nitrates and sulfates, respectively.

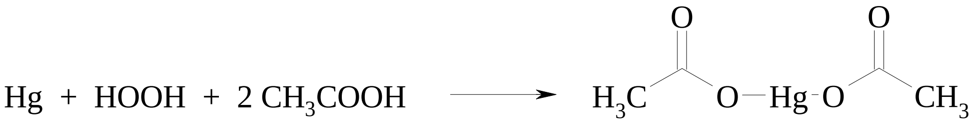
$$\mathrm{Hg} + 4\,\mathrm{HNO_3} \longrightarrow \mathrm{Hg(NO_3)_2} + 2\,\mathrm{NO_2} + 2\,\mathrm{H_2O}$$

$$\mathrm{Hg} + 2\,\mathrm{H_2SO_4} \longrightarrow \mathrm{Hg(SO_4)} + \mathrm{SO_2} + 2\,\mathrm{H_2O}$$

Mercury(I) nitrate is a known compound, but is difficult to purify. Its manufacture from hot, dilute nitric acid produces an impure grade of mercury(I) nitrate that is contaminated with the mercury(II) species (Nowak and Singer, 1995). Mercury(I) sulfate can be prepared by the electrochemical oxidation of mercury in dilute sulfuric acid (Simon et al., 2006).

D.1.4 The chemical oxidation of elemental mercury in acetic acid to form mercury(II) acetate

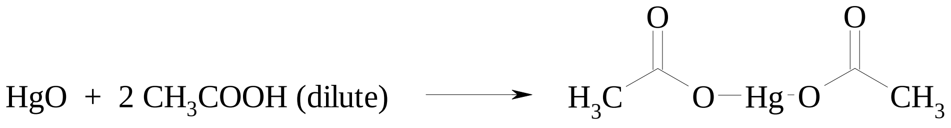
The preparation of mercury(II) acetate is accomplished by reacting elemental mercury with peracetic acid dissolved in acetic acid. However, peracetic acid requires careful handling and the reaction between mercury and peracetic acid is difficult to control. Alternatively, mercury(II) acetate may be made by reacting mercury and hydrogen peroxide in concentrated acetic acid (Nowak and Singer, 1995).



D.2 Reactivity of mercury compounds

Other examples include the preparation of mercury(I) sulfate from mercury(I) nitrate and the preparation of mercury(II) acetate from mercury(II) oxide.

$$Hg_2(NO_3)_2 + Na_2SO_4 \longrightarrow Hg_2SO_4 + 2\ NaNO_3$$



The facile conversion of water-soluble mercury compounds to insoluble materials is often used mercury control technology. For example, soluble mercury compounds can be converted to mercury(II) sulfide for waste remediation.

$$HgCl_2\ \text{(soluble)} + Na_2S \longrightarrow HgS\ \text{(insoluble)} + 2\ NaCl$$

D.3 Conversion of Mercury Compounds to Elemental Mercury

Mercury compounds can be readily converted to elemental mercury using techniques that range from the simple to the complex. The three processes commonly used to accomplish this transformation in order of increasing sophistication are thermal decomposition, chemical reduction, and electrochemical reduction.

D.3.1 Thermal Decomposition

Mercury compounds that are particularly amenable to retorting include mercury(II) oxide, mercury(II) sulfide, mercury(II) selenide, and mercury(II) nitrate.

$$HgO \xrightarrow[\text{heat}]{} Hg + 1/2\ O_2$$

$$HgS + O_2 \xrightarrow[\text{heat}]{} Hg + SO_2$$

Solid media such as soil or sludge containing mercury and mercury compounds may also be decontaminated by retorting.

A notable exception to common mercury compounds susceptible to thermal decomposition is mercury(II) chloride. This compound volatilizes before the decomposition temperature can be reached. Therefore, mercury(II) chloride cannot be converted to elemental mercury in open vessels. Export of mercury(II) chloride for conversion to elemental mercury by methods other than retorting would be expected to require additional chemical processing and facilities, albeit still inexpensively performed.

D.3.2 Electrochemical reduction

Elemental mercury is regenerated from spent scrubber solutions used in the Boliden-Norzink process by electrowinning. The spent scrubber solution, which contains mercury(I) and mercury(II) chlorides, is treated with chlorine gas to convert all of the mercury species to mercury(II) chloride. The mercury(II) chloride is reduced at a cathode made of elemental mercury in a specially-designed electrochemical cell (Louie, 2005).

$$\begin{array}{lrcl} \text{cathode:} & Hg^{2+} + 2\,e- & \longrightarrow & Hg \\ \text{anode:} & 2\,Cl^{-} & \longrightarrow & Cl_2 + 2\,e- \\ \text{overall:} & HgCl_2 & \longrightarrow & Hg + Cl_2 \end{array}$$

Grossman and George (1991, 1989) report processes for the electrochemical reduction of mercury(I) chloride and mercury(II) oxide. The cell for the reduction of mercury(I) chloride employs a platinum anode and a cathode made of copper, nickel, or a nickel/iron alloy. Mercury(I) chloride is suspended in an aqueous solution of hydrochloric acid, and a current is applied to the cell. Elemental mercury is formed at the cathode at 25°C. The process for reducing mercury(II) oxide is similar and uses an aqueous solution of acetic acid as the electrolyte.

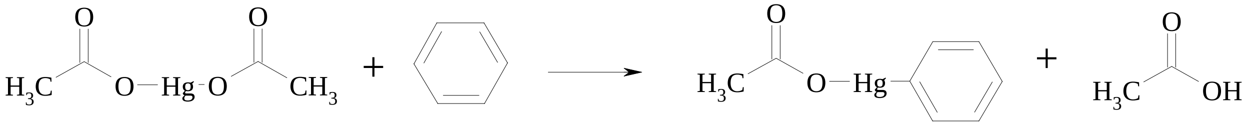
An electrolytic waste treatment method has been reported for the remediation of acidic, alkaline, or organic waste streams containing mercury compounds. Mercury(I) chloride is reduced in a cell in which the anode and cathode are made from tin, silver, or copper alloyed with gold, zinc, iron, gallium, aluminum, or sodium. As it is produced, mercury forms an amalgam with the cathode material. The amalgam may then be collected for the liberation of pure mercury (Pitton, 1994).

D.4 Organomercury compounds

Most organomercury compounds have limited use in commerce, are highly toxic and are not likely to be suitable for export. Organomercury(I) compounds are not stable and can be prepared only at low temperatures. Although organomercury(II) compounds are relatively stable to air and moisture, some of the reagents used to prepare them, such as organomagnesium reagents (known as Grignard reagents), are moisture sensitive and the reactions must be carried out in dry solvents under an inert atmosphere, greatly complicating these processes. Certain organomercury compounds have seen recent use as pesticides, preservatives, and pharmaceuticals. Reactions used to prepare some representative organomercury compounds are shown here.

D.4.1 Phenylmercury(II) carboxylates

Phenylmercury(II) carboxylates were once used as preservatives in paints. The two most common were phenylmercury(II) acetate and phenylmercury(II) oleate. The actetate is prepared from mercury(II) acetate and benzene.



Phenylmercury(II) oleate is prepared by the additional step of treating phenylmercury(II) acetate with the sodium salt of oleic acid (Nowak and Singer, 1995).

D.4.2 Thimerosal

Thimerosal is still in use as a preservative in pharmaceutical preparations, notably in ophthalmic solutions and some vaccines. Thimerosal is prepared from ethylmercury(II) chloride and thiosalicylic acid in the presence of sodium hydroxide (Lewis, 1997).