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Use and Release of Mercury in the United States

by

Barry R. Leopold
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Project Officer

Kenneth Stone
Sustainable Technology Division
National Risk Management Research Laboratory
Cincinnati, Ohio 45268

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

Although mercury use is decreasing in the United States, mercury continues to pose a serious risk to human health and the environment. This report presents the results of a two-year effort sponsored by EPA's Office of Research and Development to quantify and map the flows of mercury throughout the U.S. economy and released into the environment. Data contained in the report are intended to help prioritize research and development efforts.

Using a materials flow analysis (MFA), this report quantifies cradle-to-grave mercury use, reuse, release and disposal associated with products and processes that use mercury. Among the 100 data sources examined were industry estimates, government statistics, literature sources, and USEPA data such as the Toxics Release Inventory and emission factors. Specific industries and sectors within the following major divisions were evaluated: mercury supply, mercury use in manufacturing processes, incidental mercury use associated with coal combustion, incidental mercury use associated with non-coal sources, and other sources of mercury resulting from previous use. For each sector, mercury use is described, mercury-containing raw materials and products catalogued, and reported mercury releases into media (air, water, and solid waste) quantified. For sectors in which data are available concerning mercury speciation and geographic distributions, this information is presented.

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List of Exhibits

List of Acronyms and Abbreviations

Btu	British Thermal Unit
CaO	Calcium Oxide
CGLI	Council of Great Lakes Industries
CIBO	Council of Industrial Boiler Owners
USDHHS	United States Department of Health and Human Services
USDOE	United States Department of Energy
EEI	Edison Electric Institute
USEPA	United States Environmental Protection Agency
EPRI	Electric Power Research Institute
ESP	Electrostatic Precipitator
FETC	Federal Energy Technology Center
FGD	Flue Gas Desulfurization
GLNPO	Great Lakes National Program Office
GLNWF	Great Lakes National Wildlife Federation
HAP	Hazardous Air Pollutant
HCl	Hydrogen Chloride
Hg	Mercury
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MFA	Materials Flow Analysis
MSW	Municipal Solid Waste
NaCl	Sodium Chloride
NAICS	North American Industry Classification System
NaOH	Sodium Hydroxide
NEMA	National Electrical Manufacturers Association
NPDES	National Pollutant Discharge Elimination System
PBT	Persistent, Bioaccumulative and Toxic
POTW	Publicly Owned Treatment Works
ppm	parts per million
ppmwt	parts per million (weight)
RCRA	Resource Conservation and Recovery Act
SBIR	Small Business Innovative Research Program
SIC	Standard Industrial Classification
TCLP	Toxicity Characteristic Leaching Procedure
TSCA	Toxic Substances Control Act
UCR	University Coal Research Program
UDI	Utility Data Institute
USBM	United States Bureau of Mines
USGS	United States Geological Survey
WLSSD	Western Lake Superior Sanitary District

Acknowledgments

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Chapter 1
Introduction

1.1 Background

The United States Environmental Protection Agency (USEPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and carry out actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the USEPA to define our environmental problems, measure the impacts, and search for solutions. The National Risk Management Research Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs. These provide an authoritative defensible engineering basis in support of the policies, programs, and regulations of the USEPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities.

USEPA has identified mercury as one of 12 persistent, bioaccumulative, and toxic (PBT) substances (63 Federal Register 63926, November 17, 1998). Although mercury use is decreasing in the United States, mercury continues to pose a serious risk to public health and the environment. For several years USEPA has been coordinating efforts with other North American countries, as well as its own national and regional programs, as part of the PBT Program. The goal of USEPA's PBT Program is to reduce the risk and future exposure to PBTs using a cross-goal and cross-media approach.

Recent USEPA activities have focused on studying and reducing the impacts of mercury and other PBT chemicals on the Great Lakes, and developing initiatives to promote the recycling of mercury-containing products to reduce the quantity of mercury in landfilled wastes. These efforts have focused attention on mercury use disposal and have led to the development of some valuable use and release data. However, a thorough inventory of the mercury life cycle has not yet been developed.

Previous reports published by USEPA, States, and foreign countries have identified sources and uses of mercury. These reports include USEPA's 1997 *Mercury Study Report to Congress*, which presented nationwide air release estimates for individual sectors where mercury is used intentionally or is present as a contaminant in raw materials. Additional data describing mercury use have been available from the U.S. Geological Survey (USGS) and the U.S. Department of Commerce's Bureau of Census. These sources assist in identifying significant industrial and consumer sectors where mercury is used, released to the environment, or both. While the quality of the data in the *Report to Congress* is necessarily variable due to the diversity of sectors, it serves as a useful starting point for information on most sectors where mercury can enter the environment. Other valuable resources include USEPA's 1997 *Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds* and several other sources developed through the EPA's Great Lakes National Program Office (GLNPO). The 1997 *Mercury Study Report to Congress*, for example, identifies over 40 types of sources releasing mercury to air.

As part of the Agency-wide PBT Program, the Office of Research and Development (ORD) is identifying economic and environmental effects of implementing possible pollution prevention opportunities. The first step of this effort is to quantify rates of mercury production, use, recycling, and environmental releases. The data in this report will be used in future USEPA and ORD efforts that identify industry-specific pollution prevention opportunities and evaluate the economic and environmental effects of their implementation.

1.2 Purpose of Report

The purpose of this report is to quantify the use and release of mercury in the United States. Using a Materials Flow Analysis (MFA), this report quantifies

cradle-to-grave mercury use, reuse, release, and disposal associated with products and processes that use mercury. An MFA is largely based on the Life Cycle Assessment (LCA) concept, which is a process to evaluate the complete "life cycle" environmental impact of a product, process, or activity. Rather than take a broad multi-chemical approach, typical of an LCA, this report focuses on the flow of mercury throughout each stage, from raw materials acquisition through ultimate disposition.

1.3 Methodology Used in Report

This study examines mercury use in the United States from supply through disposal. To assess the life cycle implications of mercury use in the United States, this report used the USEPA's 1997 *Mercury Study Report to Congress* as a starting point for identifying domestic sectors where mercury is present. This report identifies the following five categories of sectors:

- *Mercury supply.* This accounts for facilities who sell purified (usually elemental) mercury for industrial use.
- *Mercury use in manufacturing processes.* Facilities may use mercury as part of a production process (e.g., in chlor-alkali production, mercury is used on-site but is not intended to be in products) or in a mercury-containing product (e.g., fluorescent lamps).
- *Incidental mercury use associated with coal combustion.* Mercury is a coal contaminant. Coal is used not only for large-scale power generation, but in other areas for combustion or as a raw material.
- *Incidental mercury use associated with non-coal sources.* Mercury is present as a contaminant in non-coal fossil fuels and in mined minerals.
- *Other sources of mercury resulting from previous use.* In some cases, the life cycle of mercury cannot be easily traced. For example, mercury may be found in wastewater which is then treated as sewage. While the initial sources of the mercury discussed in this category may be covered under another sector, such as the manufacture of a mercury bearing product, mercury from previous use is addressed in keeping with the life cycle approach to this report.

For each sector, the following data elements on a national level and annual basis are identified:

(1) A short description of how mercury is used in processes or products.
(2) Raw materials containing mercury, and the quantity of mercury in these raw materials.
(3) Products containing mercury, and the quantity of mercury in these products.
(4) Potential release points of mercury, and quantitative emissions of mercury to air, water, and land.
(5) A discussion of the quality and consistency of the above elements.

For each sector, these estimates are presented in a flow diagram format. The basis for the estimates (e.g., the data source and/or calculation method), the quality of the underlying data, and their uncertainty are also presented. This format allows easy identification of sectors in which information regarding raw materials, product content, and mercury release is incomplete, uncertain, or contradictory. When such instances occur, a speculation is made as to whether these mass imbalances are reflective of unreported emissions, data quality limitations, or other reasons. The methodology for obtaining these estimates is presented in the individual chapters of this report.

As a final step in the methodology, maps were created to show which regions of country release the largest amounts of mercury. The emissions from several data sources were mapped showing the quantity and density of mercury emissions. In addition, available speciation data were added into the maps.

1.4 Scope of Report

Using an MFA, this study profiles mercury in raw materials acquisition, product manufacturing, use, recycling, and final disposition. Additionally, it provides information from data sources that track mercury releases to different media. The report identifies uses of mercury for which data are available, and identifies uses of certain raw materials (such as coal) where mercury is present as a contaminant. However, all such raw materials are not identified, and all products containing mercury (for widespread downstream use) are not included.

In addition, this report attempts to incorporate speciation data into the analysis. Data sources were examined and mapped to provide an overview of which regions of the United States emit the largest amounts of mercury. Mercury speciation data were then collected and used to quantify each species of mercury released for a particular sector. Speciation data were available only for the combustion of utility coal and municipal waste.

The results of this study can be used in conjunction with other data to better identify mercury use and release patterns. For most of the sectors identified in this report, pollution prevention opportunities are discussed in the report titled *Identifying Research and Development Priorities to Reduce Mercury Use and Environmental Releases in the United States*. This report containing pollution prevention opportunities and the MFA are intended to be used as companion documents. The results of these two efforts could be used to help target and reduce the mercury use in specific sectors.

1.5 Summary of Results

1.5.1 Description of Exhibits

Exhibits 1-1 through 1-4 summarize the findings of this report for mercury use sectors and their categories. A "sector" is a single industry or class of similar products or processes where mercury is present. Subsequently, sector is a very flexible term because it can mean, for example, the industry of chlor-alkali manufacturing, the production and use of mercury containing-lights, or the process of oil combustion. As discussed above, there are five categories of sectors presented in this report: (1) mercury supply; (2) manufacturing and use of manufactured products; (3) incidental usage of mercury in coal; (4) incidental usage of mercury in non-coal materials; and (5) other sources resulting from previous use. Each exhibit identifies these major categories, while Exhibits 1-2 through 1-4 identify the individual sectors comprising the categories.

These exhibits present the flow of mercury on a national aggregate annual basis for mercury sectors and categories of sectors. The actual flow changes from year to year as a result of changes in demand, industry initiatives to reduce or measure mercury, and implementation of regulatory efforts by local, state, and federal governments. Additionally, the same quality of data are not available on a consistent basis from year to year for all sectors or even within individual sectors, therefore the data presented in these exhibits are intended to represent mercury flow in the latest year where data are available, rather than for any specific year.

Exhibit 1-1 provides an overview of the available data. The data are presented according to major categories. The purpose of Exhibit 1-1 is to identify principal flows of mercury through the U.S. Economy. Mercury sources are listed at the top of Exhibit 1-1. Each of these constitute 'inputs' to the flow of mercury in the United States. Mercury then flows to subsequent categories, including manufacturing and use, or straight to final disposition (represented as wastes, exports, and recycling).

Exhibit 1-2 quantifies the flow of mercury for the individual sectors evaluated in this report. The first column accounts for mercury inputs for each sector; this includes the use of elemental mercury and the presence of mercury as a contaminant in raw materials. The next three columns indicate the quantity of releases of mercury into the environment for air, water, and solids. The last column presents the quantity of mercury that has accumulated as a result of historical use (reservoir).

Other notations are used in Exhibit 1-2 to acknowledge that specific sectors represent a source of mercury but that an estimate is not provided. Reasons include an overall lack of data or unreliable data, or that all relevant quantities are small relative to the other sources presented in this exhibit (less than one ton). The basis for the estimates, or a discussion of why no estimate is presented, is provided in the subsequent chapters of this report.

Exhibits 1-3 and 1-4 present further sector-specific detail for each of the sectors evaluated in this report. Exhibit 1-3 illustrates the quantities of mercury in supply, manufacturing processes, and subsequent use of manufactured products. These are discussed in Chapters 2 and 3 of this report. Exhibit 1-4 illustrates the quantities of mercury in cases where mercury is incidentally used and in final disposition. These are discussed in Chapters 4 through 6 of this report. Data are presented for the quantity consumed (present in raw materials) which was previously shown in Exhibit 1-2. In these exhibits, however, the outputs are detailed according to the quantities in product, exports, multimedia releases (sum of air, water, and land), and recycling.

1.6 Data Limitations and Uncertainty

The quantitative data in this report are based on a combination of government data, industry data, and estimates. The quality of these data often differ by sector due to industry-specific initiatives undertaken in response to regulatory or voluntary efforts, such as reporting requirements. The use and management of mercury has been changing in the last several years in response to these initiatives, which makes even recent mercury use data unreliable. Where this is the case,

trend information has been presented, where available, to give an indication of the changes in process. Finally, it is unusual to obtain consistent information on raw material use, releases, recycling, and product content. The result is that the data presented in this report are of varying quality and is subject to future change. It is not possible to obtain data for a single consistent year throughout the report. For example, some data are applicable for 1995, others for 1999, and other estimates are calculated using data for a variety of years. This was a function of two factors:

- Use of data which was readily available; for example, the Toxics Release Inventory (TRI) data. The most recent data available, from the 1999 TRI, were used throughout this report.
- Data were only available for a certain year; for example, Department of Commerce (Bureau of Census) data. Until 1994, the Department of Commerce collected data for lamp production. In this report, such data were used because it was the most recent. However, based on later indirect indications as discussed in the report, such data may be adequate for approximating current production.

USEPA has finalized revisions to the Toxics Release Inventory (TRI), which reduce the reporting threshold of mercury to 10 pounds (64 Federal Register 58666, October 29, 1999). These changes took effect for the year 2000 reporting year, and the data were not available to the public until mid-2002. These changes mean that a facility that uses as little as 10 pounds of mercury in a year will be required to report its release and recycling activities (even if its releases are zero). Under previous reporting years, a facility was not required to report its releases unless it used 10,000 pounds of mercury in a year. The result of this change is that many more facilities that use and release mercury will be reporting this information, which will improve the quality of several of the numerical estimates presented in this report.

Additional caution should be used for Exhibits 1-2 through 1-4. Estimates are sometimes presented as single numbers, and sometimes as ranges. Ranges are used to express the range of uncertainty in the available data. However, there is uncertainty associated with much of the data expressed as discrete values, which is discussed in detail in the individual chapters of this report.

Integrating and interpreting data from various information sources in order to characterize processes, in this case the flow of mercury through key industries, inherently results in some degree of uncertainty. In this study, some sources of information were equivocal due to factors such as low sample sizes, conflicting reports, or a of lack of data. The degree of uncertainty in data collected for this report varies among sectors and by estimate (releases, consumption, and reservoirs). Despite associated uncertainties, estimations are expected to provide a relative scale ranging from industries that are heavily involved with mercury to those that are associated with the element to a much lesser degree.

In this report, sources of uncertainty are addressed in detail for each sector. The purpose of this section is to provide a summary of the uncertainty associated with the mercury usage estimates of several key sectors. Exhibit 1-5 lists the mercury quantities associated with these key sectors (use, release, and reservoir) and assigns each relevant estimate a data quality score in order to aid interpretations of this report's findings. Data scores use an A, B, or C system designed to render the sector estimates into 3 tiers of data confidence. Exhibit 1-6 discusses the supporting materials within each scored industry and is intended to elucidate the basis of the data quality scores. Justifications of data quality scores for remaining sectors are not explicitly identified, rather, a discussion of data quality for each sector is provided in their respective chapters.

The U.S. Mercury Life Cycle

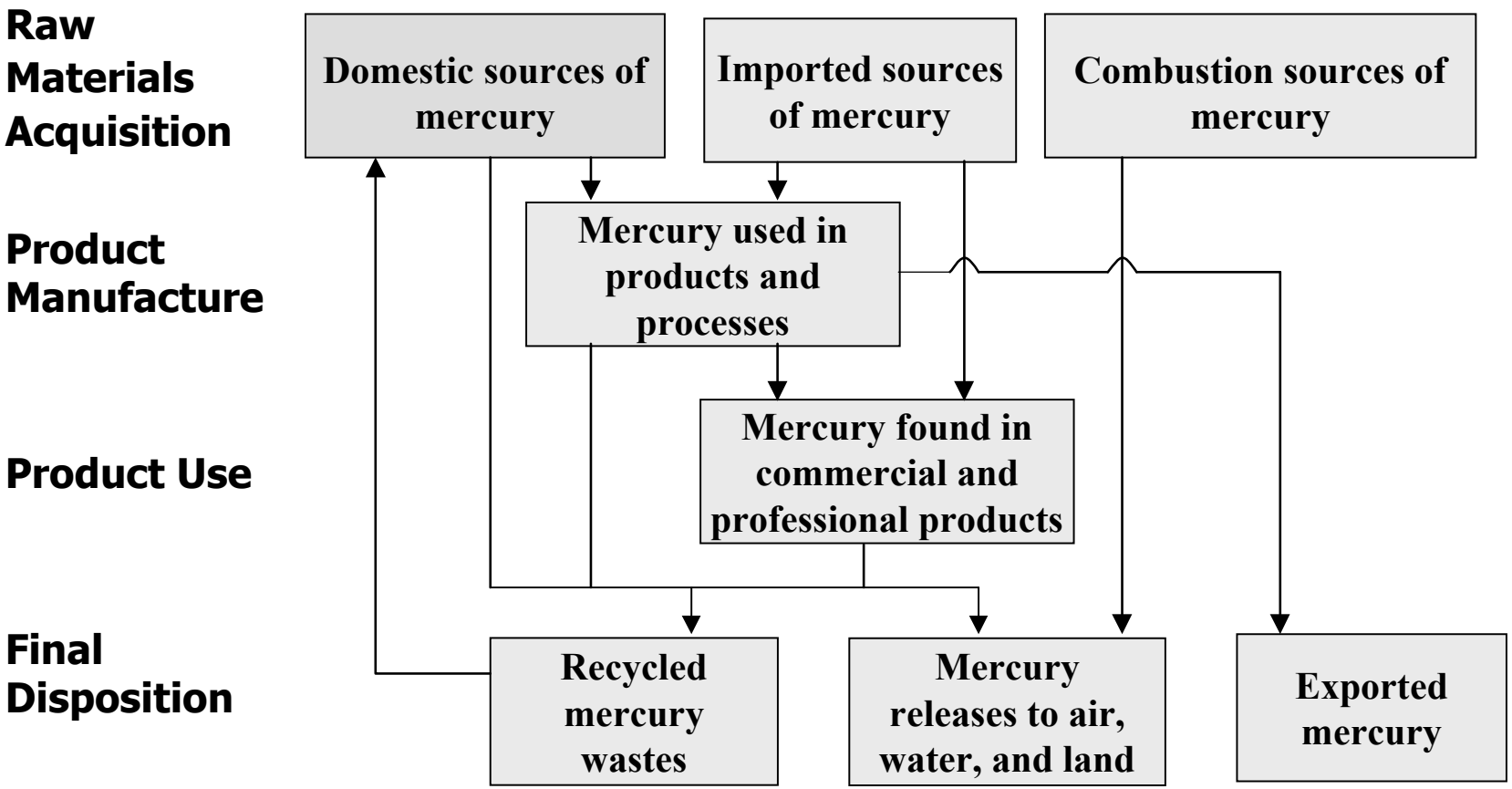


Exhibit 1-1. Summary of the U.S. Mercury Life Cycle

Exhibit 1-2. Summary of Mercury Mass Balance Data

Mercury Sector	Mercury Used in Raw Materials (ton/yr)	Waste Releases (ton/yr)			Mercury Reservoir (ton)
		Air	Water	Solid	
Mercury Supply (discussed in Chapter 2)					
Secondary Mercury Production	430	0.4	0	0.1	—
Imports and Exports	-83	0	0	0	—
U.S. Government Stockpiles	0	0	0	0	4,850
Total for Mercury Supply	*347*	*0.4*	*0*	*0.1*	*4,850*
Mercury Use in Manufacturing Processes (discussed in Chapter 3)					
Chlor-alkali Manufacturing	79	6.3	0.1	21.5	2,000
Electrical Lighting: Manufacturing	16	0.3	—	0.2	0
Electrical Lighting: Use and Disposal	17 *	3	0	11	65 - 75
Thermometers: Manufacturing	9 - 17	<0.2	0	0	0
Thermometers: Use and Disposal	9 - 17 *	2-3	0	7-14	45 - 85
Thermostats: Manufacturing	15 - 21	0	0	0	0
Thermostats: Use and Disposal	13 - 20 *	1-2	0	6-8	230
Switches and Relays: Manufacturing	36 - 63	0	0	0	0
Switches and Relays: Use and Disposal	36 - 63 *	7-13	0	29-50	630
Organic Chemical Production	—	—	—	—	—
Dental Preparations Manufacturing	34 - 54	0	0	0	0
Dental Office: Use	34 - 54 *	0.8	7.4	0	1,200
Mercury Compounds	—	—	—	—	—
Batteries	negligible	negligible	negligible	negligible	—
Total for mercury use in manufacturing	*189 - 250*	*20.4 - 28.5*	*7.5*	*74.7 - 104.7*	*4,170-4,220*
Incidental Mercury Use Associated with Coal Combustion (discussed in Chapter 4)					
Utility Coal Combustion	105	48	7	33	0
Lime Manufacturing	2.7 - 5.0	0.1	0	0.1	0
Residential/Comm/Industrial Coal Combustion	7.6 - 21.2	21.2 - 23.6	0	0.6	0
Byproduct Coke Production	3.2	0.7	0	1.5	0
Portland Cement Manufacturing	3.4 - 5.7	4.2	0	0.6	0
Coal Combustion Wastes	3	0	0	3	—
Total for Coal Combustion	*124.9 - 143.1*	*74.2 - 76.6*	*7*	*38.8*	*0*
Incidental Mercury Use Associated with Non-Coal Sources (discussed in Chapter 5)					

Mercury Sector	Mercury Used in Raw Materials (ton/yr)	Waste Releases (ton/yr)			Mercury Reservoir (ton)
		Air	Water	Solid	
Oil Combustion: U.S. Utility	0.06	0.2	0	<0.6	0
Oil Combustion: Other	0.08	7.8 - 10.9	0	<0.1	0
Carbon Black Production	0.11	0.3	0	0	0
Gold Mining	1,370	6.2	0	1,342	—
Primary Lead and Zinc Mining and Smelting	0.2	0.2	0	7.6	0
Primary Copper Mining and Smelting	6.4	0.1	0	16.4	0
Pulp and Paper Manufacturing	—	—	—	—	—
Oil Refining	2.2 - 11.5	—	—	—	—
Rubber and Plastic Products	—	—	—	—	—
Geothermal Power	—	—	—	—	—
Wood-fired Boilers	—	—	—	—	—
Utility Natural Gas Combustion	negligible	negligible	negligible	negligible	—
Total for Incidental Non-Coal Sources	*1,379 - 1,389*	*14.8 - 17.9*	*0*	*1,365*	*0*
Other Sources of Mercury Resulting from Previous Use (discussed in Chapter 6)					
Hazardous Waste Combustion	1.0	7.1	0	0	0
Crematories	1.4	<0.1	0	0	0
Sewage Treatment and Sludge Incineration	12	<0.9	5.5	5.5	0
Municipal Waste Combustion	—	—	—	—	—
Landfills	—	—	—	—	—
Medical Waste Incineration	—	—	—	—	—
Historical Mining Activities	—	—	—	—	—
Total for Previous Use Sources	*14*	*8*	*5.5*	*5.5*	*0*

— No data available or estimate was not made.
* Not included in subtotal to avoid 'double counting.'

Exhibit 1-3. Annual Flow of Mercury in Supply and Manufacturing Sectors

Mercury Sector	Manufacturing (tons/year)					Use (tons/year)		Disposal (tons/year)	
	Consumption	Product	Exports	Releases	Recycling	Domestic Source	Imports	Releases	Recycling
Supply of Mercury (Discussed in Chapter 2)									
Recycling	430	429	0	1.2	0	—	–	–	–
Net Imports	-83	-83	—	0	0	—	–	–	–
U.S. Government Stockpiles	0	0	—	—	—	—	–	–	–
Subtotal	347	346	0	1.2	0	—	–	–	–
Manufacturing Processes Involving Mercury (Discussed in Chapter 3)									
Chor-Alkali	79	<0.5	0	27.8	13.04	—	—	—	—
Electrical Lighting	16	16	2	0.5	1.1	14	3	15	2
Thermometers	9-17	9-17	—	<0.2	—	9-17	—	9-17	—
Thermostats	15-21	11-17	2-3	0	4.1	9-14	4-6	7-10	—
Switches and Relays	36-63	36-63	—	0	0	36-63	—	36-63	—
Organic Chemical Production	—	—	—	—	—	—	—	—	—
Dental Preparations	34-54	34-54	0	0	2.5	34-54	—	8.2	—
Mercury Compounds	—	—	—	—	—	—	—	—	—
Batteries	—	—	—	—	—	—	—	—	—
Subtotal	189-250	106-167	4-5	28.26	18.24	102-162	7-9	75-113	2

Estimates are on an annual basis of mercury (short tons per year).

Exhibit 1-4. Annual Flow of Mercury Associated with Incidental Mercury Use

Mercury Sector	Consumption (tons/yr)	Product (tons/yr)	Releases (tons/yr)	Recycling (tons/yr)
Incidental Mercury Use Associated with Coal Combustion or Coal Use (Discussed in Chapter 4)				
Coal Combustion by Utilities	105	3	88	0
Lime Manufacturing	2.7-5.0	—	0.2	0
Residential/Commercial/Industrial Coal Combustion	7.6-21.2	0	21.8-24.2	0
Coke Production	3.2	0	1.8	0
Portland Cement Manufacturing	3.4-5.7	0	4.8	0
Coal Combustion Wastes	3	0	3	0
Subtotal	125-143	3	120-122	0
Incidental Mercury Use Associated with Non-coal Sources (Discussed in Chapter 5)				
Oil Combustion	0.14	0	8.7-11.8	0
Carbon Black Production	0.11	—	0.28	0
Gold Mining	1,370	0	1,348	21.6
Primary Lead and Zinc Mining and Smelting	0.2	0	7.8	0
Primary Copper Mining and Smelting	6.4	0	16.4	0
Pulp and Paper Manufacturing	—	—	—	—
Oil Refining	2.2 - 11.5	0.93	—	—
Rubber and Plastic Products	—	—	—	—
Geothermal Power	—	—	—	—
Wood-fired Boilers	—	—	—	—
Utility Natural Gas Combustion	—	—	—	—
Subtotal	1,379 - 1,389	0	1,380-1,383	22
Additional Sources of Mercury Resulting from Disposal or Final Disposition (Discussed in Chapter 6)				
Hazardous Waste Combustion	1	0	7.1	0
Crematories	1.4	0	<0.1	0
Sewage Treatment and Sludge Incineration	12	0	12	0
Municipal Waste Combustion	—	—	—	—
Landfills	—	—	—	—
Medical Waste Incineration	—	—	—	—
Historical Mining Activities	—	—	—	—
Subtotal	14	0	19	0

Estimates are on an annual basis of mercury (short tons per year).

Exhibit 1-5. Summary of Data Quality for Selected Sectors

Sectors Ranked by Total Releases			Sectors Ranked by Consumption			Sectors Ranked by Reservoir		
Sector	Total (tons/year)	Data Quality	Sector	Total (tons/year)	Data Quality	Sector	Total (tons)	Data Quality
Gold Mining	1,348	B	Gold Mining	1,370	B	U.S. Government Stockpiles	4,850	A
Utility Coal Combustion	88	A (air) B (others)	Secondary Mercury Production	430	B	Chlor-alkali Manufacturing	2,000	B
Switches and Relays: Use and Disposal	36 - 63	B (releases) C (recycling)	Utility Coal Combustion	105	A	Dental Preparations	1,200	C
Chlor-alkali Manufacturing	27.8	B	Imports and Exports	-83	A	Switches and Relays: Use and Disposal	630	B
Thermometers: Use and Disposal	9 - 17	B (releases) C (recycling)	Chlor-alkali Manufacturing	79	A	Thermostats: Use and Disposal	230	B
Thermostats: Use and Disposal	7 - 10	B	Switches and Relays: Use and Disposal	36 - 63	B	Thermometers: Use and Disposal	45 - 85	B
Dental Preparations	8.2	B	Dental Preparations	34 - 54	B	Secondary Mercury Production	—	—
Secondary Mercury Production	0.5	C	Thermostats: Use and Disposal	13 - 20	B	Utility Coal Combustion	—	—
Oil Refining	—	C	Thermometers: Use and Disposal	9 - 17	B	Imports and Exports	—	—
Imports and Exports	—	—	Oil Refining	2.2 - 11.5	B	Gold Mining	—	—
U.S. Government Stockpiles	—	—	U.S. Government Stockpiles	—	—	Oil Refining	—	—

Data Quality Legend: A: Expected to be well documented, B: Data available but uncertain, C: Very little data available

Exhibit 1-6. Review of Data Quality for Selected Sectors

Estimate	Data Source(s)	Review of supporting materials	Data Quality
Secondary Mercury Production			
Consumption	USGS data from 1997	USGS estimate of 430 tons is from latest year available. This value is uncertain and higher than a conflicting industry estimate. Reassess estimations in 2000 TRI reports when more mercury recyclers may report.	B
Releases	US EPA 1997 Mercury Report to Congress 1999 TRI	Air releases estimate from Mercury Report to Congress extrapolation based on 1994 TRI data. Uncertainty results from changes in facilities and the industry since 1994. Water and solid releases are uncertain due to low sample size (n = 2). Reassess all estimations in 2000 TRI reports when more mercury recyclers may report.	C
Imports and Exports			
Consumption	USGS data for 2000	Estimate from Census Bureau is expected to be accurate. Principle uncertainty is that no data are available on trade of mercury-containing scrap or waste. Figure based on available trade data.	A
U.S. Government Stockpiles			
Reservoirs	US Defense Logistics Agency	Estimate expected to be accurate, from agency in charge of stockpile management.	A
Chlor-alkali Manufacturing			
Consumption	Chlorine Institute data for 2000	Data are based on a survey of all eleven industry facilities over a 4 year period. Principle uncertainty is that usage data are variable from year to year, possibly reflecting intermittent use.	A
Releases	1999 TRI	Data are based on the response of 13 mercury cell plants representing 96% of total production. There may be some error associated with plant's ability to measure releases.	B
Reservoir	US EPA 1997 Mercury Report To Congress and Chlorine Institute (2000 data)	Broad estimation predicated on large storage of mercury in plants, mercury cell capacity, and contamination in pipes, equipment, etc. based on number cells in operation (accurately known) and quantity of mercury per cell (not accurately known or uniform).	B

Estimate	Data Source(s)	Review of supporting materials	Data Quality
Thermometers: Use (Rather than Manufacturing)			
Consumption	1997 Bureau of Census Data US EPA report from 1992 regarding mercury in municipal waste	High-end estimate. The number of thermometers produced, as recorded by the Bureau of Census, does not delineate data for liquid-in-glass thermometers sold by liquid type. Estimations of mercury content per thermometer from a 1992 EPA report are expected to be accurate. *Key assumptions*: No import or export data available. All liquid-in-glass thermometers contain mercury.	B
Releases	Same as Consumption references	Release projections are based on consumption values, which consist of some uncertainties. Estimation of landfill waste releases (7 - 14 tons) similar to prior EPA estimations (16.3 tons in 1989). No estimate for recycling. *Key assumptions*: 80% of thermometer mercury is landfilled and 20% combusted, consistent with overall municipal solid waste management.	C (releases) C (recycling)
Reservoir	USEPA 1992b	The validity of this estimate is unclear due to lack of data (e.g. number of mercury thermometers still in use). *Key assumptions*: Thermometer life-span of 5 years. Mercury consumption is 9 - 17 tons per year.	B
Thermostats: Use (Rather than Manufacturing)			
Consumption	1997 Bureau of Census Data US EPA report from 1992 regarding mercury in municipal waste	The ultimate calculation of this value integrates figures from 3 separate studies (average amount of mercury per thermostat, number of thermostats produced annually, and percentage of thermostats exported, imported, and sold domestically). Potentially, the sum of any errors from each study may be significant, although the largest error is likely to be in the thermostat production data. *Key assumptions*: Even distribution of mercury and non-mercury devices among total thermostats produced.	B
Releases	US EPA from 1994 report	The estimate is primarily based on the number of thermostats brought out of service in 1994. While this number has certainly changed 7 years later, the largest uncertainty for a present-day estimate is the quantity recycled, which is unknown. *Key assumptions*: 80% of solid wastes are landfilled and 20% incinerated, consistent with overall municipal solid waste management.	C (releases) C (recycling)

Estimate	Data Source(s)	Review of supporting materials	Data Quality
Reservoir	US EPA reports from 1992 and 1994	The estimate is on the low-end since it is based on an estimation of thermostats in use among U.S. residences only and not commercial or government sites.	B
Switches and Relays: Use (Rather than Manufacturing)			
Consumption	USGS 1997 data US 1997 Bureau of Census data	The USGS estimate of 63 tons excludes mercury reed relays, which typically have a high mercury content but have unknown production. The 36 tons/year estimate is based on US DOC data may be highly variable because it includes non-mercury switches and also excludes mercury reed relays. Switches and relays, in general, are difficult to track due to the high number of categories used to describe them.	B
Releases	Same as Consumption references	The total releases were estimated by assuming that outflow equals inflow (disposal = consumption). No data were available for recycling. *Key assumptions*: The amount used in switch and relay manufacturing must eventually be disposed, with 80% landfilled and 20% incinerated, consistent with overall municipal solid waste management.	C (releases) C (recycling)
Reservoir	USGS 1990 - 1997 data	The estimate is but probably low. USGS estimated the consumption of mercury containing wiring devices and switches over the period of 1990 to 1997. The 630 ton reservoir figure is the sum of consumption over these 8 years. Switch life is typically greater than 8 years. Moreover, the data do not include all types of mercury switches and relays or imports.	B
Dental Preparation			
Consumption	USGS 1997 data US Dept. of Health and Human Services 1993 study 1994 literature paper	The range provided (34 - 54 tons/year) represents 2 different estimates. The lower estimate of 34 tons / year was provided by USGS (1997), the most recent year available. The higher estimate is based on the number of fillings and the mercury content of fillings. *Key assumptions*: Use of amalgams continued to decrease through time.	B

Estimate	Data Source(s)	Review of supporting materials	Data Quality
Releases (From Dental Offices)	US EPA 1997 Mercury Report to Congress 1996 research by Arenholt 1999 DAMS report	Estimated releases are probably conservative. Low-end estimates for average mercury in dental wastewater and the number of dental offices were used. Air releases based on assumption; waste water releases from single study and conservative estimate of the number of dental offices. *Key assumptions*: Two percent of the total amount of mercury used is emitted from spills and scrap.	B (releases) C (recycling)
Reservoir (Population)	Same as Consumption references	Very broad estimate based consumption data. *Key assumptions*: Twenty to forty year life-span for fillings.	C
Utility Coal Combustion			
Consumption	1999 EPA ICR and US EPA 1997 Report to Congress	The estimate of mercury into utility coal combustion is based on consumption and sampling data at over 450 coal-fired utilities during 1999. *Key assumptions*: 15% of the mercury present in coal nationwide is removed prior to introduction to the boiler. This is based on average coal cleaning efficiency from the 1997 Report to Congress.	A
Releases	US EPA Fossil Fuel Waste Reports To Congress in 1998 and 1999	The approximation of air releases (40 tons/year) is expected to be reliable since it was based on a large sample of measurements during 1999. Measurements for solid waste are not as extensive although waste generation quantities are based on relatively recent (1997) facility survey data. Water releases (7 tons per year) may be understated since generation and / or sampling data are unavailable for several wastewater sources including: Pile runoff, boiler blowdown, gas-side wastes, and FGD liquor.	A (air) B (others)
Gold mining			
Consumption and Releases	1999 TRI	Total releases from gold mining is based on 1999 TRI data submitted by 8 Nevada-based facilities, which were probably the largest sites but not all of the sites. As smaller facilities report year 2000 releases, the estimate may rise slightly. Reported air emissions are suspected to be based on estimates and not measurements. Other media releases are of unknown quality. Consumption estimate is largely based on same uncertainties as the releases estimate. *Key assumptions*: Mercury input from trace impurities in gold ore to the gold mining process is assumed to be equal to the amount released.	B

Estimate	Data Source(s)	Review of supporting materials	Data Quality
		Oil Refining	
Consumption and Products	1999 sampling data from Minnesota and US DOE Petroleum Supply Annual for 2000	The throughput data tabulated by US DOE is highly reliable. The mercury content of crude oil, however, is variable by nature and the mercury concentration published by Minnesota is based on a sample size of only two refineries.	B
Releases	1999 TRI	Waste releases according to 1999 TRI data appeared to be minimal but were largely unavailable for most refineries. Only six oil refineries and bulk fuel terminals reported out of approximately 150 facilities.	C

Chapter 2
Supply of Mercury

Mercury in the United States is supplied by three sources: secondary mercury production (recycling), imports, and a government stockpile. Presently, the government stockpile does not actually supply mercury, but rather represents a source of mercury which must be managed at some point in the future. Mercury is also obtained as a byproduct of gold mining, as discussed in Section 5.3 of this report.

2.1 Secondary Mercury Production

Facilities conducting secondary mercury production may be classified under one of several different business classifications:

SIC Code 2819: Industrial Inorganic Chemicals, Not Otherwise Specified (including redistilled mercury)
NAICS Code 325188: All Other Basic Inorganic Chemical Manufacturing

SIC Code 3341: Secondary Smelting and Refining of Nonferrous Metals (except copper and aluminum)
NAICS Code 331492: Secondary Smelting, Refining, and Alloying of Nonferrous Metals (except copper and aluminum)

SIC Code 4953: Refuse Systems
NAICS Code 562211: Hazardous Waste Treatment and Disposal

Secondary mercury production is the production of mercury through processing scrapped mercury-containing materials. Mercury-containing materials that may be recycled include dental amalgam, spent batteries, electrical switches, control instruments, thermometers, spent catalysts from chlorine and caustic soda production and laboratory and electrolytic refining wastes. These waste products are sent to mercury recycling facilities, which then process the waste to produce mercury for resale.

The production of secondary mercury from scrap began rising in 1990, as industrial consumption has been falling. In 1997, the most recently reported year, secondary mercury production was 430 tons and domestic consumption was 381 tons (USGS 2002a).

2.1.1 Mercury Recovery Process

Mercury may be recovered using two methods: extractive processes to recover mercury from scrap, and removal of liquid mercury from dismantled equipment. The extractive processes may involve either thermal or chemical treatment; thermal treatment is the most common. Extractive processes are used to recover mercury from scrapped products as well as industrial solid and liquid waste when liquid mercury cannot be drained. Because these methods involve chemical and thermal manipulation of the mercury, extractive processes are more likely to result in higher mercury emissions and waste.

Thermal Extractive Process

In thermal extraction processes, mercury-bearing scrap is heated to about 538°C (1000°F) to vaporize the mercury. The mercury vapors are condensed and the mercury is collected under water. Vapors from the condenser are combined with vapors from the mercury collector line, then purified with an aqueous scrubber to remove particulate matter (PM) and acid gases such as HCl and SO_2. Organic matter is removed by passing the vapor through a charcoal filter, then the vapor is discharged to the atmosphere.

Chemical Extractive Process

There are several chemical methods for extracting mercury from aqueous mercury-bearing waste streams. Metallic mercury may be precipitated by treating the waste stream with sodium borohydride or passing the waste stream through a zinc-dust bed. Mercuric sulfide may be precipitated using a water-soluble sulfide. Ionic mercury may be recovered using ion-exchange systems. Mercuric ions may be trapped with a chemically modified cellulose.

Liquid Removal Process

Liquid mercury may be removed from waste mercury-containing equipment by dismantling the equipment and draining the liquid mercury. Mercury recovered through this process is distilled to purify the product before resale.

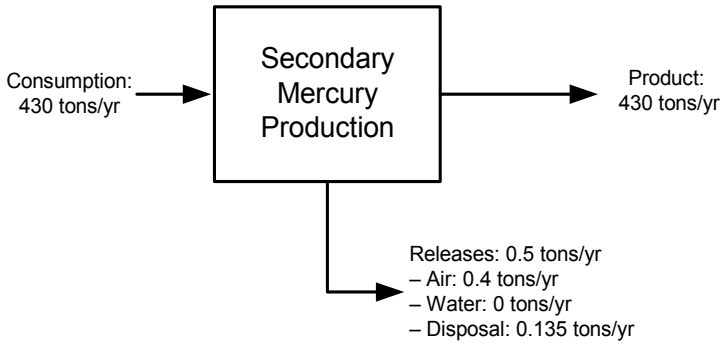
The liquid removal process is easier and less expensive than extractive processes, and may be used wherever liquid mercury can be effectively drained from equipment. Because there is no heating or chemical processing of the mercury under these circumstances, very little mercury emissions or other mercury waste is expected to be generated by liquid removal activities.

2.1.2 Materials Flow

Exhibit 2-1 illustrates the consumption, release, and product content of mercury in secondary mercury recovery.

Input

While there are no quantities available for the amount of mercury contained in the equipment, scrap, and waste sent to the recycling facilities, it was assumed that this amount is equal to the mercury emissions plus the mercury recovered, presented in Exhibit 2-1.



Sources: Mercury Release and Recycling: Air releases from EPA (1997a). Disposal releases from 1999 TRI data.
Mercury in Product: USGS (2002a).
Mercury Consumption: Assumed equal to mercury in product and mercury recycled.

Exhibit 2-1. Mercury in Secondary Mercury Production

Output

In 1997, an estimated 389 metric tons (430 tons) of secondary mercury were produced (USGS 2002a). An industry source estimates that a much lower quantity of mercury is produced: 75 to 150 tons (Lawrence 2000).

Another data source is TRI which requires all facilities to estimate and report the quantity of chemicals recycled onsite, if any. Such data for mercury represents the quantities actually recovered. Their most recent data show that the total quantity recycled onsite is 52.5 tons (two provided data for 1999). However, facilities are not required to report TRI releases if they use less than 10,000 pounds per year, therefore, some releases may not be included in these data.

Due to the uncertainty in the TRI data, the USGS data are considered more reliable and complete; these data are presented in Exhibit 2-1.

Air Releases

Two techniques used for estimating air emissions are presented here: the use of facility-aggregated reported releases and the use of an emission factor. Each technique generates different results, with advantages and disadvantages to each.

The facility-aggregated approach totals reported air releases from all facilities in the industry. Two mercury recovery facilities reported air emissions from their 1999 TRI data, totaling 0.003 tons. This estimate is incomplete because many additional mercury recovery

facilities did not submit TRI reports.

As a more appropriate alternative, emission factors can be used to estimate industry-wide emissions, based on data from a small number of facilities and extropolated to the industry as a whole. This technique was used in the *Mercury Study Report to Congress*, where an estimate of 0.4 tons was developed by extrapolating available air emissions data (using the 1994 TRI as a source) to the industry as a whole (USEPA 1997a). This estimate, however, also leads to uncertainty because some secondary mercury producers claim to not emit mercury to the atmosphere when they recycle, and it is difficult to account for this variability among reporters using available information. The air release estimates from EPA (1997a), generated using this approach, are shown in Exhibit 2-1.

Water Releases

Wastewater is generated during the vapor-condensing phase of thermal extraction. These liquid wastes are filtered to remove impurities (such as mercury). An industry-wide estimate for mercury releases to water is not available. TRI data are available from 1999 for two mercury recovery facilities. No releases were reported for either facility. Therefore, this release is shown as zero in Exhibit 2-1.

Reservoir

Mercury recycling facilities are expected to have State or federally permitted storage requirements for incoming wastes. No information is available regarding the quantities of mercury awaiting recycling by consumers or other users.

Solid Waste Releases

Solid waste is generated as a byproduct after mercury is removed from scrap and equipment. Most of this solid waste is disposed of in landfills. A relatively small amount of solid waste is sent for further treatment or recycling to recover metals other than mercury.

Two techniques used for estimating releases to land disposal are presented here: the use of reported facility-aggregated releases and the use of a release factor. Each technique generates different results and offers advantages and disadvantages.

Release factors can be used to estimate industry-wide releases, based on data from one or two facilities and applied to the industry as a whole. Based on the sampling of 'before and after' wastes from mercury recovery operations of the late 1980s, approximately 98 percent of mercury is recovered as product with the remaining present in the residue (USEPA 1998a). Therefore, using this 2 percent loss rate applied to the 1997 production level of 430 tons results in a loss of 8.6 tons. This estimate may be high due to improved process efficiencies in recent years.

Using the 1999 TRI data, two mercury recovery facilities reported releases to land and to other sites likely to treat waste prior to land disposal (e.g., commercial water treatment, waste brokers). These releases totaled 0.135 tons and are expected to be low because the estimate omits other recycling facilities. This quantity is used in Exhibit 2-1, however, because of the age of the above recovery data.

2.1.3 Discussion

There is some uncertainty in the estimated quantity of mercury recovered in the United States. The quantity presented in Exhibit 2-1 is based on USGS data. However, one mercury recovery company has indicated that the USGS data may be a high estimate because of the practice of extrapolating results for non-reporting facilities (Lawrence 2000).

There is some uncertainty in the amount of mercury in air and solid waste releases emissions generated from secondary mercury production. The 0.4 tons per year cited earlier for air releases is an extrapolated quantity based on EPA (1997a). However, each of the different methods of secondary mercury production (thermal extraction, chemical extraction, and liquid drainage) produce widely varied amounts of air emissions. The quantity of mercury remaining in the waste residue is also dependent on the form of mercury and the extent to which it can be removed from the spent material. The plants not reporting emissions data may be using a different combination of recovery processes than the plants for which data are available. New mercury recovery facilities open each year, so all aggregate estimates may be low. Without detailed knowledge of how much mercury-bearing scrap, sludge, and equipment is processed using each method, a truly representative emissions figure for this sector cannot be developed. Better estimates are expected when 2000 TRI data become available in summer 2002 for most facilities in this industry.

2.2 Imports and Exports

Mercury-containing materials are imported to and exported from the United States. Such materials include elemental mercury, mercury-containing scrap or waste for disposal or recovery, and mercury-containing products such as fluorescent lamps. No data are available for the trade of scrap or waste, while the trade of mercury-containing products is discussed in subsequent chapters for each particular product. Data for the trade of elemental mercury are presented here.

USGS reported that 113 tons of mercury were imported and 196 tons of elemental mercury were exported in 2000 (USGS 2002a), resulting in a net export of 83 tons. Principal trading partners include Australia and Germany (sources of imported mercury) and India and the Netherlands (destinations for exported mercury) (USGS 2000a).

2.3 U.S. Government Stockpiles

The U.S. Government has previously purchased mercury for the National Defense Stockpile to satisfy contingency requirements for national emergencies. A total of 4,850 tons are presently being stored in five locations in the eastern United States. Note that this cannot be directly compared to the other supply sources because this is a 'one-time' quantity while the others are annual quantities.

There has been no need for stockpiled mercury as a national security requirement, and sales of this material have been suspended since 1994. Therefore, mercury is not presently being added to or removed from the stockpile. The Defense Logistics Agency, which is responsible for maintaining the stockpile, is in the process of preparing an environmental impact statement to examine alternatives for stockpile management. At present, these alternatives include no action, and the consolidation of supply, sales, and disposal (DLA 2002). Identification and implementation of an alternative will likely take a minimum of several years.

U.S. government stockpiled mercury is being stored with no transport or processing presently being conducted. The only potential releases are from the storage. Such releases are expected to be minimal because no handling occurs.

2.4 Miscellaneous Government Uses

Another U.S. government mercury reservoir is in the Spallation Neutron Source research center; this DOE facility uses elemental mercury as the target for the neutron (SNS 2002). Because this is a new projected use, reduction opportunities are not considered. The facility is expected to begin operating in 2006.

Chapter 3
Manufacturing Processes Involving Mercury

3.1 Chlor-Alkali Manufacturing

3.1.1 Introduction

Facilities producing chlor-alkali are classified under the following business classifications:

SIC Code 2812: Alkalies and Chlorine

NAICS Code 325181: Alkalies and Chlorine Manufacturing

More mercury is used in chlorine and caustic soda manufacturing than in any other industrial sector in the United States. The SIC Code 2812 and NAICS Code 325181 describe all industries primarily engaged in manufacturing alkalies (e.g., NaOH) and chlorine (Cl_2). Chlorine and alkali manufacturing are linked because of a shared production process. Electrolysis separates the sodium and chlorine in salt brine (NaCl), producing 1.1 tons of caustic soda for every ton of chlorine. Since chlorine cannot be economically stored or moved over long distances, chlor-alkali facilities are often located near industries that require chlorine. The two largest industries for chlorine are vinyl chloride monomer manufacturing and pulp and paper manufacturing (Kirk-Othmer 1991).

There are three electrolytic methods used in chlor-alkali production: diaphragm cell, mercury cell, and membrane cell production. Although all new chlor-alkali facilities being built use either membrane cell or diaphragm cell technologies – processes that do not use mercury – several chlor-alkali facilities still use the mercury cell process. In the United States, mercury cell plants account for 10% of the chlorine production capacity; production takes place at 11 facilities using mercury cells (Chlorine Institute 2001 and ChemExpo 2000). One advantage of the mercury cell process is that it produces a low-salt caustic soda and it is much easier to scale production levels of chlorine and caustic soda based upon demand (Genna 1998).

Unlike the diaphragm cell and membrane cell processes, which are one-step processes, the mercury cell process is a two-step process: an electrolyzing stage produces the chlorine gas and a decomposing stage produces the caustic soda (USEPA 1997a). Flowing at the bottom of the cell, a few millimeters below the suspended metal anode, the mercury acts as the cathode in the electrolytic process. Each cell may contain three tons of mercury (USEPA 1997a), and through most of the 1990s there were a total of 762 mercury cells (Chlorine Institute 2001). An aqueous salt brine solution (NaCl) flows between the anode and the cathode, releasing chlorine gas at the anode. The remaining sodium and mercury amalgam flows from the electrolyzer cell to the decomposing cell, which separates the mercury from the sodium that produces sodium hydroxide (NaOH) and recycles the mercury back to the electrolyzer cell (Kirk-Othmer 1991).

3.1.2 Materials Flow

Exhibit 3-1 illustrates the consumption, release, and product content of mercury in chlor-alkali production. The environmental release estimates in Exhibit 3-1 are based on 1999 Toxic Release Inventory (TRI) mercury release data for 13 of the 14 plants operating in that year. Mercury use data are based on data from the Chlorine Institute (2001); mercury in products is estimated as described below.

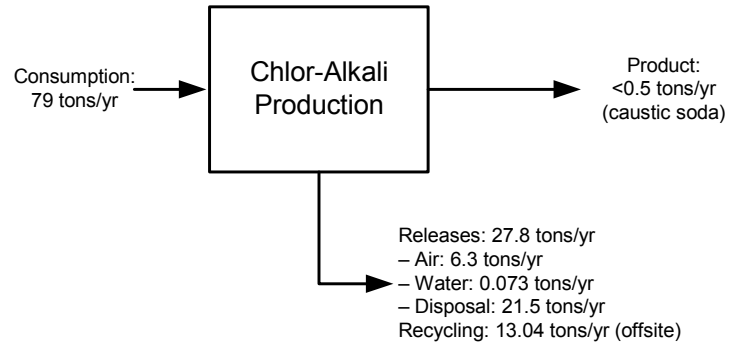
The calculation does not match the amount consumed with the total amount released. It is unknown why there is a discrepancy between consumption and release. Studies are being conducted by EPA to find out where the missing mercury goes. One explanation could be that the consumption is from the Chlorine Institute and the release data is from TRI.

Mercury Consumption

Exhibit 3-2 shows estimates of mercury consumption for several years along with mercury release data. The Chlorine Institute's (2001) estimate of mercury consumption from the domestic chlor-alkali facilities decreased from 222 tons in 1990 to 79 tons in 2000. The Chlorine Institute also provided estimates of mercury purchases by the chlor-alkali facilities. On a year-to-year basis, mercury purchases did not necessarily equal mercury use. However, over a multi-year period, mercury purchases were roughly equivalent to mercury use. Chlor-alkali facilities may purchase more mercury than they anticipate using, storing the excess mercury for later use (Dungan 1999). The 2000 consumption estimate is used in Exhibit 3-1.

Air Releases

Air releases of mercury from chlor-alkali production result from elevated process temperatures. The heat generated by the electrolysis process used to



Sources: Mercury Consumption: Chlorine Institute (2001).
Mercury Release and Recycling: 1999 TRI data.
Mercury in Product: Estimated from production capacity (Chlorine Institute 2001) and product concentration (WLSSD 1997).

Exhibit 3-1. Mercury in Chlor-Alkali Manufacturing

Exhibit 3-2. Chlor-Alkali Mercury Cell Process Mercury Used, Emitted, Recycled, and Disposed

Quantity (tons)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Total Mercury Used[1]	222	175	148	104	146	165	137	118	104	88	79
Total Mercury Air Emissions[2]	-	-	-	-	-	-	-	-	7.3	6.3	-
Total Mercury Water Emissions[2]	-	-	-	-	-	-	-	-	0.1	0.07	-
Total Onsite Mercury Recycling[2]	-	-	-	-	-	-	-	-	469	374	-
Total Offsite Mercury Recycling[2]	-	-	-	-	-	-	-	-	8.2	13	-
Total Mercury Disposal[2]	-	-	-	-	-	-	-	-	7.2	21.5	-
Total Mercury in Caustic Soda[3]	-	-	-	-	-	-	-	-	0.6	0.6	-

[1] Source: Chlorine Institute (2001).
[2] Source: 1999 TRI data for 13 of 14 chlor-alkali facilities using the mercury cell process. These thirteen facilities represented 96 percent of the total production capacity, signifying that the reported releases are an excellent estimate of industry-wide releases.
[3] Source: Estimated; represents high estimate of mercury likely to be in product. See text.
This table does not summarize environmental release data from the TRI prior to 1998.

separate the chlorine from the salt brine contributes to mercury volatilization (Johnson 1999). There are three primary sources of mercury air emissions at a mercury cell chlor-alkali facility: (1) byproduct hydrogen steam, (2) end box ventilation air, and (3) cell room ventilation air (USEPA 1997a). Ventilation systems and scrubbers reduce the amount of mercury emitted to the atmosphere. The mercury is transferred to water or to solid waste, where it may be recycled or disposed. As shown in Exhibit 3-1, industry-wide air releases are estimated at 6.3 tons based on 1999 TRI data.

Water Releases

Releases of mercury-containing water result from the large quantities of water used in the electrolysis process. Mercury is also found in the wastewater and brine of the mercury cell process. Some mercury is found in the water collected from the periodic wash-down of floors and equipment. As shown in Exhibit 3-1, industry-wide water releases are estimated as 0.07 tons based on 1999 TRI data. The estimate represents the mercury content in waters discharged to a surface water or to a publicly owned treatment works (POTW).

Solid Waste Releases and Recycling

Wastewater treatment sludges from chlor-alkali facilities were routinely landfilled until 1992, when USEPA banned the landfilling of certain mercury-containing sludges (USEPA 1988b). Because of the restriction, many mercury cell facilities now use retort and hydrometallurgical processes to remove the mercury from their wastes prior to landfilling and recycle the recovered mercury back into the mercury cell process (USEPA 1998a). As shown in Exhibit 3-2, a large quantity of mercury is recycled onsite. (However, it is not possible to identify how each facility reported this quantity, and a portion of the quantity may represent mercury that is continuously re-inserted back into the process when using mercury as a catalyst.) This onsite recycling is not accounted for as recycled quantities in the summary of Exhibit 3-1 because it is internal to the industry, rather than being sent to a commercial recycling facility such as those discussed in Section 2. As shown in Exhibit 3-1, industry-wide land disposal releases are estimated as 21.5 tons based on 1999 TRI.

Product

Because mercury has a high vapor pressure at normal operating conditions, mercury is found in trace amounts in the reaction products (chlorine and caustic soda). No estimates of mercury content in chlorine gas were found. In 1987, a Wisconsin wastewater treatment district found that caustic soda (sodium hydroxide) can contain mercury ranging from 10 to 300 parts per billion (WLSSD 1997). The Chlorine Institute identified an average level of 100 parts per billion, based on 1995 survey data (Chlorine Institute 2000).

Using conservative assumptions, the industry-wide mercury content of caustic soda is estimated as no more than 0.5 tons per year. These assumptions include using the upper end of the mercury concentration range of 300 parts per billion, and estimating annual sodium hydroxide production of 1.7 million tons per year (which is equivalent to the capacities for mercury cell facilities reported in Chlorine Institute (2001)). This estimate assumes no mercury contributions from other processes. Such contributions are possible at facilities where the mercury cell process was replaced but where residual mercury may still be present.

Reservoir

A considerable quantity of mercury is present inside a chlor-alkali facility. This is partly due to the function of mercury as a catalyst; as discussed above, each cell may contain three tons of mercury (USEPA 1997a) and there were 762 cells operating for most of the 1990s prior to the most recent closures (Chlorine Institute 2001). An industry source estimates that a single plant holds between 75 and 750 tons of mercury, which would be available to the secondary market upon dismantling of the plant (Lawrence 2000). Additional mercury is also expected to be present within pipes, equipment, etc., as an amalgam, which may not be easily recoverable. Based on these data, this report estimates that at least 2,000 tons of mercury is present at operating and recently closed chlor-alkali production facilities.

3.1.3 Discussion

There is an apparent discrepancy between the mercury consumed by the chlor-alkali industry and the mercury emitted. Mercury consumed by the chlor-alkali industry is used to replenish production losses. However, mercury consumption is much larger than the reported mercury emissions (Johnson 1999), and the mercury contained in the product is not a significant fraction. Therefore, approximately 50 tons of mercury appear to be "missing" based on the 1999/2000 data. There is increasing concern among state and federal regulators regarding this "missing mercury" (Johnson 1999). Olin Corporation, a major chlor-alkali producer, is working with USEPA to eliminate mercury discharges from its

two mercury cell chlor-alkali facilities (Johnson 1999). The head of Olin Corporation is urging the chlor-alkali industry to develop better methods to measure and control fugitive mercury emissions (Johnson 1999).

Data for 2000 mercury consumption were provided by the Chlorine Institute. USGS has not reported mercury usage statistics since 1997. Historically, USGS and Chlorine Institute data have differed. For example, the quantity of mercury consumption in 1995 as provided by the Chlorine Institute, 165 tons, is slightly lower than the quantity of mercury consumption in 1995 provided by USGS, 170 tons. This discrepancy is even more apparent when comparing 1997 data (118 tons Chlorine Institute vs. 176 tons USGS). The USGS data may include extrapolations for non-respondents. The Chlorine Institute is actively tracking mercury consumption at the plants using the mercury cell process.

3.2 Lamp Manufacturing, Use, and Disposal

3.2.1 Introduction

Facilities manufacturing lamps and lighting equipment may be classified under the following business classification:

> SIC Code 3641: Electric Lamp Bulbs and Tubes
>
> NAICS Code 33511: Electric Lamp Bulb and Part Manufacturing

SIC Code 3641 and NAICS Code 33511 are comprised of establishments primarily engaged in manufacturing electric bulbs, tubes, and related light sources. Mercury is a key component of fluorescent lamps and high intensity discharge (HID) lamps (including mercury vapor, metal halide, and high pressure sodium lamps). Fluorescent lamps are widely used for indoor lighting in businesses and increasingly in residences, while HID lamps are used for heat lamps, film projectors, dental exams, photochemistry, water purification, and street lighting. When an electrical current passes through mercury vapor, it emits ultraviolet light. In a fluorescent lamp, this ultraviolet light is converted into visible light when it excites the phosphorus coating inside the tube, causing it to fluoresce.

The mercury content in fluorescent bulbs in the United States has steadily decreased during the past two decades. In 1989, the average mercury content in a fluorescent bulb was 48.2 mg (USEPA 1999a), decreasing to 11.6 mg in 1999 for a typical four-foot lamp (NEMA 2000). In 1995, Philips Lighting introduced a low-mercury fluorescent lamp containing only 4.4 mg of mercury (USEPA 1999a). OSRAM Sylvania introduced a mercury-free high intensity discharge (HID) lamp in 1998 (Sylvania 1998).

3.2.2 Materials Flow

Exhibit 3-3 illustrates the consumption, release, and product content of mercury in electrical lighting, spanning manufacturing, use, and final disposal.

3.2.3 Manufacture

Mercury use in lamps depends on the quantity of lamps manufactured and the mercury content of the bulbs. Philips Lighting estimates that low-mercury lamps constitute 85% of its current lamp production and that they have reduced their mercury use by 13 tons per year (USEPA 1999a). Similar production information from other manufacturers was not available. OSRAM Sylvania estimates that introduction of their mercury-free HID lamp should reduce mercury consumption by 0.17 tons per year (Sylvania 1998).

Mercury Consumption

As shown in Exhibit 3-4, mercury consumption by domestic lighting manufacturers has declined from a peak of 61 tons per year in 1992 to about 32 tons per year in 1997, based on data from USGS. While these data are useful for identifying trends, the USGS estimate is not reflected in Exhibit 3-3. Instead, a lower estimate of 16 tons based on data from the Bureau of Census and the National Electrical Manufacturers Association (NEMA) was used. The NEMA estimate was used because it is based on more recent lamp composition data and, due to uncertainties with the USGS data identified in Section 3.1, the USGS data may overestimate actual use.

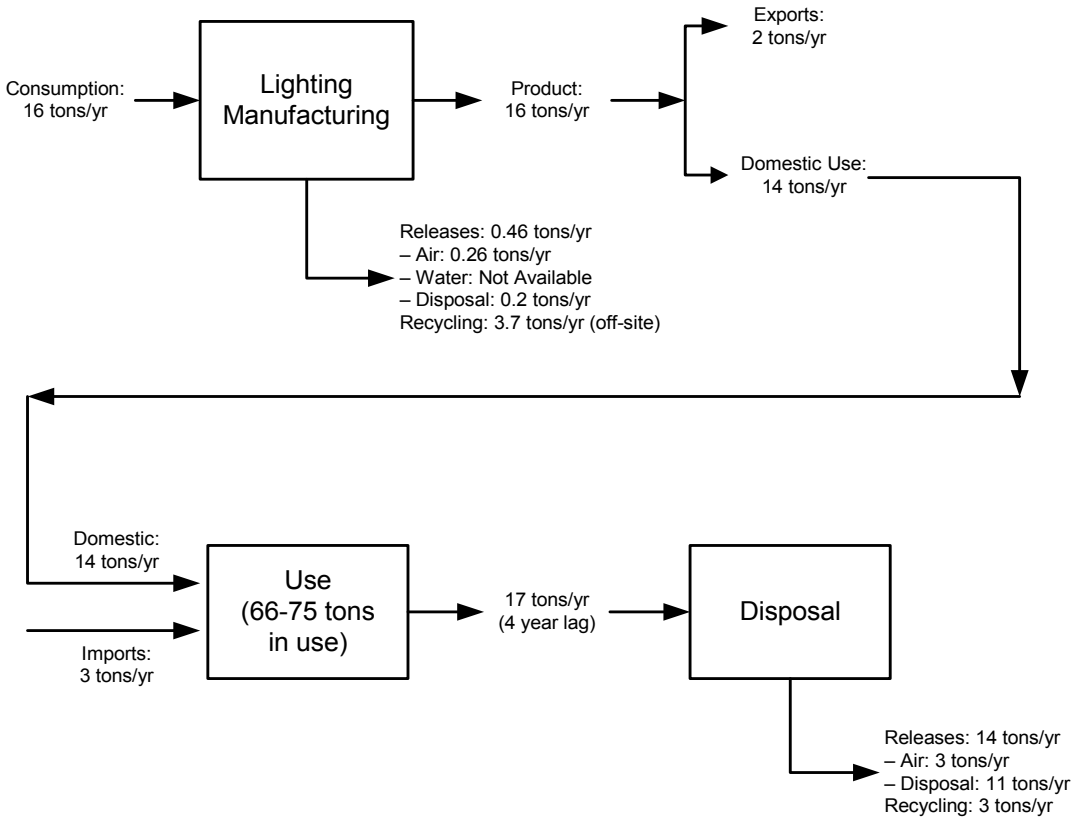
The U.S. Department of Commerce's Bureau of Census (USDOC 1995) estimates that 599 million fluorescent lamps and 28.5 million HID lamps were produced in the United States in 1994. Assuming an average mercury content of 11.6 mg of mercury per fluorescent lamp (NEMA 2000) and 25 mg per HID lamp (USEPA 1992b), lamp manufacturing consumed 16 tons of mercury in 1994. The quantity was used as an estimate for present day usage.

In 1994, the Census Bureau stopped collecting data on lamp production. Based on National Electrical

Manufacturers Association (NEMA) data, lighting system sales increased from $7.8 billion to $8.4 billion in 1997 (NEMA 1999), an increase of 8 percent. Therefore, the 1994 Bureau of Census estimate of 599 million fluorescent lamps manufactured in the United States appears to be a reasonable estimate for 1997.

Releases

Mercury can be released during transfer and parts repair, mercury handling, mercury injection into the lamps, accidents, and spills (USEPA 1997a). Two lamp manufacturing companies submitted TRI reports for 1999, reporting the release of 0.26 tons of mercury to the



Sources: Mercury Consumption: Extrapolated from the Bureau of Cencsus (DOC 1995), NEMA (2000), and EPA (1992b).
Mercury in Product: Extrapolated from lamps sold and exported (DOC 1995), lamps imported (EPA 1999b), and mercury content (NEMA 2000).
Mercury Release and Recycling: 1999 TRI data for manufacturing.
Exports and Imports: Bureau of Census (DOC 1995).
Emissions for Use: Recycling rate from NEMA (2000). Air and land disposal extrapolated using EPA (1997c).

Exhibit 3-3. Mercury in Electrical Lighting

Exhibit 3-4. Lighting Industry Mercury Consumed

	1990	1991	1992	1993	1994	1995	1996	1997
Total Mercury Consumed[1] (tons)	36	43	61	42	30	33	32	32

[1]Source: United States Geological Survey, Mineral Industry Surveys 1990-97

air and 3.7 tons recycled. Releases from these facilities are larger than the industry-wide estimate of 0.06 tons in the *Mercury Report to Congress* (USEPA 1997a). TRI data for these manufacturers are used in Exhibit 3-3. This estimate may be low due to the small number of facilities, but extrapolating to a larger population is difficult due to a lack of facility-specific information.

Exports

An estimated 68 million fluorescent lamps and 4 million HID lamps were exported in 1994 (USDOC 1995). This is approximately 1.8 tons of mercury (using the mercury content assumptions above). This number is used in Exhibit 3-3.

3.2.4 Use

Mercury Consumption

Of the nearly 600 million fluorescent lamps manufactured in the United States in 1994, 517 million lamps were sold domestically; the remainder were exported or stayed in inventory (USDOC 1995). An additional 100 million fluorescent lamps containing an estimated 2.5 tons of mercury were imported in 1995 (USEPA 1999b). Therefore, approximately 620 million fluorescent lights were sold in the United States containing 16 tons of mercury.

Of the 29 million HID lamps manufactured in 1994, 25 million were sold domestically; the remainder were exported or remained in inventory (USDOC 1995). An additional 3.5 million HID lamps containing an estimated 0.1 tons of mercury were imported in 1995 (USEPA 1999b). Therefore, approximately 29 million HID lamps (0.8 tons of mercury) were sold in the United States in 1994. The total quantity of mercury consumed from lighting (17 tons in Exhibit 3.3) reflects the combination of fluorescent lamps (16 tons) and HID lamps (1 ton).

Reservoir

Assuming a 20,000-hour lifespan for fluorescent lamps, these lamps should last about four years. Assuming the 620 million lamps sold each year are replacing one-fourth of the lamps in use, there were between 2.5 and 3 billion fluorescent bulbs in use in 1997, constituting 65 to 75 tons of mercury throughout the United States (assuming 11.6 mg of mercury per lamp).

Because HID lamps typically have a usable life of 10,000 hours and most are used 24 hours per day, USEPA (1992b) assumed that HID lamps are replaced annually. Therefore, all 29 million lamps are replacement lamps and they contained 0.8 tons of mercury (assuming 25 mg of mercury per lamp).

3.2.5 Disposal

Since fluorescent lamps have a lifespan of about four years, the quantity of mercury used in lamps today does not reflect the quantity of mercury being disposed. Instead, there is a four year lag from initial use to disposal. The estimated 620 million fluorescent lights purchased in 1994 probably entered the waste stream in 1997 - 1998. The 29 million HID lamps sold that year probably entered in 1995. Together, they equal about 17 tons of mercury removed from service in 1997.

Until 1995, most fluorescent lights were disposed of as municipal solid waste (MSW). USEPA (1992a) estimated in 1992 that 82 percent of mercury-containing lamps were landfilled, 16 percent were incinerated, and 2 percent were recycled. The number of companies collecting lamps for recycling has increased since the early 1990s to more than 60 companies. More recent estimates by the Association of Lighting and Mercury Recyclers state that the recycling rate in the late 1990s was 15 percent (NEMA 2000). Assuming rates of 15 percent recycled, 67 percent landfilled, and 18 percent incinerated (consistent with USEPA 1997c percentages of wastes that are landfilled and incinerated), this results in 11 tons that entered landfills, 3 tons incinerated, and 3 tons recycled.

The mercury lamp recycling rate is expected to continue to increase due to changes in USEPA's universal waste rule in June 1999. In this rule, USEPA streamlined recycling requirements for mercury-containing fluorescent, mercury vapor, sodium halide, and metal halide lamps that exceed mercury concentrations set by USEPA's Toxicity Characteristic Leaching Procedure (TCLP) test. A goal of this rule is to encourage recycling by making it easier for generators to collect, store, and transport bulbs destined for recycling (USEPA 1999c).

3.2.6 Discussion

The quantity of mercury consumed for production was assumed to equal the quantity estimated to be present in domestically manufactured products (16 tons). This estimate was used instead of the much greater Bureau of Mines (USGS 1997) estimate for mercury consumption of 32 tons in 1996. Therefore, this represents a source of uncertainty because additional methods to verify either

of these estimates are not available.

The quantity of mercury in lamps is expected to decrease, but based on current research, elimination in fluorescent lamps is not expected. As a result, future releases of mercury will decrease slightly.

A second source of uncertainty is the extent to which mercury in post-consumer lamps is currently recycled. The recycling rates are expected to increase due to regulatory changes such as the 1999 regulatory changes by USEPA. Therefore, the quantities ultimately recycled and disposed by commercial, industrial, and consumer users are uncertain.

3.3 Thermometers and Other Instruments

3.3.1 Introduction

Facilities manufacturing thermometers and other instruments may be classified under the following business classifications:

SIC Code 38295: Commercial, geophysical, meteorological, and general purpose instruments. Applicable SIC (Product) Codes are as follows :

Barometers:
- 20 - Barometers

Liquid in glass thermometers:
- 22 - Scientific thermometers
- 23 - Industrial thermometers (food, air conditioning, and refrigeration)
- 24 - Household and commercial thermometer
- 34 - Medical thermometer

NAICS Code 339112: Surgical and medical instrument manufacture.

NAICS Code 334519: Other measuring and controlling device manufacturing.

Mercury is often used in medical and scientific instruments because it is non-reactive, metallic, and liquid over a relatively wide range of temperatures. The most common use of mercury as a medical and scientific instrument is in the liquid-in-glass thermometer. Mercury is also used in instruments such as barometers and other pressure-sensing devices. Liquid-in-glass thermometers are commonly used for household, industrial, clinical, and scientific purposes. The U.S. Census Bureau provided estimates for each of these classes of thermometers bought and sold in the United States in 1997 (USDOC 1998). The Census Bureau did not distinguish between mercury-filled thermometers and those filled with other liquids, nor did they provide an estimate for thermometer imports and exports. Therefore, estimates for mercury use based on these Census quantities are likely to overestimate actual quantities of mercury consumed. USEPA (1997a) expects mercury use and emissions from thermometers to remain steady, with decreases resulting from digital thermometers to be offset by increased demand for thermometers by a growing population.

3.3.2 Materials Flow

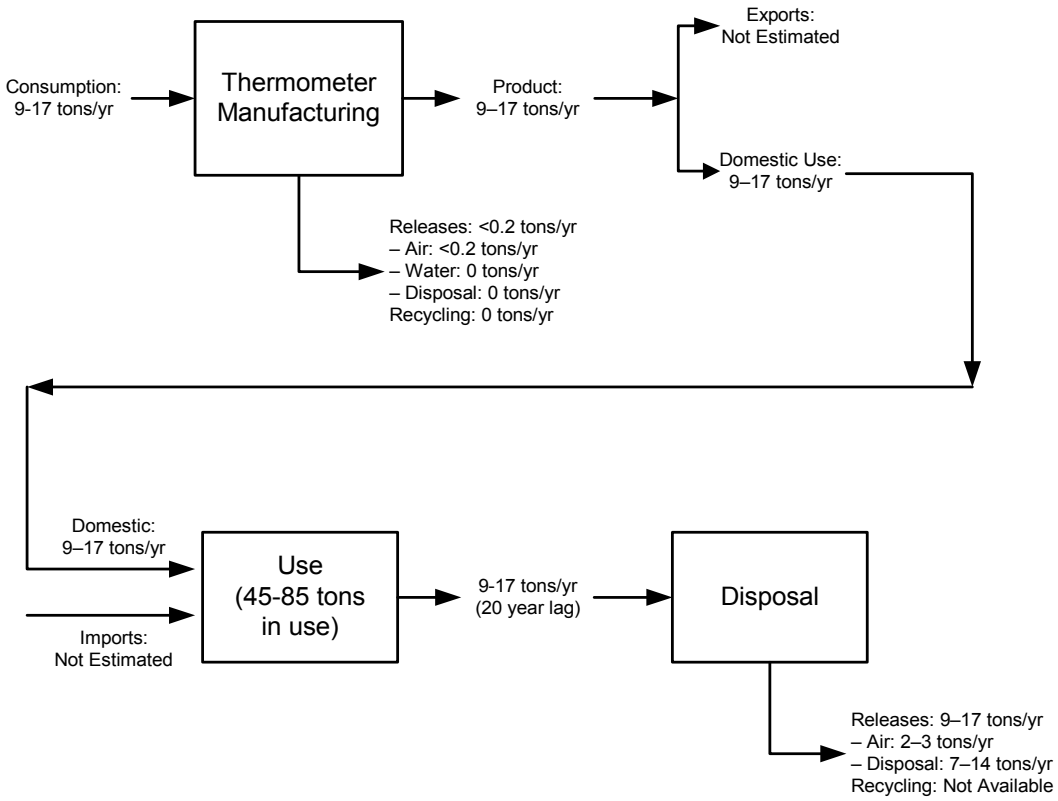
Exhibit 3-5 illustrates the consumption, release, and product content of mercury in thermometers and similar instruments in manufacturing, use, and final disposal.

3.3.3 Manufacturing

Mercury Consumption

USEPA (1992b) identified that oral/rectal/baby thermometers contained 0.61 grams mercury, and basal thermometers contained 2.25 grams mercury. They also estimated that 95 percent of clinical thermometers are oral/rectal/baby thermometers and basal thermometers comprised the remaining five percent. USEPA (1992b) did not provide an estimate of mercury content for scientific and industrial thermometers; therefore, the mercury content of these instruments were assumed to be equal to the quantity present in basal thermometers.

The U.S. Bureau of Census estimates that approximately 8.5 million medical and household thermometers (valued at $12.2 million, or $1.44 each) and 0.58 million industrial thermometers (valued at $10.2 million, or $17.60 each) were bought and sold in the United States in 1997 (USDOC 1998). The Bureau of Census did not provide an estimate for scientific thermometer production, but did provide an estimated value of $5.8 million. Assuming that each scientific thermometer costs between $1.44 and $17.60 (derived from the other thermometer types), an estimated 0.33 to 4.0 million scientific thermometers were bought and sold in the United States in 1997. The Bureau of Census also did not specify whether these thermometers were manufactured domestically or imported, although USEPA (1992b) states that thermometer imports have been increasing and assumes that exports are minimal.



Sources: Mercury Consumption: Calculated from USDOC (1998) and USEPA (1992b).
Mercury Releases: Air releases during manufacturing from USEPA (1997a). Other releases from general waste management data from USEPA (1997c).

Exhibit 3-5. Mercury in Thermometers

Exhibit 3-6. Mercury Used to Manufacture Thermometers in the U.S. in 1997

Thermometer Type	Quantity Manufactured[1]	Mercury Content per Thermometer (grams)[2]	Total Mercury (tons)
Medical and household thermometer - Basal	425,000	2.25	1.05
Medical and household thermometer - Oral/rectal/baby	8,100,000	0.61	5.45
Industrial thermometers	583,000	2.25	1.45
Scientific thermometers	330,000 to 4,000,000	2.25	0.74 to 9.0
Total	**8,300,000 to 11,900,000**	**-**	**8.7 to 17.0**

[1] U.S. Census (USDOC 1998), estimate for scientific thermometers is extrapolated from dollar value (see text).
[2] USEPA (1992b), mercury content for household thermometers is assumed to be same for oral/rectal/baby thermometers, mercury content for industrial and basal thermometer is assumed to be same as basal thermometers.

Product

For an upper-end estimate using Bureau of Census (USDOC 1998) data of liquid-in-glass thermometers bought and sold in the U.S. and USEPA (1992b) data for mercury content, Exhibit 3-6 shows that about 9 to 17 tons of mercury were contained in thermometers produced in the United States in 1997 (assuming no imports and that all liquid-in-glass thermometers are mercury-filled). This quantity is high because it assumes that all liquid-filled thermometers contain mercury.

Releases

Mercury thermometers are produced by creating a vacuum in the capillary glass tube to draw mercury into the bulb and glass tube. USEPA (1997a) cites a 1973 USEPA estimate of 18 pounds of mercury emitted for every ton of mercury used in instrument manufacture. However, USEPA (1997a) warns that this estimate is based on a survey of manufacturers during the 1960s and may be an overestimate of actual emissions. Using the 9 to 17 ton consumption estimate above, approximately 160 to 300 pounds (0.08 to 0.15 tons) of mercury are emitted to the air as a result of mercury thermometer manufacturing. Thermometer manufacturers reported no mercury releases to any media in the 1999 TRI.

3.3.4 Use

Using an estimated lifespan of 5 years (USEPA 1992b) and an annual production rate of 9 to 17 tons per year (as described in the manufacturing section), it is estimated that 45 to 85 tons of mercury are currently in use in thermometers in the United States. Because the mercury is completely contained in the thermometer, release and exposure to the mercury are unlikely under normal operating conditions.

3.3.5 Disposal

USEPA (1997a) reports that there is little data regarding mercury disposal. Most thermometers are discarded when they are cracked or broken and enter the waste stream from residential and clinical settings (USEPA 1997a). USEPA (1992b) estimates that five percent of the glass thermometers are broken each year. USEPA (1997a) cites a 1989 study that estimated that 16.3 tons of mercury were discarded in landfills from thermometers. It can be assumed that the quantity of mercury used in thermometer production (9 to 17 tons for 1997) requires eventual recycling or disposal. Assuming 80 percent is landfilled and 20 percent is combusted (based on typical municipal waste combustion rates), 7 to 14 tons are expected to be disposed to land and 2-3 tons are expected to be emitted to the air via combustion.

Increasing awareness regarding recycling of mercury thermometers has lead to programs such as Fisher Scientific's mercury thermometer trade-in program that offers to reclaim a mercury thermometer for every non-mercury thermometer ordered (Fisher Scientific 1999). Because of these recycling programs, disposal estimates may be high; there is no estimate available for the amount of mercury recycled from thermometers.

3.3.6 Discussion

The quantity of mercury in thermometers was estimated at 9 to 17 tons for 1997, based on Department of Commerce data addressing domestic sales of thermometers. Because all of the thermometers were assumed to be mercury-filled, this was intended to represent a high estimate for mercury consumption. The only other estimate is USGS data. As shown in Exhibit 3-7, 26 tons of mercury were used in 1997 for 'measuring and control instruments,' which is intended to include both mercury thermometers and thermostats (Reese 1999).

No estimates for other values could be found, so the remaining quantities on Exhibit 3-5 were calculated from this consumption quantity. Also, mercury recycling facilities are known to accept thermometers for recycling, but quantities are not available. Therefore, the quantities presented in Exhibit 3-5 as ultimately recycled and disposed are uncertain.

Exhibit 3-7. Mercury Consumption by SIC Code 382 – Measuring and Control Instruments (tons)

	1990	1991	1992	1993	1994	1995	1996	1997
Total Mercury Used[1]	119	99	88	72	58	47	45	26

[1]Source: USGS (1990-7)

3.4 Thermostats

3.4.1 Introduction

Facilities manufacturing thermostats may be classified under the following business classification:

> SIC Code 3822: Controls for Monitoring Residential and Commercial Environments and Appliance Regulating Controls.
>
> NAICS Code 334512: Automatic Environmental Control Manufacturing for Residential, Commercial, and Appliance Use.

A thermostat is a type of switch that turns on or off depending on the temperature. Thermostats are used to control the temperature in individual rooms, building spaces, appliances, and refrigerators. Mercury switch thermostats have been commonly used to control room temperatures in commercial and residential spaces for more than 50 years (USEPA 1994), although mercury-free alternatives are available. Typically, a mercury switch is mounted on a piece of bimetal. Bimetal is composed of a strip or coil of two thin layers of dissimilar metals that bend at different rates when heated or cooled. As the bimetal bends with the temperature change, a drop of mercury in a tube within the mercury switch moves under force of gravity to either complete or break an electrical circuit. Mercury thermostats have proven to be an accurate, reliable, and inexpensive means to control temperature (USEPA 1994).

3.4.2 Materials Flow

Exhibit 3-8 illustrates the consumption, release, and product content of mercury in thermostats during manufacturing, use, and final disposal.

3.4.3 Manufacturing

Mercury Consumption

Manufacturing of mercury switch thermostats consists of filling a short glass tube with a bead of mercury and sealing one end with wire contacts. There is little data available on mercury consumption in the manufacturing of thermostats. Using U.S. Bureau of Census data and consultations with thermostat manufacturers, USEPA (1994) estimates that 3 to 5 million mercury switch thermostats were manufactured in 1994. USEPA (1992b) estimates that each thermostat contains about 3 grams of mercury, therefore 11 to 17 tons of mercury are used to produce thermostats annually.

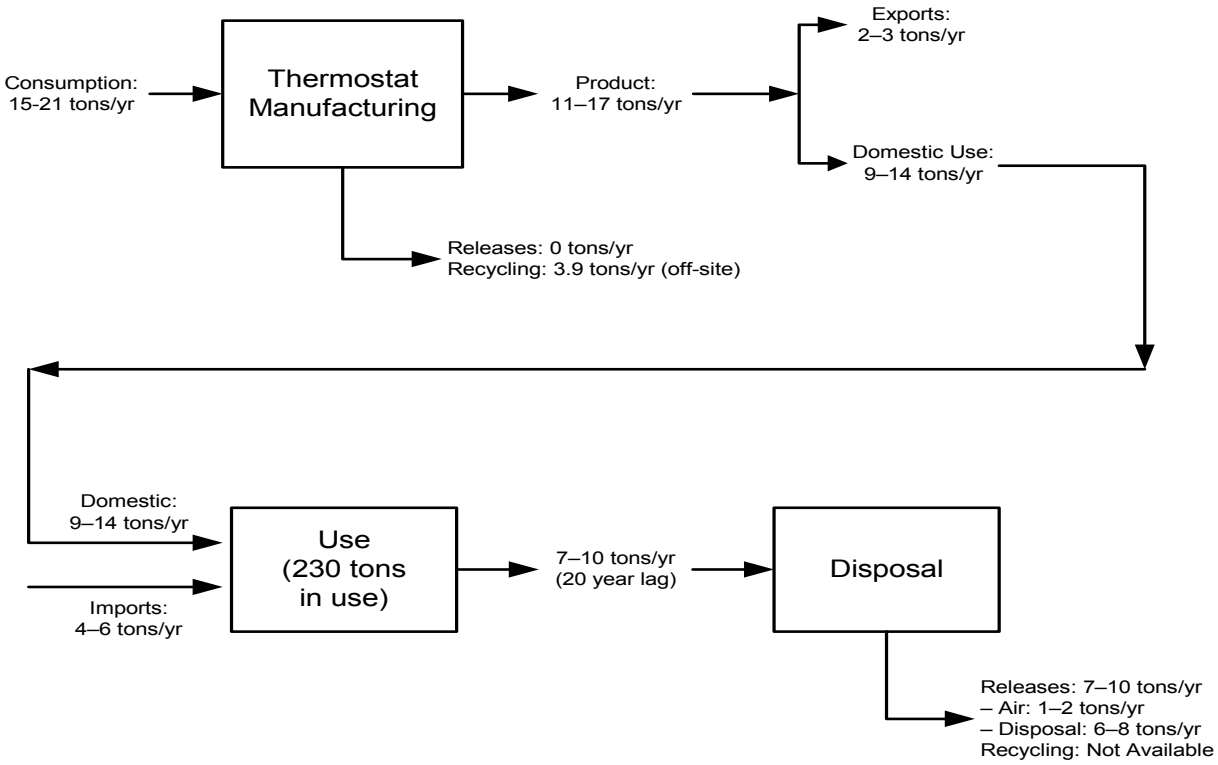
The U.S. Census Bureau (USDOC 1998) estimates that 45 million thermostats were manufactured in the United States in 1997, but some of these units may not contain mercury. Exhibit 3-7 shows the USGS estimates for domestic industrial consumption of mercury for SIC Code 382, which includes thermostat and thermometer manufacturing. Export data on mercury switch thermostats were not available.

Review of the 1999 TRI data shows four facilities involved in electronic component manufacturing (SIC Code 3679) reporting mercury releases; it is not known for certain whether these releases are a result of thermostat manufacturing (as opposed to switches or other products produced by the facility). Mercury may be emitted during the manufacturing process from spills and breakages, product testing, and product transfer (USEPA 1997a). Total emissions from these three facilities show negligible releases to air (0.002 tons), no releases to water, and 3.9 tons of mercury recycled off-site in 1999. This recycling quantity may be the result of off-spec product, spill collection, etc.

These quantities may not reflect other companies involved in thermostat production, and may be overestimates by including releases resulting from unrelated facility activities. Therefore, in Exhibit 3-8, it is assumed that the quantity present in products (11-17 tons), plus the quantity recycled (4 tons) equaled consumption (15-21 tons).

3.4.4 Use

Because mercury is contained in a sealed glass tube within the mercury switch thermostat, release and exposure to the mercury is unlikely under normal operating conditions. USEPA (1994) estimates that 70 million mercury switch thermostats were used in U.S. residences in 1994, which is associated with 230 tons of mercury (assuming 3 grams per thermostat as explained above). Since a mercury switch thermostat is a mechanical device with few moving parts, its lifespan is typically between 20 and 40 years, often exceeding that of the room or building within which it is housed (USEPA 1994). USEPA (1997a) cites a 1995 National Electrical Manufacturing Association finding that upgrading, remodeling, and building demolition are the principal causes of mercury switch thermostat removal.



Sources: Mercury Consumption: Sum of mercury in product and releases.
Mercury Release and Recycling: 1999 TRI for 3 facilities
Mercury in Product: Estimated from average mercury content (EPA 1992b) and number of thermostats produced (DOC 1998).

Exhibit 3-8. Mercury in Thermostats

Imports and exports may also affect the flow of mercury in thermostats. Bureau of Census data (USDOC 1998) indicate that the total value of thermostats produced was $718 million in 1997, the quantity imported was $259 million (36 percent of domestic production) and exports were $121 million (17 percent of domestic production). These data include mercury and non-mercury devices. Assuming an even distribution of mercury and non-mercury devices and a constant annual production rate, this indicates 11 to 17 tons of mercury are present in domestically produced devices, 4 to 6 tons of mercury are in imported products, and 2 to 3 tons are in exported products. The net result is that 13 to 20 tons of mercury annually enter the domestic consumer market in thermostats.

3.4.5 Disposal

USEPA (1994) estimates that 2 to 3 million thermostats were brought out of service in 1994. Assuming that all of the disposed thermostats contained mercury at 3 grams per unit, this corresponds to 7 to 10 tons of mercury per year. In the past, most thermostats have been disposed of as municipal solid waste. Assuming that 80 percent of solid wastes are landfilled and the remaining is sent to municipal waste combustors, 80 percent of the mercury (6 to 8 tons) is landfilled and the remainder emitted to the air.

Efforts to recycle mercury switch thermostats are increasing; however, it is unknown what proportion of the thermostat wastestream is being recycled. USEPA (1999b) cites Thermostat Recycling Corporation as recycling 120 pounds (0.06 tons) of mercury in the Great Lakes region in 1998.

3.4.6 Discussion

Since mercury switch thermostats have such long lives, they are expected to enter the waste stream for at least

the next 30 to 40 years. USEPA (1992b) projects programmable (non-mercury) thermostats to steadily replace mercury switch thermostats, gaining an additional one percent of the market share annually.

The quantity of mercury in thermostats estimated to enter the consumer market (13 to 20 tons) is greater than the quantity of mercury estimated to be in thermostats removed from service (7 to 10 tons). This may represent an inaccuracy in one or both of these estimates. Alternatively, and perhaps more likely, it may be indicative of the large lag time between generation and disposal. For example, it may be the case that a larger number of thermostats are being sold today than 20 to 40 years ago (i.e., the thermostats just now being removed from service), or that new construction (rather than replacement) comprises a significant percentage of the new thermostat market and the number of thermostats in buildings in the United States increases every year.

The USGS consumption data were not used for consumption estimates because the data are combined with other product categories (i.e., thermometers). The estimate used here, however, is consistent with the USGS estimate from Exhibit 3-7.

Estimates are not available addressing the quantity of mercury in used thermostats sent for recycling. Potentially, this is a significant data gap, because numerous programs are in place to recycle mercury containing thermostats. Identifying an accurate estimate is difficult due to the varied methods by which the thermostats may enter the recycling market, not all of which are accountable. Therefore, the quantities ultimately recycled and disposed by commercial, industrial, and consumer use are uncertain.

3.5 Switches and Relays

3.5.1 Introduction

Facilities manufacturing switches and relays may be classified under the following business classifications:

SIC Code 36251 66: Relays and Industrial Controls, General Purpose and Other Relays, Reed Relays; Mercury Wet Reed

SIC Code 36433 69: Wiring Devices and Supplies, Current Carrying Wires, Switches for Electrical Circuitry, All Other Switches: Appliance and Fixture, Including Surface Mounted, Mercury, etc.

Mercury switches and relays are used in many household and automotive applications. Mercury switches are typically used to detect motion. A mercury switch consists of a glass or ceramic tube with electrical contacts at one end. When the tube is tilted or jolted, a bead of mercury flows over the electrical contact and completes the circuit. A mercury switch is often called a "silent switch" because electrical contact is established instantaneously due to the surface tension of the mercury. In a hard contact switch, the microscopic "bounce" that occurs as contact is established may cause electrical noise (USEPA 1994).

Tilt switches are mercury switches that are used to sense tilt. Mercury tilt switch applications include level controls, security alarm systems, vending machine alarms, washing machine covers, and automobile trunk light switches. Mercury tilt switches are also used as motion and vibration sensors in anti-theft devices, "smart appliances" that turn off when not in use, and automobile anti-lock brakes.

A relay is an electromechanical switch where the variation of current in one electrical circuit controls the current in another circuit. A relay consists of an electromagnet that is connected to a moveable contact. When the electromagnet is energized, the contact is moved to either complete or break a circuit. In a mercury reed relay, the electrical contacts are wetted with mercury to provide an instantaneous circuit (USEPA 1994).

3.5.2 Materials Flow

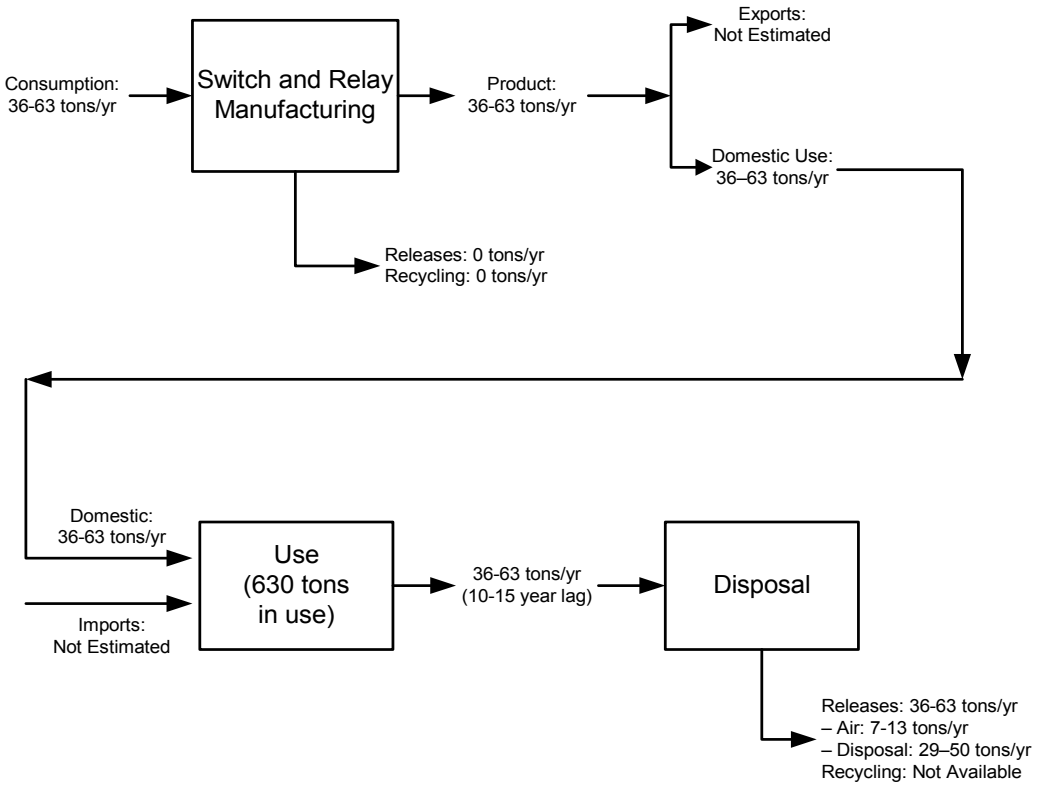
Exhibit 3-9 illustrates the consumption, release, and product content of mercury in switches and relays, in manufacturing, use, and final disposal.

3.5.3 Manufacturing

Mercury Consumption

USGS data in Exhibit 3-10 show that the total amount of mercury used to produce wiring devices and switches peaked in 1995 at 92 tons and dropped to 63 tons in 1997. The USGS estimate does not include mercury reed relays because relays are classified under SIC Code 3625. The mercury content of various switches and relays is shown in Exhibit 3-11.

Data from both the Department of Commerce's Bureau of Census and USGS (1997) were used for estimating mercury flow in this sector. The data are expressed as a range: 36-63 tons per year.



Sources: Mercury Consumption: Low end range from USDOC (1998) and M2P2 (1996). High end range from USGS (1997).
Mercury Releases: General waste management data from USEPA (1997c).

Exhibit 3-9. Mercury in Switches and Relays Manufacturing

The number of mercury switches manufactured in the United States is uncertain. Mercury switches could be included under various product codes within SIC code 36433 (Switches for Electrical Circuitry). Mercury switches are specified in product sub-code 69 (All other general use switches, including mercury). However, the quantities and values in the 1998 Current Industrial Report (USDOC 1998) combines product code 69 with other AC-DC switches (product code 51) to protect proprietary information. Moreover, mercury switches may be found within other product codes such as automotive switches and other special type of switches. Mercury reed relays are classified under SIC code 3625, however, specific production data were withheld in the 1997 Manufacturing Profiles report (USDOC 1998).

Assuming that all 16.5 million general use switches (SIC Code 36433-69) bought and sold in the United States (USDOC 1998) are mercury switches and each contains 2 grams of mercury results in approximately 36 tons of mercury. This estimate could be high because SIC Code 36433-69 includes non-mercury switches, but it could also be low because it does not include mercury reed relays and may not include automotive and other switches. In 1996, 11.2 tons of mercury was used in U.S.-made vehicles, primarily as lighting switches (GLU 2001).

Releases

Mercury may be released during the manufacturing process from spills and breakages, product testing, and product transfer (USEPA 1997a). The wastes associated

with mercury switch manufacturing are uncertain. Mercury switch manufacturing consists of filling a glass or ceramic tube with 0.5 to 3 grams of mercury and sealing the end with electrical contacts. Although four facilities within SIC Code 3679 (Electric component manufacturing) reported mercury waste emissions to the Toxics Release Inventory in 1999, it is uncertain whether those releases result from manufacturing mercury switches or relays. Total emissions from these three facilities show negligible releases to air (0.0025 tons), no releases to water, and 3.9 tons of mercury recycled off-site in 1999. These estimates were previously accounted for in thermostat manufacturing, and are not repeated here. Applied to the industry as a whole, these quantities are not necessarily representative of other switch and relay manufacturers.

3.5.4 Use

Mercury switches are very reliable, and certain types of mercury switches can last up to 50 years (USEPA 1992b). Because the mercury is contained in a sealed glass or ceramic tube within the mercury switch, it is unlikely that it will be released under normal conditions. Because mercury switches are used in various applications, from lighting switches to anti-lock brakes, the number of switches currently in use is not easy to determine. Using the USGS mercury consumption data since 1990 (see Exhibit 3-10), and assuming that the mercury contained in those switches is still in use, there are at least 630 tons of mercury contained in switches in the United States. This estimate is probably low because of the long life span of mercury switches; most switches manufactured in the 1970s and 1980s are probably still in use. The amount of mercury imported into the U.S. contained in imported mercury switches is also unknown.

3.5.5 Disposal

USEPA (1992b) estimates that 1.9 tons of mercury are discarded from mercury electric light switches each year, assuming that 10 percent of the switches are disposed after 10 years of production, 40 percent discarded after 30 years of production, and the remaining 50 percent after 50 years. However, that estimate does not include other mercury switches such as those found in household appliances, automobiles, and mercury reed relays. Exhibit 3-10 assumes the amount used in switch and relay manufacturing (36-63 tons/year) must eventually be disposed, with 80 percent landfilled and 20 percent incinerated.

3.5.6 Discussion

Because mercury switches have such long life spans, they are expected to steadily enter the waste stream for at least the next 30 to 40 years. The automobile industry is working to reduce mercury consumption (CGLI 1999). Mercury reed relays are gradually being replaced by solid state relays (USEPA 1994).

Exhibit 3-10. Mercury Consumption by SIC Code 3643 – Wiring Device and Switches

	1990	1991	1992	1993	1994	1995	1996	1997
Total Mercury Used[1] (tons)	77	78	90	91	87	92	54	63

[1]Source: USGS (1990-7)

Exhibit 3-11. Mercury Content of Various Mercury Switches and Relays

Description	Mercury Content (mg)
Automobile trunk and hood light switch	500-1,000
Freezer light	2,000
Silent Switches	2,600
Mercury Reed Relay	140-3,000

Source: M2P2 1996

The wide variety of mercury switches and their applications in consumer and industrial products makes accounting extremely difficult. This variety results in different classifications of switches with some portion of each containing mercury. The most significant example is the classification of thermostats, which contain a mercury switch but is categorized separately (and discussed elsewhere in this report). Nevertheless, there may be difficulties with data interpretation, especially in cases where a manufacturer produces a wide variety of mercury-containing products that contain switches, but classifies its business activities according to a more limited set of SIC codes. Such a problem was apparent when interpreting TRI data for manufacturers of various electrical devices and attributing the data to different products (such as thermostats and switches).

The quantity of mercury used for switches is uncertain. The quantity provided by USGS (1997) is 63 tons. Bureau of Census data (36 tons) were also used to account for switches that are likely to contain mercury. Both values are included in Exhibit 3-10, as a range, to account for this uncertainty.

3.6 Organic Chemical Production

3.6.1 Introduction

Facilities producing organic chemicals may be classified under the following business classifications:

SIC Code 2869: Industrial Organic Chemicals

NAICS Code 325: Chemical Manufacturing

Mercury is used as a catalyst in the organic chemicals industry. One known use is in the production of vinyl chloride monomer using acetylene as a raw material. In this process, acetylene (C_2H_2) is combined with hydrogen chloride (HCl) and flows through a fixed bed of solid mercuric chloride catalyst. The product is vinyl chloride (C_2H_3Cl), which is subsequently purified. This process is used by a single facility, Borden Chemicals and Plastics in Geismar, Louisiana. In 1996, this facility had a capacity to produce 950 million pounds of vinyl chloride per year, but by 1998 was expected to increase this capacity by 250 million pounds per year (USEPA 2000a). As a result, the quantity of mercury used and subsequently released is expected to increase. In 1999, a total of three facilities (the Geismar facility was not one of them) reported releases of mercury; however, the releases were negligible (0.0005 tons).

3.6.2 Materials Flow

No estimates of mercury consumption data were available for this industry, therefore neither consumption nor release data can be presented due to insufficient data.

3.7 Dental Preparations

3.7.1 Introduction

Facilities manufacturing or using dental equipment may be classified under the following business classifications:

SIC Code 3843: Dental Equipment and Supplies
NAICS Code 339114: Dental Equipment and Supplies Manufacturing

SIC Code 8021: Offices and Clinics of Dentists
NAICS Codes 6212 and 62121: Offices of Dentists

This section focuses on use of mercury by the dental profession. Amalgam fillings, used to fill cavities in teeth, contain about 50 percent mercury. Not all of the mercury used by the dental profession ends up in the fillings. Some is lost as air emissions, some is discharged in wastewater, and some is disposed as hazardous waste or is recycled.

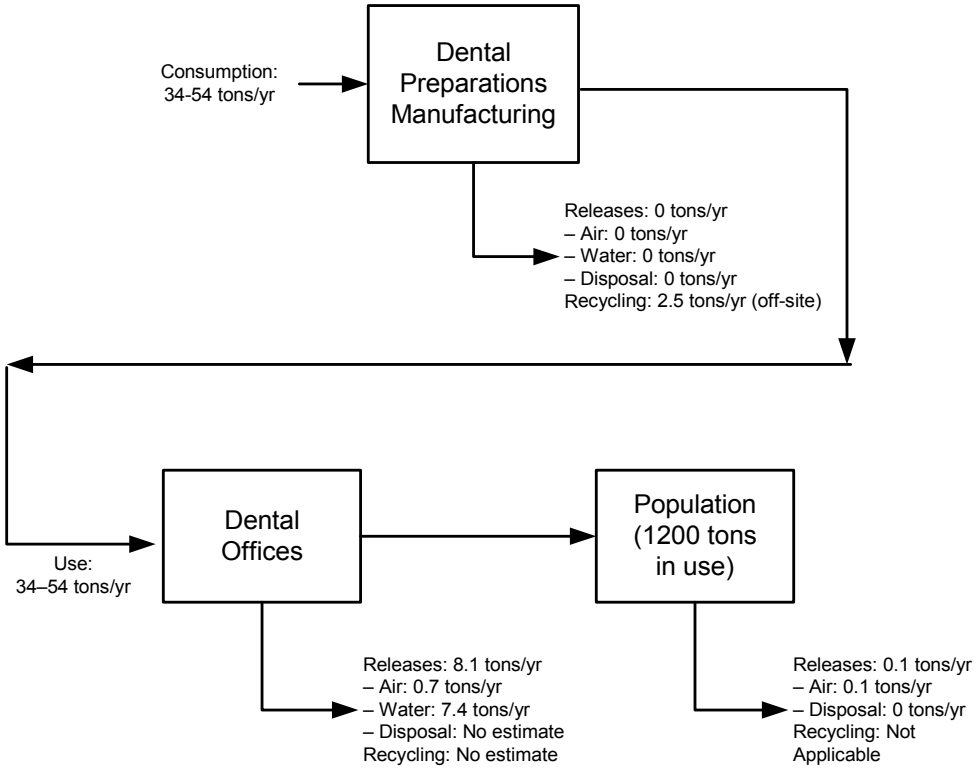
3.7.2 Material Flows

Exhibit 3-12 illustrates the flow of mercury in the dental profession.

Mercury Consumption

Mercury consumption is assumed equal to the amount of mercury used in amalgam fillings.

Mercury is a major component (50 percent) in amalgam fillings. Using data from USGS (1997), USEPA (1997a) assumed that 34 tons of mercury were used in the dental industry during 1996, including amounts found in equipment and supplies. However, another approach presented below results in a slightly higher estimate of 54 tons per year. To account for this uncertainty both estimates are given in Exhibit 3-12. In 1990, about 96 million of the more than 200 million restorative procedures that were performed used amalgam (USDHHS 1993). Amalgam use decreased by 12.5 percent among dentists from 1990 to 1995, and since the beginning of 1993 the trend has been steady (USDHHS 1997). Assuming that amalgam use continued to steadily decline results in 81.6 million amalgam fillings in 1996. According to a study by Yoshida (1994), an



Sources: Consumption and Use: USGS (1997) for low end, and Yoshida (1994) and USDHHS (1993, 1997) for high end.
Manufacturing Releases: 1999 TRI.
Dental Office and Popluation Releases: Air releases from EPA (1997a), water and population releases from DAMS (1999).

Exhibit 3-12. Mercury in Dental Preparations

amalgam filling contains 0.6 grams of mercury. Therefore, almost 49,000 kilograms (54 tons) of mercury were used in fillings during 1996.

Air Releases

Mercury in fillings can be released in various ways, including emissions from spills and scrap, air discharged by the dental office's vacuum pump system (Rubin 1996), and constant emissions from the fillings in people's mouths over time. USEPA (1997a) assumed that two percent (0.7 ton out of 34 tons) of the total amount of mercury used is emitted from spills and scrap, but admits that number is likely an underestimate of the total emissions. This estimate is reflected in Exhibit 3-12.

Studies have been conducted to determine the amount of mercury that is released from fillings once they are placed in people's mouths. As presented in USDHHS (1993), a study by Mackert found that, on average, a person's intake of mercury from fillings is 1.24 micrograms each day; results from other studies ranged from 1.7 to 27.0 micrograms per day. Using the U.S. Census Bureau estimate of 281 million people in the U.S. in 2000 (USDOC 2001) and 1.24 micrograms of daily release per person results in 0.35 kilograms (1 pound) of mercury released from fillings per year. This estimate is not presented in Exhibit 3-12 because it is not directed towards media releases to the environment but rather direct exposure.

Water Releases

Wastewater from a dental office may contain, on average, 270 milligrams per day (range 65 to 842) (based on data from Arenholt [1996] in DAMS [1999]). Using the mean daily level of 270 milligrams per day per office times 250 working days per year times 100,000 dental offices (conservative estimate, DAMS 1999)

results in 6,750 kilograms or 7.4 tons of mercury entering wastewater each year.

Amalgam separators can reduce the mean mercury content in a dental office's wastewater from 270 to 35 milligrams per day (based on data from Arenholt [1996] in DAMS [1999]). However, few dental offices in the United States have amalgam separators (DAMS 1999).

Solid Waste Releases

No data are available to estimate quantities of mercury recycled or disposed.

Recycling

The quantity of mercury recycled by dental offices is unknown. 1999 TRI data showed one dental equipment manufacturing company reporting mercury emissions. Offsite recycling was reported as 2.5 tons, while releases to all other media were reported as zero.

Reservoir

The total quantity of mercury in the population is estimated based on the annual use rate of 34 to 54 tons. No data were available to estimate the lifetime of a filling. Assuming a 20 to 40 year span, this results in an estimated quantity of 1200 tons in use.

3.7.3 Discussion

The estimate used for the amount of mercury per filling was based upon a Japanese study. The mercury content of fillings in Japan may be higher than in the United States, which may help account for the discrepancy between this estimate of 54 tons of total mercury used and USEPA's estimate of 34 tons. Additionally, this is a single average value, where in reality the quantity used is a function of many factors such as the patient's needs and the technique of the dentist. Furthermore, non-amalgam fillings are being used for certain applications.

3.8 Pharmaceutical Use

3.8.1 Introduction

Mercury finds its way into a variety of pharmaceutical products, including opthalmics, vaccines, and topical products. Although use of mercury in these products has been scaled back in recent years both from voluntary actions by manufacturers due to increasing concerns over mercury toxicity and as the result of Food and Drug Administration (FDA) regulations, mercury is still found in many products.

To assess the presence of mercury in food and drugs, the FDA issued a request for data to identify food and drug products that contain intentionally introduced mercury compounds (63 FR 68775, December 14, 1998). FDA's analysis of these responses (USFDA 1999) indicate that three mercury compounds are intentionally introduced as a preservative into both prescription and over the counter (OTC) nonhomeopathic products such as nasal spray. These preservatives are thimerosal (TM), phenylmercuric acetate (PMA) and phenylmercuric nitrate (PMN). The responses also showed that more than twenty other mercury compounds are used in homeopathic drug products, usually as therapeutic ingredients.

3.8.2 Materials Flow

Exhibit 3-13 shows the consumption and release of mercury pharmaceutical product manufacturing.

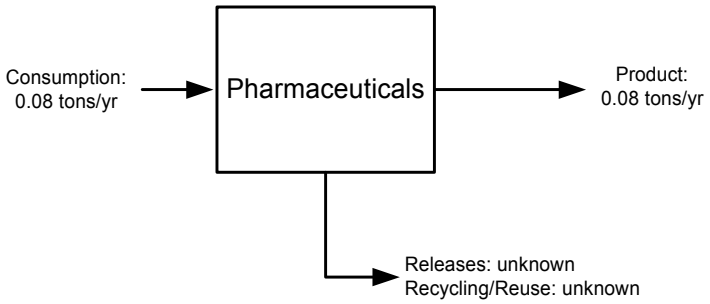
Mercury Consumption

USFDA (1999) calculated that approximately 75,000 grams (0.08 tons) of mercury compounds are used per year. The FDA calculated this amount by tallying the responses received from the request for data; categorizing the responses by compound used and product type; searching its databases for additional products that fall into these product type categories that were not reported in the responses to the request for data; applying the same average amounts of mercury compounds reported for that product type and category to the additional products found in the databases; then totaling the amounts of mercury compounds from each category to reach an estimated total amount of mercury compounds used in pharmaceutical products.

The 75,000 grams of mercury compounds estimated comes exclusively from the three common preservatives: TM, PMA, and PMN. While many homeopathic product uses were reported, the FDA concluded that the dilutions of mercury compounds in products were so low as to be negligible in comparison to pharmaceutical use. Thimerosal in products accounts for approximately 99% of the mercury compounds included in the FDA's estimate.

Releases

Releases may result from the manufacture or formulation of the mercury compounds themselves. No pharmaceutical manufacturers reported mercury releases in 1999 to the TRI.



Source: Mercury Consumption: FDA (1999).
Mercury Release and Product: Assumed equal to consumption.

Exhibit 3-13. Mercury in Pharmaceuticals

The potential release mechanisms for mercury in pharmaceutical products include excretion, exhalation, volatilization, spillage during administration, and the destruction or disposal of unused products. Because these products may be administered in any location, especially in the case of OTC products, there is no way to quantify the amounts that are spilled or discarded. Many studies have been conducted examining the output of mercury from the human body, but these are largely dependent on dose, method of exposure, and the specific mercury compound. Because mercury in pharmaceuticals can be introduced orally, nasally, dermally, ocularly, or through injection, it is also impossible to quantify the output of these compounds once introduced to the human body.

3.8.3 Discussion

While mercury preservatives in pharmaceuticals were reported to the FDA in a large array of products, their use is dwindling due to consumer and regulatory pressure. The few uses remaining are likely to be discontinued due to the requirements of the New Drug Approval process, which requires demonstration that a product is safe and effective. The estimated total amount of mercury compounds used annually, 0.08 tons, indicates that pharmaceutical use is negligible in comparison to other sources and uses of mercury.

3.9 Laboratory Use

3.9.1 Introduction

This section focuses on the use of mercury and mercury compounds in laboratory chemicals. Mercury compounds are used in laboratories in two ways: as chemical reagents in experiments and processes and in chemical products used for laboratory work. Mercury is also found in many laboratory instruments, such as thermometers and manometers, as discussed in other sections of this report; this section focuses specifically on non-equipment use.

Histology, the processing of body tissues for examination, comprises several types of steps. These steps include fixation and staining, both of which frequently use mercury-bearing compounds. It is important to note that these chemicals often contain mercury in concentrations less than 1 percent, so the mercury compound may not be listed on the product Material Safety Data Sheet (MSDS). A certification of analysis from the manufacturer will reveal the small amounts of mercury in these products.

3.9.2 Materials Flow

Mercury Consumption

Because there are a wide variety of mercury compounds used in laboratories, and these chemicals are made by many different manufacturers, it is not possible to determine the quantity of mercury annually being used in laboratory settings. One source notes a decline from 35 tons of mercury compounds used in 1990 to 11 tons of these compounds used in 1991 (NC DEHNR 1996). It can be assumed that the current total usage of the chemicals has continued to decline in the past nine years, in light of the recent revisions of standard analytical methods and growing concern over environmental hazards.

Releases

Releases may result from the manufacture or formulation

of the mercury compounds themselves. No manufacturers of laboratory chemicals reported mercury releases in 1999 to the TRI.

Mercury can to be released in two additional ways: as unused product (e.g., expired or otherwise discarded reagent), and as a result of use (e.g., in samples at dilute concentrations). In general, laboratories prepare their own guidelines regarding handling procedures for these waste materials. Releases as solid waste and as water discharges are expected to be most prevalent. Solid wastes are expected to be the result of unused reagent that is sent offsite for recycling or disposal as a hazardous waste. Water releases would result from the disposal of analyzed samples which contain small concentrations of the reagent, which is rinsed down the sink. Water releases may also result from the disposal of unused reagent down the sink. The presence or absence of local regulations or permitting requirements regarding sewer discharges is expected to influence the laboratory practices used.

3.9.3 Discussion

Because data estimating the use of mercury-containing laboratory chemicals and equipment are not avaiable, it is impossible to determine the contribution of this sector to domestic mercury use and release. The only available estimate of use, 11 tons of mercury-bearing chemicals used in 1991 (NC DEHNR 1996), does not estimate the amount of mercury in these chemicals; because most of these chemicals contain only trace amounts of mercury (less than one percent), it can be assumed that the amount of mercury used and released from laboratory chemicals is negligible in comparison to other sources and uses of mercury.

3.10 Batteries

3.10.1 Introduction

Facilities manufacturing or storing batteries may be classified under the following business classification code:

SIC Code 3691: Storage battery manufacturing
SIC Code 3692: Primary battery manufacturing
NAICS Code 33591: Battery manufacturing

The use of mercury in electrical batteries has decreased significantly from more than 1,000 tons annually in the early 1980s to less than 1 ton in 1996 (USGS 2000e). The use of mercury in battery production was sharply reduced in the early 1990s. Mercury is presently used in two types of batteries: button cell batteries and mercuric oxide batteries. Button cell batteries are used in watches and other consumer electronics. Mercuric oxide batteries are larger cylindrical batteries used mostly for non-consumer use items such as medical or military applications (USEPA 1997a). The Mercury-Containing and Rechargeable Battery Management Act of 1996, in part, phased out the use of alkaline-manganese and zinc-carbon batteries containing intentionally added mercury and button cell mercuric-oxide batteries (USGS 2000e).

3.10.2 Materials Flow

At present, most batteries are expected to last no more than a few years either as a result of use or slow discharge over time. Therefore, little to no mercury is expected to be present as part of consumer use of batteries from applications prior to 1992. Furthermore, such a quantity from past use cannot be estimated.

Releases of mercury to air from battery manufacturing were estimated by USEPA (1997a). This estimate showed negligible mercury emissions (<0.001 tons) in 1995. Examination of the 1999 TRI data showed one battery manufacturer reporting mercury releases of 0.0125 tons. This facility corresponded to the only domestic mercuric oxide battery manufacturer (Maine 2000).

3.10.3 Discussion

In conclusion, mercury is consumed in very small amounts for battery production, relative to other sources. Quantities of mercury used and subsequently released are correspondingly small. For this reason, no exhibit illustrating mercury flow is presented.

3.11 Miscellaneous

TRI data for 1999 identified several facilities reporting releases of mercury that do not appear to be engaged in the manufacturing processes described above. The industries include electroplating (three facilities), explosives (one facility), food (one facility), transportation (one facility), jewelry and precious metals (one facility). The combined releases of all the industries is 0.21 tons of mercury.

Chapter 4
Incidental Mercury Use Associated With Coal Combustion or Coal Use

4.1 Coal Combustion by Utilities

4.1.1 Introduction

This section focuses on utilities that burn coal for electric power generation. This sector is of concern because electric utilities are the largest source of anthropogenic air emissions of mercury in the United States (USEPA 1997a). Facilities may fall under several SIC and NAICS Codes.

SIC codes:

491: Electric Services
4911: Electric Services
493: Combination Electric and Gas, and Other Utility
4931: Electric and Other Services Combined
4939: Combination Utilities, Not Elsewhere Classified

NAICS codes:

22: Utilities
221: Utilities
2211: Electric Power Generation, Transmission and Distribution
22111: Electric Power Generation
221112: Fossil Fuel Electric Power Generation

Utility boilers that generate electricity can be fired by coal, oil, natural gas, or some combination of these fuels. This section focuses on utilities that use coal. Coal is burned in a boiler to heat water and produce steam. The steam is used to generate electricity and, in some cases, heat. There are approximately 440 coal-fired utility plants in the United States, and they use about 1250 boilers (USEPA 1999d). Coal-fired utilities tend to be concentrated in the Northeast and Midwest.

In 1994, 81 percent of the energy generated from utility boilers came from the burning of coal (USEPA 1997a). Coal accounts for over three-quarters of electricity generation in some areas including the Great Lakes area (USEPA 1988a). For example, Ohio generates roughly 90 percent of its electricity from coal (GLNWF 1997). Coal consumption is expected to increase 26 percent between 1997 and 2020 as utilities use more of their generation capacity, costs of natural gas and oil rise and nuclear plants close (USEPA 1999d).

Mercury is present in the mined coal. After mining, the coal may be cleaned to remove sulfur and improve burning characteristics. It is then transported by rail to end users such as utilities. Coal is stored in storage piles or silos at the plant. From storage, the coal is subjected to mechanical sizing operations and is charged to the boiler. There are three basic types of boilers: pulverized, cyclone, or stoker systems. Most (92%) coal-fired boilers are pulverized coal systems where the coal is pulverized before combustion. Cyclone systems, named because of the cyclone-like vortex created by the coal particles in the furnace during combustion, make up 8 percent of utility boilers. A third, less common type (<1%) is the "stoker," which is used for smaller capacities (e.g., 20-30 megawatts) and burns coal in a variety of sizes (USEPA 1999d; USEPA 1988a).

In the removal of sulfur during coal cleaning, some portion of the mercury is coincidentally removed as well. The most widely used methods of coal cleaning use specific gravity, relying on the principle that heavier particles (i.e., impurities) separate from lighter ones (i.e., coal) when settling in liquid. A common method for cleaning coarse pieces is to pulse currents of water through a bed of coal in a jig so impurities like shale and pyrite sink. A mixture of water and ground magnetite is used to clean coarse and medium-sized pieces. A concentrating table, an inclined vibrating platform with diagonal grooves that trap the impurities, is also used to clean intermediate sized pieces. Fine coal particles are often cleaned with froth flotation. The coal pieces are coated with oil and then agitated in a controlled mixture of air, water, and reagents until froth is formed on the surface. Bubbles tend to attach to the coal, keeping it buoyant, while heavier particles remain dispersed in the water (USEPA 1988a). On average, coal cleaning removes about 21 percent of the mercury contained in

coal (USEPA 1998c). Seventy percent of coal used by electric utilities is cleaned to some extent (USEPA 1999d). Putting these two estimates together, 15 percent of the mercury present in coal nationwide is removed prior to introduction to the boiler.

Mercury is a trace element (i.e., contaminant) in coal and is a highly volatile metal that vaporizes at the temperatures reached when coal is burned. Consequently, mercury is emitted in the gas stream during combustion. The concentration of mercury in the coal varies considerably depending on the coal type, where it was mined, and how it is processed before combustion (Massachusetts 1996). There are four types of coal: anthracite, bituminous, subbituminous, and lignite. Ninety-one percent of the coal burned by coal-fired utilities in the United States in 1997 was bituminous and subbituminous, 9 percent was lignite, and less than one percent was anthracite (USEPA 1999d). The different types of coal have varying mercury content.

To estimate the quantity of mercury present in coal used by coal-fired utility boilers, data from the EPA's 1999 Information Collection Request (ICR) were used, which measured coal samples from every U.S. coal-fired power plant as well as coal usage data. Using these data, a consumption 89 tons mercury was calculated (after processing and cleaning) from 925 million tons of coal. In the 1999 ICR, EPA identified the mercury content of coal at all 450 coal-fired utilities used in that year, and also conducted air sampling at a subset of these units. Based on analysis of the data, EPA estimated that 48 tons of mercury was released to the air (USEPA 2001). (The remainder is assumed to be collected in air pollution control residues and handled as solid waste.)

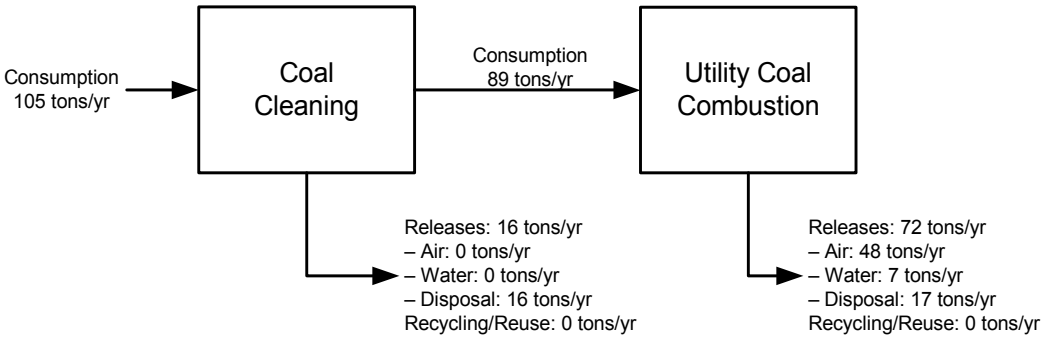
The combustion of coal results in the vaporization of much of the contained mercury and its release to the atmosphere, from which it is ultimately deposited in soil or into bodies of water (USBM 1994). The part of the mercury in coal that is not emitted to the atmosphere during combustion is trapped in wastes such as bottom ash and recoverable fly ash. Landfills are often the ultimate repositories for these wastes (USBM 1994). The ash can also be used in products such as concrete.

4.1.2 Materials Flow

Exhibit 4-1 demonstrates the flow of mercury during the coal combustion process.

Mercury Consumption

Based on evaluation of EPA's 1999 Information Collection Request, an estimated 89 tons of mercury entered boilers in cleaned coal. As noted above, about 15% of mercury is removed from coal during cleaning nationwide. Therefore, the quantity of mercury leaving the mine is estimated as 105 tons, which is reflected in Exhibit 4-1.



Source: Mercury Consumption: USEPA (2001) to estimate boiler input.
Mercury Release: Air releases from EPA (2001). Water releases calculated using EPA (1988a). Disposal releases from coal cleaning based on cleaning efficiency from EPA (1997a). Disposal and product releases from combustion: Based on EPA (1999d) and EPA (1988a).

Exhibit 4-1. Mercury in Utility Coal Combustion

Air Releases

In 1999, the nationwide rate of mercury emissions from coal-fired utility boilers was estimated to be 48 tons per year (USEPA 2001). This estimate is reflected in Exhibit 4-1.

Although small quantities of mercury may be emitted as fugitive particulate matter from coal storage and handling, the primary source of mercury from both coal and combustion in utility boilers is the combustion stack. Because the combustion zone in boilers operates at temperatures above 1100 ºC (2000 ºF), mercury in the coal is vaporized and exhausted as a gas. Some of the gas may cool and condense as it passes through the boiler and air pollution control device. Mercury is released in both elemental and compound form (believed to be mercuric chloride), with significant variation due to site-specific factors. Additional discussion regarding speciation is presented in Section 7 of this report.

The primary types of control devices include electrostatic precipitators (ESPs), wet scrubbers, fabric filters or baghouses, and mechanical collectors. ESPs are the most widely used control device by the electric utility industry. None are specifically designed to remove mercury, but all have some effect. Extensive efficiency data were collected by EPA in 1999 (USEPA 2001). These efficiency data are presented in Exhibit 4-2.

Exhibit 4-2. Efficiencies of Various Control Devices in Removing Mercury from Coal-fired Boiler Flue Gas

Control Device	Median Mercury Removal Efficiency (%)	
	Bituminous Coals	Subbituminous Coals
Fabric filter	89	73
Cold-side Electrostatic precipitator (ESP)	29	3
Hot-side ESP	11	0
Fabric filter followed by wet desulfurization (scrubber)	97	No data
Cold-side ESP followed by wet desulfurization (scrubber)	78	16
Hot-side ESP followed by wet desulfurization (scrubber)	39	8

Source: USEPA 2001

Water Releases

Releases of mercury to water come from three main sources: runoff from coal piles, wastewater from coal cleaning, and maintenance and cleaning wastes (e.g., boiler blowdown, cooling tower blowdown, demineralizer reagents, boiler cleaning wastes, and liquors from flue gas desulfurization (FGD)). Each of these sources may contain mercury. Waters such as these are typically sent to settling basins prior to discharge, where mercury may either be present in the settled solids or be discharged with the effluent. As shown below, only one source, cooling tower blowdown, contained significant quantities of mercury or had sufficient data to assess its contribution.

Cooling tower blowdown is waste removed periodically from recirculating cooling tower systems to maintain water quality. The average production is 2.6 billion gallons per year per plant, and from the limited data available, the concentration of mercury was measured as 1.5 micrograms per liter (USEPA 1988a). This results in 7 tons of mercury contained in cooling tower blowdown each year industry-wide (i.e., generated by 440 plants). This estimate is reflected in Exhibit 4-1.

Demineralizer regenerants are wastes resulting from the periodic cleaning and regeneration of ion exchange beds used to remove mineral salts from boiler makeup water. The average plant production is 5 million gallons per year, with a mercury concentration of 0.05 micrograms per liter (USEPA 1998c). This results in less than 1 pound of mercury contained in these wastes each year.

"Water-side" boiler cleaning wastes result from the periodic cleaning of the boiler tubes, the superheater, and the condenser. The average plant production is 180,000 gallons per year for water-side boiler cleaning. No mercury data were available for water-side alkaline cleaning wastes, but the mercury concentration for water-side hydrochloric acid cleaning wastes ranges from 0.0 to 0.002 milligrams per liter (USEPA 1998c). Assuming acid is used 100 percent of the time and using the high limit of mercury results in less than 2 pounds of mercury in this waste each year.

Coal pile runoff is produced by precipitation falling on coal storage areas. A typical coal storage pile is 25-40 feet high and can cover an area up to 75 acres. Most utilities keep a supply on hand of at least 90 days' worth of coal, which equals about 600-1800 cubic meters per megawatt of generating capacity (USEPA 1999d). The mercury content in runoff ranges from 0.0002 - 0.007 mg/L, and the average runoff is 20 inches per year per plant (USEPA 1988a). No estimate for the quantity of mercury from this source can be made.

Boiler blowdown is waste continuously or intermittently removed from boilers that recirculate water to maintain water quality. The average plant production is 11 million gallons per year (USEPA 1998c). No mercury concentration data were available.

"Gas-side" or "fire-side" wastes are produced during maintenance of the gas-side of the boiler, which includes the air preheater, economizer, superheater, stack and ancillary equipment. The residues are normally removed with water only. The average plant production is 700,000 gallons per year for gas-side boiler cleaning, but no data on mercury content in those wastes were available (USEPA 1988a).

FGD sludge is the waste produced during the process of removing sulfur oxide gases from the flue gas and is discussed in more detail later. Wet systems use aqueous solutions to remove the sulfur oxides from the flue gas. A portion of FGD waste is wet FGD sludge liquors. In this waste stream, mercury ranges from 0.00006 to 0.1 mg/L, with a median concentration of 0.005 mg/L (USEPA 1988a). No data on generation quantities were available.

Solid Waste Releases

Wastes from the coal combustion process go primarily to landfills and surface impoundments. There are two main solid waste streams from coal combustion: ash and flue gas desulfurization (FGD) sludge.

In addition, coal cleaning may generate solid and/or aqueous wastes containing mercury. No hard data on amounts of wastewater or solid wastes generated by coal cleaning facilities were available, but assuming that 15 percent of mercury in coal is removed in this process (discussed above) results in 16 tons of mercury in coal cleaning wastes. As identified above, mercury is likely associated with the solids, however, an unknown portion of the mercury may be present in water as suspended solids or dissolved mercury. This estimate is reflected in Exhibit 4-1.

Ash is the noncombusted waste material that remains after coal is burned. Ash may be collected from the flue gas (fly ash and FGD sludge), or remain in the boiler (bottom ash and boiler slag).

Fly ash is small, uncombusted material carried out of the boiler with the flue gases. In mechanical hopper fly ash, mercury content ranges from 0.008 to 3.00 mg/kg of coal, with a median of 0.073 mg/kg, and in fine fly ash mercury content ranges from 0.005 to 2.50 mg/kg with a median concentration of 0.10 mg/kg (USEPA 1988a). There were 60.26 million tons of fly ash produced in 1997 (USEPA 1999d). Using the median concentration of 0.10 mg/kg, an estimated 6.0 tons/year of mercury is present in fly ash.

FGD sludge is the waste produced from the removal of sulfur oxide gases from the flue gas. Wet systems use aqueous solutions to remove the sulfur oxides from the flue gas. Dry FGD systems use no water for sulfur oxide removal, although dry FGD wastes may be mixed with water before disposal (USEPA 1988a). Fly ash is the primary source of most of the trace elements found in scrubber sludge (as shown in Exhibit 4-2, scrubbers do not have particularly high mercury removal efficiencies). In wet scrubbers that also serve as fly ash collection devices, more than 50 percent of the sludge solids may be ash (USEPA 1988a). In wet FGD sludge solids, mercury ranges from 0.01 to 6.0 mg/kg, with a median concentration of 0.4 mg/kg (USEPA 1988a) (dry FGD sludge solids are assumed to have similar concentrations). Utility boilers produced 25.16 million tons of FGD wastes in 1997 and are expected to produce 50 million tons of sludge in 2000 (USEPA 1999d). Using the median concentration of 0.4 mg/kg and the 1997 waste generation quantity, an estimated 10.1

tons/year of mercury is present in fly ash.

Bottom ash and boiler slag are uncombusted material that does not completely melt and settles on the bottom of the boiler. In both materials, mercury content ranges from 0.005 to 4.2 mg/kg of coal, with a median of 0.023 mg/kg (USEPA 1988a). There were 16.9 million tons of bottom ash and 2.7 million tons of boiler slag produced in 1997 (USEPA 1999d). Using the median concentration of 0.023 mg/kg, an estimated 0.45 tons/year of mercury is present in bottom ash and boiler slag.

A sum of the above sources (fly ash, FGD sludge, bottom ash, and boiler slag) results in an estimated 16.6 tons per year of mercury. This estimate is shown in Exhibit 4-1.

Product

In 1997, 26.8 percent of all waste generated at coal-fired electric utility power plants was reused (e.g., as cement additives, high volume road construction material, wallboard, flowable fill, and blasting grit). The reused quantity included 19.3 million tons of fly ash (31.5% of fly ash generated), 2.18 million tons (7.9%) of FGD wastes, 5.10 million tons of bottom ash (27.7%), and 2.58 million tons of boiler slag (92.9%). Using the mercury concentrations discussed previously, an estimated 3.0 tons/year of mercury were contained in the reused material. This quantity is already included in Exhibit 4-1 as solid waste. No quantity is listed in Exhibit 4-1 for recycled, because mercury is not recovered from any coal combustion waste.

4.1.3 Discussion

The total annual quantity of mercury in coal processed in utility boilers is estimated to be 89 tons. The annual quantity of mercury released or in products is estimated to be 48 tons to air, 17 tons to solid waste and products and 7 tons to water; therefore, 89 tons per year are assumed to enter the process and 72 tons per year leaves the process. This discrepancy is due to the different sources used in compiling these estimates. In these calculations, air emissions do not assume all the mercury present in the fuel is emitted in stack gas.

The following list mentions some of the actions that have been taken to address the problem of mercury in coal and resulting environmental release:

- Coal cleaning reduces the amount of ash produced, thereby reducing the amount of mercury released. On average, coal cleaning removes about 21 percent of the mercury contained in coal (USEPA 1997a). Seventy percent of the coal used by electric utilities is cleaned to some extent (USEPA 1999d).

- Control devices have reduced mercury air emissions. The effectiveness of current control devices at removing mercury was discussed earlier in this section.

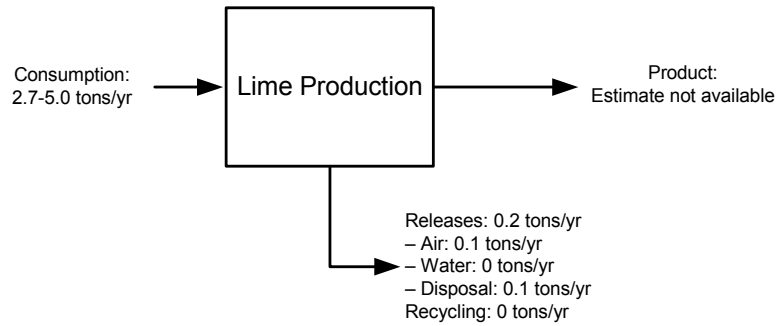
- Many collaborative efforts on trace element research focused on mercury have been conducted by Department Of Energy/Federal Energy Technology Center (USDOE/FETC) and USEPA, the U.S. Geological Survey (USGS), the Electric Power Research Institute (EPRI), the utility industry, other governmental agencies at both the federal and state levels, and other U.S. and foreign research organizations. Other groups such as the Small Business Innovative Research Program (SBIR), University Coal Research Program (UCR), and the Jointly Sponsored Research Program at the University of North Dakota Energy and Environmental Research Center have focus areas in research and development for the coal-fired utility industry.

- EPA's Information Collection Request data represent a comprehensive analysis of mercury both entering and being emitted from boilers.

4.2 Lime Manufacturing

4.2.1 Introduction

Lime is produced from the calcination of limestone. Limestone is present throughout the United States and comprises primarily calcium and magnesium in a carbonate form. The limestone is fed to a rotary kiln where it is heated and rotated slowly to ensure mixing. This drives off carbon dioxide (and other volatile species such as water). The product, quicklime, is discharged from the opposite end of the kiln from which the limestone is introduced. Most domestic kilns use coal as a heat source, although the kiln can be adapted to oil or natural gas. The coal is combusted separately and the offgases travel through the kiln, to avoid mixing coal ash with the lime product (Kirk-Othmer 1995). Because both the limestone and the coal are heated to temperatures well above the volatilization point of mercury, it is expected that any mercury initially in the raw materials is discharged to the air.



Source: Mercury Consumption: Estimated from coal and limestone use and concentration data from Kirk-Othmer (1995), USGS (2002b), USGS (1998), and CIBO (1997).
Mercury Release: Air releases from EPA Mercury Study Report to Congress (1997a). Disposal releases estimated using utility coal combustion information.
Mercury in Product: Estimate not available.

Exhibit 4-3. Mercury in Lime Production

4.2.2 Materials Flow

Exhibit 4-3 illustrates the consumption, release, and product content of mercury in lime production. No lime manufacturing facilities reported mercury releases to the 1999 TRI.

Mercury Consumption

The concentration of mercury in limestone is estimated as 0.04 mg/kg (Council of Industrial Boiler Owners 1997). The quantity of limestone used as raw material is estimated to be about 2 tons per ton produced (Kirk-Othmer 1995), and the quantity of lime produced in 2000 is 21.6 million tons (USGS 2002b). This corresponds to approximately 1.7 tons of mercury in the limestone feed. The concentration of mercury is expected to be variable, but no data demonstrating this variability are available.

The other source of mercury in the feed results from the coal fuel. The energy consumption of lime production is variable depending on the efficiencies of the kiln. Energy consumption is estimated as 5.5 to 8 million Btu per ton lime (Kirk-Othmer 1995), or approximately 124 to 181 trillion Btu in 1999. The concentration of mercury in coal is estimated as 4.8 to 36.4 pounds per trillion Btus for 14 different coal types (USGS 1998). Accounting for the two orThe quantity is assumed to be zero.

Solid Waste Releases

Mercury is potentially present in coal combustion wastes generated from the burning of fossil fuels in an onsite boiler. Estimates of coal combustion wastes generated from lime production are not available. However, a very rough estimate can be obtained by using the results of the assessment of utility coal combustion (even though characteristics regarding particulate control and burner technology may be different). In Section 4.1.3, air releases of 48 tons and solid waste releases of 17 tons were estimated. Applying this proportion to the 0.1 tons of mercury released to air, no more than 0.1 ton of mercury is estimated to be in the waste residues. This estimate is reflected in Exhibit 4-3.

Product

Approximately 21.6 million tons of lime were produced in 2000 (USGS 2002b). No data regarding the mercury content in lime are available.

4.2.3 Discussion

The quantity of mercury entering the lime production process results from limestone and coal. The total is estimated to be 2.8 to 5.1 tons per year. However, the quantity of mercury leaving the process is only estimated to be 0.1 ton from air and 1 ton from solids. This discrepancy can be due to the following factors:

- Poor estimates of mercury input. The quantity of mercury present in the feed limestone is based on a single concentration value of limestone, from a single location. The mercury content of limestone is expected to vary by location throughout the United States. Additionally, the energy use in kilns is obtained from a single source (Kirk-Othmer 1995), and although this is useful for a 'ballpark' estimate, a second data source would be required to help ensure representativeness.

- Poor estimates of mercury output. The only estimate of mercury releases or mercury in product is an air estimate from the *Mercury Study Report to Congress* (USEPA 1997a), and an estimate of mercury present in coal combustion ash. Other estimates of mercury in water releases and in the product are not available, although the quantity of mercury in water is likely to be zero. However, even small concentrations of mercury in the product would result in sizable accounting (e.g., if the concentration of mercury in the product equaled the concentration of mercury in the limestone feed, this would account for an additional 0.9 tons). In addition, quantities of mercury in coal combustion ash as a solid waste were only roughly estimated.

4.3 Residential, Commercial, and Industrial Coal Combustion

4.3.1 Introduction

This section focuses on residential, commercial and industrial boilers that burn coal to produce steam. This sector is of concern because mercury in the coal is vaporized during combustion and appears as a trace contaminant in the gas exhaust stream. Facilities will fall under many SIC or NAICS Codes. There is no category specifically for industries that use coal-fired boilers, and residential sources do not fall under the purview of SIC or NAICS.

While boilers can be fired by coal, oil, natural gas, or a combination, this section focuses on the use of coal. Coal is burned in a boiler to heat water and produce steam. The steam is used to generate heat or electricity or as a production process input.

In 2000, residential, commercial, and industrial facilities (excluding power producing utilities/non-utilities and coke production) consumed approximately 69 million tons of coal (USDOE 2002).

There are a wide range of boiler sizes and types used in the commercial and industrial sector. Larger boilers use a suspension-fired system similar to the systems in place at coal-fired utilities. Moderate and small boilers use grate-fired systems (USEPA 1997a). Residential boilers tend to be small, stoker systems.

Mercury is a contaminant in coal, the raw material used for combustion. The mercury content in coal can range from 4.8 to 36.4 pounds per trillion Btus (USGS 1998). In USEPA's *Mercury Study Report to Congress*, the emission factor is determined by coal type. For bituminous coal it is assumed that 16 pounds of mercury per trillion Btus is emitted; for anthracite coal, 18 pounds per trillion Btus (USEPA 1997a); estimates which are in the range of the mercury content of coal from the USGS data showing that much of the mercury was assumed to be emitted to the air.

4.3.2 Materials Flow

Exhibit 4-4 demonstrates the flow of mercury during the coal combustion process for industrial, commercial, and residential boilers.

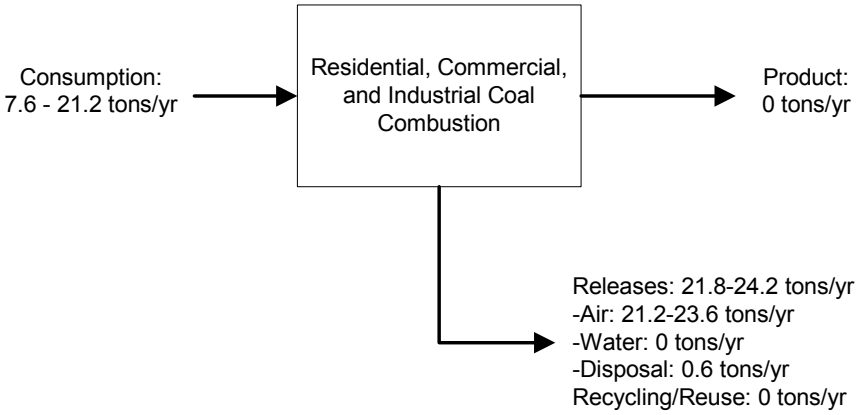
Mercury Consumption

Mercury is a contaminant in coal, the raw material used for combustion. As identified above, approximately 69 million tons of coal for commercial, industrial, and residential applications are used annually. In Section 4.1, it was estimated that 925 million tons of coal contained 105 tons of mercury (about 0.11 tons mercury per million tons coal). Assuming that the mercury content of coal burned in each industry is similar, approximately 7.6 tons of mercury is contained in incoming coal for residential, commercial, and industrial boilers.

An alternative calculation was presented in USEPA (1997a). The same energy consumption of 2.8 quadrillion Btus was used but a different mercury concentration in coal was assumed: for bituminous coal it was assumed that 16 pounds of mercury per trillion Btus are present, and 18 pounds per trillion Btus for anthracite coal. This resulted in an estimate of 21.2 tons of mercury per year. Exhibit 4-4 contains both numbers as a range.

Air Releases

In USEPA (1997a), it was assumed that all mercury present in the raw material would be released to the air. Mercury control practices, including the purchase of washed coal and the control of emissions, were not assumed to occur. As a result, this source estimated that mercury releases totaled 21.2 tons annually, corresponding to 20.7 tons per year for commercial/industrial boilers and 0.5 tons per year for residential boilers (USEPA 1997a; USEPA 1993a). It is similar to an estimate of 23.6 tons in USEPA (1997b); calculated using the same emission factors for bituminous and anthracite coal, but slightly different energy consumption data. The air release estimate shown in Exhibit 4-4 presents both estimates.



Source: Mercury Consumption: Estimated using USEPA (2001) and USDOE (2002) for low end and USEPA (1997a) for high end.
Mercury Release: Air releases estimated using USEPA (1997a) and USEPA (1997b). Disposal releases estimated using USEPA (1999d) and USEPA (1988a).

Exhibit 4-4. Mercury in Residential, Commercial, and Industrial Coal Combustion

Water Releases
No water release estimate is available.

Solid Waste Releases
Mercury may be present in ash that is generated from the combustion process and is subsequently landfilled. The ash may also be used as a product; the estimate presented here includes ash managed using both methods. Ash generation for these boilers includes bottom ash and fly ash. The quantity and composition of each are a function of the boiler technology as well as the specific coal used (e.g., coal with high ash content generates larger quantities of ash). Furthermore, the degree to which air pollution control devices are used is extremely variable.

Control devices used include mechanical (e.g., cyclone), fabric filter, and electrostatic precipitators. Facilities may not use any control devices at all or may use devices with low collection efficiency (USEPA 1999d). The type of air pollution control equipment in place affects whether fly ash will be generated at all, as well as its characteristics.

Through the consideration of these factors on a plant-specific basis, an annual ash generation rate from commercial and industrial non-utilities was presented in USEPA (1999d) using data from the 1990 National Interim Emission Inventory Database (USEPA 1990).

This estimate is 5.8×10^6 tons ash per year, for all types of ash. As shown above, much less coal is used in residential applications and its contribution to ash generation is ignored. Data regarding the mercury content of ash from non-utilities are not available. Therefore, data from utility coal combustion wastes were used: median concentrations of mercury in fly ash are about 0.10 mg/kg and 0.02 mg/kg in bottom ash (USEPA 1988a). Using the fly ash concentration as a conservative value, about 0.6 tons of mercury are present in land disposed wastes.

Product
Mercury content of byproducts (e.g., recycled ash) are included in the "disposal" quantities.

4.3.3 Discussion

The total annual quantity of mercury in the raw material is estimated to be 9.3 tons. The annual quantity of mercury released or in products is estimated to be 21.2 tons to air, 0.6 tons to solid waste and products, and 0 tons to water. Therefore, about 9 tons per year are assumed to enter the process and 22 tons per year are assumed to leave the process. This discrepancy is due to the different sources used in compiling these estimates.

There is a wide range in the quantity of mercury present in the raw material. USEPA (1997a) used median values in estimating this quantity, resulting in an estimate within the range used here. This estimate was subsequently used as the basis for air emissions. An independent source for air emissions data is not

available; therefore, it is very difficult to better identify air releases. The above estimates show that almost all the mercury present in the coal burned is emitted in the stack gas.

Several other industrial sectors discussed in this report use coal combustion as an onsite source for energy or steam (this differs from coke production where coal is a raw material). As discussed in USEPA (1999d), industries accounting for a significant portion of coal-fired non-utility generating capacity include pulp and paper, primary metals, food products, and chemical production. Therefore, there is potential for 'double counting' in cases where coal combustion industries are specifically discussed in this report.

4.4 Byproduct Coke Production

4.4.1 Introduction

Facilities producing coke byproducts may be classified under the following business classifications:

SIC Code 3312: Steel Works, Blast Furnaces (including Coke Ovens), and Rolling Mills (except coke ovens not integrated with steel mills).

NAICS Code 324199: Coke oven products (e.g., coke, gases, tars) made in coke oven establishments not integrated with steel mills.

NAICS Code 333111: Coke oven products made in steel mills.

Coke has been used in iron and steel production for over 100 years. As a byproduct of certain types of coal combustion, coke is composed of nearly pure carbon. Coke revolutionized iron and steel production in the 1870s because it burned at much higher temperatures than coal (Keller 1997). Coke is also used in other metallurgical applications, for ferrous and nonferrous metal production, forming, and recycling activities.

Coke may be produced at large integrated steel mills that use coke for blast furnace operation. It may also be produced by independent facilities who subsequently sell the product in a wide variety of markets. Coke is produced by burning coal in an oxygen-poor environment at temperatures in excess of 2,200°F (Buss 1999), releasing the noncombustible contents within the coal as gases (Keller 1997). In 1991, there were 19 byproduct coke producers in the United States (Huskannen 1991 cited in USEPA 1997a). Most coke in the United States is produced in slot oven byproduct batteries (USEPA 1997a). The slot oven coke battery consists of a series of narrow ovens with heating flues between each oven pair. Pulverized coal is fed into each oven and combusted for 12 to 20 hours, burning off nearly all volatile matter and forming coke. The coke is then unloaded into a rail car where it is cooled by a water rinse (USEPA 1997a).

4.4.2 Materials Flow

Exhibit 4-5 illustrates the flow of mercury in coke production.

Mercury Consumption

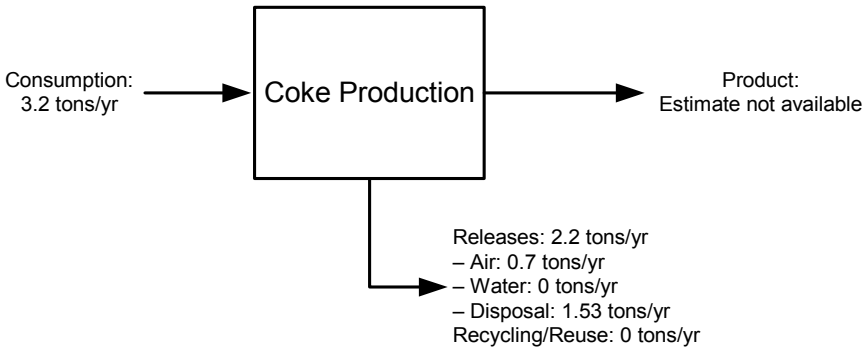
Kirk-Othmer (1993) estimates that 27 million tons of coke were produced in the United States for the steel industry in 1990. The quantity of coal used as raw material for 2000 is estimated as 29 million tons (USDOE 2002). In Section 4.3.2, the mercury content of coal was estimated as about 0.11 tons of mercury per million tons of coal (using USEPA 2001). This nationwide weighted average is most appropriate for fuel coal and may not be applicable to coal used for coke production. Nevertheless, using these data results in an estimate of 3.2 tons mercury in the incoming coal per year, which is reflected in Exhibit 4-5.

Product

There were no data regarding the mercury content in product coke. Additionally, there were no data regarding mercury emissions in the iron and steel manufacturing process where coke is used. It is assumed that nearly all of the mercury is volatilized from the coke during the coke production process.

Air Release

There are no reported mercury emissions from byproduct coke plants in the Toxics Release Inventory. However, mercury is probably present in the volatilized gases released during the coking operation (USEPA 1997a). Mercury may also be emitted through door leaks and from the stacks. Sang and Lourie (1995) report that 306 kg (0.7 tons) of mercury are released from coke-making operations in the Great Lakes Basin. Using emissions factors from European coke plants, USEPA (1997a) also estimates that potential emissions from domestic coke plants are about 0.7 tons per year. This estimate is used in Exhibit 4-5.



Source: Mercury Consumption: Estimated from coal use (USDOE 2002) and concentration data (USEPA 2001).
Mercury Release and Recycling: Air releases estimated using EPA Mercury Study Report to Congress (1997a).
Disposal releases from 1999 TRI.
Mercury in Product: Estimate not available.

Exhibit 4-5. Mercury in Coke Production

Water Release
Mercury may be found in the rinse water. However no estimate of this quantity is available.

Solid Waste
Evaluation of 1999 TRI data showed three steel production companies reporting mercury emissions. These releases were assumed to be the result of coke production. A total of 1.53 tons were disposed in landfills; zero releases were reported to other media. This estimate is shown in Exhibit 4-5.

4.4.3 Discussion

Due to the severity of the process conditions, the coking process should volatilize nearly all of the mercury within the coal. There is, however, a large apparent discrepancy between the estimate of mercury within the coal entering the coking facility (4.9 tons), and the estimate of mercury leaving the facility as emissions (1.8 tons). This discrepancy may be the result of differences in the data sources used.

4.5 Portland Cement Manufacturing

4.5.1 Introduction

Facilities manufacturing portland cement may be classified under the following business classifications:

SIC Code 3241: Hydraulic Cement Manufacture

NAICS Code 32731: Cement Manufacturing

USEPA's *Report to Congress on Cement Kiln Dust* (1993b) states that United States clinker production in 1990 was 65.1 million tons from 115 plants, representing a production capacity of 76 million tons per year. This is somewhat lower than the data presented in the *Mercury Study Report to Congress* (81 million tons of capacity at 212 plants for 1990).

Mercury emissions are a byproduct of Portland cement manufacturing because the raw materials and fuel contain small amounts of mercury. Portland cement is manufactured using a mixture of gypsum, limestone, and silica. After the rock is quarried, a series of crushers reduce it to an appropriate size to be used as cement kiln feed. The final rock size is approximately three inches or smaller. The raw material is then processed through either the "wet" or the "dry" process, depending on the cement manufacturing facility. In the "wet" process, the raw material is mixed with water during the grinding step to form a slurry, and is then fed to the kiln as a liquid. In the "dry" process, rather than mixing the raw materials with water, the raw materials are dried to reduce the moisture content, then fed to the kiln. The remainder of the cement production process is essentially the same.

The wet or dry material is pyroprocessed at abouthi,700/ F in a rotary kiln fed with powdered coal, oil or gas. Some gases are released during this process, and the raw material is transformed into clinker, hard gray nodules about the size and shape of marbles. The clinker is then

cooled, and the heated air from the coolers is returned to kilns to save fuels and increase burning efficiency (Portland Cement Association 1999).

4.5.2 Materials Flow

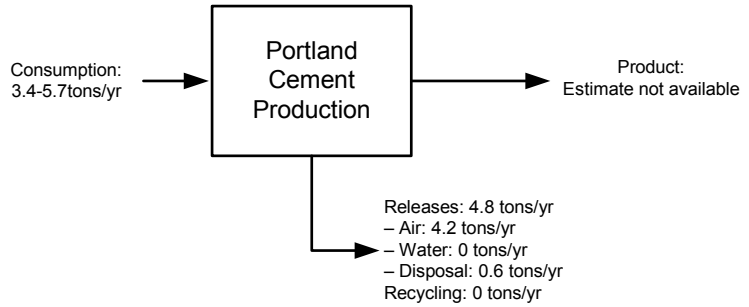
Exhibit 4-6 presents the flow of mercury through the cement manufacturing process.

Mercury Consumption

Approximately 74.6 million tons of limestone were consumed in cement production in 1990 (USEPA 1993b). This represents the most significant raw material by weight, accounting for 85 percent of kiln inputs (coal or other fuels were not included). The mercury content of limestone is between 0.02 - 2.3 ppm (USBM 1994), with a second source (CIBO 1997) estimating a value of 0.04 ppm. Using the CIBO value gives an estimated mercury input of 3 tons of mercury nationwide. The use of the USBM data would result in an extremely wide range of mercury.

Additional mercury is present in fuels combusted onsite for heating the kilns. These fuels include coal, oil, natural gas, and hazardous wastes (e.g., organic solvents). However, in 1990 coal was the dominant fuel used, accounting for 71 percent of the total heating value (147×10^{12} Btu) (USEPA 1993b). The mercury content in coal ranges from 4.8 to 36.4 pounds per 10^{12} Btu (USGS 1998), accounting for about 0.35 to 2.7 tons of mercury per year for this process.

Adding the contributions from coal and limestone, the two most significant contributors, gives an estimated mercury loading of 3.4 to 5.7 tons per year.



Source: Mercury Consumption: Estimated from coal use and concentration data (USGS 1998; USEPA 1993b).
Mercury Release and Recycling: Air releases estimated using EPA Mercury Study Report to Congress (1997a). Disposal releases estimated using Cement Kiln Dust Report to Congress (USEPA 1993b).
Mercury in Product: Estimate not available.

Exhibit 4-6. Mercury in Cement Manufacturing

Product

No data regarding the mercury content of the final cement product is available. Because mercury evaporates at approximately 660/F while the kilns operate at 2700/F, most of the mercury present in the raw materials probably volatilizes during production.

Air Release

Most of the mercury emitted during cement production comes from the kiln and preheating/precalcining steps. Minor sources of mercury emissions may include particulate matter (PM) from raw material processing and emissions from fuel combustion. The mercury emission rate for the entire cement production process was estimated to be 1.3×10^{-4} pounds of mercury per ton of clinker (USEPA 1997a). With 65.1 million tons of clinker produced in 1990, this results in approximately 4.2 tons mercury emitted to the air each year.

Solid Waste Release

Particulate emissions are controlled during the pyroprocessing steps by fabric filters and ESPs. The resultant material from dust collection is cement kiln dust, a material that can be reused onsite (i.e., in the cement production process) or disposed. A total of 14.2 million tons of this material was generated in 1990, of which 5 million tons was not recycled to the system. Based on the analysis of 17 samples collected by USEPA, a mercury concentration range of 0.005 to 14.4 mg/kg (median of 0.11 mg/kg) was determined. Using

the median value and the quantity of 5 million tons cement kiln dust that was not recycled, a mercury loading of 0.6 tons of mercury is estimated (range 0.03 to 72 tons). There are no additional data on the specific ability of these systems to capture mercury emissions from cement kilns, so the quality of this estimate cannot be compared with other data sources.

4.5.3 Discussion

There are no mercury TRI data for Portland cement manufacturing facilities for 1999.

The estimates presented here are based on data from 1990. An uncertainty is the trends of the domestic production of cement, as well as trends in raw material use. As shown above, coal contributes a significant amount of mercury to the raw material input of kilns.

Most of the estimates vary widely, mostly due to the large quantities of materials involved. The result is that the quantity of a given raw material used or waste generated is not likely to have as much error as the composition of that material with regard to mercury. Limited data with wide ranges were used in characterizing the composition of these materials. A more accurate approach would be to consider a plant-by-plant analysis, considering the composition of mercury in the raw materials and emissions together with the site-specific generation rate. However, such data (or immediate plans to obtain it) are not available.

4.6 Coal Combustion Waste Products

4.6.1 Introduction

Large quantities of coal combustion wastes are used or sold for applications other than disposal. Wastes (such as ash) generated from utilities, industries, and commercial applications can be re-used. In all cases, any mercury in the ash is present as a contaminant which may potentially be released to the environment during or following use.

In 1997, the following quantities of utility coal combustion wastes were reused: 19.3 million tons of fly ash (31.5% of all fly ash generated), 5.1 million tons of bottom ash (27.7% of all bottom ash generated), 2.6 million tons of boiler slag (92.9% of all boiler slag generated), and 2.2 million tons of flue gas desulfurization (FGD) wastes (7.9% of all FGD wastes generated). Although similar quantitative data are not available for non-utility sources of ash, available information indicates that the wastes are used in similar or identical applications. The largest uses of utility coal combustion wastes are the following (in decreasing order of quantity used in 1997): cement and concrete; structural fill; waste stabilization; road base; blasting grit; mining applications; wallboard; snow and ice control; mineral filler; flowable fill; and agriculture (USEPA 1999d).

4.6.2 Materials Flow

Using the compositional data presented in Section 4.1, the quantity of mercury in product uses is estimated to be 3.0 tons per year (median), with a range up to 103 tons per year (the upper end of the range assumes that all wastes exhibit their highest concentrations).

By reviewing the above list of product applications, many of the uses involve direct placement on the land where the material is not expected to be moved. For example, in agricultural uses the waste is applied directly to soil, and in structural fill or road base applications the material is used as a base for further construction that is expected to last for many years. In waste stabilization, the ash becomes part of the solid waste matrix which is subsequently landfilled.

Other uses, including use as wallboard, blasting grit, and mineral filler, do not include immediate placement on the land. Instead, any mercury in the coal combustion waste would be incorporated into the commercial or consumer product and then eventually landfilled. Using the compositional data presented in Section 4.1, the quantity of mercury in these three uses is estimated to be 0.73 tons (median), with a range up to 22 tons (the upper end of the range assumes that all wastes exhibit their highest concentrations). Therefore, this quantity of mercury is used in commerce, then probably disposed in a landfill.

Very little information is available discussing the fate of contaminants, including mercury, in product applications. For example, it is not known if the mercury migrates from its land-based applications to air, stormwater runoff, or other media.

4.6.3 Discussion

Section 4.1 of this report identified that solid coal combustion wastes, such as fly ash and bottom ash, are either disposed of or are used as products. The estimates from Section 4.1 are intended to present all management methods for coal combustion wastes, and therefore the estimates presented in this section necessarily duplicate

those identified in Section 4.1. This section is intended to highlight specific management methods of coal combustion wastes. The same uncertainties regarding the quality of the estimates in Section 4.1 are applicable here. Chief among these concerns is the variability of waste composition and the small amount of data that exists regarding mercury in wastes. Methods being considered for reducing mercury in stack air emissions include capturing the mercury in fly ash. The use of such controls are expected to increase in the future, with a corresponding increase in the quantity of mercury present in the generated solid wastes. However, the magnitude of such changes cannot be predicted.

As discussed in this section of the report, many of these applications involve placement of the material on the land so that, regardless of whether the waste is disposed or used as a product, the mercury present in the waste is placed on the land. Once on the land, however, there is no information regarding its environmental fate as staying in the ash matrix, entering the air, or entering the water.

Chapter 5
Incidental Mercury Use Associated With Non-Coal Sources

5.1 Oil Combustion

5.1.1 Introduction

Oil combustion is used by utilities to generate electricity and is used by industrial and commercial (non-utility) facilities to generate steam, electricity, or heat for miscellaneous industrial applications (USEPA 1999d). Additionally, there are residential applications of oil combustion as a heating fuel. Fuel usage and technologies differ between each of these three sectors, and therefore the use and releases of mercury differ in each as well.

In the utility sector, the total amount of electricity generated from oil combustion is small relative to the total generation of electricity by coal and other technologies. Oil is used at a much larger number of industrial and non-utility facilities, and accounts for a larger capacity as well: oil-fired utilities have a capacity of 43,000 MW, and oil-fired non-utilities have a capacity of 54,000 MW, based on 1994 data (USEPA 1999d).

Utilities predominantly use residual (No. 6) fuel oil, while lighter and more expensive distillate (No. 2) fuel oil is used for auxiliary or start-up purposes. Residual oil has a higher ash content than distillate oil, leading to increased levels of combustion bottom ash and air pollution control fly ash. However, the majority of oil-fired utility power plants do not use air pollution or particulate control equipment, and therefore do not collect fly ash. This is because the ash content of oil (even residual oil) is much lower than coal and their emissions characteristics may not require the addition of air pollution control equipment (USEPA 1999d). The predominant fuel used in non-utility and residential applications is distillate oil. These units are smaller than combustion units in the utility sector. Therefore, the quantity of ash generation in these sectors are expected to be even less than in the utility sector. Nonetheless, mercury releases still occur.

5.1.2 Materials Flow

Exhibit 5-1 illustrates the flow of mercury in oil combustion in utility, non-utility, and residential combustion units.

Mercury Consumption

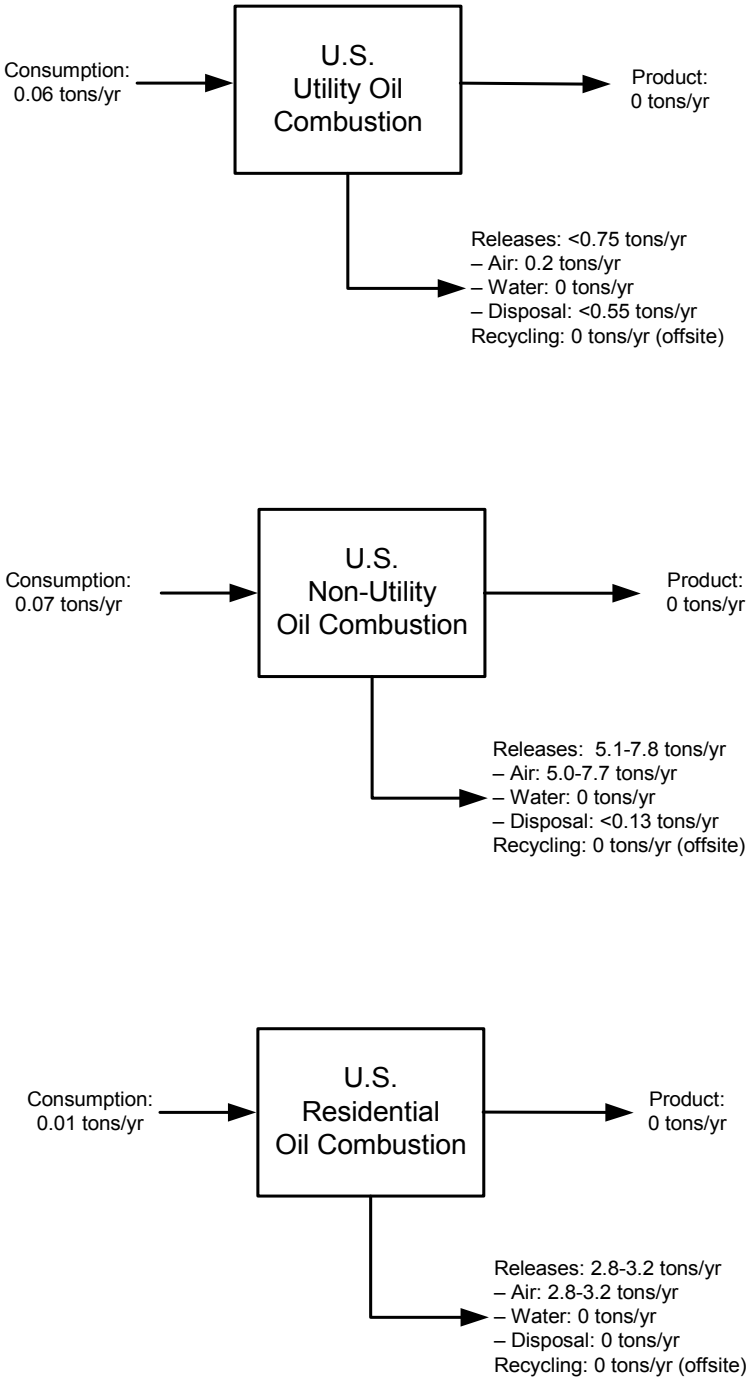
Data are available quantifying the amount of fuel oil used in utility, non-utility, and residential applications. For the utility and non-utility sectors, the quantity of fuel oil used in 1996 is as follows (USEPA 1999d):

- Utility, residual oil: 3,900 million gallons
- Utility, distillate oil: 684 million gallons
- Non-utility, residual oil: 3,100 million gallons
- Non-utility distillate oil: 5,500 million gallons

For the residential sector, the quantity of oil is not directly available. However, the heating content of oil used in the non-utility and residential sectors is reported as 2,180 and 880 trillion Btu, respectively, in 1994. Assuming that the heating value of oil used in these two sectors is similar, and that only distillate oil is used for residential applications, the quantity of oil estimated to be used in residential applications is 3,500 million gallons of distillate oil.

The mercury content of these fuels is expected to be variable. Minnesota (1999) provides estimates of the mercury content of product oils, reporting that residual oil has 0.004 ppm mercury and distillate oil has 0.001 ppm mercury. Using the concentration data together with the above volume data provides the following estimates for the mercury content of raw materials in 1996:

- Utility: 0.06 tons of mercury (corresponding to 0.06 tons from residual oil and 0.003 tons from distillate oil)
- Non-utility: 0.07 tons of mercury (corresponding to 0.05 tons from residual oil and 0.02 tons from distillate oil)



Source: Mercury Consumption: Composition data from Minnesota (1999). Use data from USEPA (1999d). Mercury Release and Recycling: Disposal releases estimated from USEPA (1999d). Air releases estimated from USEPA (1997a) and USEPA (1997b).

Exhibit 5-1. Mercury in Utility, Non-Utility, and Residential Oil Combustion

- Residential: 0.01 tons of mercury (corresponding to 0.01 tons from distillate oil).

Product
There are no products. In cases where ash is recycled, these estimates are incorporated as solid waste releases.

Air Releases
The estimates of mercury releases from utility, non-utility, and residential combustion of oil vary depending on the mercury emission factors that were used in the calculations. These estimates are as follows:

Utility: 0.2 tons/year
Non-utility: 5.0 - 7.7 tons
Residential: 2.8 - 3.2 tons

For utility boilers, mercury emissions were estimated using emissions data available from 58 emission tests conducted by USEPA, the Electric Power Research Institute (EPRI), the Department of Energy (USDOE), and individual utilities. Boiler-specific emission estimates were then calculated by multiplying the calculated inlet mercury concentration by the appropriate emission factor for each boiler configuration and control device.

For non-utility and residential boilers, the ranges account for the different mercury emission factors for oil that were used in the *Mercury Study Report to Congress* (USEPA 1997a) and in *Locating and Estimating Air Emissions from Sources of Mercury and Mercury Compounds* (USEPA 1997b). The following factors were used in the *Report to Congress*:

Residual Oil (No. 6): 2.9 kg/10^{15} J
Distillate Oil (No. 2): 3.0 kg/10^{15} J

The following emission factors were used in the *Locating and Estimating Air Emissions* document:

Residual Oil (No. 6): 2.7 kg/10^{15} J
Distillate Oil (No. 2): 0.02 kg/10^{15} J

The mercury emission factors for residual oil and distillate oil were multiplied by oil consumption estimates in order to estimate the amount of mercury released to air.

Solid Waste Releases
Air pollution control devices are most frequently used in the utility sector. An estimated quantity of 23,000 tons of oil combustion waste were collected in 1995. Air pollution control equipment is less frequently used in the non-utility sector, and therefore fewer oil combustion solid wastes are produced. An estimated quantity of 5,500 tons of oil combustion waste are collected annually (USEPA 1999d). Solid waste releases in the residential market is assumed to be negligible. This sector operates smaller boilers than the utility sector, and is more likely to use lower ash distillate oil. As a result of these factors, this sector is the least likely to employ air pollution control devices which generate solid waste.

The mercury content in these wastes is variable, depending on their type and other facility-specific factors. The overall range for mercury is approximately 0.06 ppm to 24 ppm (USEPA 1999d). Using the upper end of this range in conjunction with the waste quantities listed above, the mercury loadings from these solid wastes are as follows:

- Utility: <0.55 ton
- Non-utility: <0.13 ton
- Residential: Negligible

Water Releases
No water releases are expected. Water is used for air pollution control, but solids in the water which may contain mercury are expected to settle prior to discharge or other release to the environment.

5.1.3 Discussion
In all cases the quantity of mercury assumed to be released is less than the quantity of mercury assumed to be present in the raw material. This discrepancy is probably due to the variability of mercury in the raw material. The data reported in USBM (1994) are probably high.

The estimates for air releases are based on the use of emission factors. Emissions are expected to vary from facility to facility based on the mercury content of the raw material and the type of control technology in place.

5.2 Carbon Black Production
5.2.1 Introduction
Carbon black consists of fine particles of carbon usually formed by incomplete combustion of hydrocarbons in the oil-furnace method. This substance is frequently used as a filler in rubber manufacturing to add both toughness and abrasion resistance to the final product.

The mercury in carbon black production comes from the hydrocarbon feedstock, similar to Number 6 (residual) fuel oil, which has an average mercury content of 0.06 ppm (USBM 1994).

The three primary raw materials used in the production of carbon black are feedstock (either a petrochemical oil or a carbochemical oil), air, and an auxiliary fuel such as natural gas. The feedstock is preheated to a temperature of between 150 and 250^{0}C, and the air is also preheated. A turbulent, high-temperature zone is created in the reactor by combusting the auxiliary fuel and the preheated oil feedstock. The feedstock is introduced into this zone as an atomized spray. In this zone of the reactor, most of the oxygen is used to burn the auxiliary fuel, resulting in insufficient oxygen to combust the oil feedstock. Thus pyrolysis of the feedstock is achieved, and carbon black is produced (USEPA 1997a). The air stream containing the product is cooled and the product is collected in a fabric filter. It is shipped in dry form, primarily for use in the rubber industry.

5.2.2 Materials Flow

Exhibit 5-2 illustrates the consumption, release, and product content of mercury in carbon black production.

Mercury Consumption

Mercury may be present in the residual oil feed. Assuming that the concentration of mercury in the feed is 0.06 ppm (USBM 1994), and the quantity of oil consumed is equal to the production capacity of the carbon black (1,830,000 tons/year from USEPA 1997a), the quantity of mercury in the feed is estimated as 0.11 tons/year.

Product

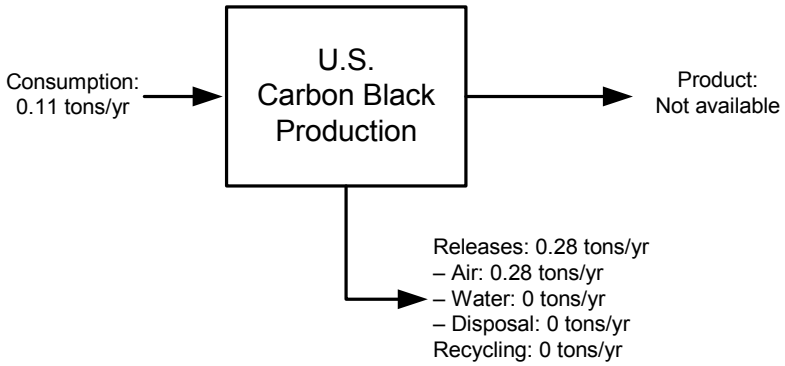
The quantity of mercury in the product is not known. It is reasonable to expect that some of the mercury would be collected in the fabric filter.

Air Releases

In 1995, mercury emissions from carbon black production were estimated to be 0.28 tons (USEPA 1997a). This estimate is expected to be an overestimate because it is based on production capacity (rather than actual production, which is not known), and the use of a furnace emission factor developed from 1980.

Water and Solid Waste Releases

No release points for these media are identified. Releases are estimated as zero.



Source: Mercury Consumption: USBM, 1994.
Mercury Release and Recycling: EPA, 1997a
Mercury in Product: No estimate available.

Exhibit 5-2. Mercury in Carbon Black Production

5.2.3 Discussion

The estimates for the mercury in raw material and mercury in air releases are both uncertain because of the limited information each is based upon. Additionally, the quantity estimated to be released is greater than the quantity estimated to be fed to the process, indicating additional difficulties with the data quality. Finally, an estimate for the quantity of mercury in the product could not be developed although this may not necessarily be a zero quantity.

5.3 Gold Mining

5.3.1 Introduction

While the major source of mercury is supplied by secondary sources, additional quantities of mercury are obtained as a byproduct of gold mining. Mercury is present in gold ore; one source estimates a concentration of 9 ppm although the concentration is expected to vary based on location (USBM 1994). As of 2001, less than 10 gold mines recovered mercury from the ore (USGS 2002a). The remaining gold mines did not recover mercury, although some mercury is expected to be present in the gold ore and in waste materials.

In gold mining, gold-containing ore is crushed and then, if necessary, roasted to remove sulfur. Mercury that is present in the ore is vaporized and collected in air pollution control devices; mercury in these wastes may be either disposed or recovered in an onsite retort furnace. Following roasting, the ore is mixed with water and reacted with a cyanide leach solution where gold and mercury are dissolved and solids removed via filtration. The purified solution is sent to an electrowinning process, where the gold is deposited on a steel cathode. If necessary, the cathode is sent to a retort furnace for mercury removal, then to a smelting furnace to volatilize and purify the gold. In a retort furnace, the mercury is collected by a condensor for subsequent sale (USEPA 1997a). Therefore, mercury present in gold ore may be released to the land (e.g., in disposed air pollution control wastes and spent ore tailings), to the air (e.g., not removed by air pollution control devices), or in the gold product (i.e., as an impurity).

Mercury was used through the early 1900's throughout the western United States during gold mining (i.e., gold amalgam process). Mercury was added to the ores to aid in recovery, which resulted in widespread contamination of mine waters and sediments (USGS 2000b). In the United States, mercury is no longer used in gold recovery operations although such use continues in other parts of the world.

5.3.2 Materials Flow

Exhibit 5-3 illustrates the consumption, release, and product content of mercury in gold mining.

Mercury Consumption

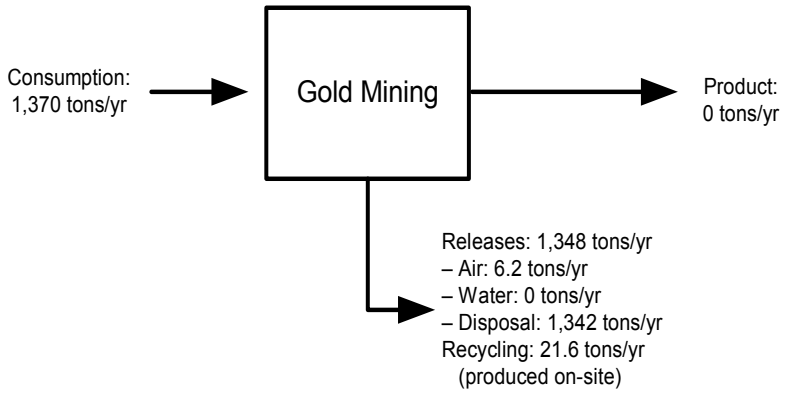
The mercury input from trace impurities in gold ore to the gold mining process is assumed to be equal to the amount released, as estimated below.

Releases

Mercury that is present in the ore can remain in the waste rock or can be vaporized; the volatile mercury can be released to the atmosphere or be collected in air pollution control devices for mercury recovery or disposal. Specific sources of mercury during gold ore processing have been estimated by one company. Of 1,500 pounds of mercury estimated to be released to air during processing, 23 percent were from milling (e.g., crushing), 29 percent from autoclaves, 31 percent from electrowinning and retort, and 15 percent from furnace stack. Other facilities reporting significant mercury releases also operate autoclaves or roasters (Elko Daily 2000b). An estimated 10 to 50 percent of mercury contained in the rock is removed for recovery (or release) later in the process (Menne 1998).

There is contradictory information regarding the quantity of mercury recovered during gold mining. USGS (1997) indicates that this quantity is insignificant in comparison to the quantity of mercury produced from mercury recyclers (420 tons in 1997), while a newspaper indicates that Nevada mines alone supply 110 to 150 tons per year (Elko Daily 2000a). An industry source estimates that total worldwide byproduct production (from gold, copper, etc.) is 400 tons per year (Lawrence 2000). Finally, 1999 TRI data shows that four Nevada facilities reported onsite recycling (recovery) of 21.6 tons of mercury. Onsite recycling data from TRI were not available for any other domestic gold or silver mining facility. The TRI estimate is shown in Exhibit 5-3 as a recovered product.

Both industry and academic sources suspect that most of the 1999 TRI air emission estimates for mercury in this industry are based on estimated, rather than measured, mercury data (Elko Daily 2000b).



Source: Mercury Consumption: Equal to releases plus recycling.
Mercury Release and Recycling: 1999 TRI Data.

Exhibit 5-3. Mercury in Gold Mining

Eight facilities, all from Nevada, reported releases of mercury (or mercury compounds) in the 1999 TRI. Not all of these facilities produce mercury as a product. Total air releases were 6.2 tons. Total water releases were 4 pounds (0.002 tons). Total (offsite) mercury recycling was 0.06 tons. Total onsite land releases were 2,700,000 pounds (1,342 tons). The high disposal quantity consists primarily of tailings in waste rock. These estimates are shown in Exhibit 5-3.

5.3.3 Discussion

The available estimates of mercury releases from gold mining vary widely, from 400 tons per year to 1,350 tons per year, indicating a need for better data.

Beginning with the 1998 reporting year, mining operations (including gold mining) have been required to complete toxic release inventory (TRI) reports. These data will show reported releases of mercury (and other TRI pollutants), and may subsequently serve as incentives to better monitor or control these emissions so that companies can report decreases for these emissions. Lowering of the reporting threshold for mercury in the 2000 reporting year for TRI will result in many smaller facilities (including gold mining operations that presently do not recover mercury) being required to report multimedia emissions, which will improve the quality of data for this sector.

5.4 Primary Lead and Zinc Mining and Smelting

5.4.1 Introduction

Mercury is potentially present in lead ores. Lead is primarily mined in Missouri and Alaska for smelting (USGS 2000c). The variability of mercury in lead ore is expected to be less than the variability from other mined materials that are recovered from a wider area of the U.S.

Zinc ore is primarily mined in Alaska, with smaller quantities obtained from Tennessee, New York, and Missouri. Ore is processed in one of three domestic U.S. smelters (USGS 2000a).

The ores are mined and then concentrated, generating tailings as a waste. The concentrate is fed to a sintering process, where sulfides are driven off using heat (mercury is likely volatilized in this step). The sintered material is fed to a blast furnace with coke and slag forming constituents. Crude metal (elemental lead or zinc) is removed as molten material and then refined.

5.4.2 Materials Flow

Mercury Consumption

The concentration of mercury in lead ore concentrate (representative of the ore presently mined) is less than 0.2 ppm (USEPA 1997a). This results in approximately 0.18 tons/year; this quantity is reflected in Exhibit 5-4. This is based on primary (mined) lead production of 400,000 tons in 1994, use of emission factors for air

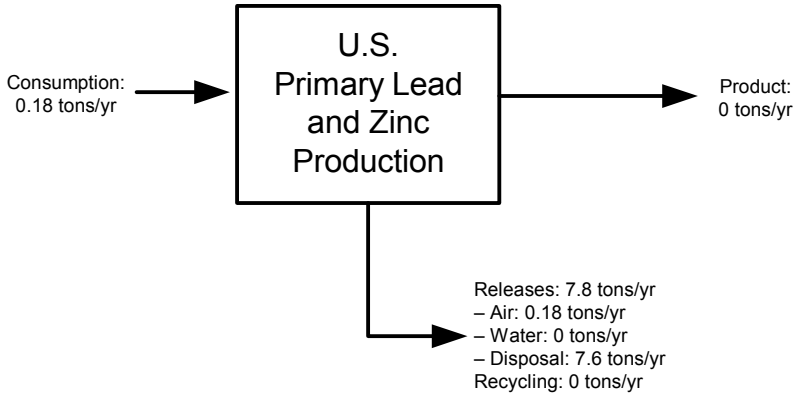
pollution control equipment following the sintering and furnace operations, and the assumption that 10 tons of ore concentrate produces 4.5 tons of lead. No data are available for zinc ores.

Air Releases

Based on the lead ore concentration and the use of an emission factor, USEPA (1997a) estimated annual air emissions of mercury from lead smelting as 0.11 ton (USEPA 1997a). Evaluation of 1999 TRI data showed that one zinc smelting company reported mercury releases. Mercury released into the air was 0.07 ton. The TRI air release is shown in Exhibit 5-4.

Water Releases

No water releases were identified.



Source: Mercury Consumption: Based on USEPA (1997a) for lead ore.
Mercury Release and Recycling: Air releases estimated using USEPA (1997a) and 1999 TRI data. Disposal releases estimated using 1999 TRI data.

Exhibit 5-4. Mercury in Primary Lead and Zinc Production

Solid Waste Releases

It is assumed that mercury present in the lead ore is either released to the atmosphere or collected in air pollution control waste and disposed. The quantity of mercury present in such solid wastes and disposed is estimated as 0.07 tons, which is the difference between the mercury in the ore and mercury released to air.

Evaluation of 1999 TRI data showed one company in this sector reported mercury release. This facility is a zinc smelter that accepts both ores and waste materials (electric arc furnace dust from iron production) (USGS 2000a); mercury is a contaminant in these raw materials. Mercury releases were 7.6 tons as solid waste. The sum of these two releases are reflected in Exhibit 5-4.

5.4.3 Discussion

Exhibit 5-4 shows a large discrepancy between consumption and release. This is potentially due to the absence of information regarding the mercury content of raw materials accepted by zinc processing facilities; only the mercury content of raw materials accepted by lead processing facilities are identified in Exhibit 5-4.

5.5 Primary Copper Mining and Smelting

5.5.1 Introduction

Mercury is potentially present in copper ores. As with other ores, copper ore is mined and then concentrated, generating tailings as a waste. The copper concentrate is fed to a smelting furnace with coke and slag forming constituents. Crude elemental copper is removed as molten material and then is further processed, using heat to remove iron and other impurities. Mercury may be driven off in the furnace or subsequent melting of the copper (USEPA 1997a).

5.5.2 Materials Flow

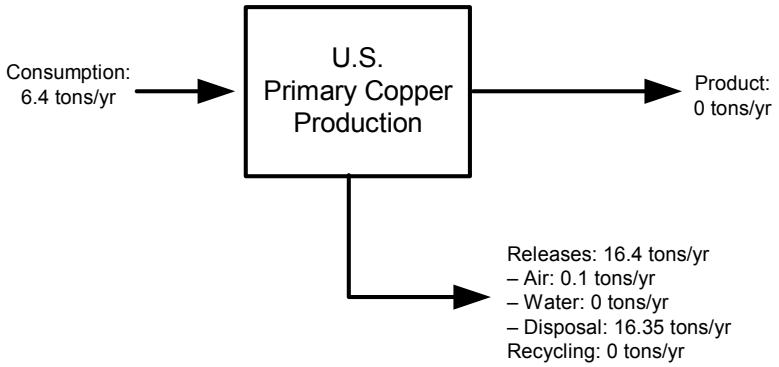
Copper was recovered at 27 mines in the U.S. (USGS 2000d) and loadings of mercury in the ore were reported for five facilities. Air releases for seven plants were provided, with air releases much less than the reported ore loadings on a plant-by-plant basis. The cumulative, industry-wide total for mercury in ore concentrate is 6.4 tons, and the industry-wide total for mercury in air releases is 0.06 tons (USEPA 1997a). The remaining mercury is assumed to be present in the solid air pollution control wastes. Exhibit 5-5 illustrates the

consumption, release, and product content of mercury in primary copper mining and smelting.

Evaluation of 1999 TRI data showed two facilities reported mercury. One facility was an ore concentrator operation and the second facility was a smelting operation. Mercury releases were 16.35 tons as solid waste, 0 tons to surface water, and 0.036 tons released to the air. The air emissions from the facility were added to the industry-wide total for air releases, as shown in Exhibit 5-5.

5.5.3 Discussion

The discrepancy between consumption and release in Exhibit 5-5 may be the result of variation in the ores.



Source: Mercury Consumption: USEPA 1997a.
Mercury Release: USEPA (1997a) for air releases and 1999 TRI data for other releases.

Exhibit 5-5. Mercury in Primary Copper Production

5.6 Pulp and Paper Manufacturing

5.6.1 Introduction

Mercury can be present in pulp and paper facilities as a raw material impurity. It may also be present at facilities that operate chlor-alkali mercury cells as part of the pulp and paper manufacturing process; however, the latter operations are discussed elsewhere in this report.

Pulp and paper plants use a variety of raw materials that potentially contain mercury. These include the wood, purchased chemicals containing mercury as a contaminant, and coal used in onsite boilers for steam generation. Key process steps of pulp manufacturing with regard to potential mercury use include: (1) debarking and chipping of the logs; (2) chemical pulping using sodium hydroxide and sodium sulfide as typical raw materials; (3) bleaching using chlorine, chlorinated compounds, and sodium hydroxide as raw materials; and (4) combustion or recovery processes (Kirk-Othmer 1996). There are approximately 150 pulp mills in the U.S. (USEPA 1997a).

5.6.2 Materials Flow

Based on the above process description, and on available mercury content information for several raw materials, mercury may be present in the following raw materials: coal (used in onsite boilers), sodium hydroxide (mercury may be present if generated from chlor-alkali process), bark (mercury may be present at levels from 0.08 ppm to 0.84 ppm [USEPA 1999d]), and sulfuric acid (mercury was found to be present in sulfuric acid purchased from a lead smelter [USEPA 1997b]). Any mercury present in these raw materials is likely released to the environment through air, water, or land disposal.

The quantities of mercury entering a pulp and paper process are not known. In cases where concentration data are available, the quantity of the raw material is typically not available. Data for releases are incomplete. An estimate of 1.9 tons of mercury per year, presented in USEPA's *Report to Congress* (1997a), is principally based on the combustion of coal and/or waste products such as bark. Quantities of mercury in water and land disposal are unavailable; no pulp and paper facilities

reported releases to the 1999 TRI.

5.6.3 Discussion

Pulp mills are one of many industries that combust coal for steam or electricity production. The combustion of these industrial sources of coal are presented elsewhere in this report, and would therefore account for at least some of the use and release of mercury from this sector.

5.7 Oil Refining

5.7.1 Introduction

Mercury is present in crude oil in varying amounts depending on its source. U.S. refineries process, or refine, crude oil from domestic and imported sources. The mercury present in the crude oil subsequently is transferred to the products or is released to air, water, or other media.

5.7.2 Materials Flow

Quantitatively, there are several sources of data available to estimate the mercury content of crude oil processed in the U.S. Recent data from Minnesota (1999) identifies a range of 2.5 to 13 ppb. USEPA's (1997a) *Mercury Study Report to Congress* reports the mercury content of crude oil as 0.023 to 30 ppm weight, and USBM (1994) gives a 'typical' mercury content of 3.5 ppm. Like other properties of crude oil, it is likely that the mercury content is extremely variable. The 2000 U.S. refinery throughput was 5,514 million barrels (USDOE 2001), or about 865 million tons per year. Using the concentration range of 2.5 to 13.3 ppb from Minnesota (1999) results in a range of 2.2 to 11.5 tons per year. These data are summarized in Exhibit 5-6.

Exhibit 5-6. Mercury Content of Crude Oil and Petroleum Products

Material	Mercury Conc., ppb	Production, million bbl	Total Mercury Throughput, tons	
Crude Oil	2.5 to 13.3	5,514	2.2 to 11.5	
Gasoline	1	2,910	0.46	Σ = 0.93
Distillate Oil	1	1,310	0.21	
Residual Oil	4	255	0.16	
Jet fuel/ kerosene	1	612	0.10	
Other Products	—	1,224	—	

Source: Mercury content of materials from Minnesota (1999). Nationwide throughput data for 2000 from U.S. DOE (2001).

Mercury release data for six oil refineries and bulk fuel terminals are available from the 1999 TRI. Total releases from these six facilities are 5 pounds to water and 10 pounds to land. Other estimates are not available, although additional refineries and bulk terminals are expected to report mercury releases to the 2000 TRI due to a change in reporting requirements for mercury (data expected to be released in Summer 2002).

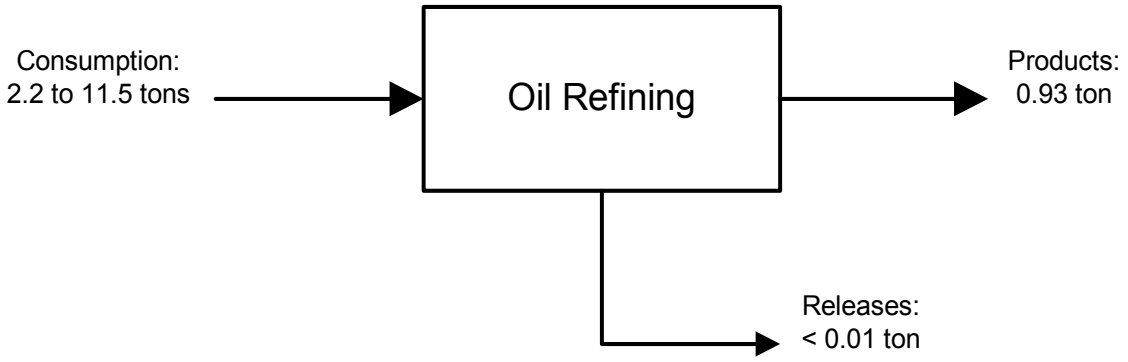
Refineries produce many products. The 2000 production volume of these products and their mercury content are presented in Exhibit 5-6. As shown, the apparent mercury content of crude oil (2.2 to 11.5 tons) is greater than the mercury content of the products (0.93 tons), indicating that 'missing mercury' is unaccounted for. Exhibit 5-7 summarizes the mercury flow in petroleum refining.

5.7.3 Discussion

The quantity of mercury in crude oil can be extremely variable. The release quantity in Exhibit 5-7 is underestimated because data are available for only six of more than 100 US refineries. Additionally, mercury releases to certain media, especially air, are not routinely measured by refineries and emissions of volatile metals are difficult to estimate using conventional approaches. Therefore, obtaining accurate accounting of mercury from petroleum refining activities is a particular research need.

5.8 Rubber and Plastic Products

In rubber manufacturing, carbon black is used as a raw material. Carbon black is commonly produced from petroleum products, which may contain mercury as an impurity.



Source: Mercury content of materials from Minnesota (1999).
Nationwide throughput data for 2000 from U.S. DOE (2001).
Releases: 1998 TRI.

Exhibit 5-7. Mercury from Oil Refining

There are no data regarding the mercury content of the carbon black product. A lack of data regarding the presence of mercury in this industry prevents any estimates of mercury use and release.

5.9 Geothermal Power

5.9.1 Introduction

Geothermal power accounted for 2,650 megawatts of power production capacity in 1992 (USEPA 1997a). For comparison, coal combustion (the principal source of energy in the U.S.) accounted for approximately 300,000 megawatts of power production in 1996 (USEPA 1999d).

Geothermal plants operate in the western United States, specifically in California, Hawaii, Nevada, and Utah. Turbines in the plants are powered by steam that is naturally present in the form of hot, high pressure water or steam below the earth's surface (USEPA 1997a).

5.9.2 Materials Flow

Sources of mercury in geothermal plants are expected to result from off-gas ejectors and cooling towers (USEPA 1997a). Quantitative estimates of air emissions from these sources are presented in USEPA (1997a) based on estimates developed from 1977 data. An estimate of 1.4 tons of mercury released to the air was developed. Estimates to other media, and estimates of the quantity of mercury present in the raw materials (geothermal steam or water) are unavailable.

Mercury may be present in water or solid wastes. Hydrogen sulfide (present in the raw material) requires removal prior to venting of the gas; the sulfur is collected in a solid form for disposal where mercury may simultaneously be collected. Condensed water is also collected, where mercury may also be present (Kirk-Othmer 1994). No estimates for these quantities are available.

5.9.3 Discussion

The estimate for air releases of mercury has uncertainty. The data were developed from 1977, when operations and air pollution control configurations may have differed from today; which would affect the partitioning of mercury to other media. Additionally, mercury compounds were used in cooling towers as a biocide and it is unknown if the factor developed in 1977 was developed from a site where mercury was present in this fashion. If so, present day mercury releases would be overestimated because mercury is no longer used in cooling towers.

5.10 Wood-Fired Boilers

5.10.1 Introduction

No mass balance estimates are available for wood-fired boilers. These boilers are used in both residences and industries. On a residential scale, wood is burned as logs in a small stove. On an industrial scale, wastes or byproducts from onsite processing of wood are burned in an onsite boiler; these wastes could include sawdust and wood chips (USEPA 1997a).

5.10.2 Materials Flow

The mercury content of bark is reported to range from 0.08 to 0.8 ppm mercury (USEPA 1997a). The mercury content of other wood products is not available. The total quantity of wood burned in industrial boilers is estimated as 100 million tons per year (USEPA 1997a). Due to the uncertainty in mercury composition of the feed, an estimate is not presented.

Air releases of mercury from industrial boilers are presented as 0.26 tons per year (USEPA 1997a). Another USEPA document estimates that the total 1994 mercury emission from wood combustion are 0.1 tons (USEPA 1997b), but notes that the data are suspect. Water releases are likely to be negligible, and estimates for solid releases (e.g., combusted wood) are not available. USEPA (1997a) presented air release factors for industrial and residential boilers. The release factor for residential boilers was not used because it was based on a single data point (e.g. one wood type and one burner). The value of this release factor was approximately 4 orders of magnitude higher than the value of the release factor used for industrial boilers. Use of this release factor would have resulted in an unreasonable estimate of mercury releases and therefore was not used.

5.11 Utility Natural Gas Combustion

5.11.1 Introduction

Natural gas is used as a fuel at electric generating utility power plants, and it is the second most significant fossil fuel behind coal. In the production of electricity from natural gas combustion, the gas is fed to a furnace with excess air (USEPA 1999d). Generated heat is used to transform water to steam, which drives a turbine to generate electricity.

5.11.2 Materials Flow

An estimate for mercury air releases from natural gas combustion was provided as 0.002 tons per year (USEPA 1997a). Estimates for the quantity of mercury in the incoming fuel were not available. Additionally, no solid or aqueous wastes are expected from the combustion of natural gas (USEPA 1999d). Therefore, any mercury present in the fuel is probably released to the air.

5.11.3 Discussion

No estimates for the mass balance of mercury in natural gas combustion are presented. Only one number is available (for air releases), and the value is so low in comparison to quantities in other industries as to be negligible.

Chapter 6
Additional Sources of Mercury Resulting from Disposal or Other Final Disposition

Information in this chapter may overlap in part with solid waste disposal figures from other sectors and may also capture data from numerous unreported sources. Waste management facilities were required to report to the TRI for the first time in 1998. In 1999, seven hazardous waste management facilities reported releases of mercury or mercury compounds. These are facilities that conduct a variety of services such as landfilling, stabilization, incineration, consolidation, etc. Therefore the data can not be neatly presented in any one section of this report.

These seven facilities reported the following releases of mercury and mercury compounds in 1999. A total of 272 tons were landfilled, 42 tons were sent offsite for mercury recovery, and 0.03 tons were released to air. This is a total of 314 tons.

6.1 Hazardous Waste Combustion

6.1.1 Introduction

USEPA's hazardous waste regulations have been in effect for approximately 20 years. Under these regulations, both commercial and captive (on-site) facilities must have a permit in order to combust hazardous waste. The types of facilities that combust hazardous waste include incinerators (which almost exclusively combust hazardous waste) and industrial furnaces (which have the dual purpose of destroying hazardous waste and deriving energy for use in other industrial processes (USEPA 2000b)). An example of an industrial furnace is a cement kiln.

Almost all hazardous wastes must be treated prior to land disposal, and combustion is a common method to remove organic constituents from wastes. Inorganic constituents commonly remain in the ash or waste residue, or are collected by air pollution control devices. Such wastes would be subsequently treated or disposed. Hazardous wastes are extremely variable in physical form and composition, and include spent solvents, tank bottoms, and electroplating sludge. However, not all of these wastes are amenable to hazardous waste combustion, or in fact undergo combustion as treatment. For example, hazardous wastes high in mercury are sent to mercury recovery and recycling facilities. Mercury may be present in other hazardous wastes in small amounts, and contribute to the mercury loading of a hazardous waste combustion facility.

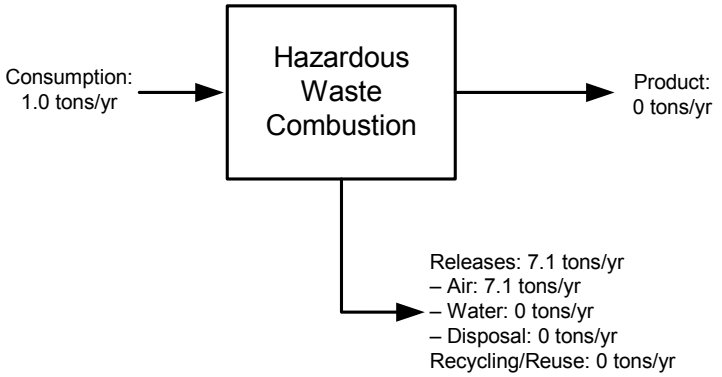
6.1.2 Materials Flow

Exhibit 6-1 illustrates the flow of mercury in hazardous waste combustion.

Mercury Consumption

The quantity of hazardous waste combusted, both onsite and offsite, is tracked biannually by USEPA. However, the composition of this waste is not reported; therefore, assumptions must be made regarding which of these wastes are expected to contain mercury and the concentration of mercury in the wastes.

Approximately 1,800,000 tons per year of hazardous waste are combusted in commercial combustion units, based on data from 1993 (USEPA 2000b); additional waste is combusted in onsite (captive and noncommercial) units. Extremely rough estimates can be made regarding the quantity of mercury present in these wastes. Specifically, by accounting only for three hazardous waste types that are known to contain mercury, and ignoring the mercury content of other waste types, the total quantity of these wastes combusted is 58,000 tons in 1995 (USEPA 1998b). These wastes were probably combusted because they contained organic constituents in addition to mercury. The concentration of mercury in these types of wastes can hypothetically range from less than 1 part per million to 100 percent, although such high mercury wastes are typically not incinerated.



Source: Mercury Consumption: Estimated using USEPA (1998b) and USEPA (1998d).
Mercury Release and Recycling: Estimated using EPA Mercury Study Report to Congress (1997a).

Exhibit 6-1. Mercury in Hazardous Waste Combustion

Based on data from a separate and less comprehensive survey of hazardous waste treatment operations, an estimate for the quantity of mercury in mercury-containing wastes can be made. Over one hundred waste treaters (not all of them conducting combustion) provided data regarding the average composition of their wastes. Mercury composition data for wastes being combusted was extracted from this data set. The concentration of mercury ranged from not detected (or not reported) to 18 mg/kg, with the median concentration below 1 mg/kg (USEPA 1998d). Applying this high concentration of 18 mg/kg to the 58,000 tons of mercury-containing waste results in approximately 1 ton of mercury in the raw material feed. This estimate has significant uncertainty. It may be biased low because other wastes that may contain mercury in low concentrations are not accounted for. It may also be biased high because the highest reported concentration is used as representative of all wastes. Finally, the inherent variability of mercury composition in hazardous wastes prevents an accurate accounting.

Releases

Air releases from hazardous waste combustion are estimated as 7.1 tons of mercury in 1995 (USEPA 1997a). Mercury releases to other media are not known. It can be assumed that all of the mercury in the waste is vaporized during combustion. Potential releases include the collection of mercury in air pollution control devices for subsequent disposal.

6.1.3 Discussion

While the quantities of hazardous waste combusted are carefully tracked by USEPA, the quantity of mercury in these wastes is largely unknown. The imbalance in the input and output of mercury from hazardous waste combustion is the result of using two different sources of estimates.

6.2 Crematories

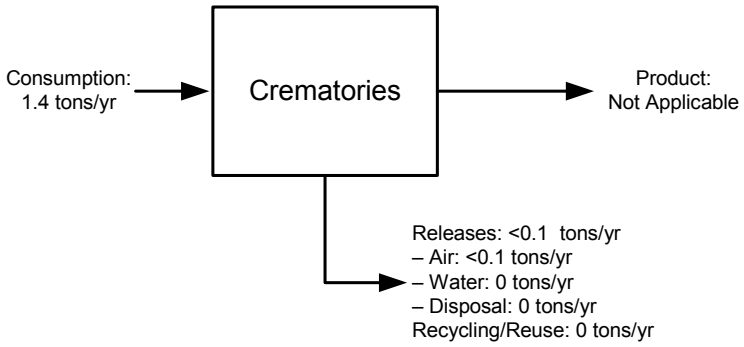
6.2.1 Introduction

This section focuses on crematories, i.e. establishments that cremate human corpses. Facilities may fall under the following SIC or NAICS codes.

SIC Code 7261: Funeral Service And Crematories

NAICS Codes 81222: Cemeteries and Crematories

Cremation is the process of reducing a body to ash and bone fragments through the process of high heat. Mercury associated with crematories comes from the volatilization of amalgam tooth fillings that contain approximately 50 percent mercury. The combustion of fillings results in the vaporization of much of the contained mercury and its release to the atmosphere, from which it is ultimately deposited in soil or into bodies of water.



Source: Mercury Consumption: Extrapolated from USDHHS (1993) and Yoshida (1994).
Mercury Relase and Recycling: Estimated using EPA Mercury Study Report to Congress (1997a).

Exhibit 6-2. Mercury in Crematories.

6.2.2 Materials Flow

Exhibit 6-2 demonstrates the flow of mercury during the cremation process.

Mercury Consumption

Mercury is a component in tooth fillings used to prevent further tooth decay in humans. Amalgam, or "silver filling," is made from fifty percent elemental liquid mercury, thirty-five percent silver and fifteen percent tin, or tin mixed with copper, and sometimes small amounts of zinc, palladium, or indium (Kennedy 1996). The filling is placed in the cavity of a tooth after a dentist drills out decay. A Japanese study showed that the mercury content per amalgam filling is 0.6 grams (Yoshida 1994). From 1971-74, U.S. adults 18 to 74 years old had an estimated average of 6.9 filled teeth, but since 1979, amalgam use has decreased 38 percent (USDHHS 1993). Assuming the average number of cavities per person has similarly decreased, the 4.3 fillings per person results in 1.4 tons (1260 kg) of mercury in the teeth of the 488,224 people cremated in the U.S. in 1995.

Air Releases

There were 488,224 cremations in the United States during 1995. Mercury emissions from a body during cremation range from 3.84×10^{-8} to 1.46×10^{-6} kilograms (8.45×10^{-8} to 3.21×10^{-6} pounds). The average emission is 0.94×10^{-6} kilograms per body (2.06×10^{-6} pounds per body), resulting in 0.46 kilograms (5.1×10^{-4} tons, or 1 pound) of mercury emissions from cremation in 1995 (USEPA 1997a).

Solid Waste Releases

Cremated remains are the noncombustible bone fragments. No data were available for mercury concentration in remains.

6.2.3 Discussion

Differences between the input and output could be accounted for in several ways. Only one set of data were used to determine the average quantity of mercury emitted during a cremation (USEPA 1997a). The data are inconsistent with previous literature. For instance, previous USEPA research indicated that, on average, 1 gram of mercury is emitted during a cremation, but that estimate was based on European data that may not accurately reflect U.S. dental practices and thus is somewhat uncertain (Massachusetts 1996). Using 1 gram per body results in 1,076 pounds per year (or 0.5 tons per year). In addition, an estimated 40 pounds of mercury were released via cremation in Michigan in 1994 (M2P2 1996). Using cremation emissions in Michigan as a per capita average emission rate for the total U.S. population (USDOC 2001) results in 1,100 pounds or 0.6 tons per year of mercury as an air release across the country. This supports the hypothesis that temperatures in a crematory (1400-1800 ^{o}F) are high enough to combust all the mercury, which boils at 674 ^{o}F.

Mercury vapors are constantly emitted from fillings. However, since the average daily intake for a person with fillings is 1.24 micrograms of mercury (USDHHS 1993), the amount of mercury “lost” before cremation is

minuscule.

No information regarding pollution control or other actions that have been taken to address mercury emissions from crematoria. While control devices are present on stacks, no information regarding mercury capture is available.

6.3 Sewage Treatment and Sludge Incineration

POTWs are likely to be included under the following SIC and NAICS codes:

SIC Code 4952: Sewerage systems

NAICS Code 221320: Sewage Treatment Facilities

6.3.1 Introduction

Publicly owned treatment works (POTWs) accept and treat wastewaters from domestic and industrial operations. Mercury may enter these wastewaters from the sources listed in this report. Additionally, mercury emitted to the air may ultimately deposit and be present in stormwater discharged to the treatment plant.

The sewage treatment process includes the following steps: (1) collection of wastewater for centralized treatment; (2) treatment of the wastewater through processes including filtration, biological treatment, and clarification; are (3) discharge of treated wastewater to a surface water. The sludge generated may be managed by land treatment (e.g., in designated treatment areas or as use on public or private lands for soil enrichment purposes) or by incineration.

6.3.2 Materials Flow

Exhibit 6-3 illustrates the flow of mercury in sewage treatment, accounting for management of sludge by both incineration and land disposal or land application.

Mercury Consumption

Due to the varied sources of mercury potentially present in waters influent to a POTW, it is impossible to identify the quantity of mercury entering such a facility without monitoring data. Monitoring data for industrial facilities discharging to a POTW are sometimes available for mercury; however, the lack of automation for these data in a national framework makes the data extremely cumbersome to use for the many industrial sources. Due to these data limitations, an estimate of the quantity of mercury entering POTWs on a national level was developed from the quantity of mercury released from POTWs.

Water Releases

The Permit Compliance System (PCS) identifies monitoring data for facilities with NPDES permits (i.e., those that discharge to a surface water). The PCS was searched for monitoring data relevant to mercury which, depending on the facility-specific permit, may be present in the database in a number of forms such as total, dissolved, etc. Furthermore, the search was limited to those facilities identified in SIC code 4952 (as identified above, such facilities conduct sewage treatment). Using the calculation procedure below, it is estimated that 5.5 tons of mercury were released to water.

Data were available from PCS for approximately 700 facilities that reported monitoring data for mercury in 1997. While there are several different forms of mercury presented in the database, two forms were predominant: "total mercury" and "total recoverable mercury." In compiling the data, the most complete, recent year's data were used for each facility. In most cases this was 2000 or 2001, but in some cases 1999 represented the most complete monitoring for mercury. For each facility, a calculation was done to develop a single average value.

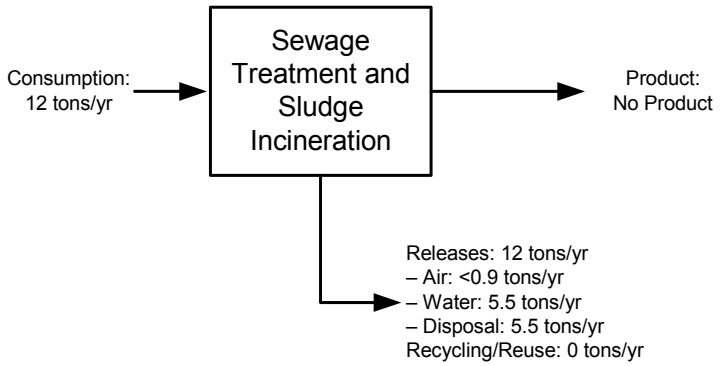
PCS presents data as concentrations (e.g., ppm) as well as quantity loadings (e.g., lbs. per day). Quantity loadings were used preferentially; when not available, the average concentration was multiplied by the facilities permitted flow rate (which overestimates releases).

In measuring mercury, many facilities report non-detect values. These are handled in two different ways: the concentration is assumed to be zero when the facility did not detect mercury at anytime during the year. If at least one measurement was detected, then non-detect values were assumed to be one-half of the detection limit.

The following uncertainties apply to the above estimate:

- Data are only available for facilities actually monitoring for mercury. There may be instances where additional facilities are discharging mercury but are not recorded in PCS.

- Facilities do not conduct continuous monitoring for mercury. These loadings may be calculated from as little as a single data point collected during the year. Therefore, the collected data may not necessarily be representative of the actual discharges.



Source: Mercury Consumption: Estimated from releases.
Mercury Release and Recycling: Water and disposal releases estimated from 1999–2001 PCS data, and EPA (1985) sludge partitioning data. Air releases from USEPA (1997a).

Exhibit 6-3. Mercury Flow in Sewage Treatment

- Data in PCS may, in some cases, be incorrect due to entry errors. In developing the U.S. estimate, particular attention was given to double checking facilities with significant impacts on the results.

Air Releases

Potential sources of air releases are from the wastewater treatment itself, and the incineration of the sludge generated from treatment. No estimates are available for fugitive air emissions from the sewage treatment plant; the release of mercury is likely to be much less than the release of mercury from incineration. The results from USEPA (1985) indicate that a very small percentage of mercury volatilizes during treatment (this source is explained in greater detail below). Estimates are available from the incineration of the treatment sludge, however. A total of 0.94 tons of mercury are estimated to be released to air from incineration (USEPA 1997a). This estimate is calculated from the estimated quantity of sludge incinerated in a year, average emission factor for various types of combustion and air pollution control units, and distributions of the type of combustion units and air pollution control units.

Solid Waste Releases

Potential sources of solid waste releases (releases to land) result from the disposal of the generated sludge and disposal of any ash or air pollution control wastes generated from combustion of the sludge. Estimates regarding mercury in air pollution control residues are not available. The data in USEPA (1997a) did not indicate the efficiency associated with various control devices for sewage sludge incineration.

The quantity of mercury in sewage sludge can be roughly estimated based on the results of an USEPA study from the 1980s (USEPA 1985). As part of this study, removal efficiencies of various contaminants were estimated using data from 40 POTWs as well as from other sources (e.g., USEPA research projects). Mercury was estimated to partition 50 percent to sludge and 50 percent to released effluent, with negligible air emissions. Applying this percentage to the present-day data, it can be estimated that 5.5 tons of mercury are present in sludge. This quantity is assumed to be land disposed directly or remain in air pollution control residues for incineration.

The use of the 50 percent figure likely represents an average value of various systems applicable at the time of the study. There is probably variation in mercury partitioning on a facility-specific basis.

6.3.3 Discussion

As discussed above, estimates for mercury loading to water were available using PCS. Using these data, loadings to solid waste disposal were subsequently estimated. Releases to air were available from a second source. No data are available regarding the loading of mercury to POTWs. This necessitated the 'back calculation' of this quantity using the release data, and could not serve as a check for the accuracy of the release data.

To better support the estimate, additional research could be conducted regarding the PCS data used for the water release estimate. This could include determining the portion of POTWs represented by the data set, verification of the loadings calculations, and better assessing the influence of non-detect values on the calculations.

6.4 Municipal Waste Combustion

6.4.1 Introduction

USEPA has estimated that in 1995 approximately 80 percent of municipal solid waste is landfilled and 20 percent is combusted (this excludes material removed from the wastestream for recycling) (USEPA 1997c). In previous sections of this report, this partitioning was used to estimate the quantity of a particular product (e.g., fluorescent lamps) that was eventually released as a solid waste (i.e., sent to a landfill) and that which is emitted as an air release (i.e., sent to a combustion unit).

6.4.2 Materials Flow

Municipal waste combustors were estimated to emit 30 tons of mercury in 1995 (USEPA 1997a). Mercury is present in the municipal solid wastes that are burned in these units, such as from consumer products. Subsequently, mercury may also be present in the bottom ash (noncombustible) residue, in air pollution control wastes such as collected fly ash, or in the stack gas emitted to the atmosphere.

The quantity of mercury emitted to the air during combustion is estimated to be decreasing. This is due to the decrease of mercury-containing products in municipal solid waste (due to both source reduction and recycling) and the implementation of state and federal laws to control air emissions from municipal waste combustion units. For example, final emission standards have been promulgated for "large" municipal waste combustors in 1995 (60 Federal Register 65387; December 19, 1995) and proposed for "small" units in 1999 (64 Federal Register 47233; August 30, 1999), as discussed in http://www.epa.gov/ttn/atw/129/mwc/rimwc2.html. In both cases, mercury is one of the contaminants addressed in the regulations.

The quantity of mercury estimated to be present in incoming wastes to a municipal solid waste combustion unit can be developed from examination of the data presented in Chapter 3 of this report. Specifically, a total of 13 to 21 tons of mercury in the products were assumed to enter a combustion unit as part of municipal solid waste. Finding alternative methods of estimating the quantities of mercury present in incoming wastes is difficult due to its heterogenous nature. Furthermore, while this report estimates that 13 to 21 tons per year may enter municipal waste combustion units nationwide, no estimate is presented regarding the quantity that is eventually released to the air, to the land (as pollution control waste), or sent for mercury recovery (if any).

6.4.3 Discussion

Data regarding the mercury content of ash are available from characterization studies of the late 1980s and early 1990s. However, such data may not be representative of present-day ash. This is due to changes in the mercury composition of municipal solid waste, as well as revised control technologies in place since the 1995 air rules.

Various control technologies are available for controlling mercury emissions. In response to the new air regulations, such controls are likely to be added or optimized. Such controls include removal of mercury entrained on ash in particulate collection devices (USEPA 1997a), and the control of vapor through activated carbon (Krishnan 1994).

6.5 Landfills

6.5.1 Introduction

As mentioned throughout this report, a variety of mercury-containing wastes are disposed on the land. This includes industrial wastes (e.g., from manufacturing processes where mercury is used), air pollution control wastes (e.g., where mercury is present in the influent fossil fuel or ore), and municipal solid wastes (e.g., where mercury is present in consumer products. These materials can be disposed in industrial waste landfills, municipal solid waste landfills, and hazardous waste landfills. Much of the mercury containing waste described in this report may be managed with general household trash, which may be combusted or landfilled.

6.5.2 Materials Flow

Mercury may be re-released from these landfills in the form of air emissions, runoff, and leachate. An estimated 0.08 tons of mercury is emitted in air releases from municipal solid waste landfills (USEPA 1997a). This is a small quantity in comparison to the total quantity of mercury disposed to land. It is also small in comparison to other air releases.

6.5.3 Discussion

All instances of landfill disposal were discussed previously in this report as part of individual products or processes involving mercury. These estimates are not presented here in order to avoid "double counting" of such sources.

6.6 Medical Waste Incineration

6.6.1 Materials Flow

There are an estimated 7,000 hospitals in the U.S. with approximately 34% operating their own incinerator (62 FR 48347; September 15, 1997). Sources vary with respect to the amount of waste hospitals generate annually. High-end estimates indicate 2 million tons of waste is generated (Citizens for Environmental Health 2002) while another projection suggests the level may be as low as 600,000 tons (Valenti 2000). USEPA (1997a) estimated that the quantity of mercury emitted to the air from this source is 16.0 tons per year in the 1994 to 1995 time-frame. Since that estimate was made, USEPA published a final rule relevant to the control of mercury and other emissions from this source category (62 FR 48347; September 15, 1997).

6.6.2 Discussion

Several pollution prevention activities are underway for the reduction of mercury in the medical field, which should reduce the amount of mercury fed into medical waste incineration. For example, a Memorandum of Understanding was developed between the American Hospital Association and USEPA on June 25, 1998. This memorandum discusses the elimination of mercury in hospital wastes (AHA 1998).

Chapter 7
Geographic Distribution of Mercury

7.1 Purpose

In previous chapters, data were presented to show how product and industrial sectors use and release mercury in the U.S. on a national basis. That profile, or Materials Flow Analysis (MFA), shows the flow of mercury through the U.S. economy and released into the environment. The data obtained from the MFA can be used to target sectors that emit the largest quantities of mercury throughout their product lifecycle.

In conjunction with quantifying mercury use and release on an industry-specific basis, this chapter presents data geographically. Specifically, the releases from all industries are identified for each State and for selected local regions. This analysis allows for the targeting of specific areas of the country in which the largest quantities of mercury are released. The profile is useful in identifying local, regional, and national importance of mercury activity.

7.2 Data Sources and Limitations

Exhibit 7-1 lists the data sources presented in this chapter that allow for regional distinctions. Exhibit 7-1 includes many of the same data sources used for estimating the materials flow of mercury on a national level. However, not all of the data sources discussed earlier in this report are presented in Exhibit 7-1. In most cases, this is because insufficient information is available to allow for adequate treatment below the national level. For example, the estimation of releases of mercury from lighting use is dependent on data regarding lamp sales at the national level. Since state-level sales data are not available for these and other products, it is not possible to estimate the geographic distribution of mercury use and release from this particular source.

An important limitation with a geographic presentation of data is that a single complete geographic distribution cannot be presented. This is because the analysis uses multiple data sources which vary in scope and objective. For example, TRI data present multimedia releases of mercury but omit a significant number of facilities known to release mercury. Alternatively, the 1996 National Toxics Inventory (NTI), while somewhat dated, presents a more complete geographic description of mercury releases to air but it is not possible to identify the degree of overlap with other data sources because not all of the data are facility-specific. It is very difficult to combine these different data sets into a single presentation to identify a 'single' release estimate for a particular locality.

A second limitation of presenting data by geographic region is that the release estimates cannot be 'rolled up' to identify national estimates of flow and release. Using TRI as an example, the data provide differing levels of coverage depending on the industry and therefore estimates are made using different data sources from one industry to the next. In addition, as mentioned previously, estimates used for national estimates such as lighting sales data do not have a local component.

Each source identified in Exhibit 7-1 is described in detail below, with descriptions of the availability, completeness, and quality of the data source. Data from each source are presented later in this chapter.

7.2.1 Toxics Release Inventory

TRI provides facility-specific environmental data for mercury, mercury compounds (this category does not distinguish between the type of compound), and other chemicals. The data include releases to air, water, land, and solid waste. TRI does not require all facilities that emit mercury to report emissions; a facility only reports emissions if it meets thresholds set by the TRI program. Data are provided annually (the most recent data are for 1999) through Envirofacts (http://www.epa.gov/enviro/html/tris/). Limitations of the data are that, as discussed above, not all facilities

Exhibit 7-1. List of Data Sources For Geographic Distribution of Mercury

Data Source	Media	Description
Toxics Release Inventory (TRI)	Multimedia	U.S. EPA data from 1999 for approximately 80 facilities where relatively large quantities of mercury are present during a year.
National Toxics Inventory (NTI)	Air	U.S. EPA data from 1996 identifying mercury releases for virtually all U.S. counties.
National Response Center Database (NRC)	Spills	Data for accidental releases of about 100 materials identified as containing mercury as a primary component in 2000.
U.S. EPA Utility Information Collection Request	Air	Data collected by EPA in 1999 and extrapolated to each of the approximately 450 U.S. coal-fired power generation facilities.
National Fish and Wildlife Fish Consumption Advisories	Environment	Identification of all existing and news wildlife advisories in 2000 where mercury is identified as the reason for the advisory.

are required to report mercury or are required to identify releases from all mercury-related activities. In addition, the data reported by the facilities themselves are of varying quality, being either estimates or measured results.

7.2.2 National Toxics Inventory (NTI) Data

The NTI database provides air release information for mercury as well as for other chemicals. The inventory contains estimates of emissions from major, area, and mobile source categories. The database is different from TRI in that no specific reporting threshold is included in the inventory. Larger sources are identified by facility and smaller sources (e.g., gasoline stations) are grouped as area sources and categorized both by industry and location. Major and area sources both are stationary sources differing in their potential to release air toxics (as well as differing in their regulatory requirements and the availability of data). Mobile sources include highway traffic, aircraft, etc. The data are updated every three years and the latest data available are from the 1996 inventory. The 1996 inventory incorporates information collected from states, TRI data, other EPA information, and estimation procedures. The data are available from EPA's web site (http://www.epa.gov/ttn/chief/net/index.html).

7.2.3 National Response Center Database

The National Response Center (NRC) manages the reporting of all chemical and fuel spills (or other accidental releases) in the U.S., consolidating and simplifying reporting required by many legislative statutes. Facilities are required to report spills or accidental releases if they are subject to certain statutes, such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). These requirements generally require the reporting of spills greater than certain quantities although in reviewing the data for 2000 there is a wide range in the quantities reported. The data are continuously updated with the most recent whole-year data available for 2000. The data are available as data files from the National Response Center's Internet site (http://www.nrc.uscg.mil/index.htm).

These data were reviewed for spills involving mercury. Identifying quantities from this data source is problematic for a number of reasons. First, the data collected by NRC are based on preliminary information, and therefore quantities reported may be subject to error. In other instances the quantity of mercury spilled is not known. For this reason, data regarding the number of incidents are expected to provide a better indication of accidental mercury releases than the quantities reported.

7.2.4 National Listing of Fish and Wildlife Consumption Advisories

EPA collects advisory information from states regarding the consumption of fish by general and sensitive populations.

This data source is unique among the others identified in this chapter because it identifies mercury in the environment, rather than from the source. In this instance, it is impossible to know the source of the mercury. Data on mercury advisories are available from fact sheets from EPA's web site (http://www.epa.gov/waterscience/fish/).

A principal limitation of using the fish advisory data is in reaching conclusions. Because there are many species, waterways, and potential contaminants, a state is limited by the extent of sampling it can conduct. Therefore, differences in the number of fish advisories from one year to the next, or from one state to another, may simply be the result of differences in the number of assessments conducted or the sampling and analysis techniques employed.

7.2.5 U.S. EPA Information Collection Request

EPA has collected extensive data regarding the mercury emissions of coal-fired power plants and the mercury content of coals used at coal-fired power plants. These data were collected in 1999 and 2000 for a one-time data collection effort. These data are extremely useful because they can characterize the use and emissions of mercury from all coal-fired boilers in the 1999 timeframe. Data from this effort are available from EPA (http://www.epa.gov/ttnatw01/combust/utiltox/utoxpg.html).

Data regarding the mercury content of coals, coal usage, and boiler characteristics were collected from all coal-fired power plants. More comprehensive air sampling data were collected from 10 to 20 percent of the facilities, which EPA statistically extrapolated to the population as a whole. The air sampling activity included quantifying total mercury emissions as well as the species emitted.

7.3 Findings

The data gathered from the above sources were used to map the releases of mercury in the United States. Each data source provides estimates of the overall quantity of mercury emitted. The resulting data maps can be used to identify local and regional hotspots of mercury emissions. Examination of the maps allow researchers to identify which local and regional areas of the country emit the largest quantities of mercury. In addition, the map will assist in determining which areas of the country produce mercury of global concern.

7.3.1 State-Level Maps

Each of the five data sources discussed above were used to generate data for mercury at the State level. Data for each parameter identified in Exhibit 7-1 were aggregated for each state and plotted on a map of the U.S. using a simple spreadsheet. The results are presented in Exhibits 7-2 through 7-8.

Exhibits 7-2 and 7-3 present 1999 TRI data for multimedia releases and air releases, respectively, for facilities reporting for both 'mercury' and 'mercury compounds.'

Exhibit 7-2 sums all quantities of mercury reported to be released. The predominance of releases are from the Eastern states. Many States have no facilities reporting mercury releases. The only Western states that had significant emissions according to TRI was Nevada and Arizona. The Nevada emissions are mostly due to gold and copper mining in the state, and represent by far the highest emissions.

In the context of TRI, release refers to virtually any quantity of mercury entering the environment in any form, regardless of the potential risk posed or the media impacted. Therefore, for a more comparable analysis of TRI data and to facilitate comparisons with other data sources, Exhibit 7-3 presents data for air releases only. Again, Nevada leads the States for air releases of mercury.

Exhibits 7-4 and 7-5 present NTI data. Exhibit 7-4 presents total mercury air releases for each State while Exhibit 7-5 presents emission density (i.e., emissions per square mile) for each state. While related, there are some differences. For example, small mid-Atlantic States with moderate emissions have extremely high emission densities, while some larger Western States with low emissions have even lower emission densities.

The NTI map shows the highest emissions and concentration of mercury occur in the Midwest and Eastern United States. The density of mercury are highest in the following states: Delaware, Maryland, Massachusetts, New Jersey, and Rhone Island (*Appendix B*). However, the overall top five state mercury emitters are Texas, Florida, New York, Pennsylvania, and Indiana.

Exhibit 7-2. Total Mercury Releases by State (1999 TRI)

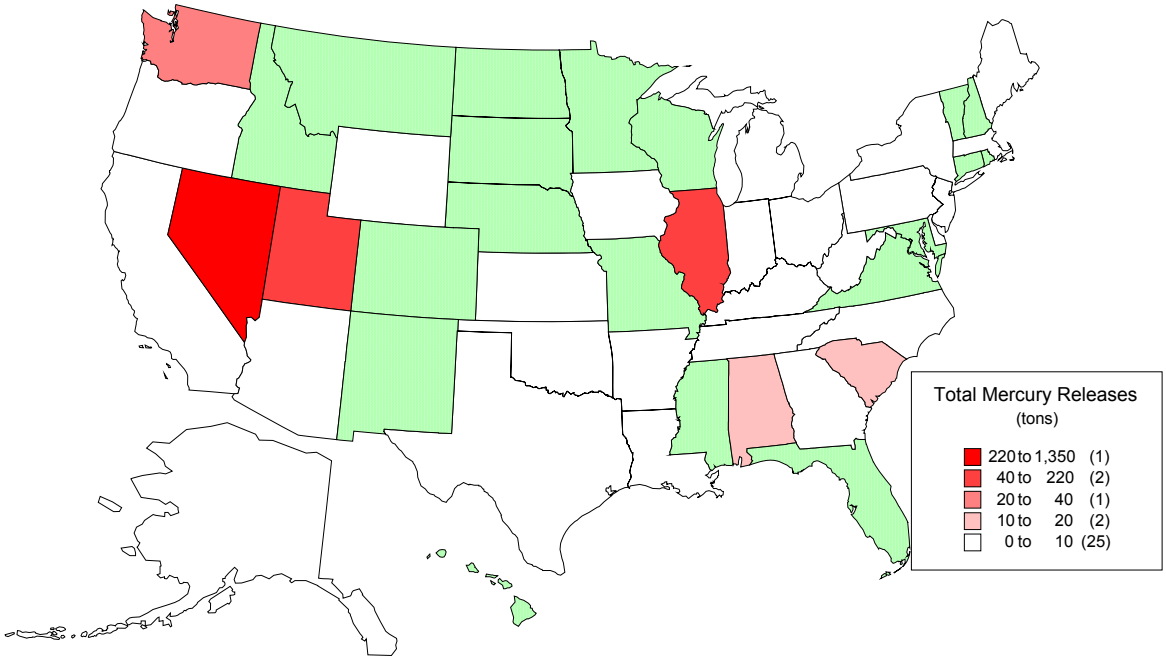
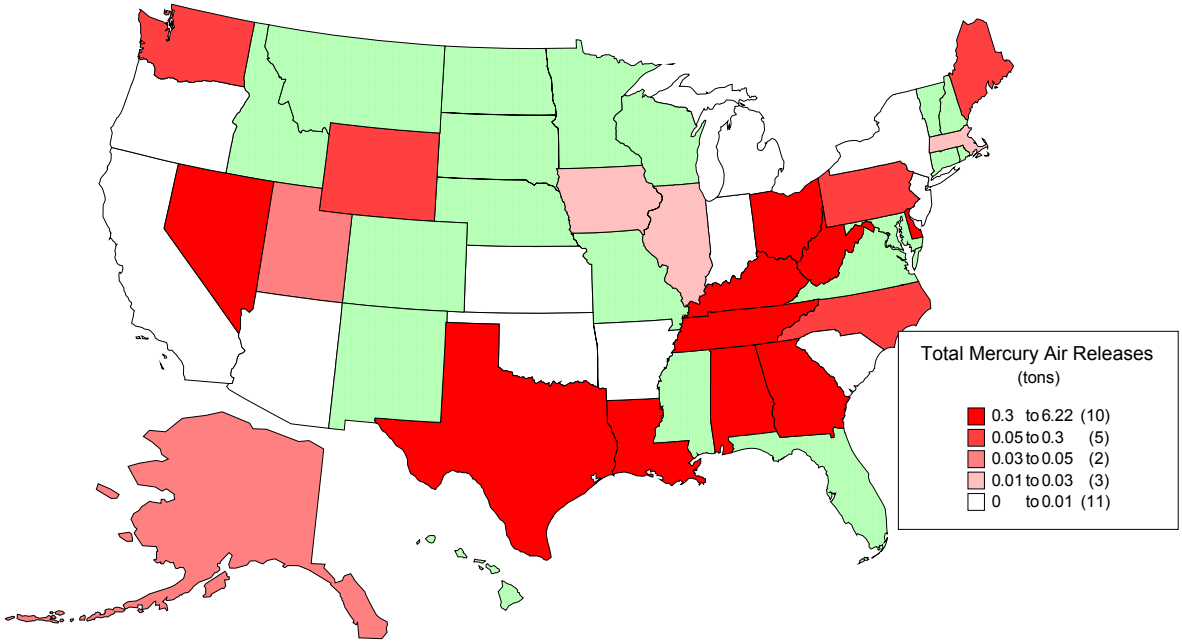


Exhibit 7-3. Total Mercury Air Releases by State (1999 TRI)



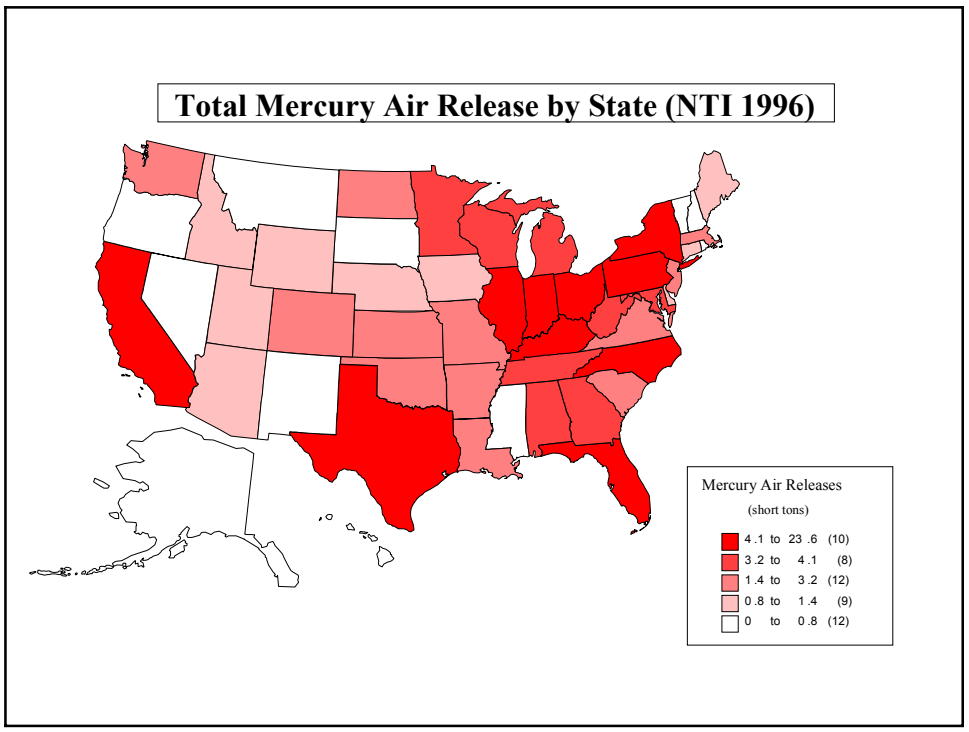


Exhibit 7-4. Total Mercury Air Releases by State (NTI 1996)

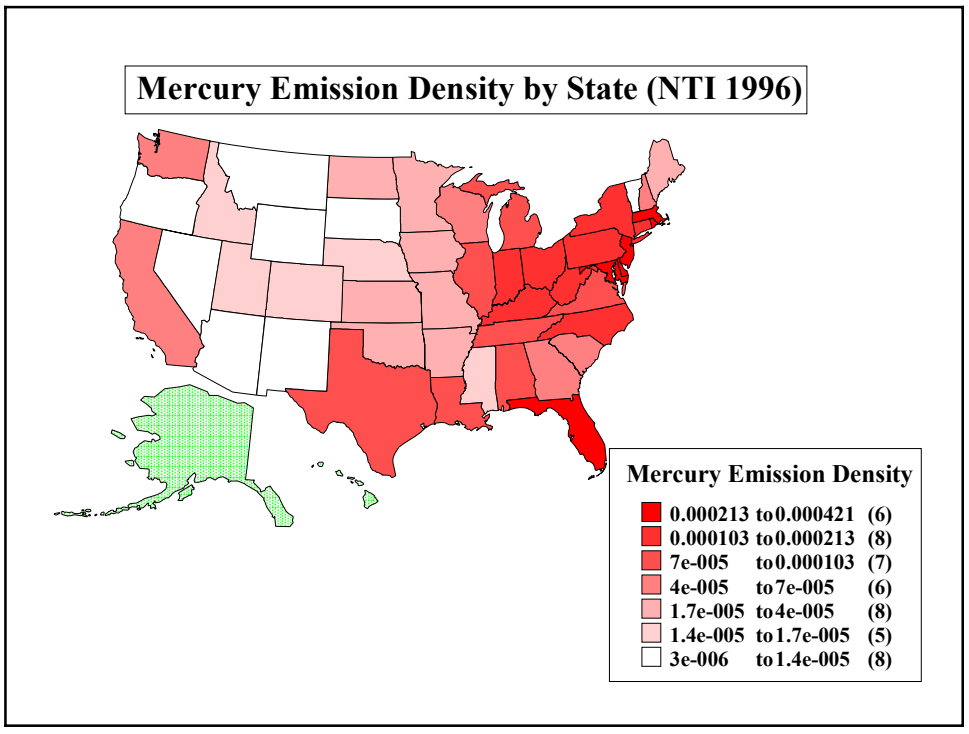


Exhibit 7-5. Mercury Emission Density By State (NTI 1996)

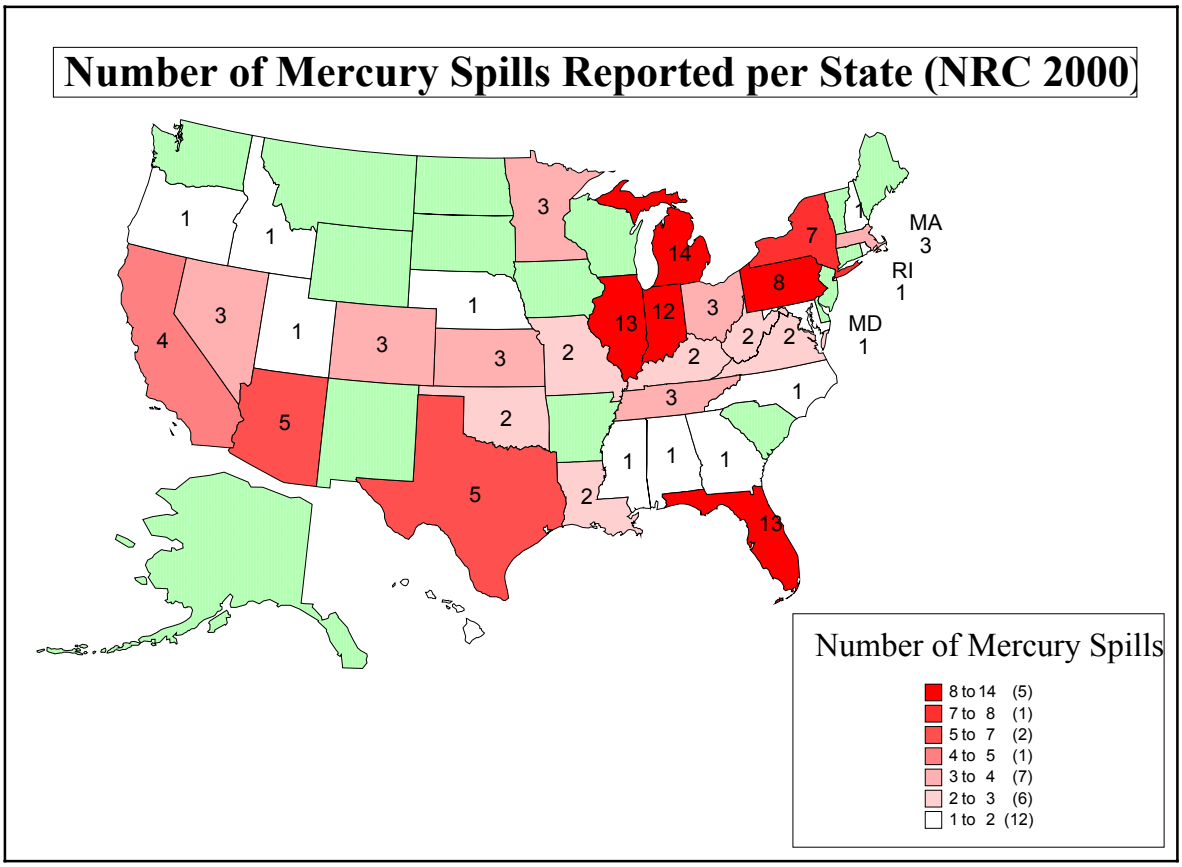


Exhibit 7-6. Number of Mercury Spills Reported per State (NRC, 2000)

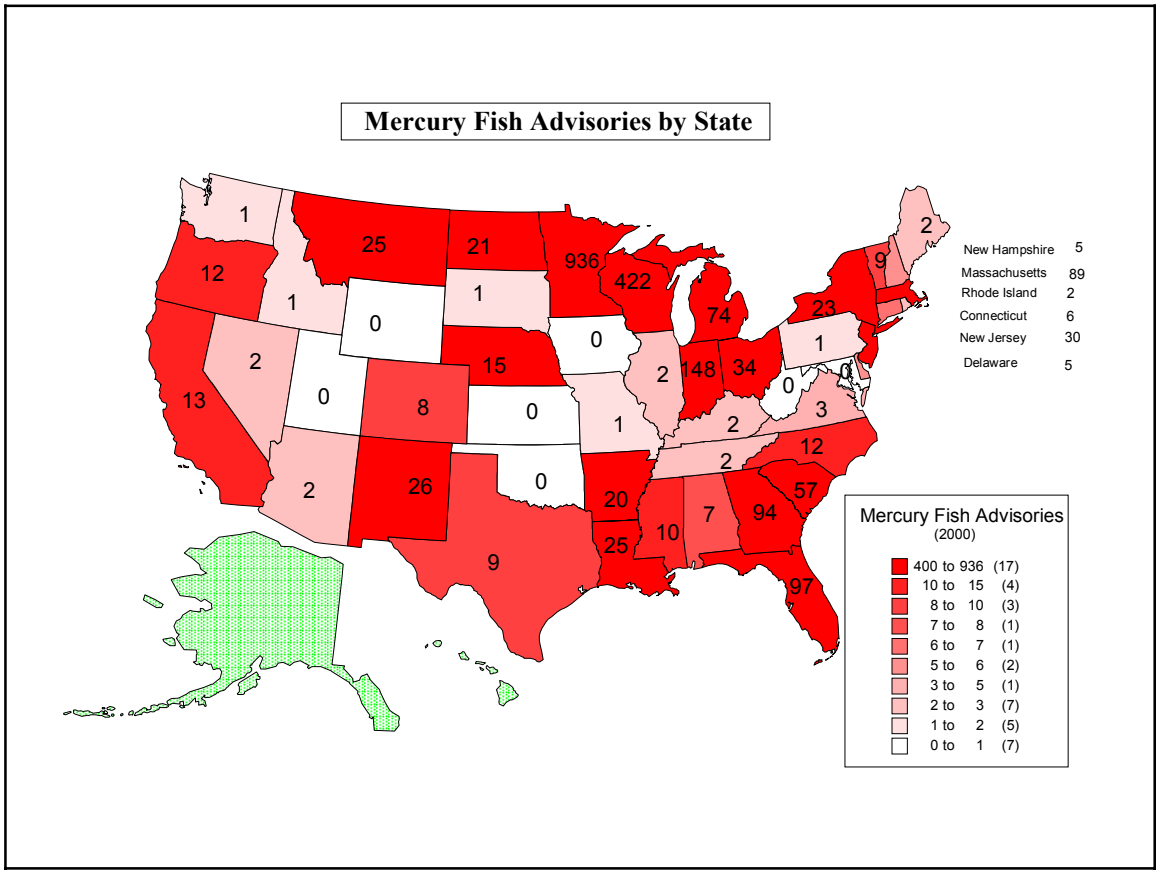


Exhibit 7-7. Mercury Fish Advisories By State

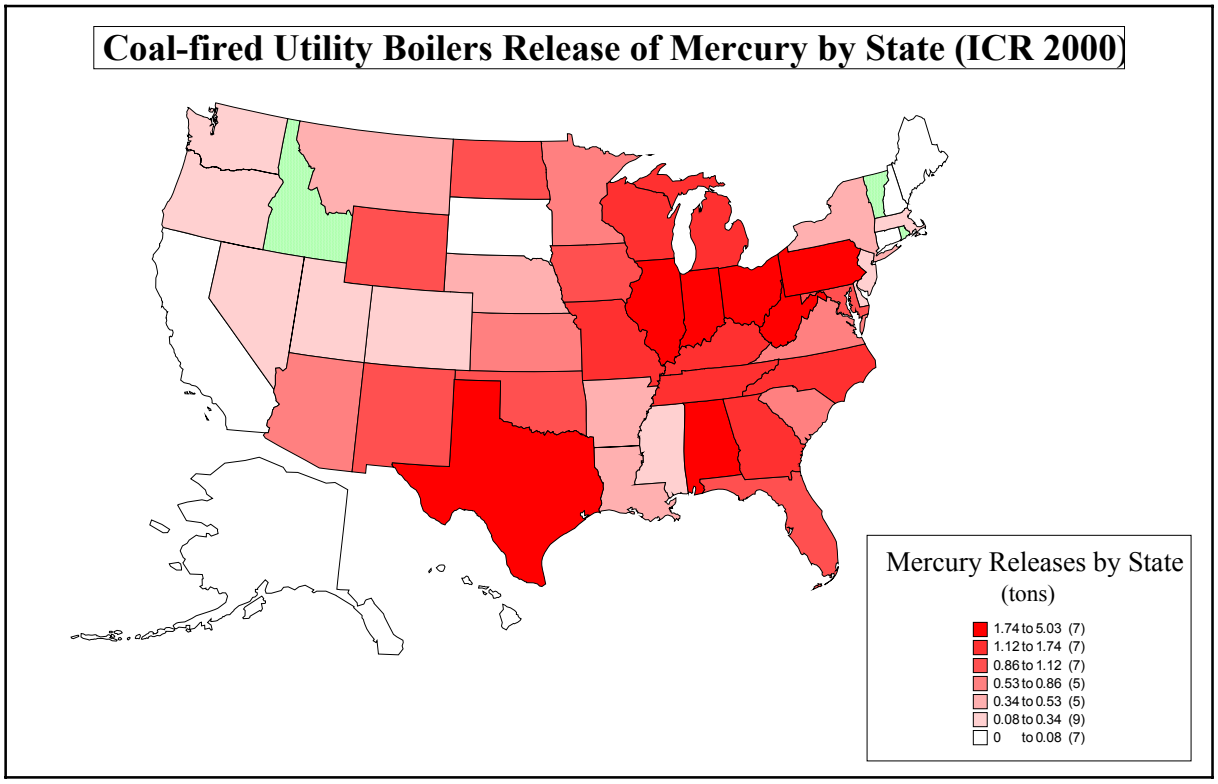


Exhibit 7-8. Coal-fired Utility Boilers Releases of Mercury per State

The NTI results are consistent with the TRI data in that mercury releases are concentrated in the Eastern States, whether measured by total emissions or emission density. However, two important deviations exist. Most significantly Nevada is identified from the NTI data as having virtually no releases, while it was a nationwide leader for TRI air emissions. This is likely due to the differences in the age of the data. NTI data are from 1996 when estimates for releasing mercury from mining activity were less available. A second observation with the NTI data is that estimates are provided for all States in the continental U.S., versus much less complete coverage from the TRI.

Exhibit 7-6 presents data for spills from the NRC over the course of a year (2000). Even in the states with the highest number of spills, the rate is just over once per month in the entire State, which is not an abnormally high occurrence. As stated previously, data for spill quantities are not expected to provide useful information and therefore were not analyzed. Therefore, on the whole, data from the NRC do not suggest that spills of mercury containing materials are particularly problematic for any State.

Exhibit 7-7 presents the number of fish advisories for each state in 2000. Advisories are highly clustered around the Great Lakes and in general are not well correlated with releases in a State. For example, of the ten States identified from Exhibit 7-4 as having the highest airborne mercury releases from NTI, only three (Indiana, Ohio, and Florida) are identified as having the highest number of fish advisories. This information can be interpreted in several ways. Some states may be more diligent in their monitoring and advisory efforts than others, or it may reflect the fact that mercury emitted from one location can be transported to another.

Exhibit 7-8 presents air emissions data from coal-fired utilities. With a few exceptions, these data provide an excellent correlation with air release data from TRI. Releases in the Appalachian and Great Lakes states and Texas are similar for both the NTI data and the coal-fired utility data. Significant exceptions include California and the Northeast.

7.3.2 County-Level Data

Only three of the data sources identified above were evaluated below the aggregate State level: TRI, NTI, and coal-fired utility emissions (ICR).

For this analysis, county level data were used as a reasonable aggregate of a local area: data below this level (e.g., ZIP codes) would be expected to be too 'noisy,' while data above this level (e.g., Congressional District or Regional area) would be too difficult to generate. NRC and Fish advisory data were not evaluated below the State level. The small number of spills in each State would not be expected to be informative at the County level. For fish advisories, data would be too cumbersome to analyze when dealing with bodies of water that transverse multiple counties.

County level data for NTI are presented in Exhibit 7-9. NTI was expected to be the most informative for evaluation at the county level because of the large number of data points. Exhibit 7-9 presents emission densities at the county level. As expected, variations are seen within each state. Sometimes higher emission densities are consistent with higher population densities, as seen near cities. In other cases, high emission densities outside of population centers are the result of a small number of significant point source emissions.

Exhibits 7-10 through 7-12 present tabular data of the 25 counties from each data source where mercury emissions are highest. In the case of the NTI and ICR data sources, the top 25 counties represent about one-third of all air emissions from all counties. For TRI however, the top 25 counties represent greater than 99 percent of the nationwide emissions. This is a further result of the relatively low number of data points available from the TRI for 1999. Additionally, Table 7-12 shows that two Nevada counties account for a disproportionate amount of releases, due to mining activities.

7.3.3 Integration of County-Level Data

County-level data for TRI, NTI, and coal-fired boilers were aggregated in an attempt to better draw conclusions from all of the data sources. The maps in Exhibits 7-2 through 7-8 allow for comparisons at the State level. However, such a visual comparison is impossible for the thousands of counties in the U.S. A quick comparison of Exhibits 7-10 through 7-12 ('top 25' counties for each data source) shows very few counties repeating from one data source to another. For this reason, an analysis was conducted which attempts to combine TRI, NTI, and ICR air release data for each county.

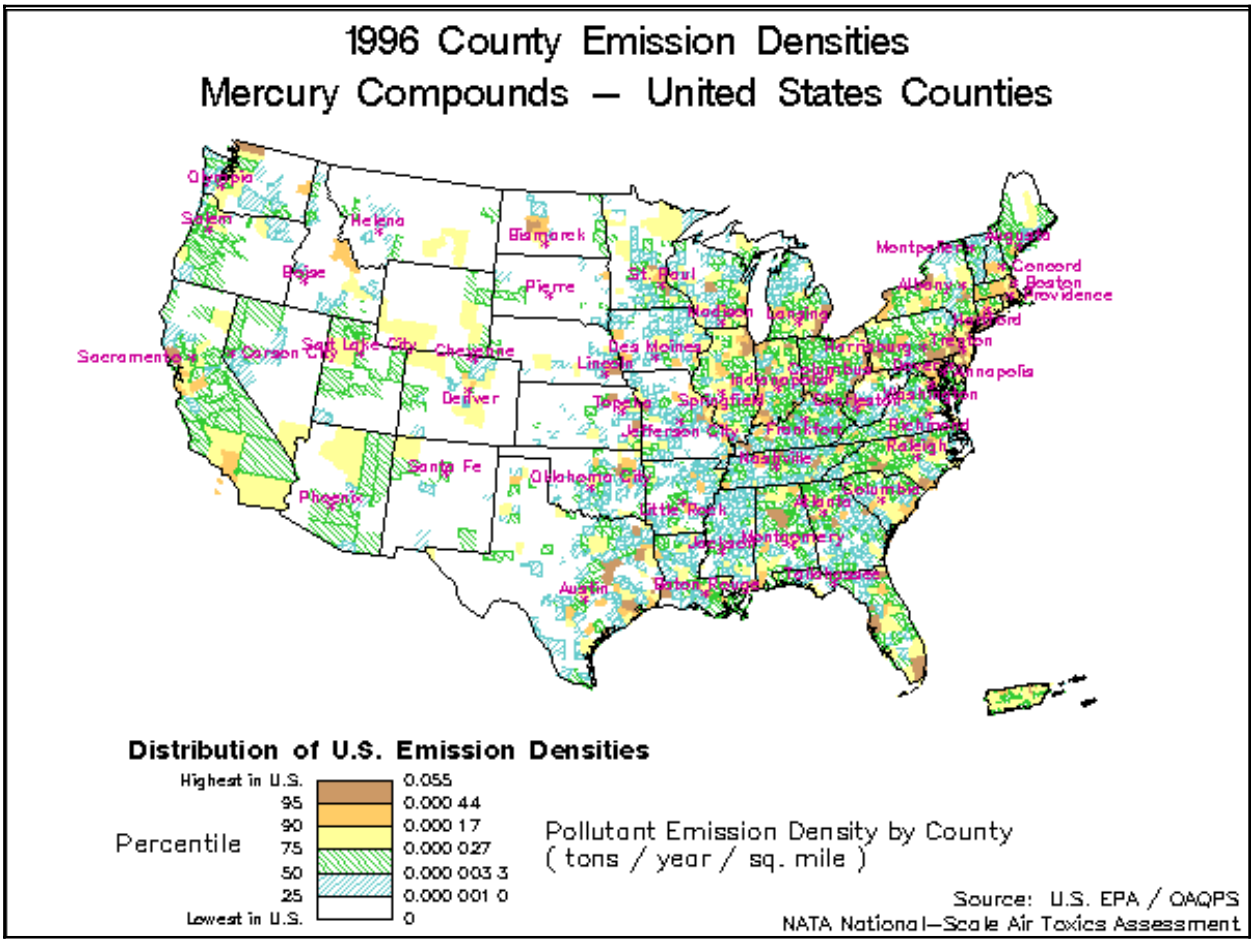


Exhibit 7-9. NTI County Density Map for Mercury Compounds

Table 7-10. 25 Counties Reporting Highest Mercury Air Emissions from NTI

County	State	NTI emissions lb	% of Total NTI Releases
Jasper	TX	24,473	7.51%
Dade	FL	5,846	1.79%
Pinellas	FL	5,683	1.74%
Hillsborough	FL	5,373	1.65%
Westchester	NY	4,472	1.37%
Greene	NY	4,384	1.34%
Noble	IN	3,916	1.20%
Frederick	MD	3,596	1.10%
Whatcom	WA	3,536	1.08%
Broward	FL	3,436	1.05%
Los Angeles	CA	3,296	1.01%
Harris	TX	3,240	0.99%
Cook	IL	3,108	0.95%
Essex	MA	2,939	0.90%
Marshall	KY	2,768	0.85%
Delaware	PA	2,734	0.84%
Grant	WV	2,460	0.75%
Titus	TX	2,452	0.75%
Marion	IN	2,359	0.72%
Fairfax	VA	2,283	0.70%
Rusk	TX	2,277	0.70%
Wood	WI	2,164	0.66%
Tulsa	OK	2,151	0.66%
New York	NY	2,109	0.65%
Calhoun	TX	2,098	0.64%
All Others (3,191 total)		222,873	68.36%
Total		295,707	100%

Table 7-11. 25 Counties Reporting Highest Mercury Air Emissions from Coal-fired Boilers

County	State	ICR Hg total lb	% of Total ICR Releases
Walker	AL	2,490	2.60%
Armstrong	PA	2,154	2.25%
Titus	TX	2,093	2.19%
San Juan	NM	2,089	2.18%
Indiana	PA	1,848	1.93%
Will	IL	1,600	1.67%
Rusk	TX	1,363	1.42%
Montour	PA	1,216	1.27%
Monroe	GA	1,201	1.25%
Jefferson	OH	1,179	1.23%
Tazewell	IL	1,125	1.17%
Kanawha	WV	1,093	1.14%
Mercer	ND	1,057	1.10%
Beaver	PA	1,036	1.08%
Person	NC	1,024	1.07%
Spencer	IN	1,018	1.06%
Gallia	OH	1,011	1.06%
Grant	WV	974	1.02%
Leon	TX	964	1.01%
Mason	WV	963	1.01%
Monroe	MI	936	0.98%
Clearfield	PA	926	0.97%
Coshocton	OH	897	0.94%
Rosebud	MT	891	0.93%
Shelby	AL	877	0.92%
All Others (368 total)		63,747	66.56%
Total		95,772	100%

Table 7-12. 25 Counties Reporting Highest Multimedia TRI Releases

County	State	Multimedia TRI lb	% of Total TRI Releases
Humboldt	NV	1,231,260	36.68%
Elko	NV	1,190,814	35.48%
Tooele	UT	404,140	12.04%
Eureka	NV	220,359	6.57%
St. Clair	IL	81,599	2.43%
Pershing	NV	43,008	1.28%
Whatcom	WA	35,807	1.07%
Salt Lake	UT	32,802	0.98%
Sumter	SC	28,325	0.84%
Sumter	AL	24,841	0.74%
Beaver	PA	15,230	0.45%
Lorain	OH	14,943	0.45%
King	WA	4,458	0.13%
Harris	TX	3,667	0.11%
Porter	IN	2,800	0.08%
Bradley	TN	2,640	0.08%
New Castle	DE	2,172	0.06%
Ashtabula	OH	1,895	0.06%
Platte	WY	1,824	0.05%
Penobscot	ME	1,734	0.05%
Marshall	KY	1,662	0.05%
Iberville	LA	1,512	0.05%
Colbert	AL	1,499	0.04%
Marshall	WV	1,316	0.04%
Richmond	GA	1,268	0.04%
All others (49 total)		4,996	0.15%
Total		3,356,571	100%

Exhibit 7-13. 25 Counties Reporting Highest Releases from 3 Data Sources

County	State	NTI Rank	ICR Rank	Multimedia TRI Rank	Cumulative Rank
Humboldt	NV	0.03%	0.01%	36.68%	36.72%
Elko	NV	0.00%	0.00%	35.48%	35.48%
Tooele	UT	0.36%	0.00%	12.04%	12.40%
Jasper	TX	7.51%	0.00%	0.00%	7.51%
Eureka	NV	0.00%	0.00%	6.57%	6.57%
Titus	TX	0.75%	2.19%	0.00%	2.94%
Walker	AL	0.22%	2.60%	0.00%	2.82%
Armstrong	PA	0.45%	2.25%	0.00%	2.70%
Indiana	PA	0.62%	1.93%	0.00%	2.55%
St. Clair	IL	0.05%	0.00%	2.43%	2.48%
San Juan	NM	0.25%	2.18%	0.00%	2.43%
Whatcom	WA	1.08%	0.00%	1.07%	2.15%
Hillsborough	FL	1.65%	0.48%	0.00%	2.13%
Rusk	TX	0.70%	1.42%	0.00%	2.12%
Will	IL	0.36%	1.67%	0.00%	2.03%
Dade	FL	1.79%	0.00%	0.00%	1.79%
Grant	WV	0.75%	1.02%	0.00%	1.77%
Pinellas	FL	1.74%	0.00%	0.00%	1.74%
Beaver	PA	0.16%	1.08%	0.45%	1.70%
Monroe	GA	0.34%	1.25%	0.00%	1.59%
Montour	PA	0.32%	1.27%	0.00%	1.59%
Jefferson	OH	0.31%	1.23%	0.00%	1.55%
Mercer	ND	0.37%	1.10%	0.00%	1.47%
Gallia	OH	0.37%	1.06%	0.00%	1.43%
Person	NC	0.34%	1.07%	0.00%	1.41%

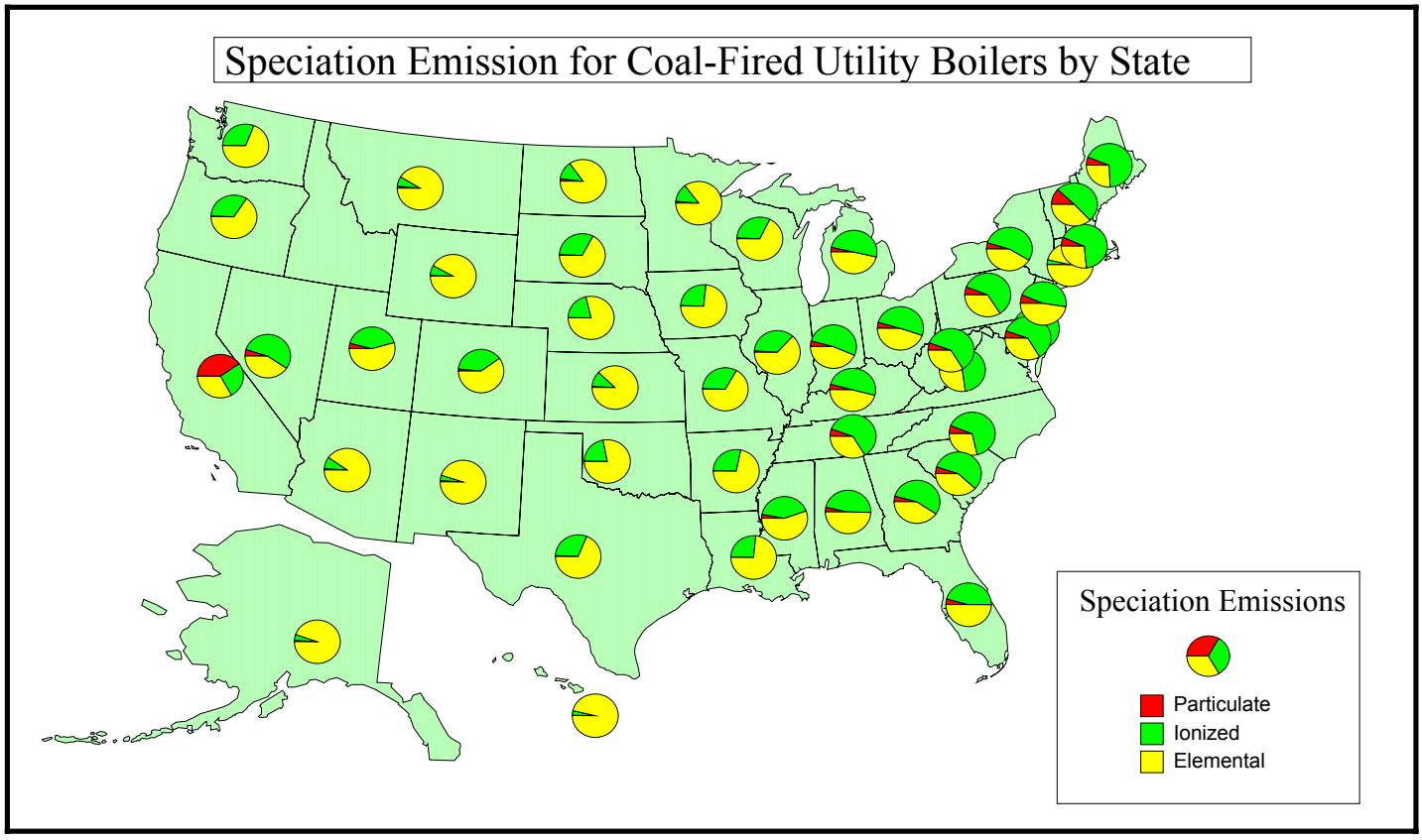


Exhibit 7-14. Speciation Emissions by State for Coal-Fired Utility Boilers

Simply adding the releases reported would not be appropriate, because each data source identifies a different total quantity of mercury across the U.S. In addition, TRI provides multimedia release information while the NTI and ICR data represent air emissions only.

Instead, the far right hand columns in Exhibits 7-10 through 7-12 were used. These columns represent the proportion of releases from the data source originating from that county, and serves as a 'score' for the data source. The percentages from each data source are summed to create a basis for a final ranking. Exhibit 7-13 presents these results for the top 25 counties. Exhibit 7-13 shows that, in most instances, a county's score is driven by a single data source. For example, the top two counties reported extremely high releases to TRI but low releases from the other two data sources. In addition, in only two cases does a county identified in Exhibit 7-13 report a non-zero ICR release and a non-zero TRI release, indicating that in most instances these releases occur in different localities. (NTI data are available for essentially every county.)

This analysis can be repeated for additional data sources as new data become available. For example, annual updates to TRI can be integrated into the analysis, while additional mercury release data sources not discussed in this chapter can be added and integrated into the 'scoring' system. However, Exhibit 7-13 shows that data limitations (in this case, the low number of counties reporting TRI data) can greatly influence the results.

7.4 Speciation

Methyl mercury is, from an environmental perspective, the form of mercury which is of most concern. However, methyl mercury is not known to be emitted from any anthropogenic source in significant quantities. Instead, methylmercury is formed within the environment through a complex series of transformations. Nevertheless, the species of mercury emitted from a given source is important for assessing geographical impacts.

This section is limited to assessing speciation in air releases. When released to water, mercury has an obvious local impact. Landfill and similar releases are more complex because migration of the mercury through the environment is dependent on leaching and volatilzation, but nevertheless is also of local concern. Air releases, however, do not necessarily have immediate local impacts. Oxidized forms of mercury (mercury compounds such as mercuric chloride) readily deposit in a localized area once emitted. In contrast, emissions of elemental mercury can remain airborne for long periods of time and be transported across the country, or the world, prior to deposition (Hanisch 1998).

There are limited data available for mercury speciation. Speciation data are only available for emissions from two categories: utility coal combustion and municipal waste combustion. However, these two sources are both significant in terms of mercury air releases. Data from the Mercury Study Report to Congress (EPA 1997a) show that these two sources comprise about 50 percent of air emissions quantified in that report.

The most comprehensive data available is the EPA's ICR from the coal-fired utility boilers. The results show that, nationwide, the average mercury speciation breakdown is 54 percent elemental, 43 percent oxidized, and 3 percent particulate. Therefore, the 48 tons of mercury emitted by coal-fired utility boilers (see Chapter 4) breaks down to 26 tons elemental, 20 tons oxidized, and 1.5 ton particulate.

The studies that estimated mercury speciation had limitations. Although sampling was conducted at a large number of boilers and facilities, it is difficult to apply data to individual plants since it was only a snapshot in time and may be affected by future changes in coal supply, plant operations, etc. Additionally, as facilities install control devices which affect mercury capture, the resulting speciation profile will change.

Exhibit 7-14 presents speciation data for each state from the ICR data analysis. Some interesting trends are apparent from this map. First, many states in the midwest and west emit elemental mercury as the predominant species, while the ionic form predominates in most states in the Eastern U.S. One reason is due to the type of coal burned in each area. Data from the ICR showed that western coals, in general, emit a higher proportion of elemental mercury than do Appalachian coals.

Secondly, there is wide variation in speciation results from one state to the next. This further demonstrates that generalities concerning a national distribution may not necessarily apply to a local condition.

Further data collection for mercury speciation can result in similar maps created for emissions. For example, by combining speciation and emissions data for multiple industries, a map can be created showing areas of the country emitting a particular species of mercury. Such a map was not prepared for this report because it would essentially only reflect coal combustion emissions. Sufficiently robust

speciation and emissions data are unavailable for other industries.

Limited speciation data for municipal waste combustion are also available from EPA's Office of Air (phone interview with Jim Kilgore, EPA). EPA estimated that air emissions from MSW combustion consisted of 85 percent ionic mercury, <5 percent particulate, and 10 percent was elemental. Due to MACT regulations, many facilities are in the process of installing mercury control technologies which will affect the speciation of stack gas. Additionally, variation is expected between facilities due to site-specific factors such as waste composition, boiler configuration, etc. Therefore, the estimation has its limitations.

Nevertheless, these data show that municipal waste combustion emissions are significantly different than coal combustion emissions, with a much higher proportion of oxidized mercury. One potential reason for this is the increased chloride loadings in MSW feed, resulting in higher rates of transformations to mercuric chloride in MSW stack emissions.

The predominance of oxidized mercury in MWC combustor stack gas is confirmed by a European study (Paur 1999), although quantitative estimates are not provided. Additionally, this source identified that sewage sludge incineration resulted in higher levels of elemental mercury.

Data for mercury speciation in mining are available, however this reflects data only for solid tailings material. The study (Kim 2001) estimated the make-up of mercury from twelve U.S. mercury and gold mine tailings using X-ray absorption spectroscopy (XAS). The study found that most tailings consist of cinnabar (HgS, hex) and metacinnabar (HgS, cub). Other species of mercury found included: montroydite (HgO), schuetteite (Hg3O2SO4), corderoite (Hg3S2Cl2), and various chlorides which may be more mobile than the cinnabar.

Chapter 8
Conclusions

8.1 Conclusions

Even if all mercury use ended today, mercury would be present well into the future due to the quantities of the element in reservoirs and stockpiles. For example, some items in commerce, such as thermostats, will not be disposed or removed from service for a long period of time. Given that the use of mercury in the economy and its associated health implications will not end for many years, mercury management will continue to be a prominent responsibility.

The 37 sectors discussed in this report present a thorough analysis of the life cycle of mercury throughout the U.S. economy. Ideally, these data will be utilized in some way to assist mercury management decisions, such as policy formulation or the prioritization of research and development efforts. This section summarizes the estimates calculated in the report and categorizes findings by life cycle stages and releases in key sectors. Additionally, a section devoted to high-profile sectors is included. Finally, observations concerning the application of these findings to prioritize future research needs are provided.

8.1.1 Life Cycle Stages

Acquisition

Mercury can be supplied by secondary production facilities (430 tons per year), imports (variable), or government stockpiles, and is often present within raw materials as a contaminant. The majority of mercury supply for use in product manufacturing can be accounted for by secondary production, and secondly from imports. Government stockpiles generally don't supply mercury but act as a reservoir. In fact, the U.S. Government stockpiles represent just over 50% of the total domestic mercury reservoir (9,050 tons), indicating that at least half of the US reservoir can be tightly managed.

According to the data in this report, the supply of mercury to product manufacturing is greater than the demand. If this observation indicates a trend, then the main domestic supply of mercury may be compromised since the industry may become at risk of financial non-viability in such a business environment. It seems likely that a decrease in mercury demand is inevitable as product manufacturers gradually use less mercury or substitute materials, as seen in electrical lighting manufacturing. A consistent fall in mercury demand will probably result in decreased prices for mercury and lower profits for secondary production facilities. In such a scenario, recycling facilities may close, resulting in increased use of landfills and incinerators for mercury-containing wastes.

Product Manufacture

Mercury use among industries can be characterized as either intentional (i.e., from secondary mercury production or government stockpiles) or unintentional (i.e., constituent in raw material). Mercury is intentionally used as a raw material in product manufacturing, these mercury-containing products are subsequently used commercially as well as by the general populace. Alternatively, mercury is used unintentionally when present in trace concentrations within raw materials. The amount of mercury used for product manufacturing is comparable to the quantity of mercury present from incidental uses where mercury is a contaminant. Therefore, both uses (intentional and unintentional) contribute significant quantities of mercury to the total amount consumed.

Approximately 90% of the 1,700 tons per year of mercury consumption in the U.S. can be attributed to three sectors: gold mining (80%), chlor-alkali (5%), and utility coal combustion (5%). The use of mercury by gold mining and utility coal combustion is incidental since the element is a constituent in the raw materials used. These results limit the ability to rely on innovations in product design as a solution for the industrial handling of mercury. Industries that use mercury intentionally have more technological options

for reducing mercury consumption compared to industries that use mercury unintentionally. For example, a lamp manufacturer has a broader technological horizon for manufacturing a product using/releasing reduced or zero mercury. Conversely, a gold mining or utility coal combustion facility may find it difficult, if not impossible, to choose raw materials without mercury. Consequently, most industries that use mercury incidentally are limited to managing the releases of mercury consumed. While eliminating mercury from production processes is critical, the discussion above demonstrates the importance of continued innovation in mercury control technologies.

Where sufficient data are available to estimate the quantities of both mercury used (consumed) and mercury leaving the system or process, in most cases the quantity reported entering is greater than the quantity reported leaving. This indicates that mercury is either accumulating within the system, or an error exists for at least one of the estimates. This mercury 'imbalance' is most evident for chlor-alkali manufacturing. The estimated consumption is 79.1 tons per year, while the quantity of mercury leaving the process in waste or product is 27.9, a difference of 51.2 tons per year. This may be partly accounted for by chlor-alkali's large mercury reservoir (22% of total domestic mercury reservoir). However, it is unlikely that these manufacturers are storing an additional 51.2 tons of mercury per year, rather, mercury leaving the system may be under-reported or there is a substantial unaccounted for sink within the system.

Product Use

Mercury is found in various commercial and professional products that tend to be long-lived such as thermometers, electrical lighting, and thermostats. Dental office preparations were found to have the highest quantity of mercury in use accounting for 13% of the total domestic mercury reservoir. With the exception of chlor-alkali manufacturing and dental amalgams, mercury can be contained or recovered following product use. Compared to the manufacturing stage, use of mercury-containing products is characterized by considerably higher releases of mercury into the environment. Despite numerous efforts to collect fluorescent lights, thermometers, thermostats, switches, and relays a majority of the mercury in use is disposed of as solid waste. As mentioned above, there are several industry efforts to decrease the mercury content in certain products and to develop mercury-free products. This does not imply, however, that managing the disposal of these products has a limited utility since past and present mercury-containing products are expected to remain in use for several years.

Final Disposition

The disposition of mercury occurs through recycling, exports, and releases into the environment. Much of present mercury consumption is met by existing recycled material. However, available data do not provide a full inventory of the total quantity of mercury recycled. Exhibit 1-2 indicates that 430 tons per year of mercury is estimated to be produced from U.S. mercury recycling. However, based on examination and accounting of mercury-containing materials, only 17 tons of mercury is accounted for as scrap materials sent to recycling facilities. Because most data on recycling rates are based on older or unpublished sources, these estimates are assumed to be low. This highlights an information gap that occurs throughout the report in estimating the quantities of mercury in scrap and wastes being recycled. Data detailing sector-specific quantities of mercury recycling rates were not available.

Generally, the export of mercury is in the form of elemental mercury (220 tons per year) as opposed to mercury-containing products or scrap. Accordingly, exports do not currently act as a significant mode of spent product disposition. It is conceivable, however, that if the secondary mercury production industry diminishes due to reasons discussed above, industries still generating mercury-containing scrap may prefer to export the waste to overseas recycling facilities or waste sites. This situation is a possibility if the total cost of exporting the waste is less than domestic disposal. Otherwise, scrap would be disposed of by landfilling and incineration.

8.1.2 Releases

Segregated by media type, releases to solid waste are greatest (1,500 tons/year), followed by air (125 tons/year) and water (20 tons/year). Gold mining alone accounts for 90% of solid waste releases. Without gold mining, annual releases to solid waste falls to 158 tons. After gold mining, switches and relays disposal (29 - 50 tons/year) and utility coal combustion (33 tons/year) contribute the greatest amount to solid waste releases. Management of mercury-containing solid waste is complicated because the mercury is embodied in various forms such as a switches, flyash, or ore tailings. Solid wastes are generally stored in landfills where the

possibility of mercury leaching into the environment is monitored. It is expected that mercury-containing solid waste will decrease as product manufacturers develop alternative, mercury-free processes. However, this is not expected to be as noticeable for industries handling mercury incidentally such as gold mining and utility coal combustion, particularly as these industries grow and as mercury removed from air continues to be disposed as solid waste.

Mercury releases to air are clearly a significant issue because of their transport over long and short distances. The most significant input of mercury into air is utility coal combustion. This industry has already been identified as a significant input and has received substantive attention over the past decade. Second to this industry is coal combustion by residential, commercial, and industrial sources with 21.2 to 23.6 tons per year released into air. Based on this report's mercury use and release estimates, utility coal combustion releases approximately 45% of mercury input into the air, whereas non-utility coal combustion may release 39 - 100% of the mercury consumed into air. A lower effectiveness of mercury capture by non-utility coal combustion renders this sector as a major source of mercury releases, particularly if industries utilizing coal combustion (non-utility) continue to grow.

Similar to air, mercury releases to water can result in serious health issues. According to this study's data, sewage treatment and sludge incineration (5.5 tons per year) as well as dental offices (7.4 tons per year) release some of the highest quantities of mercury into water. Compared to mercury releases into air and solid waste, water releases were considerably lower. However, data on mercury releases to water were only found for four of the thirty-seven industries included in this report. Because data are not available for many industries, mercury releases to water may be a larger problem than depicted in this study. The limited data may reflect a lack of industry efforts to monitor mercury releases to water. For example, laboratories commonly dump chemicals into sinks in low concentrations but potentially high volumes. Ultimately, the burden is passed to POTWs, which probably explains why this sector has the highest releases of mercury to water. The problem may not be the inability of POTWs to handle mercury-containing waste, rather, it is the disposal of mercury in places such as sinks and drains without monitoring.

Data on the geographic distributions of mercury as a pollutant demonstrate that total releases are most abundant in the eastern United States and Nevada. Furthermore, available data revealed differences in mercury speciation in air emissions between utility coal combustion and municipal waste combustion sites. Specifically, the average mercury speciation breakdown for coal-fired utility boilers is 54% elemental, 43% oxidized, and 3% particulate. When broken down by state, the eastern boilers release mostly oxidized forms while the west is characterized by higher elemental releases. This contrast is most likely due to differences in coal. Average municipal waste combustion releases are estimated to be 85% oxidized, 5% particulate, and 10% elemental. Given that different mercury species have varied regional or global impacts, this finding is significant relative to air pollution control strategies. These data have much potential for illustrating the large-scale patterns and potential effects of mercury releases. While the data in this report provide a reasonably accurate depiction, more consistent data would minimize uncertainties.

8.1.3 Key Sectors

To help identify research priorities, the sectors corresponding to the highest quantities in mercury use, release, and reservoirs are identified. Sectors included are those estimated as using or releasing at least 100 tons of mercury annually, or representing a mercury reservoir of at least 100 tons. The selection of 100 tons is somewhat arbitrary, but allows for a narrowing of sectors from the 37 evaluated to a more manageable number. A summary of this review can be found in Exhibit 8-1. Ten sectors are listed and discussed below.

Chlor-alkali manufacturing

Chlor-alkali production using the mercury cell process (the only process that employs mercury) is conducted at 11 U.S. locations accounting for 12% of total US chlorine production capacity. Approximately 79 tons of mercury are used in chlorine production annually, with an additional 2,000 tons present in the U.S. operating plants. These data suggest that the presence of mercury in the chlor-alkali industry is a concern both in terms of currently used quantities as well as the large quantities contained in the plant that might be released into the economy or the environment at a later date. The latter concern is particularly relevant given the 50 ton gap between mercury consumption and releases discussed in section 8.1.1. Mercury releases from chlor-alkali production is currently regulated by USEPA air, water, and solid waste policies.

Exhibit 8-1. Summary of Sectors with 100+ Tons of Mercury in a Life Cycle Stage

Mercury Sector	Mercury Present in Raw Materials > 100 Tons per Year	Mercury Released to All Media > 100 Tons per Year	Mercury Present as Reservoir > 100 Tons Total
Chlor-alkali Manufacturing			2,000
Dental Preparations			1,200
Gold Mining	1,370	1,348	
Landfills			*
Secondary Mercury Production	430		
Thermometers			**
Thermostats			230
Switches and Relays			630
Government Stockpiles			4,850
Utility Coal Combustion	105		

** - There were no available data on mercury quantities in land fills. Presumably, landfills have large mercury reservoirs based on the amount of industrial solid waste delivered to the sites.*
*** - Thermometers have an estimated reservoir of 45-85 tons; the sector was included based on the widespread use of these instruments and, consequently, its relatively high reservoir.*

Ongoing research needs include more accurately quantifying the emissions and destination of mercury used as a raw material. Based on consumption data and release estimates, much greater quantities of mercury are consumed per year than are estimated to be released. More accurate accounting would serve to identify where pollution prevention and control activities could be targeted, or, if previously unknown, the identification of mercury 'sinks' within the plants could potentially be addressed.

Dental Preparations

Up to 1,200 tons of mercury are present in the U.S. population as part of use in dental preparations (i.e., amalgam fillings). Among all sectors, the use of mercury in fillings is the most intimate and direct with respect to the manner in which it is consumed (i.e., in a person's mouth). Unfortunately, very little opportunity exists to address this mercury. Instead, pollution prevention and control opportunities focus on activities in dental offices across the United States, including alternatives to mercury fillings and better management of mercury wastes (including old fillings). Many technologies are in use but are not universally adopted. Non-mercury fillings have been successfully used, but costs are reportedly higher. For facilities that continue to use mercury, technologies and practices can be employed to reduce the releases of mercury to the environment. One technology reduces the quantity of mercury in washwater, consisting of an amalgam separator to recover the mercury from the water prior to sewer discharge. The development of less expensive non-mercury alternatives could be one key to increased usage.

Gold mining

Mercury is present as a contaminant in the ore and requires removal during processing, typically as mine tailings (solid waste) rather than as air or water releases. Among all industries included in this report, gold mining was distinguished by having the highest quantity of mercury released into solid waste. Gold is mined at about 100 locations in the United States, mostly located in Nevada and Alaska. Presumably, solid waste from gold mining presents limited risk to the general population since mines are typically located in population-sparse areas. Ranking states by population size places Nevada at 35th (although it is the fastest growing population in the U.S.) and Alaska at 48th (USDOC 2001). However, ecological risk from the relatively high quantities of mercury in mine tailings may be an issue.

Several pollution prevention opportunities have been implemented by a portion of the gold mining industry. One such opportunity is mercury recovery. As a result of processing, mercury becomes concentrated in certain wastes which can be managed onsite in retorters. However, not all facilities have retorting processes. Therefore, this may be a candidate technology for technology transfer emphasis. Other pollution prevention and control opportunities involve removing mercury early in the process. In gold processing, the valuable elements (e.g., gold and silver) are leached from the ore and concentrated prior to being recovered in solid form. Other impurities such as mercury can be simultaneously leached from the rock as well, and similarly concentrated and separated.

An additional need is to better quantify the mercury actually present and released in order to develop a more accurate and consistent measure of both mercury in incoming ore and mercury released to air, water, and solids. Additionally, waiting for more data as relatively small gold mines are being required to report may help clarify uncertainties. Such programs will assist in identifying whether this particular sector should be a priority for additional research needs, and may help to identify facility-specific pollution prevention and control needs. Similarly, information on the extent to which mercury leaches from tailing piles into the environment can help gauge the size of the potential problem.

Landfills

Unknown quantities of mercury are present in thousands of surface landfills used for disposal of municipal and industrial waste, however, mercury quantities are expected be relatively high as a result of previous and current disposal of products containing mercury. Few options are available to address the mercury already in the landfill, however, opportunities exist to decrease the quantities of mercury entering landfills. As long as the mercury remains in the landfill, its effects are much less severe than if it migrates to air or groundwater. Monitoring of mercury in the vented gas and of ground water from down-gradient wells will identify any site-specific mercury concerns, and will assist in identifying necessary remedial actions. Such monitoring technology already exists, although application of monitoring and analysis requirements is on a site-specific basis.

Secondary Mercury Production

Over 400 tons per year of mercury is supplied from secondary mercury sources to satisfy existing demand. Opportunities to impact the quantity of mercury produced depend entirely on mercury demand, which is better addressed from other sectors. Recovering mercury from scrap likely results in overall reduced releases, since without this sector the same scrap would be landfilled or incinerated. Current estimates of releases from secondary mercury production are relatively low, however, aggregate sums may increase as the number of recovery facilities continues to increase. A more up-to-date estimate will be available in summer 2002 when 2000 TRI data are released. However, the discrepancy between the quantity reported in secondary mercury facility TRIs and the aggregate recycling rate reported among various industries is likely to remain.

Thermometers, Thermostats, Switches, and Relays

Up to 860 tons of mercury is associated with thermostats, switches, and relays in commerce. An additional 45-85 tons of mercury is estimated to be associated with thermometers in commerce. These relatively high quantities are due to a wide array of manufactured products which utilize mercury, the uneven application of existing mercury recycling programs for such products, and the long life of these products (in the case of switches, the device typically lasts longer than the product containing the switch).

Government Stockpiles

For government stockpiles, management opportunities are currently being studied and assessed as part of a government-wide strategy led by the Defense Logistics Agency. Almost 5,000 tons of elemental mercury are stored in locations across the country as part of the U.S.

Government Stockpiles. It is likely that stabilization, treatment, and disposal alternatives will be identified as potential management options. These options may require additional research to assess their feasibility.

Utility Coal Combustion

Utility coal combustion is practiced at over 400 utility plants nationwide and has been identified as a significant source of mercury air emissions. USEPA (1997d) estimates that this industry accounts for 33% of all mercury air releases. An estimated 105 per year is present in coal that is burned in boilers and 88 tons per year enters the environment as air, water, or solid waste releases (the discrepancy is probably due to different calculation methods for consumption and release).

Mercury air releases from utility coal combustion are approximately 54% elemental (Hg^o). When compared to other mercury species, elemental mercury generally has the largest global impact since it can be carried over long distances. The USEPA has published its intent to regulate mercury-containing air releases from utility coal combustion (65 FR 79825; December 20, 2000). To date, mercury associated with utility coal combustion has received the most attention compared to other sectors in the report. Reactions have included strong public concern, policy actions, and significant R&D efforts.

Energy conservation measures represent the most obvious method to decrease electricity demand and therefore decrease associated mercury emissions. Additionally, a migration toward existing and emerging alternative energy applications represents substantial potential for reduction of coal use; such applications include an array of products and design alternatives, including passive and active solar building design, and a variety of distributed generation technologies such as geothermal heat pumps and fuel cells. Changes to the coal combustion process itself may also reduce mercury releases. These process changes could include enhanced coal pretreatment to precipitate and capture mercury from coal prior to combustion.

8.1.4 Prioritizing Research Needs

The estimates presented in this report act as a balance sheet or "snap shot" of mercury in the U.S. economy. While the data are useful for understanding relative magnitudes, they provide little information on the temporal trends of mercury use. Changes in the use, release, and disposal of mercury that occur over time from industry to industry are important when establishing new and ongoing priorities for research and development efforts. A valuable area for further work includes generating updates to the baseline data presented in this report so that trends can be identified. Such data could help reveal important changes that can have an influence on future mercury priorities.

Appearing from this "snap shot" is a divergence between the quantity of mercury supplied and the quantity demanded for use in manufacturing processes. This imbalance may have significant ramifications with respect to the future of secondary mercury production. Specifically, if the recycled mercury supply consistently and increasingly outpaces demand, the industry will likely deteriorate as prices fall. Consequently, a potential research priority is to analyze current and future financial solidity of mercury recycling markets in order to determine if intervention is necessary to maintain viability. The secondary mercury market plays an important role throughout the use of mercury in the economy. Most apparent is that secondary mercury production reduces the quantities of mercury-containing products from being incinerated (releasing mercury into air) and / or reaching landfills. If the industry were to collapse, there would be significant implications for mercury reservoir and disposal management.

Clearly, these data alone can be helpful in providing a foundation for any prioritization of research and development expenditures. For example, relative sector rankings of mercury quantities may be sufficient for high-level prioritization. Alternatively, additional information can be overlaid on this report's data for a more refined analysis. Relevant information could include the presence (or absence) of regulatory drivers or the existing level of support by EPA and other entities going toward new technological developments in specific sectors. Whether the data are used alone or juxtaposed with new information, they can serve two purposes. First, they can act as a way of calling attention to sectors deserving of research and development prioritization. Secondly, the data can serve as a baseline from which to project and measure the quantifiable impact of existing and new technological and policy developments.

While data quality is important, it should not be given overriding emphasis in a prioritization scheme. The reasonable accuracy of these estimates may be sufficient for the purpose of differentiating between sectors associated with negligible quantities of mercury and

those associated with substantial quantities of mercury. Accordingly, efforts to improve data should address significant gaps or inconsistencies rather than trying to obtain exact estimates in industries that are already relatively well-documented. Examples of significant data gaps include estimates of recycled mercury available compared to the reported quantities sent to recycling facilities or the apparent accumulation of mercury in chlor-alkali facilities.

Lastly, these data can form the start of a foundation of mercury use, release, monitoring and exposure data to begin to draw connections between mercury use, release, transport, fate, exposure and risk. This would involve juxtaposing facility and location-specific data used in this report with geographically-specific monitoring and exposure data to detect patterns and relationships between points of release and points of exposure.

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Note: Due to the dynamic nature of the Internet, the location and content of World Wide Web sites given in this document may change over time. If you find a broken link to an EPA document, use the search engine at http://www.epa.gov/ to find the document. Links to web sites outside the U.S. EPA web site are provided for the convenience of the user, and the U.S. EPA does not exercise any editorial control over the information you may find at these external web sites.

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