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Project Summary

Mercury Usage and Alternatives in the Electrical and Electronics Industries

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Many industries have already found alternatives for mercury or have greatly decreased mercury use. In some applications, however, the unique electromechanical and photoelectric properties of mercury and mercury compounds have made replacement of mercury difficult. This study was initiated to identify source reduction and recycling options for mercury in the electrical and electronics industries (SIC 36) and in measurement and control instrument manufacture (SIC 382). The project reviewed sources and use of mercury to identify trends in pollution prevention for mercury use throughout the U.S. economy. Regulatory trends encouraging mercury pollution prevention were examined, and current practices in the electrical and electronics industries were reviewed in detail to identify potential source reduction and reuse options for mercury. Industrial and economic data suggest that the quantity of mercury used in electrical and electronic control and switching devices is significant. Opportunities have been identified to replace mercury-containing devices. For applications where mercury cannot be avoided, recycling, mainly by vacuum retorting, is commercially available.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The objective of this study was to identify source reduction and recycling options for mercury in the electronics industry. To accomplish this objective, the sources and uses of mercury in the U.S. economy were reviewed and regulatory trends encouraging mercury pollution prevention were examined to provide a background for a detailed review of the electronics industry. Current practices in the electrical and electronics industries (SIC 36) and in measurement and control instrument manufacture (SIC 382) were reviewed in detail to identify potential source reduction and reuse options for mercury. Use of mercury-bearing chemicals as preservatives in paint has been eliminated, and mercury use in many other industries has declined. The electrical, electronic, and instrument industries have, however, found mercury difficult to replace because of the unique electromechanical and photoelectric properties of mercury and mercury compounds. The project tabulated data on mercury use throughout the U.S. economy to quantify historical use. Recent regulations were reviewed to indicate possible future trends for mercury use. Current practices in the electrical and electronics industries were analyzed and potential source reduction and reuse options for mercury were identified.

This study was conducted as part of the U.S. Environmental Protection Agency's (EPA) effort to develop pollution prevention options for Resource Conservation and Recovery Act (RCRA) wastestreams that have been difficult or expensive to treat. Mercury-containing RCRA wastes are difficult to treat reliably by conventional techniques such as solidification/stabilization. This project was undertaken, with the coordination and cooperation of the Office of Solid Waste, to help define pollution prevention technologies for mercury-containing RCRA problem wastes. Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes. Pollution prevention should be considered the first step in a hierarchy of options for reducing the generation of pollution. The next step in the hierarchy is responsible recycling of any wastes that cannot be reduced or eliminated at the source. Wastes that cannot be recycled should be treated in accordance with environmental standards. Finally, any wastes that remain after treatment should be disposed of safely.

Mercury Economic Data and Regulation

Recent Patterns of Mercury Use

Mercury for domestic use in 1990 came from domestic mines, sales of surplus from government stocks, imports, and waste recovery. Mercury was produced as the main product of the McDermitt Mine and as a byproduct of eight gold mines in Nevada, California, and Utah. The McDermitt Mine has since been closed. Market expectations indicate a continuing decline in both the production and use of mercury and an increased reliance on recycled mercury.

Common secondary mercury sources include spent batteries, mercury vapor and fluorescent lamps, switches, dental amalgams, measuring devices, control instruments, and laboratory and electrolytic refining wastes. In 1992, commercial secondary mercury reprocessors produced 176 metric tons of mercury. The secondary processors typically use high-temperature retorting to recover mercury from compounds and distillation to purify the contaminated liquid mercury metal.

The main uses for mercury are in chemical production, particularly chlorine/caustic manufacture; electrical and electronic components; and instruments and related products. Recent mercury use patterns are indicated by Table 1. As shown in the table, the use of mercury has declined in response to regulatory pressures, particularly in paints and chemicals. The full report presents more detailed data on mercury use in the electrical and electronics industries indicating that, although total mercury usage has declined over the past decade, use in electrical and electronic devices (other than batteries) has remained fairly constant.

State and Federal Regulations

Solid wastes containing leachable mercury above the Toxicity Leaching Characteristic Procedure (TCLP) limit (0.2 mg/L) and certain source-specific wastestreams are regulated at the federal level under RCRA (40 CFR 261.10). Mercury air emissions are regulated at the federal level under the National Emissions Standard for Hazardous Air Pollutants (NESHAP) (40 CFR 60.50). States are beginning to enact legislation to limit the quantities of mercury in non-RCRA-listed wastes entering municipal waste disposal facilities.

Mercury Treatment Standards Under RCRA

From the mid-1980s to early 1990, the EPA collected and evaluated process performance data to identify Best Demonstrated Available Technologies (BDATs) for the treatment of RCRA-listed wastes. These studies collected performance data for industrial applications of recycling for a wide range of metal-contaminated wastes, including mercury-bearing wastes. The EPA BDAT process considered recycling as a treatment alternative for many nonwastewater streams and identified recycling as the BDAT for some nonwastewater subcategories.

Recycling of mercury increased after the development of Land Disposal Restrictions (LDRs) on mercury-containing wastes. Like other metals, mercury cannot be destroyed. Further, EPA review of treatment data for the development of a BDAT indicated that mercury is difficult to reliably stabilize when present either at high concentrations or in elemental form. The analysis of treatability data did, however, indicate that low concentrations of elemental mercury could be stabilized to meet acceptable leachability levels for land disposal. Applicable technologies for the low-concentration mercury wastes were stabilization, amalgamation, or acid leaching followed by sulfide precipitation.

Because of lack of data on mercury waste treatment by acid leaching followed by solution processing, the EPA established roasting and retorting as the BDAT for all mercury nonwastewaters having total mercury concentrations above 260 mg/kg, except for radioactive mixed wastes. The affected RCRA wastes are D009 (mercury characteristic), P065 (mercury fulminate), P092 (phenyl mercury acetate), U151 (mercury), and K106 (wastewater treatment sludge from the mercury cell process in chlorine production). The EPA also established incineration as a pretreatment step for P065, P092, and D009 (or-

Table 1. *Mercury Consumption in the United States by Use**

Use	*Use in 1989 (MT)*[†]	*Use in 1992 (MT)*
Chemical and allied products		
Mercury cell chloralkali process	*379*	*209*
Laboratory uses	*18*	*18*
Paint	*192*	*0*
Other chemical related uses	*40*	*18*
Electrical and electronics		
Electric lights	*31*	*55*
Devices and switches	*141*	*69*
Batteries	*250*	*16*
Instruments and related products		
Measuring and control instruments	*87*	*52*
Dental	*39*	*37*
Other	*32*	*148*
Total	*1,209*	*622*

** Source: U.S. Bureau of Mines (1993).*
[†] MT = metric ton (1 MT is equivalent to 1000 kg, 2,205 lb, 1.102 short tons, and 29 flasks).

ganics) before retorting in its June 1, 1990 rule (55 FR 22572 and 22626).

State Regulations

Several states have enacted or are considering legislation to prohibit mercury disposal in municipal waste, discourage or prohibit mercury use, or encourage mercury recycling. The states with active or planned mercury control regulations are:

- California
- Connecticut
- Florida
- Michigan
- Minnesota
- New Jersey
- New York
- Vermont

Source Reduction Alternatives for Mercury in the Electrical and Electronics Industries

The industry sectors covered by this report are electrical and electronic device manufacture (SIC 36) and measuring and control instrument manufacture (SIC 382). Source reduction alternatives to mercury use continue to be developed and are being used in the electrical lighting, battery, switching device, instrument, and thermostat manufacturing areas. These alternatives are discussed in the following sections.

Electrical Lighting

In 1992, approximately 55 metric tons of mercury were used in the electrical lighting industry. Mercury-containing lamps include fluorescent lamps and high-intensity discharge (HID) lamps. Examples of HID lamps include mercury vapor, metal halide, and high-pressure sodium lamps. Today, fluorescent lamps and HID fluorescent lamps are the second largest source of mercury in municipal solid waste (household batteries are primary). By the year 2000, mercury contamination resulting from the disposal of fluorescent lamps to municipal solid waste is projected to increase to 37.1 metric tons. Although manufacturers are working to reduce the mercury content of each lamp, increased use of fluorescent lamps is expected because of their energy efficiency. The average life of an electrical fluorescent lamp is 4 yr, whereas that of a HID lamp is less than 1 yr.

All fluorescent lamps contain mercury. Mercury acts as a multiphoton source in fluorescent lamps. The mercury content typically ranges from 20 to 50 mg/tube, depending on the size. Ultraviolet (UV) light is produced by mercury when it is bombarded by electrons produced by current flowing through the tube. Phosphor powders coated on the inside of the glass tube convert the UV light to visible light.

The research to date shows that there is no economically feasible alternative to mercury in fluorescent lighting although work is being done to find a way to reduce the amount of mercury used in electrical lighting. Light bulbs produced today contain 60% less mercury than those manufactured 10 yr ago. Today a standard fluorescent lamp contains 0.05 mg/m^3 mercury, approximately 0.02% of the total weight of the bulb.

Although the amount of mercury in lamps is small, there is a growing market for recycling the mercury, glass, and aluminum from fluorescent and mercury vapor lamps. Fluorescent lamps can be processed to recover several valuable resources. The recovery process typically involves crushing the tube and separating the metal end pieces from the glass. Metal components such as the end caps often are sent to other recyclers for recovery. The tube components are then roasted and retorted to recover mercury. The glass, phosphor, and mercury may be treated together, or the glass may be separated and only the phosphor treated. The resulting glass often is recycled. Mercury recovered by retorting is purified by distillation for reuse.

Batteries

In 1992, approximately 16 metric tons of mercury were used in the United States by the battery manufacturing industry. In the past, mercury was added to alkaline-manganese and zinc-carbon batteries to control gassing, and U.S. manufacturers were successful in reducing the mercury content to below 250 ppm. In 1992, U.S. manufacturers began producing mercury-free alkaline-manganese batteries. Most zinc-carbon batteries manufactured in the United States no longer contain any mercury.

Batteries represent the largest current source of mercury in municipal solid waste. In 1989, household batteries accounted for 563.9 metric tons of the mercury discarded in municipal solid waste. It is estimated that by the year 2000, household batteries will be responsible for only 89.4 metric tons of the mercury discarded in municipal solid waste.

Beginning in 1992, several battery manufacturers began selling mercury-free alkaline batteries. Other metals such as indium, gallium, and magnesium are substituted for mercury. In addition, the use of mercuric oxide batteries, primarily for hearing aids and pagers, is being replaced by zinc-air batteries. Mercuric oxide batteries will however, continue to be used for medical and military applications because, currently, there are no acceptable substitutes.

Switching Devices

Industrial and economic data suggest that the quantity of mercury used in electronic control and switching devices is significant. The characteristics of mercury switching devices and some possible alternatives that avoid mercury use are summarized in Table 2.

Control Instruments

Mercury is used in many instrumentation devices such as thermometers and mercury manometers. Mercury manometers are considered reliable absolute-pressure gages, and they provide the accuracy needed for a system analysis. A common application is in the steam jet air ejectors used in process plants that have a supply of available steam. Some mercury-free units, such as electronic vacuum gages, however, are accurate, portable pressure-measuring instruments. Formerly, gas regulators used mercury in a safety device (a U-shaped tube with mercury at the base of the tube) that was designed to divert gas flow outside of a building if the gas line pressure became too high. If the pressure were to exceed a safe value, a weighed amount of mercury would be ejected through an outside vent, subsequently relieving gas pressure. Modern gas regulators use a mechanical spring mechanism instead of mercury, although older homes may still have gas regulators that contain mercury.

Thermostats

Thermostats are temperature control devices that usually consist of a temperature-sensing element, an electrical switch that activates heating and cooling equipment, and a mechanism for adjusting nominal temperature. Thermostats control temperatures in large building spaces, individual rooms, and appliances, and some types of thermostats use mercury in the switch mechanism. Historically, mercury switches have proven reliable, accurate, long-lived, and cost efficient. These are important qualities because thermostats control the dispensation of large amounts of electrical power, and their operational efficiency has a large effect on fuel consumption. Unoptimized thermostatic control can lead to many times more energy consumption than necessary. Poor perfor-

Table 2. *Comparison Between the Mercury Switch and Its Alternatives.*

Type	Properties	Application	Hazardous Content*
Mercury switch	*Smooth contact, simple in design, versatile, inexpensive*	*On/off relay, thermostats, circuit control*	*Mercury*
Hard-contact switch	*Metal-to-metal contact, may be open or sealed, versatile, inexpensive*	*On/off relay, general circuit controls, high or low voltage*	*None*
Solid-state switch	*More sophisticated design features, versatile*	*Communications, circuit control, electronic thermostats*	*Arsenic, gallium*
Electro-optical switch	*Higher speed, expensive, multiple user*	*Communications*	*Lithium, niobate*
Inductive sensor	*Senses metal targets, 10 to 20 mm detection*	*Shaft rotation, conveyors*	*None*
Capacitive sensor	*Senses mass*	*Conveyors*	*None*
Photoelectric sensor	*Senses nontransparent, non-reflective materials, up to 50 m away; high speed*	*Conveyors*	*III-V semiconductor materials*
Ultrasonic sensor	*Senses all objects, range of about 0.5 m; high speed*	*Conveyors*	*None*

** Indicates hazardous materials other than lead, which may be used in solder.*

mance may be caused by one of several reasons, the main reason being hysteresis in the temperature-sensing component, the electrical switch, or both. Hysteresis may lead to large differentials, or swings, in room temperature.

Analysis of thermostat markets indicates that approximately 10 to 15 metric tons of mercury are used annually in the United States for the production of thermostats, primarily for home heating and cooling applications. Of the 70 million thermostats in residential use today in the United States, it is estimated that 90% use mercury. Thermostat manufacturers estimate that 2 to 3 million thermostats are brought out of service each year. Most of these thermostats are replaced by the homeowner or contractor. The characteristics of mercury tilt switch thermostats and potential mercury-free alternatives are summarized in Table 3.

Recycling Alternatives for Mercury in the Electronics Industry

There is a well-established infrastructure for recycling mercury-containing scrap and waste materials. Industrial production of mercury from recycling of secondary sources amounted to 176 metric tons in 1992.

Many mercury compounds will convert to metal at atmospheric pressure and 300°C or at lower temperature by direct dissociation. With its boiling point of 357°C, mercury also is substantially more volatile than most metals. As a result, mercury and mercury compounds can be separated by roasting and retorting more easily than most metals, making it an ideal candidate for recycling from a wide variety of waste materials. A U.S. Bureau of Mines study showed that thermal desorption processes are potentially cost-effective for recovery of mercury from a wide variety of electrical manufacturing wastes. The full report outlines the general characteristics of several companies that recover mercury from industrial wastestreams or spent fluorescent lamps.

Conclusions

This study identified mercury sources and consumption patterns and source reduction and recycling options for mercury in the electronics industry. The alternatives to mercury-containing electronic devices are compared with mercury-containing devices. The survey of alternatives shows that many nonmercury options are available for the diverse applications that make up the electronics industry. Overall, it can be said that, although mercury has had an important role in manufacturing of high-quality electromechanical products, it undoubtedly will be replaced by more versatile and faster, fully electronic equivalents in the future. The shift from mercury-containing to nonmercury-containing devices is governed as much by the natural evolution of technology as by environmental awareness. Devices based on newer technologies continually become more cost-competitive than more conventional devices that may contain mercury. For the present, environmental awareness plays a key role among industries that use mercury in their products and processes. In these industries, pollution prevention and recycling are viable means for preventing mercury escape to the environment.

Finally, recycling alternatives for mercury in electronic products are given. Vacuum retorting, a viable means of recycling mercury, is becoming commercially available. These recycling programs however, are unlikely to be available nationwide unless a means is found to streamline the federal, state, and local approval processes necessary for implementation.

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Table 3. *Comparison Between the Mercury Switch Thermostat and Its Alternatives*

Switch Type	*Performance*	*Applications*	*Thermostat Price**
Mercury tilt switch	*Accurate, reliable, long service life*	*Premium residential heating/cooling*	*$40-80*
Mechanical snap-acting switch	*Inexpensive, less reliable*	*Electric strip heating, ventilation*†	*$10-30*
Open-contact magnetic snap switch	*Accurate, moderate service life*	*Standard residential heating/cooling*	*$30-50*
Sealed-contact magnetic snap switch	*Accurate, reliable, long service life*	*Premium residential heating/cooling*	*$60-100*
Electronic thermostat	*Accurate, reliable, unproven service life*	*Premium residential heating/cooling*	*$70-140*‡

† *Primarily used on line-voltage equipment.*
* *Manufacturer's list price; includes thermostat unit, without clock or other options available in product line.*
‡ *Includes programmable features.*

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Paul M. Randall *is the EPA Project Officer (see below).*
The complete report, entitled "Mercury Usage and Alternatives in the Electrical and Electronics Industries," (Order No. PB94-165362AS; Cost: $19.50, subject to change) will be available only from:
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