# PRACTICAL SOURCEBOOK ON MERCURY WASTE STORAGE AND DISPOSAL

UNEP

ISWA
International Solid Waste Association

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# ABOUT THE SOURCEBOOK

## How was the Sourcebook prepared?

The United Nations Environment Programme (UNEP) Governing Council (GC), in decision 25/5, requested UNEP to enhance capacity for mercury storage and provide information on the sound management of mercury and mercury wastes. The project for the preparation of the 'Practical Sourcebook on Mercury Waste Storage and Disposal' (hereinafter referred to as the 'Sourcebook') is one of UNEP's responses to this request. The project is a joint initiative of UNEP Chemicals Branch, Division of Technology Industry and Economics (DTIE), UNEP's International Environmental Technology Centre (IETC), and the International Solid Waste Association (ISWA) under the UNEP Global Mercury Partnership. Drawing on existing work within the Global Mercury Partnership (notably the Partnership areas on waste management, supply and storage, products, and chlor-alkali), including studies, guidance and information material disseminated by the Partnership, as well as other relevant documents, reports and publications, the Sourcebook has been prepared in a consultative process, involving experts from governments, the private sector, civil society, academia and intergovernmental organizations (IGOs). Selected experts were partners of the Global Mercury Partnership, other experts UNEP Chemicals has worked with under the Partnership umbrella, and members of ISWA's Working Group on Hazardous Waste. Their role was to provide input for preparation of the Sourcebook and to give feedback on the various drafts, including at a face-to-face meeting held in Vienna in August 2014.

## Who is the audience?

The main target audience of the Sourcebook are technical staff, line officers and managers in governmental bodies involved in the management of mercury wastes, particularly in developing countries and countries with economies in transition. The Sourcebook may also serve as a useful reference for other stakeholders involved in the management of mercury wastes, including industry and civil society.

## What is the purpose?

The overall objective is to enhance the capacity of governments – but also industry and the general public – to store and dispose mercury wastes in an environmentally sound manner. The Sourcebook aims to do so by providing information on commercially available storage and disposal technologies. This document is envisaged to address practical questions such as: What are mercury wastes? Where are they generated? How can mercury wastes be recovered and recycled? Which options and experiences exist for the storage and disposal of mercury wastes? The Sourcebook synthesizes existing knowledge in the field of storage and disposal to provide answers to these questions. It will thus allow relevant stakeholders to make informed choices and ensure the environmentally sound management (ESM) of mercury wastes.

## What is the format?

The Sourcebook is a practical introduction to mercury waste storage and disposal. The Sourcebook should not be used as guidance. Other sources, such as the 'Updated Technical Guidelines for the Environmentally Sound Management of Wastes Consisting of, Containing, or Contaminated with Mercury or Mercury Compounds'[1] (hereinafter referred to as Basel Technical Guidelines) provide greater detail regarding mercury waste storage and disposal and are cross-referenced in this document. The updated Basel Technical Guidelines were adopted by the Conference of the Parties (COP) to the Basel Convention at its twelfth meeting in May 2015.

## What is the scope?

The focus is on the environmentally sound storage and disposal of mercury wastes. However, storage and disposal cannot be understood in isolation. Rather, it is necessary to take a holistic approach towards mercury waste management. To the extent possible, the Sourcebook therefore also discusses issues such as the types and sources of mercury wastes, handling, packaging, labelling and transport of mercury wastes, traceability, and recovery/recycling.

## Which aspects are not covered?

The Sourcebook does not go into detail regarding the waste prevention/minimization dimension, for example green chemistry. Thus, the question of mercury-free alternatives and similar issues are not discussed. The Sourcebook also does not address commodity mercury.

## What is the relationship with other documents and processes?

The Sourcebook aims to provide a practical perspective to existing technical documents, such as the Basel Technical Guidelines. The Sourcebook may also identify issues and approaches governments may wish to evaluate when planning their implementation of the Minamata Convention on Mercury[2], in particular Art. 11 on mercury wastes. The Minamata Convention on Mercury is a global treaty to protect human health and the environment from the adverse effects of mercury. It was agreed at the fifth session of the Intergovernmental Negotiating Committee in Geneva, Switzerland, on 19 January 2013 and was adopted and opened for signature on 10 October 2013, at the Conference of Plenipotentiaries in Kumamoto, Japan. The Convention shall enter into force on the ninetieth day after the date of deposit of the fiftieth instrument of ratification, acceptance, approval or accession.

The Sourcebook does not introduce any new definitions or meanings. In particular, it does not in any way modify or otherwise affect existing terminology that is consolidated under the Basel Technical Guidelines. Where deviating terminology is used, this is solely for the purpose of providing practical language within the framework of this Sourcebook. Nothing in the Sourcebook is intended to pre-empt any relevant international processes. This document is for informational purposes only and is not intended to create precedents on the issues and topics covered. This document may not be used to interpret the obligations of the Basel and Minamata Conventions.

## Towards the Environmentally Sound Storage and Disposal of Mercury Wastes

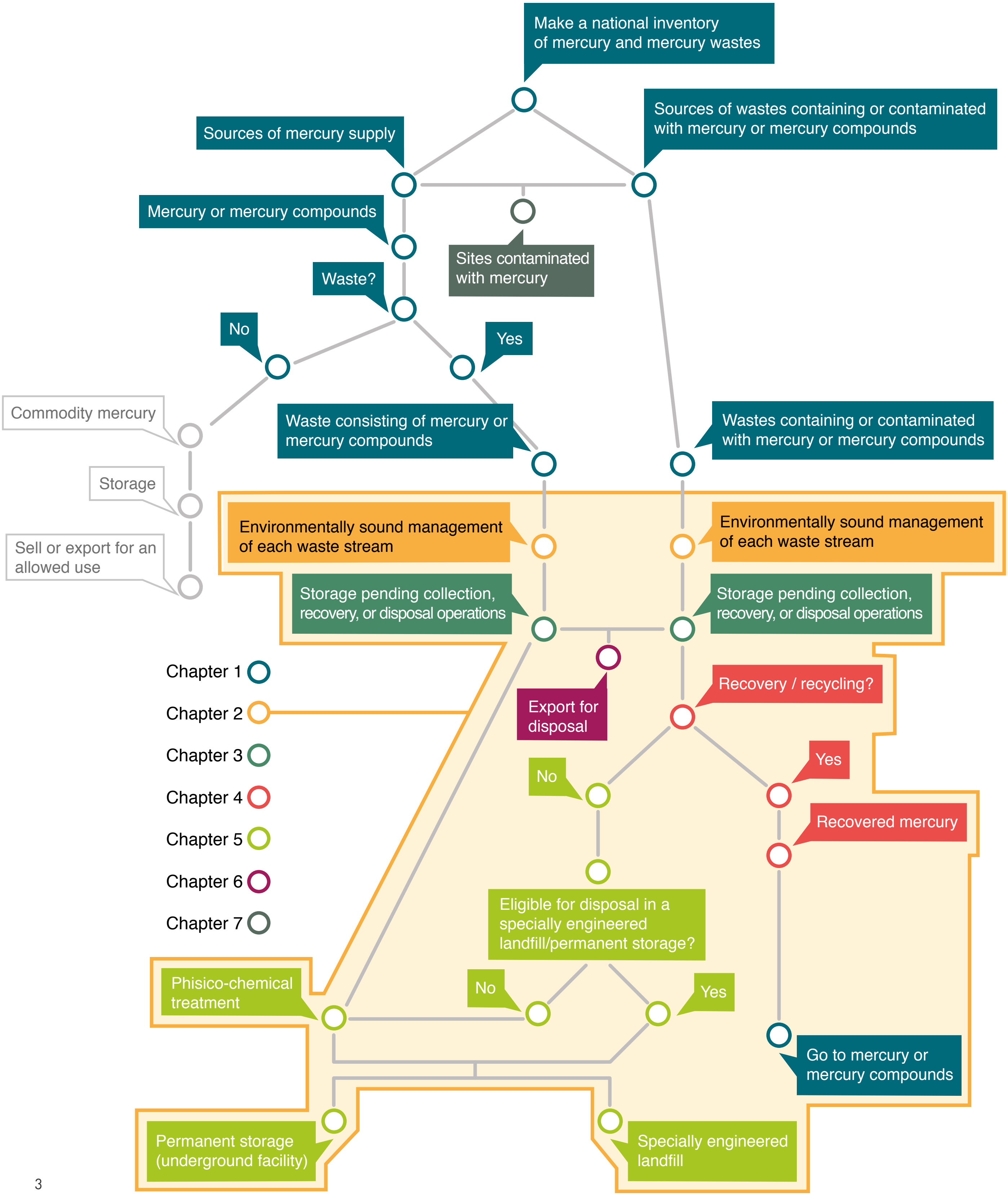

Figure 1: Towards the Environmentally Sound Storage and Disposal of Mercury Wastes

# INTRODUCTION:
# Mercury as a Global Pollutant

*“Mercury is a chemical of global concern owing to its long-range atmospheric transport, its persistence in the environment once anthropogenically introduced, its ability to bioaccumulate in ecosystems and its significant negative effects on human health and the environment” (first preamble of the Minamata Convention on Mercury)*

Mercury is a naturally occurring chemical element with symbol Hg that cannot be destroyed. It exists in several forms: as elemental/metallic mercury, methylmercury, and other organic or inorganic compounds. Mercury is a heavy metal and the only metal that is liquid at room temperature. It has a very low vapour pressure and slowly evaporates even at ambient temperature.

Mercury is released to the environment from natural sources and as a result of human activities. Once it has been released, mercury persists in the environment, cycling between air, land and water, and biomagnifies up the food chain. Mercury is highly toxic, especially affecting the nervous system, the brain, the heart, the kidneys, the lungs and the immune system.

Because of its significant negative effects on human health and the environment, mercury has increasingly become the focus of decision-makers. In 2013, governments took decisive action by adopting the Minamata Convention on Mercury, whose objective is to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.

Mercury wastes are recognized as hazardous wastes for which special precautions are necessary in order to avoid emissions and releases of mercury into the environment. Mercury wastes can lead to releases of mercury into the environment if they are not managed in an environmentally sound manner.[1]

In the past, there were a number of cases of mercury pollution that occurred because mercury wastes were not managed in an environmentally sound manner. For example, in Japan, methylmercury was discharged for several decades in the industrial wastewater into the bay of Minamata. Due to the consumption of fish, large parts of the local population suffered from methylmercury poisoning, the so-called ‘Minamata disease’.[3]

Due to the threats mercury wastes pose to human health and the environment, these wastes need to be managed in an environmentally sound manner. This Sourcebook aims to present ways of doing so. In particular, the last chapter summarizes options as well as possible steps for the implementation of environmentally sound storage and disposal of mercury wastes.

As a further source of information on mercury, see for example the ‘Global Mercury Assessment 2013’[4], the website of the UNEP Global Mercury Partnership[5] or UNEP’s publication ‘Mercury: Time to Act’[6].


Hg
Cu
Zn
Hg
Hg
Hg

# CHAPTER 1:
# Types and Sources of Mercury Wastes

In order to ensure environmentally sound storage and disposal of mercury wastes, it is useful to understand the types of mercury wastes that exist at national level as well as the sources generating them. This chapter starts with a short introduction on types, characteristics, and inventories of mercury wastes. The idea that mercury supply may exceed demand is introduced to alert the reader that sufficient capacities may be needed to manage excess mercury in an environmentally sound manner. The chapter closes with an overview of the sources of each of the types of mercury wastes. Each of the types of mercury wastes may come from different sources. Some sources may generate several types of mercury wastes.

## 1.1 Types of Mercury Wastes

The Basel Technical Guidelines as well as the Minamata Convention on Mercury identify three categories of mercury wastes: **Wastes consisting of mercury or mercury compounds**, **wastes containing mercury or mercury compounds** and **wastes contaminated with mercury or mercury compounds** (see Box 1, Box 2, and Box 3). ‘Mercury’ means elemental mercury (Hg(0), CAS No. 7439-97-6).

### Wastes Consisting of Mercury or Mercury Compounds

For example excess mercury from the decommissioning of chlor-alkali facilities, mercury recovered from wastes containing mercury or mercury compounds or wastes contaminated with mercury or mercury compounds or surplus stock of mercury or mercury compounds designated as waste.

Photo 1: Mercury

Box 1: Wastes Consisting of Mercury or Mercury Compounds

### Wastes Containing Mercury or Mercury Compounds

Wastes of mercury-added products that easily release mercury into the environment including when they are broken (e.g. mercury thermometers, fluorescent lamps); other wastes of mercury-added products (e.g. batteries); and wastes containing mercury or mercury compounds that result from a treatment of mercury.

Photo 2: Example of Spent Mercury-added Products

Box 2: Wastes Containing Mercury or Mercury Compounds

### Wastes Contaminated with Mercury or Mercury Compounds

For example residues generated from mining processes, industrial processes, or waste treatment processes.

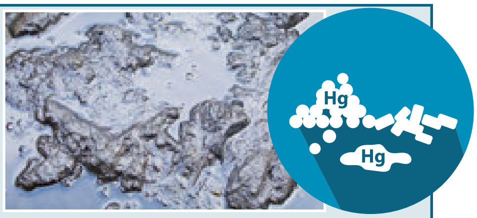

Photo 3: Example of Waste Contaminated with Mercury

Box 3: Wastes Contaminated with Mercury or Mercury Compounds

Art. 11, para. 2 of the Minamata Convention provides a definition of mercury wastes (see Box 4).

### Mercury Wastes under the Minamata Convention: Art. 11, Para. 2

*“For the purposes of this Convention, mercury wastes means substances or objects:*

*a) Consisting of mercury or mercury compounds;*
*b) Containing mercury or mercury compounds; or*
*c) Contaminated with mercury or mercury compounds,*

*in a quantity above the relevant thresholds defined by the Conference of the Parties, in collaboration with the relevant bodies of the Basel Convention in a harmonized manner, that are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law or this Convention. This definition excludes overburden, waste rock and tailings from mining, except from primary mercury mining, unless they contain mercury or mercury compounds above thresholds defined by the Conference of the Parties.”*

Box 4: Mercury Wastes under the Minamata Convention: Art. 11, Para. 2

Wastes contaminated with mercury and wastes containing mercury mainly differ in their origin, not necessarily in their mercury content. It may also be important to note that the volume of wastes containing or contaminated with mercury may be much larger than the volume of waste consisting of mercury, although they may contain mercury at very low concentrations.[7,8]

## 1.2 Characterization of Mercury Wastes

The first step is to **determine whether mercury is present in the waste**. Equipment for this purpose is commercially available at relatively low costs. Some handheld equipment such as the X-ray Fluorescence (XRF) or Lumex can initially determine if mercury is present. In many mercury-added products it is relatively easy to determine the type and amount of mercury present. In industrial cases it may be useful to conduct a chemical analysis of mercury wastes to determine its characteristics. Among others, information may be gathered on **speciation, mobility of mercury in the waste** (see Box 5), **mercury content and concentration, vapour pressure** etc.

### Examples of Methods to Determine the Mobility and Leachability of Mercury in Wastes

Detailed laboratory methods are available to determine the mobility of mercury in wastes (also see the Basel Technical Guidelines), two of which are the 'Toxicity Characteristic Leaching Procedure' (TCLP) and the 'Leaching Environmental Assessment Framework' (LEAF), designed by the United States (US) Environmental Protection Agency (EPA). The TCLP analysis simulates landfill conditions to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes.[9,10] The recently-developed LEAF leach test methods allow assessment of leaching potential over a range of conditions (pH values), or defined site-specific conditions. In the European Union (EU), the sampling and test methods which have to be used to determine the leachability of mercury wastes are set in Section 3 of the Annex to the Council Decision 2003/33/EC on waste acceptance criteria.[12]

Box 5: Examples of Methods to Determine the Mobility and Leachability of Mercury in Wastes

Among others, this information may be used for the following purposes:

- Evaluate whether a waste classifies as mercury waste.
- Assess compliance with regulatory standards.
- Determine suitability/necessity of specific recovery or disposal operations (see for example Table 1).

### Classification of Mercury Wastes under the US EPA Land Disposal Restrictions Program[13]

| **Low mercury wastes** |
|---|
| Hazardous wastes containing less than 260 mg/kg of total mercury. |
| Must be treated up to 0.20 mg/L as measured using the TCLP for mercury waste from retorting and 0.025mg/L for all others. |
| **High mercury wastes** |
| Characteristically hazardous mercury wastes containing greater than 260mg/kg of total mercury. |
| Required to undergo roasting or retorting in a thermal processing unit capable of volatilizing mercury and subsequently condensing the volatilized mercury for recovery. |

Table 1: Classification of Mercury Wastes under the US EPA Land Disposal Restrictions Program

Sampling and analysis needs to be done by trained professionals, in accredited laboratories, using internationally accepted or nationally approved methods, and subjected to **rigorous quality assurance and quality control**[1]. An overview of methods to determine the mobility, concentrations, content and speciation of mercury in waste can be found in the Basel Technical Guidelines.

## 1.3 Inventories of Mercury and Mercury Wastes

Inventories can be an important tool for identifying, quantifying and characterizing stocks and sources of mercury and mercury wastes. Under the Minamata Convention, Parties shall endeavour to **identify stocks of mercury as well as sources of mercury supply** above certain thresholds (see Box 6). Governments may also wish to identify stocks and sources below the thresholds set by the Minamata Convention to further refine their knowledge about mercury within their country.

### Identification of Stocks and Sources of Mercury under the Minamata Convention: Art. 3, Para. 5 (a)

*"Each party shall endeavour to identify individual stocks of mercury or mercury compounds exceeding 50 metric tons, as well as sources of mercury supply generating stocks exceeding 10 metric tons per year, that are located within its territory."*

Box 6: Identification of Stocks and Sources of Mercury under the Minamata Convention: Art. 3, Para. 5 (a)

Potential sources of mercury that is not waste are noted in Figure 2.[14,15] It is suggested that the potential illegal sources of mercury supply be carefully evaluated.

With the switch to more efficient and environmentally sound alternatives and the restrictions on uses imposed by national and international law, including the Minamata Convention, where applicable, **demand for mercury may decrease** in many areas.[16] Meanwhile, supply from some sources, notably within the chlor-alkali sector and from primary mercury mining (see Box 7 and Box 8), should decrease as the Minamata Convention is universally implemented. Excess mercury may therefore become available (also see Chapter 1.4).[17,18, 19]

## Potential Sources of Mercury Supply

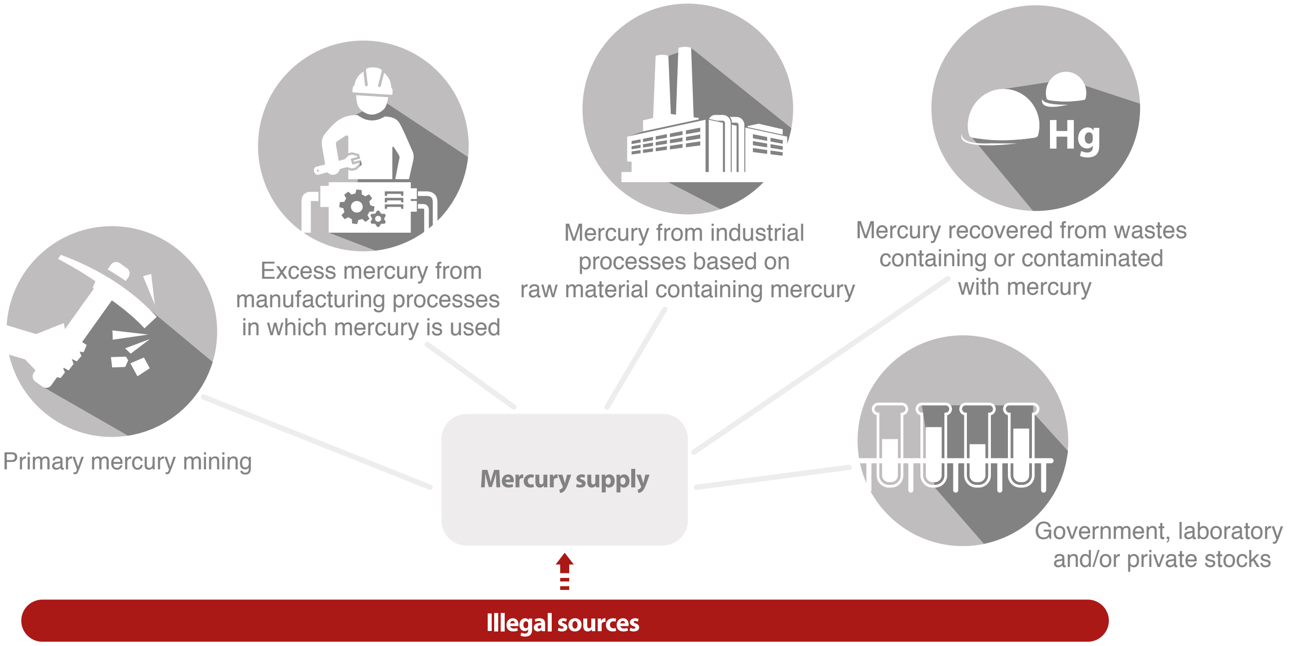

Figure 2: Potential Sources of Mercury Supply

### Excess Mercury from the Decommissioning of Chlor-alkali Facilities under the Minamata Convention: Art. 3, Para. 5 (b)

*“Each Party shall take measures to ensure that, where the Party determines that excess mercury from the decommissioning of chlor-alkali facilities is available, such mercury is disposed of in accordance with the guidelines for environmentally sound management referred to in para. 3 (a) of Art. 11, using operations that do not lead to recovery, recycling, reclamation, direct re-use or alternative uses.”*

Box 7: Excess Mercury from the Decommissioning of Chlor-alkali Facilities under the Minamata Convention: Art. 3, Para. 5 (b)

### Primary Mercury Mining under the Minamata Convention: Art. 3, Para. 4

*“Each Party shall only allow primary mercury mining that was being conducted within its territory at the date of entry into force of the Convention for it for a period of up to fifteen years after that date. During this period, mercury from such mining shall only be used in manufacturing of mercury-added products in accordance with Art. 4, in manufacturing processes in accordance with Art. 5, or be disposed in accordance with Art. 11, using operations which do not lead to recovery, recycling, reclamation, direct re-use or alternative uses.”*

Box 8: Primary Mercury Mining under the Minamata Convention: Art. 3, Para. 4

The development of inventories of mercury wastes may help in the identification of priorities, form the basis of next steps, and allow effective action to be taken to ensure ESM. Among others, data can be gathered on:

- the sources of mercury wastes;
- the types of mercury wastes; and
- the amounts of mercury wastes from each source and for each type.

In conducting inventories of mercury wastes, relevant guidance material can be relied upon (see Box 9 and Box 10).

### The 'Methodological Guide for the Development of Inventories of Hazardous Wastes and Other Wastes under the Basel Convention'

The 'Methodological guide for the development of inventories of hazardous wastes and other wastes under the Basel Convention'[20] can be used to compile inventories of hazardous wastes, including mercury wastes. The guide provides a road map for conducting a first national inventory of hazardous wastes. It discusses some of the challenges faced, provides guidance and proposes good practices in overcoming common obstacles. The revised guide has been adopted by the COP to the Basel Convention at its twelfth meeting in May 2015.

Box 9: The Methodological Guide for the Development of Inventories under the Basel Convention

### The 'Toolkit for Identification and Quantification of Mercury Releases' and 'MercuryLearn'

UNEP's 'Toolkit for identification and quantification of mercury releases'[21] provides guidance through the different stages of identifying sources and quantifying the consumption and releases of mercury for these sources. The Toolkit exists in two versions: 'Inventory Level 1' provides a simplified version of the Toolkit to make the development of an overview inventory easier. 'Inventory Level 2' is the comprehensive version and is useful if more detailed information on specific release sources is needed. UNEP and the United Nations Institute for Training and Research (UNITAR) have recently launched the 'MercuryLearn'[22] online training modules to support countries in developing national mercury inventories.

Box 10: The UNEP Toolkit for Identification and Quantification of Mercury Releases

## 1.4. Mercury Supply Exceeding Demand

**Excess mercury is the amount of mercury supply that exceeds demand for uses allowed under national law and international law**, including the Minamata Convention, where applicable (see Figure 3).[23, 24, 25] As mercury is a naturally occurring element, it cannot be destroyed. Excess mercury needs to be stored in an environmentally sound manner or transformed to a form having minimal mobility, and reliably sequestered from the environment.

**The amount of excess mercury may influence a country's choice of policies to ensure environmentally sound storage and disposal**. Assessing the situation at the regional or global level may also be important. It can be estimated that a total of 30,000-50,000 tonnes of excess mercury will become available globally by 2050.[17, 18, 19, 26, 27]

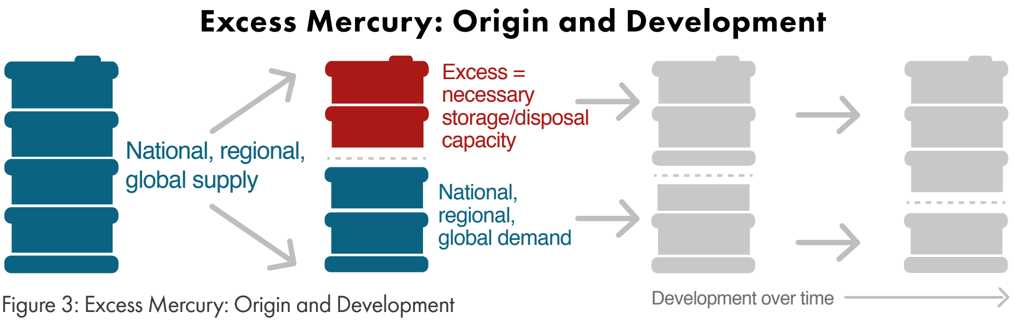

Figure 3: Excess Mercury: Origin and Development

## 1.5. Sources of Wastes consisting of Mercury or Mercury Compounds

Wastes consisting of mercury or mercury compounds may become available from manufacturing processes in which mercury is used (e.g. mercury cell chlor-alkali facilities), be extracted from end-of-life mercury-added products or wastes contaminated with mercury, or be captured during the processing of raw materials with mercury impurities (such as non-ferrous metals (NFM) (e.g. zinc) or natural gas) (also see Figure 2).[14, 15] Excess mercury stocks remaining after allowable uses may be classified as waste and may therefore be a significant source of wastes consisting of mercury or mercury compounds. Primary mercury mining should be phased out under the Minamata Convention as it is universally implemented (also see Box 8). Mercury can either be:

i) **classified as commodity for a use allowed** under national and international law, including the Minamata Convention, where applicable; or

ii) **classified as waste and managed in an environmentally sound manner** in accordance with national and international law, including the Minamata Convention, where applicable (see Figure 4).

**Potential Sources of Wastes Consisting of Mercury or Mercury Compounds**

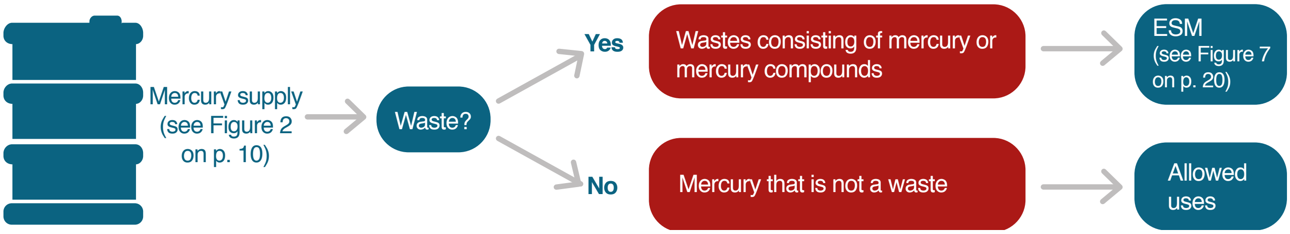

Figure 4: Potential Sources of Wastes Consisting of Mercury or Mercury Compounds

It may be useful to **establish clear rules and criteria regarding the classification of mercury as waste or commodity**. Countries may, for example, decide, consistent with national and international law, including the Minamata Convention, where applicable, that mercury from specific sources is not allowed to enter the market.

Many industrial processes generate wastes contaminated with mercury. Often those wastes undergo recycling or reclamation and in turn may generate mercury. Unless otherwise determined by national law, this mercury may or may not be considered a waste depending on whether it is used in products or processes allowed under national and international law, including the Minamata Convention, where applicable.

In this context, it is important to highlight that **the use of mercury is not encouraged**. The objective of this document is to assist countries in their efforts to isolate mercury from the biosphere in order to protect human health and the environment from anthropogenic emissions and releases of mercury. It is suggested to only use mercury where no alternatives exist and only for those uses allowed under national law and international law, including the Minamata Convention, where applicable. This may help in some cases to reduce the demand for primary mercury mining, which is the least preferred source of mercury.[28]

## 1.6. Sources of Wastes Containing Mercury or Mercury Compounds

Wastes containing mercury or mercury compounds mainly come in the form of spent (end-of-life) mercury-added products and applications, but also include stabilized/solidified mercury.[23]

The list shown in Figure 5 is not exhaustive and does not go into detail regarding sub-categories. For more information and examples, see among others Annex A of the Minamata Convention, or information provided by UNEP[29], the US EPA[30] or the Northeast Waste Management Officials Association[31]. In addition to the examples given in Figure 5, stabilized/solidified mercury wastes are also classified as wastes containing mercury.

The categories shown in Figure 5 may or may not contain mercury, depending on the specific type of product or the production process used. The products only become waste containing mercury at the end of their life (often also referred to as 'spent' products).

**Potential Sources of Wastes Containing of Mercury or Mercury Compounds**

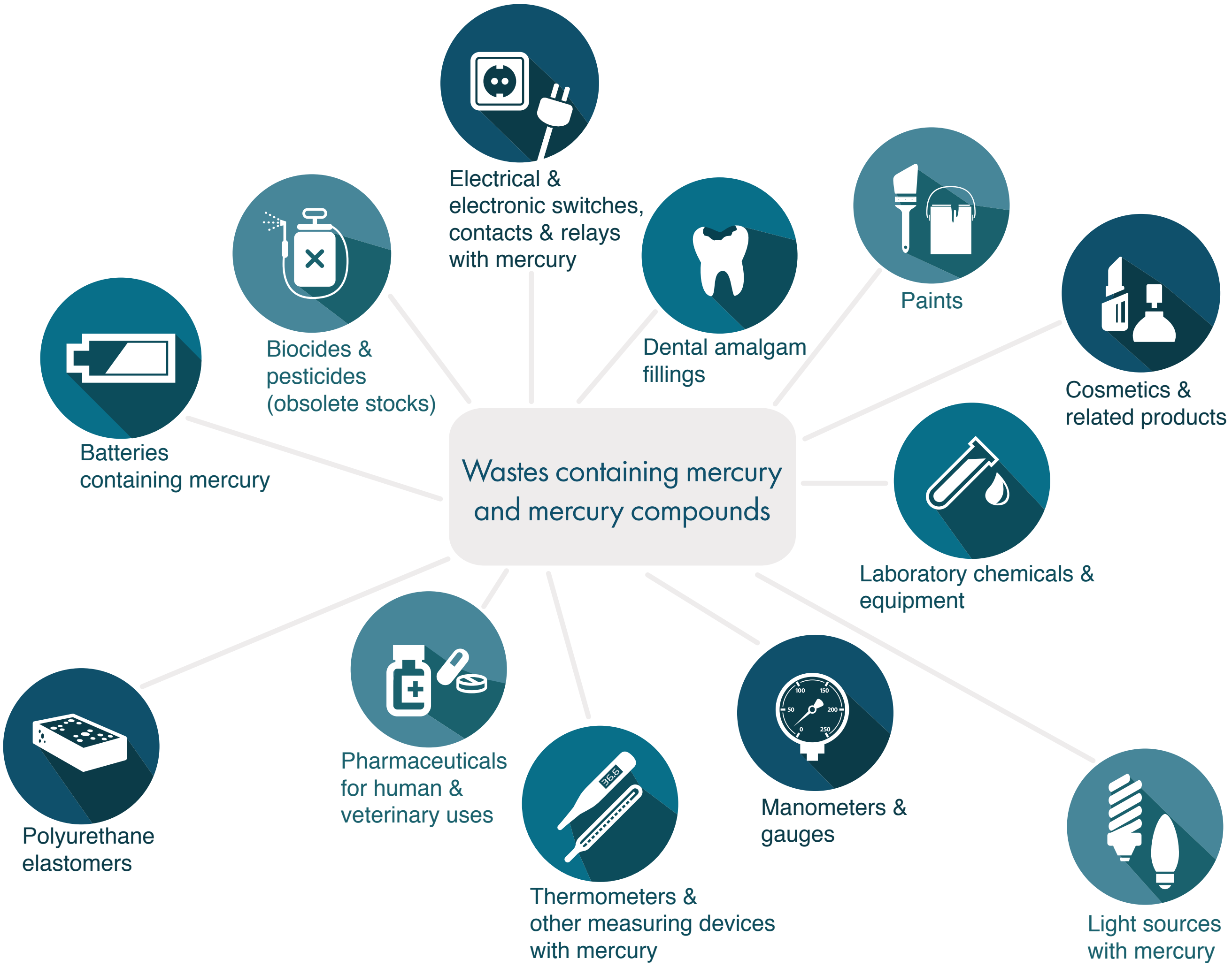

Figure 5: Potential Sources of Wastes Containing Mercury or Mercury Compounds

## 1.7. Sources of Wastes Contaminated with Mercury or Mercury Compounds

Wastes contaminated with mercury are mainly generated via industrial processes using materials with mercury impurities (e.g. natural gas) and industrial processes with intentional use of mercury (e.g. vinyl chloride monomer (VCM)) (see Figure 6). Some sources (e.g. primary mining or chlor-alkali) may generate both wastes consisting of mercury or mercury compounds and wastes contaminated with mercury or mercury compounds. Artisanal and small-scale gold mining (ASGM) is another significant source of wastes contaminated with mercury or mercury compounds.[1]

**Potential Sources of Wastes Contaminated with Mercury or Mercury Compounds**

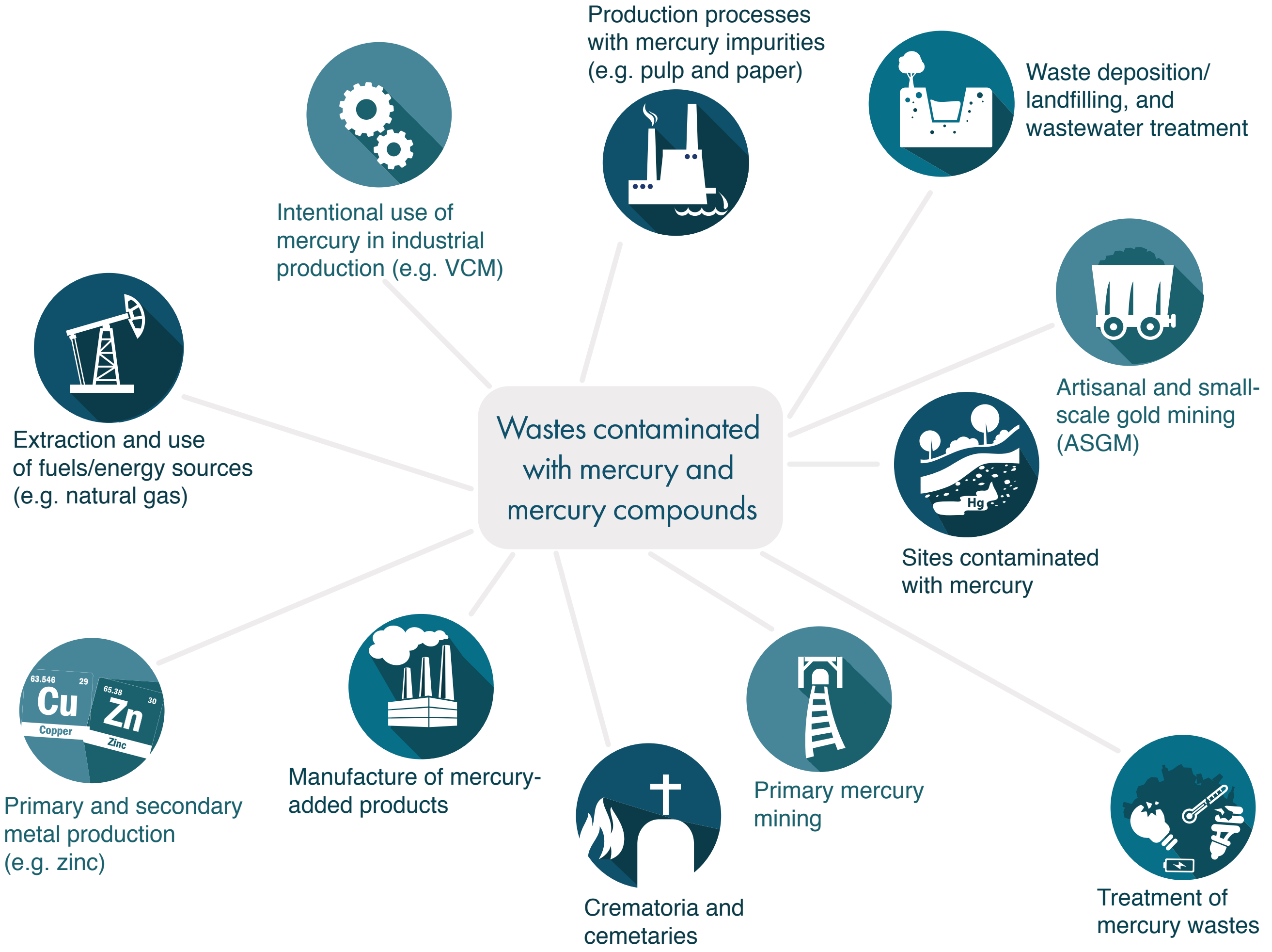

Figure 6: Potential Sources of Wastes Contaminated with Mercury or Mercury Compounds


Hg
Cu
Zn
Zinc
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Hg

# CHAPTER 2:
# Environmentally Sound Management of Mercury Wastes

This Chapter begins with an overview of important concepts and considerations related to the ESM of mercury wastes, including in the context of the Minamata Convention and the Basel Technical Guideline. The first preferred option in the ESM of mercury wastes is the prevention and minimization of mercury wastes. The basic options that are available to ensure environmentally sound storage and disposal for waste streams of important source categories are noted below. Waste management covers source separation, collection, transportation, treatment, storage and disposal.[1]

## 2.1. Important Concepts and Considerations in the ESM of Mercury Wastes

The 'Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal'[32] defines ESM as "**taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes**" (Art. 2, para. 8).

Under the Basel Convention, 'disposal' is defined as meaning "any operation specified in Annex IV of this Convention". Annex IV contains two sections: Section A lists "operations which do not lead to the possibility of resource recovery, recycling, reclamation, direct reuse, or alternative uses". These are the so-called '**D-operations**'. Section B lists "operations which may lead to resource recovery, recycling, reclamation, direct reuse, or alternative uses". These are the so-called '**R- operations**'. Thus, the term 'disposal' under the Basel Convention covers both disposal operations covered in Section A and recovery operations listed in Section B.

The Basel Technical Guidelines suggest permitting the operations listed in Table 2 for mercury wastes.

| Code | Recovery operations |
|---|---|
| R4 | Recycling/reclamation of metals and metal compounds |
| R5 | Recycling/reclamation of other inorganic materials |
| R8 | Recovery of components from catalysts |
| R12 | Exchange of wastes for submission to operations R4, R5, R8 or R13 |
| R13 | Accumulation of material intended for operations R4, R5, R8 or R12 |

| Code | Disposal operations |
|---|---|
| D5 | Specially-engineered landfill |
| D9 | Physico-chemical treatment |
| D12 | Permanent storage |
| D13 | Blending or mixing prior to submission to D5, D9, D12, D14 or D15 |
| D14 | Repackaging prior to submission to D5, D9, D12, D13 or D15 |
| D15 | Storage pending any of the operations D5, D9, D12, D13 or D14 |

Table 2: Recovery and Disposal Operations for Mercury Wastes as listed in the Basel Technical Guidelines

In order to achieve ESM, it is suggested that mercury wastes are:

- **not mixed with other wastes** (where regulation prescribes the extraction of mercury above a certain threshold, there is a danger that some may be motivated to circumvent it by diluting the waste);
- **not discarded in uncontrolled landfills** (subject to the eligibility criteria defined by national law, mercury wastes may be disposed of in specially engineered landfills (SELs));
- **not (co-)incinerated without dedicated flue gas cleaning and controls** (while it is not recommended to incinerate mercury wastes, it may sometimes be difficult to avoid, e.g. where mercury cannot be filtered out completely from the feed and because other contaminants require such treatment; if justified, incineration should be done in compliance with national legislation as well as international rules and obligations); and
- **treated to extract the mercury or to immobilize it in an environmentally sound manner.**[1, 8]

## ESM of Mercury Wastes under the Minamata Convention: Art. 11, Para. 3

*“Each party shall take appropriate measures so that mercury waste is:*

*(a) Managed in an environmentally sound manner, taking into account the guidelines developed under the Basel Convention and in accordance with requirements that the Conference of the Parties shall adopt in an additional annex in accordance with Art. 27. In developing requirements, the Conference of the Parties shall take into account Parties’ waste management regulations and programmes;*
*(b) Only recovered, recycled, reclaimed or directly re-used for a use allowed to a Party under this Convention or for environmentally sound disposal pursuant to para. 3 (a);*
*(c) For Parties to the Basel Convention, not transported across international boundaries except for the purpose of environmentally sound disposal in conformity with this Art. and with that Convention. In circumstances where the Basel Convention does not apply to transport across international boundaries, a Party shall allow such transport only after taking into account relevant international rules, standards, and guidelines.”*

Box 11: ESM of Mercury Wastes under the Minamata Convention: Art. 11, Para 3

## Lifecycle management:

When developing an ESM programme for mercury wastes, it may also be useful to conduct lifecycle management studies. These studies can help to identify where mercury and mercury wastes enter and leave various sectors of an economy. Lifecycle analyses may also help to **prioritize the avoidance/prevention and reduction of mercury used in products and processes** in order to avoid/prevent and reduce the mercury content in the wastes to be disposed of and in wastes generated in industrial processes and other activities. For information on alternatives to mercury-added products and processes using mercury, please see the ‘Guide for Reducing Major Uses and Releases of Mercury’[33] as well as material published under the umbrella of the Global Mercury Partnership, including the ‘List of Alternatives to Mercury-Added Products’[34].

## Choosing between ESM options:

When choosing between environmentally sound waste management system options, the following variables may be considered:

- **Sources of mercury wastes**: Different sources may generate different waste streams and thus require different management considerations. For instance, countries with industrial processes generating wastes contaminated with mercury may need to ensure that disposal options are available.

- **Types of mercury wastes**: The characteristics of the waste (mercury concentration, leachability etc.) will determine eligibility of certain options, such as disposal in SELs or permanent storage. For some wastes, the mercury concentration may be too low to allow cost-effective extraction. Sometimes, stabilization/solidification (S/S) may be needed.

- **Volumes of mercury wastes**: The volumes of mercury wastes generated domestically may affect cost-benefit calculations for investing in specific management infrastructures. For example, export may be a reasonable option for countries with low volumes, while investment in disposal infrastructure may be cost-effective for countries with significant volumes of mercury wastes that are generated on a continuous basis.

- **Existing management infrastructure**: Countries vary in their capabilities and capacity to manage their mercury wastes. Those without adequate capacity may wish to identify countries capable of ensuring ESM and export their mercury wastes, so as to avoid site contamination and possible exposures resulting from inadequate handling. Previous experiences and existing infrastructure may be taken into account when assessing management options and built upon. For example, existing sites may be retrofitted.

- **Characteristics of the management options**: The technical feasibility of recovering waste constituents and the availability of the process may need to be taken into account. Management options may differ in terms of investment and/or operational costs. Moreover, some options may require significant technical expertise that may not be available in some countries.

- **The value of recoverable components**: Wastes containing or contaminated with mercury often contain valuable components that may be recovered for re-use (this may also include mercury, which may be used for uses allowed under national and international law, including the Minamata Convention, where applicable; where appropriate and in line with national, regional and international rules and obligations, selling/trading mercury recovered from wastes may facilitate environmentally sound treatment by reducing overall costs).

- **Legal issues**: Management options will need to be assessed in the light of the national, regional and international regulatory framework. This may include, for example, national criteria and thresholds, import/export bans and the Minamata Convention.

- **Other factors**: Decision-makers may also need to take into consideration factors such as geology, weather patterns (e.g. susceptibility to floods, hurricanes or earthquakes) or public opinion.[1, 8]

## 2.2 Health and Safety

Two key aspects of an environmentally sound programme for the management of mercury wastes are the development and implementation of (1) public health and safety activities and (2) worker health and safety activities which prevent and minimize exposure to mercury wastes.

**Public Health and Safety**: Public health activities may include **programmes which prevent and minimize exposure** by establishing mercury limitations from commercial and industrial sources which may emit, discharge or dispose mercury or mercury wastes into the environment. These activities may also include approaches to reduce exposure from the breakage of mercury thermometers and implement rapid clean-up of such spills. Public health and safety programmes may also wish to pay particular attention to **protecting populations that are more sensitive to the effects of mercury wastes**, including fetus, newborns and children, as well as new mothers and pregnant women.[35]

People living and working in the vicinity of facilities handling mercury wastes may also be exposed to environmental health and accident risks. These risks relate mainly to emissions and releases from the process and transport to and from the facility. Adequate measures are necessary to prevent and minimize impacts on human health and the environment. **Monitoring programmes** may help to identify problems and take appropriate measures to remedy them.[1]

An acute threat may come from spills of mercury. Box 12 lists special considerations for such cases.

### Special Considerations for Spillage of Mercury

- Contact local authorities
- Never use a vacuum cleaner or a broom to clean up mercury
- Never pour mercury down a drain[1]

Box 12: Special Considerations for Spillage of Mercury

**Worker Health and Safety**: Worker health and safety programmes may consider activities which assure that workers who collect, transport, store and dispose mercury wastes **are adequately trained and are provided equipment which prevents or minimizes them from exposure** to mercury wastes (see Box 13). These workers could have high occupational exposures.[35]

### Worker Health and Safety Measures

- Provide employee training in effective ESM
- Use respirators with mercury filters and personal protective clothing (see Photo 4 for an example)
- Regularly measure mercury concentrations in the air
- Take urine samples from workers on a continuous basis
- A regular intake of selenium may protect against mercury exposure[90]
- Health, safety and emergency plans in place
- The principal elements of an emergency plan include identification of potential hazards, actions to be taken in emergency situations, communication targets and methods in case of emergency, and testing of emergency response equipment[1, 10]

Photo 4: Protective Clothing
(courtesy: Kummel Consulting AB)

Box 13: Worker Health and Safety Measures

In conclusion the general steps towards addressing health and safety may include the following:

- Establishing an appropriate **policy framework**, taking into account international agreements, principles and standards;
- paying special attention to **sites** engaged in storage, recovery operations or disposal operations; and
- taking necessary measures at the facility level to protect **workers** from any adverse effect on their health during the handling and processing of mercury wastes.

## 2.3 Government, Laboratory and/or Private Stocks

If government, laboratory and/or private stocks of mercury are classified as waste, they become waste consisting of mercury. The following options are available to ensure ESM of such wastes (see Figure 7):

i) **Storage pending further collection or disposal operations** (see Chapter 3): The waste is removed from the market, but not isolated from the biosphere. This is an intermediate step before the waste is eventually submitted for disposal in SELs, permanent storage in underground facilities, or export for environmentally sound disposal. Meanwhile, some countries may wish to store mercury wastes for a longer period of time (i.e. several decades). Safeguards can help to prevent emissions and releases as well as theft.

ii) **Disposal in SELs** (see Chapter 5.2) or permanent storage in underground facilities (see Chapter 5.3) following prior S/S (see Chapter 5.1). The idea is to isolate the waste from the biosphere for a long period of time. S/S processes may be available only in some countries.

iii) **Export for environmentally sound disposal** (see Chapter 6) may be an option for countries if the necessary infrastructure is not (yet) domestically available. Export is followed by options i) or ii) noted above. The importing country should have infrastructure to guarantee ESM and permit the import according to national legislation. If one of the countries involved is a Party to the Basel Convention, applicable provisions under that Convention must be followed.[1, 8, 24, 36, 37]

It is important that safeguards are in place to avoid illegal trafficking of wastes consisting of mercury (for more information on traceability, see Chapter 3.2).

## Options for the ESM of Wastes Consisting of Mercury or Mercury Compounds

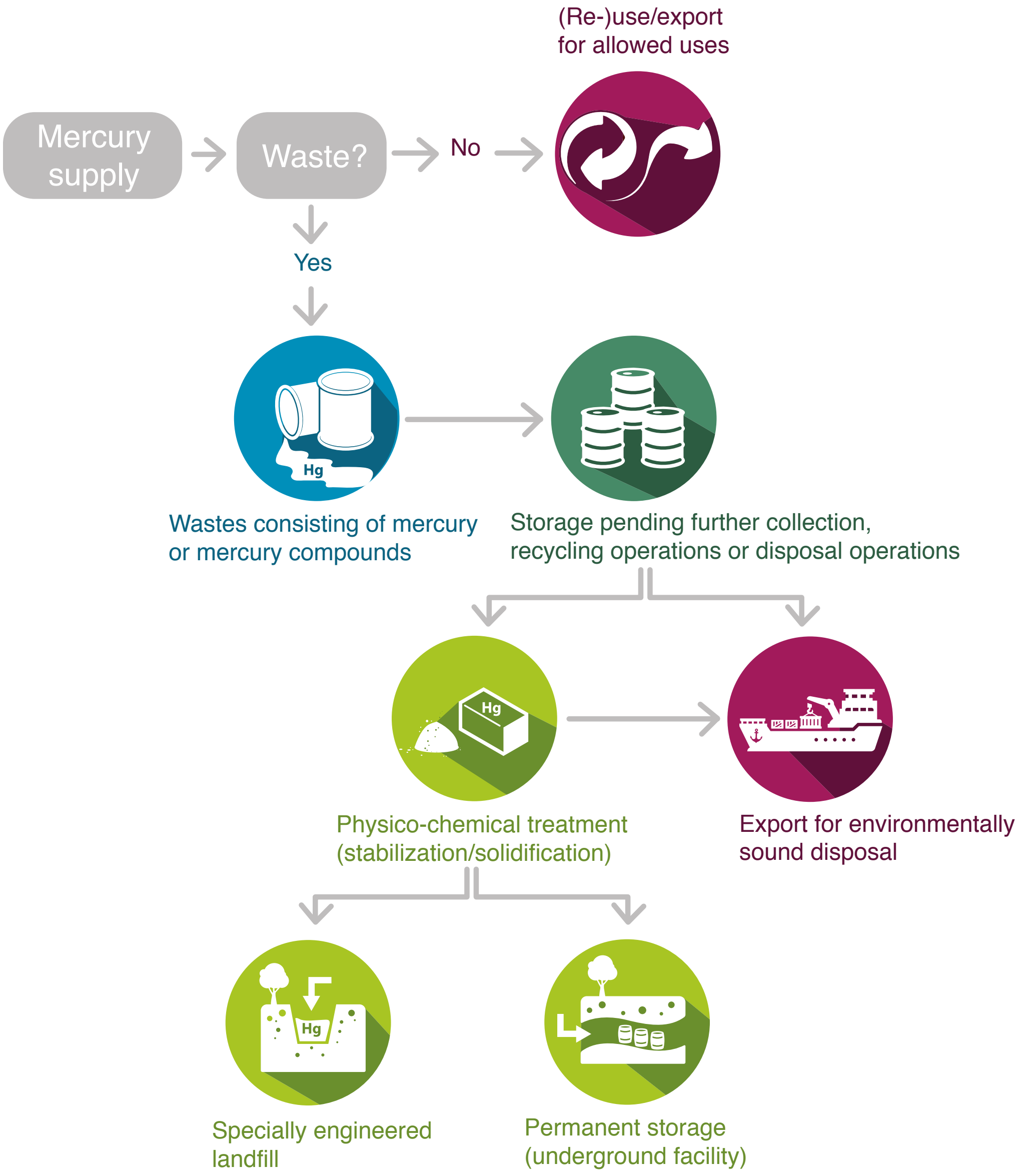


Figure 7: Options for the ESM of Wastes Consisting of Mercury or Mercury Compounds

## 2.4 Spent Mercury-added Products

Critical steps in the management of end-of-life mercury-added products are source segregation, collection and separation. Without adequate source segregation, **collection, and separation schemes**, most end-of-life mercury-added products will end up in the municipal waste and might be incinerated without adequate emission controls or dumped in uncontrolled landfills.

Large volumes of end-of-life mercury-added products are generated in public institutions as well as the private sector. These need to be stored on-site in an environmentally sound manner. Collection points may be needed to be set up for individual, industry or institutional users. Following appropriate transport, end-of-life mercury-added products may be stored in a centralized facility with appropriate security measures in place before they are sent off-site for recovery operations or disposal operations (also see Chapter 3).

The Basel Technical Guidelines identify three options for collection:

I. **Waste collection stations or drop-off depots**: End-of-life mercury-added products may be discarded in a specially designed container at a waste collection station or depot. Appropriate boxes or containers may be made available for public use, according to national priorities and capabilities. It is important that the collection stations or drop-off depots are designed in such a way as to prevent/minimize breakage.

II. **Collection at public places or shops**: Collection may be done via specially designed collection vehicles or at public places or shops. Properly labelled containers should be placed in well ventilated areas or outside in a covered and protected area. Collection rates will be higher if the waste can be deposited free of charge.

III. **Collection at households by collectors**: Collection at households by authorized collectors may be applied for certain wastes, such as waste electrical or electronic equipment (WEEE/e-waste). For efficient collection, an initiative or legal mechanism may be required.[1]

**Collection**: The collection of end-of-life mercury-added products as well as subsequent recovery operations or disposal operations requires investment. How the costs of collection are distributed is a critical decision that national governments will need to determine. Some manufacturers are bearing some collection costs via their ‘extended producer responsibility’ (EPR) programmes (see Box 14). Two examples of how EPR can be implemented in practice are given in Case Study 1 and Case Study 2.

### Extended Producer Responsibility

EPR is defined as an environmental policy approach in which a producer’s responsibility, physical and/or financial, for a product is extended to the post-consumer stage of a product’s life cycle. It relies on shared responsibilities among stakeholders. Private companies can participate, for example, by establishing collection systems or promoting public participation. Governments may have to take the lead via regulatory incentives and, among others, may need to establish standards and monitor performance.[38]

Box 14: Extended Producer Responsibility

### The Waste Electrical and Electronic Equipment Directive (EU) and its Implementation (Austria)

The Waste Electrical and Electronic Equipment Directive (WEEE) implemented EPR in the EU. It set collection, recycling and recovery targets for electrical and electronic equipment and aims to make equipment manufacturers financially or physically responsible for their products at the end-of-life. Users should have the possibility of returning WEEE at least free of charge and manufacturers must dispose of it in an environmentally friendly manner, by disposal, reuse, or refurbishment. Collection targets of 45% by 2016 and 65% by 2020 were established.[39]

In order to implement the Directive, Austria introduced a system where a fee of one euro is added on the price of lamps. The consumer can recover this deposit upon return of the lamp to a point of sale and is thus encouraged not to dispose of it in the household waste. The fee is used to cover costs of collection and recycling and has resulted in a more than 50% return rate, with 80% of all retired mercury-added lamps being recycled.[40]

Case Study 1: The Waste Electrical and Electronic Equipment Directive (EU) and its Implementation (Austria)

### The National Environmental Waste Act (South Africa)

South Africa introduced EPR for the management of hazardous waste, including mercury-added lamps, through the National Environmental Waste Act. Responsibility for environmentally sound management has thus been shifted from government to industry. An important step in the implementation of this Act was the development of an Industry Waste Management Plan for Lamps by the lighting industry. In addition, the Consumer Protection Act requires suppliers, producers, importers or distributers to accept and take responsibility for the disposal of hazardous goods, including mercury-added lamps. As a consequence, collection facilities were made available to consumers.[40]

Case Study 2: The National Environmental Waste Act (South Africa)

Further information, including on collection schemes, is available in the Basel Technical Guidelines. An example of a collection schemes is given in Case Study 3. For further examples, consult the 'Good Practices for Management of Mercury Releases from Waste'[41]. For information on the management of mercury-added lamps, see 'Achieving the Global Transition to Energy Efficient Lighting Toolkit'[40].

### Collection Campaign for Fluorescent Lamps (Kingdom of Thailand)

From 2006 to 2007, the government implemented a pilot partnership programme with major fluorescent lamp manufactures to collect and recycle fluorescent lamps from about 100 project partners, including government offices, academic institutions, business offices, retailers, hotels and hospitals from Bangkok and the surrounding areas.

The following steps were taken to establish a collection system: In 2007, the Kingdom of Thailand adopted a law authorizing local governments to collect and manage household hazardous waste. A waste management scheme was developed and disseminated to large-sized municipalities which also received financial and technical support. About 16 large municipalities implemented the scheme in 2009.

In terms of fluorescent lamps, the municipalities collect them from households or designated collection points and transfer them to a storage facility. In order to raise awareness, several measures are implemented: For example, municipalities organize special events and community meetings, training workshops are organized for community leaders who will then disseminate their knowledge, and media (including posters, pamphlets and DVDs) are used.

While municipalities currently bear the costs, a new law has been drafted to authorize agencies in the Ministry of Finance to impose a product fee on manufacturers and importers in order to cover the costs of ESM, including of fluorescent lamps.

The campaign produced some promising initial results. The number of collected fluorescent lamps increased from 60,000 in 2007 to 700,000 in 2009. It was estimated that in 2009 alone, 4-5 kg of mercury were not thrown in municipal landfills as a result of the campaign.[41]

Case Study 3: Collection Campaign for Fluorescent Lamps (Kingdom of Thailand)

ESM options: The following options are available to ensure ESM of end-of-life mercury-added products:

i) **Recovery/recycling** (see Chapter 4): End-of-life mercury-added products can be recovered/recycled in facilities which often use specialized processes depending on the specific product. The various components are separated and decontaminated (for example glass, phosphor powder and metals in the case of fluorescent lamps) and the mercury recovered. Recovered mercury may be re-used for uses allowed under national law and the Minamata Convention, where applicable.

ii) **Extraction of mercury for disposal operations** (see Chapters 4 and 5): Using the same or similar processes as in recovery/recycling, the mercury can be extracted from the waste and, following S/S, sent for disposal in SELs or permanent storage in underground facilities.

iii) **Export for environmentally sound disposal** (see Chapters 6): Exporting spent mercury-added products and/or wastes consisting of mercury or mercury compounds extracted from spent-mercury added products for recovery operations or disposal operations may be an option for countries where treatment technologies are not (yet) domestically available. Export is followed by options i) or ii) noted above. The importing country should have infrastructure to guarantee ESM and permit the import according to national legislation. If one of the countries involved is a Party to the Basel Convention, applicable provisions under that Convention must be followed.

**It is suggested not to dispose spent mercury-added products in landfills without prior treatment**, as the mercury contained in the product can easily be released into the environment. It should be noted that recovery/recycling and physico-chemical treatment processes may generate residues contaminated with mercury which need to be disposed of in an environmentally sound manner.[1, 8]

Figure 8 illustrates the various steps on environmentally sound disposal operations not leading to recovery of mercury or mercury compounds.

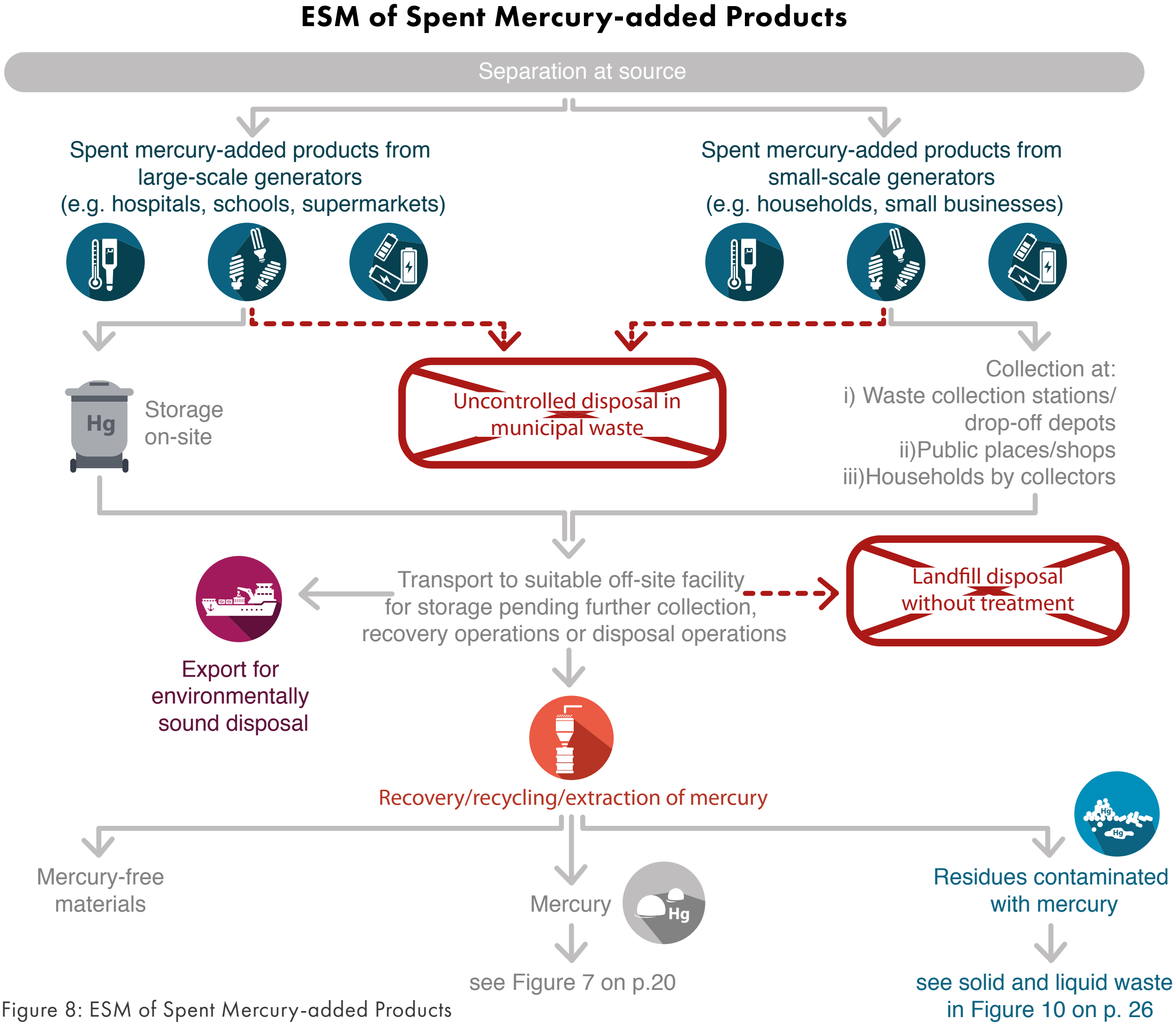


Figure 8: ESM of Spent Mercury-added Products

**Dental Amalgam**: The inappropriate disposal of dental amalgam waste and the lack of best practices in some dental clinics are sources of mercury releases to the environment.[4, 42] By observing the following steps, further releases to air, water and soil may be avoided (also see Figure 9 below):

- **Recycle dental amalgam**. This is economically beneficial, most notably due to the silver that is recovered.
- **Use ISO 11143 accredited amalgam separators** to capture mercury. Separators can be re-used after appropriate processing. Introducing a collection and audit system will help to remind dentists that the units need to be replaced periodically and encourage better recycling practice.
- **Train dental professionals** in the ESM of dental amalgam.
- **Use amalgam capsules** instead of bulk mercury. This may help to avoid the diversion of mercury that has originally been imported through legal channels for legitimate use in dental amalgam into ASGM.[42, 43, 44, 45]

Dental clinics may hold stocks of mercury which are in need of ESM and – if classified as waste – disposal.[45]

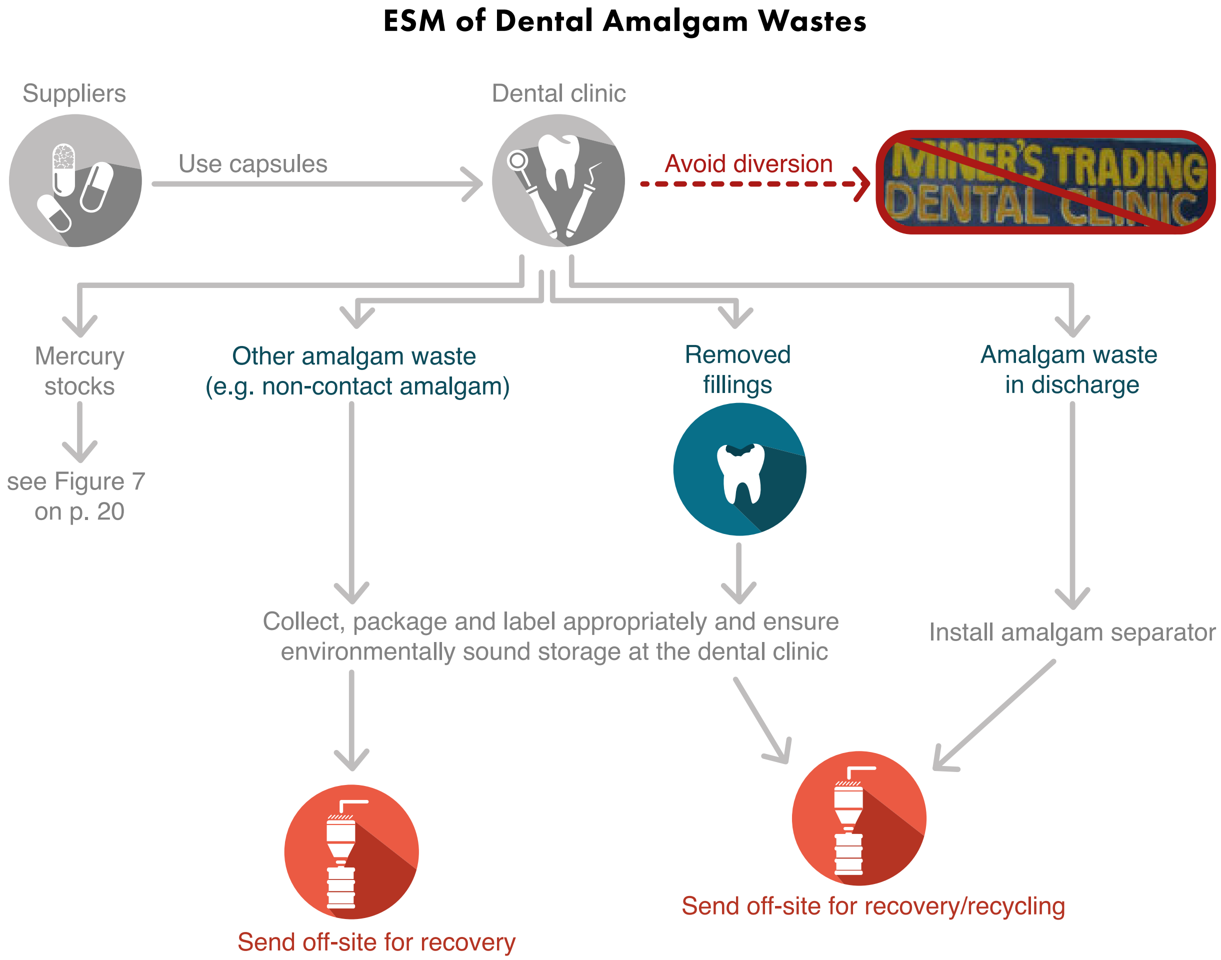


Figure 9: ESM of Dental Amalgam Wastes

## 2.5 Industrial Processes Using Raw Materials Containing Mercury

**Mercury is present as an impurity** in non-ferrous metals (NFM) ores, natural gas, mineral oil, and coal. When these crude resources are processed, mercury may be mobilized and released into the environment. This makes industrial processes based on raw material containing mercury **important sources of emissions, releases and wastes contaminated with mercury**.[4]

Under the Minamata Convention, the definition of mercury wastes excludes overburden, waste rock and tailings from mining, except from primary mercury mining, unless they contain mercury or mercury compounds above thresholds defined by the COP (Art. 11, para 2).

**Control technologies**: **Technologies to control mercury from industrial processes using raw materials containing mercury are available.** This includes, among others, activated carbon injection, wet scrubbers or electrostatic precipitators for air pollution control; activated carbon filter beds, selenium filters or mercury condensers for mercury specific control; and ion exchange or sulphide precipitation for liquid phase removal. Existing equipment used to reduce emissions and releases of other pollutants can often be used to capture mercury. This also applies to pre-treatment steps: For example, pre-combustion measures such as coal washing are often performed to reduce sulphur and ash contents of the coal. A variable fraction of the mercury in the coal is also removed in this operation.[46, 47, 48, 49, 50]

For more information, see UNEP's 'Guide for Reducing Major Uses and Releases of Mercury'[33], UNEP's 'Para. 29 Study'[46], or the EU's relevant 'Best Available Techniques Reference Documents'[51].

Control technologies have an effect on output pathways, shifting mercury from emissions and releases to residues or other process wastes, such as fly ash or scrubber sludge.[46, 52] These wastes contaminated with mercury will need to be managed in an environmentally sound manner. Captured mercury, for instance from non-ferrous metals processing, can either be marketed for uses allowed under national and international law, including the Minamata Convention, where applicable, or, following stabilization and/or solidification (S/S), be sent for disposal.

The **environmentally sound on-site management** will help to minimize emissions and releases. Ensuring ESM could include precipitating mercury as stable compounds, lining and covering the waste deposit area, and others. The sites may eventually have to be remediated (see also Chapter 7).[53, 54]

Industrial facilities may have on-site capacity for recovery/recycling or physico-chemical treatment and disposal in SELs. These on-site treatment and disposal facilities should be operated in an environmentally sound manner.

**ESM options**: It is beneficial to take measures to facilitate the development of downstream waste management system options (e.g. authorized hazardous waste treatment facilities). In short, the following off-site options are available for wastes contaminated with mercury (see Figure 10):

i) **Recovery/recycling** (see Chapter 4): The aim is to separate the mercury from other components in order to decontaminate the waste. Various processes are available and may allow recovery/recycling of the valuable and mercury-free components (e.g. copper or activated carbon). Recovered mercury may be re-used for uses allowed under national and international law, including the Minamata Convention, where applicable.

ii) **Disposal in SELs or permanent storage in underground facilities** (see Chapter 5): Disposal in SELs or permanent storage in underground facilities without prior treatment may be an option if the wastes meet national acceptance criteria. Where this is not the case, the waste may be treated to meet national acceptance criteria, including via S/S. S/S processes are available for wastes contaminated with mercury, but for large waste volumes, assessment of the cost should be performed.

iii) **Extraction of mercury for disposal operations** (see Chapter 4 and 5): Using the same or similar processes as in recovery/recycling, the mercury can be extracted from the waste and, following S/S, sent for disposal in SELs or permanent storage in underground facilities.

iv) **Export for environmentally sound disposal** (see Chapter 6): Export may be an option for countries where the necessary infrastructure is not available within the territory of the exporting country. Export is followed by options i) or ii) noted above. The importing country should have infrastructure to guarantee ESM and permit the import according to national legislation. If one of the countries involved is a Party to the Basel Convention, applicable provisions under that Convention must be followed.

## ESM of Industrial Processes Based on Raw Material Containing Mercury

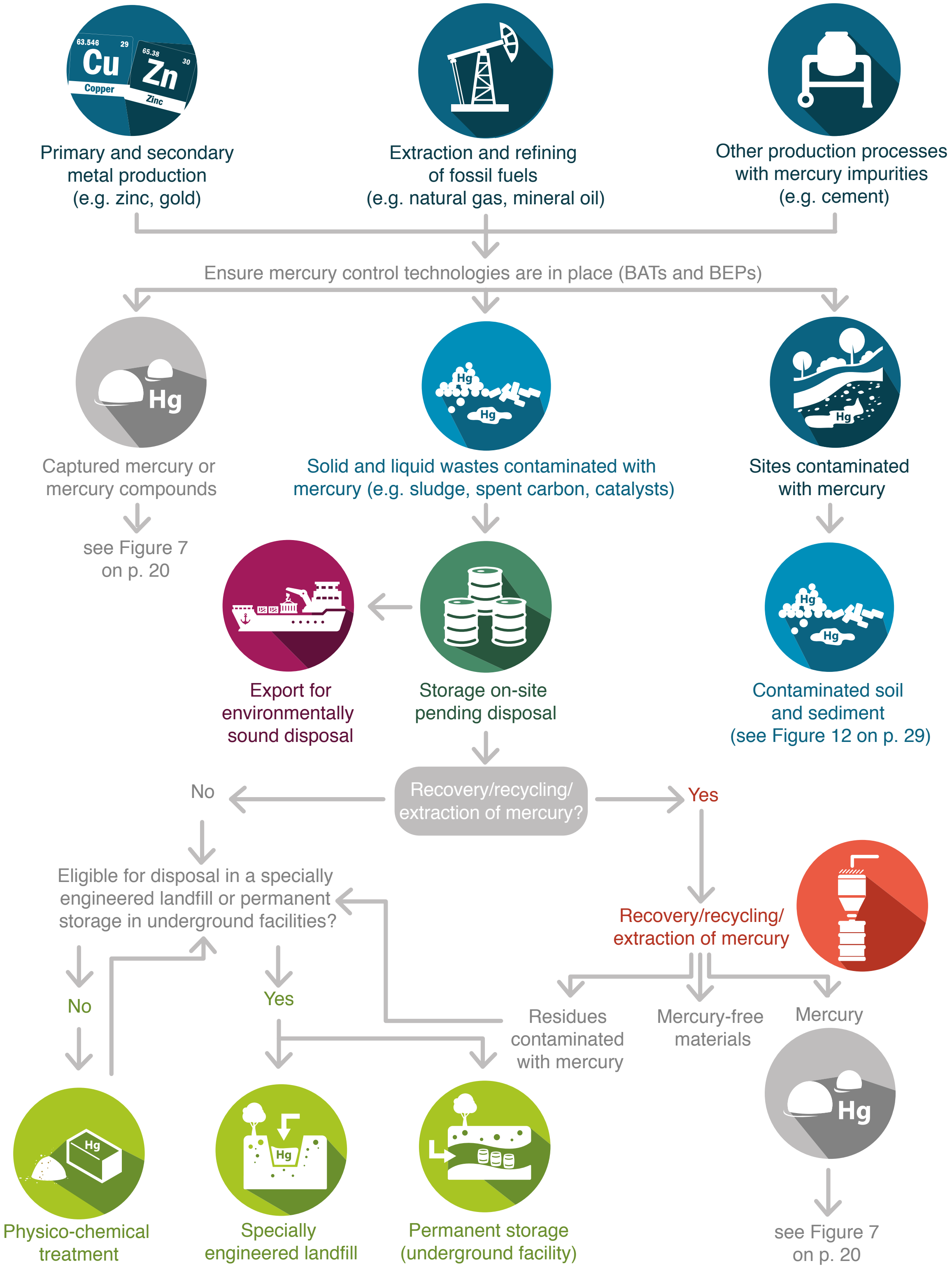


Figure 10: ESM of Industrial Processes Based on Raw Material Containing Mercury

**Non-ferrous Metals (NFM)**: This section illustrates mercury capture in the NFM sector. The processing of NFM is a source of mercury emissions and releases, a possible source of mercury supply as well as a generator of mercury wastes.[4, 14, 15, 16]

Mercury is present as an impurity in most NFM ores (zinc, copper, gold, lead etc.). **During processing, the mercury is mobilized**. Depending on the specific processes used, mercury may be released in gaseous form, remain in liquid and solid wastes, or be trapped in sulphuric acid which is recovered in most NFM plants as a by-product. **Dedicated mercury control technologies are commercially available** and may be used to capture mercury or mercury compounds, such as calomel ($Hg_2Cl_2$). Mercury compounds may need to undergo treatment before re-use or disposal.[52, 55]

Figure 11 shows the flow and the fate of mercury in a plan with combined pyrometallurgical processing and dedicated mercury control technology.

## Simplified Process Flow and Mercury Fate for Combined Pyro- and Hydrometallurgical Processing with Dedicated Mercury Control

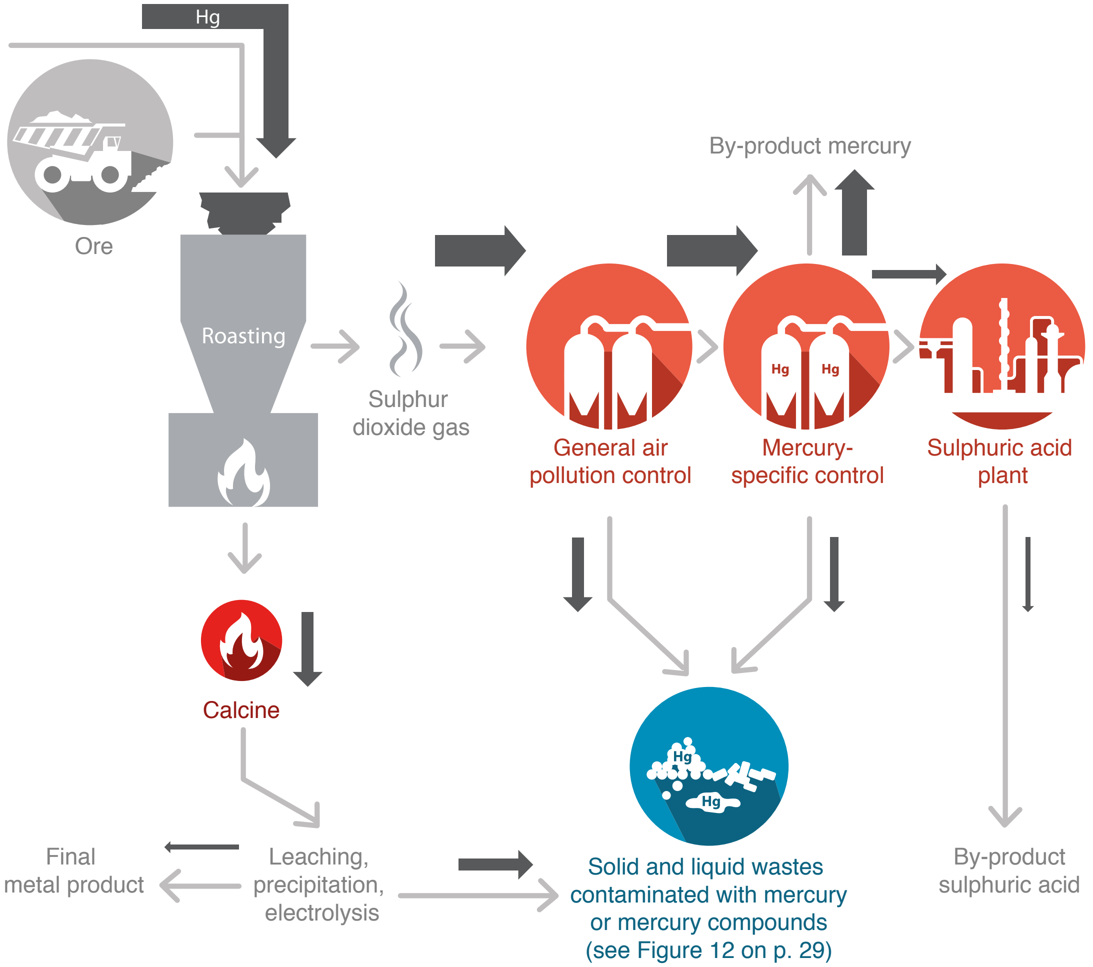


Figure 11: Simplified Process Flow and Fate of Mercury in NFM Processing with Dedicated Mercury Control[46, 52, 55]

The presence of dedicated mercury removal steps will influence the amount of mercury wastes generated onsite. Instead of being emitted to the atmosphere or contaminate by-products, in many cases mercury is captured in elemental form or as compound and contained in solid and liquid wastes. Depending on which combination of technologies is used, **mercury removal efficiencies may vary considerably**.[52, 55]

### Recovery/recycling of Mercury-contaminated Sludge from NFM (Japan)

Japanese zinc and copper refineries send their mercury-contaminated sludge offsite to a specialized mercury-recycling company for treatment and recovery. The mercury is extracted via roasting in a multiple hearth furnace (photo). This includes flue gas cleaning via condensation, scrubbing, electrostatic precipitation of dust and adsorption through activated carbon. Spent carbon and treatment residues are re-processed in the furnace until they are mercury-free. Emissions are continuously monitored and a strict voluntary limit is set by the company. The decontaminated sludge, which contains valuable metals, is sent back to the refineries. Currently, the recovered mercury is further purified and then sold for uses allowed under national and international law, including the Minamata Convention, where applicable, thus reducing the need for primary mining.[8]

Photo 5: Multiple Hearth Furnace
(courtesy: Nomura Kohsan Co., Ltd.)

Case Study 4: Recovery/recycling of Mercury-contaminated Sludge from NFM (Japan)

## 2.6 Industrial Processes Using Mercury

Industrial processes (notably VCM, acetaldehyde, sodium/potassium methylate/ethylate and polyurethane production) with intentional uses of mercury – often in catalysts – may be a **source of mercury emissions**, releases, and wastes. In VCM production, for instance, some of the mercury is lost in the catalyst during processing.[1, 56, 57]

**BATs and BEPs** can be utilized to avoid such emissions and releases and to prevent and minimize mercury wastes (see Figure 12). In VCM, for example, this may include recycling and reuse of mercury-containing effluent, collection of mercury containing sludge, and recovery of mercury from evaporated substances containing mercury.[1, 41, 57, 58] In the chlor-alkali sector, it is necessary to monitor possible leakages, reduce mercury evaporation, and recover mercury from wastewater.[59, 60]

As regards the decontaminated soil, it should be noted that even where the mercury concentration is negligible, other pollutants may still require further treatment.

**Decommissioning of mercury cell chlor-alkali facilities**: Mercury cell chlor-alkali facilities which close or convert to alternative technologies may have significant amounts of excess mercury.

A number of **preparatory steps should be considered prior to decommissioning**. This includes the preparation of a well-documented plan of action to be approved by the authorities, identification of downstream management options, and provision of equipment for mercury handling, including storage containers (see Figure 13).[59, 60, 61, 62] Decommissioning also determines approaches which would eliminate or minimize releases to the air, soil and water during this activity. Decommissioning can be grouped into the following three areas:

i) **Disposal of wastes contaminated with mercury or mercury compounds** (recovery/recycling, disposal in SELs etc.);

ii) **disposal of wastes consisting of mercury or mercury compounds** (in part after prior vacuum distillation/purification); and

iii) **site remediation** if warranted (see Chapter 7).[59]

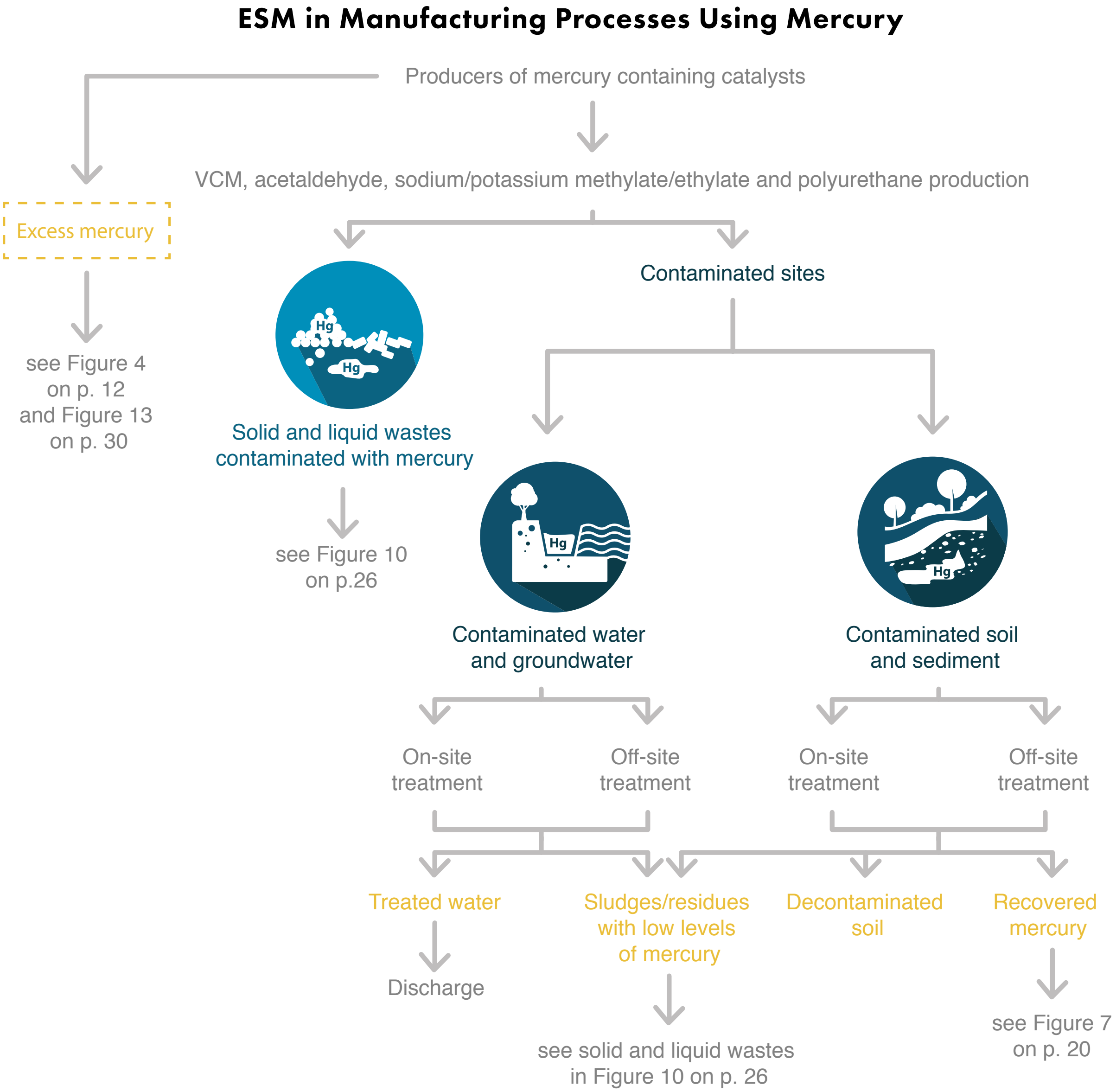


Figure 12: ESM in Manufacturing Processes Using Mercury

## Preparation for Permanent Storage of Metallic Mercury and Site Remediation

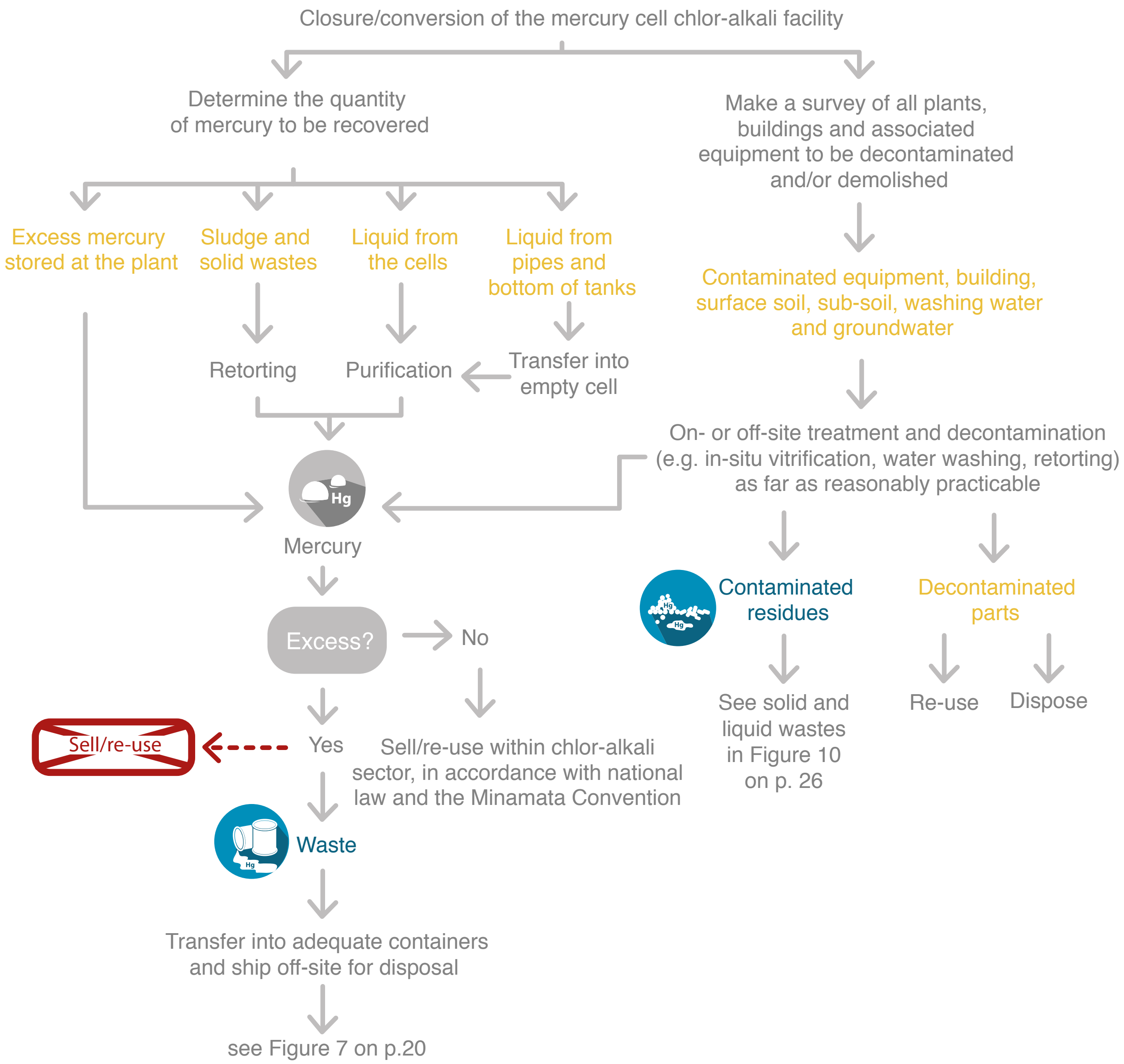


Figure 13: Preparation for Permanent Storage of Metallic Mercury and Site Remediation

Detailed guidance documents have been developed by the World Chlorine Council and are available on the website of the Global Mercury Partnership area on mercury reduction in chlor-alkali[63] as well as on the website of Euro Chlor.[64]


Hg
Cu
Zn
Zinc
Hg
Hg
Hg

# CHAPTER 3:
# Storage of Mercury Wastes

The Basel Technical Guidelines list two disposal operations for the storage for mercury wastes, namely R13 and D15:

i) **R13 – Accumulation of material intended for operations R4, R5, R8 or R12**: Mercury wastes may be accumulated with intent to conduct recycling/reclamation or recovery . Such storage is often regulated at the national level, where specific time periods may be set after the expiry of which the mercury wastes are transported to the appropriate recycling/reclamation or recovery facility.

ii) **D15 – Storage pending any of the operations D5, D9, D12, D13 or D14**: Mercury wastes may be stored pending physico-chemical treatment or placement into SELs or permanent storage.

Prior to either of these activities, mercury wastes may be collected. The following section discusses the handling, packaging, labelling, transport and traceability of mercury wastes as well as the various storage options.

## 3.1 Handling, Packaging, Labelling and Transport

By ensuring that the handling, packaging and transport of mercury wastes is undertaken with great care and in accordance with the technical requirements stipulated by national and international law, including the Minamata Convention, where applicable, **evaporation and spillage of mercury into the environment can be minimized or avoided**. For detailed information, see the Basel Technical Guidelines.

**Handling**: When handling wastes consisting of mercury, it is important to pay particular attention to the prevention of evaporation and spillage of mercury into the environment. Breakage or damage to mercury-added products is to be prevented whenever possible.[1]

**Packaging**: The containers in which mercury wastes are transported provide the most direct barrier to prevent releases. It is therefore necessary to carefully package mercury wastes in **appropriate containers** that have been manufactured to conform to UN standards for the packaging of mercury wastes or hazardous wastes before shipping them to designated facilities. Simple, but effective measures can help to prevent spillage and breakage. This includes, for example, properly placing the waste in the truck during transport in order to avoid shifting or sliding or to use plastic bubble wrap or plastic packing foam to prevent breakage of spent mercury-added products inside the containers.[1, 65]

Box 15, Box 16 and Box 17illustrate appropriate packaging for wastes consisting of, containing, or contaminated with mercury.

## Packaging of Wastes Consisting of Mercury

**Wastes consisting of mercury** are stored in exclusively designed stainless steel containers. These are stored in a dry location, upright on pallets off ground with overpacking and have the following characteristics:

- Gas-and liquid-tight
- Coated from the outside
- No damage to the structural integrity of the container
- No materials adversely reacting with mercury (e.g. ammonia or halogens) previously stored in the container.[1]

Photo 6: Mercury Flasks (Courtesy: Umwelt Technik Metallrecycling GmbH)
(2.5 litre) are commonly used and are also the standard unit for trading. 1 ton stainless steel pressure receptacles may also be used.

Box 15: Packaging of Wastes Consisting of Mercury

## Packaging of Wastes Containing Mercury

**Wastes containing mercury** are transported in appropriate packages (such as original boxes or closed containers) that prevents them from breaking and releasing mercury.[1]

Photo 7: 125 Litre UN-approved Plastic Drum (courtesy: Umwelt Technik Metallrecycling GmbH)

Box 16: Packaging of Wastes Containing Mercury

## Packaging of Wastes Contaminated with Mercury

**Liquid wastes contaminated with mercury** are packed in appropriate containers which are placed in containment trays or a curved and leak-proof area. **Solid wastes contaminated with mercury** are stored in sealed containers, steel waste containers or specially constructed containers.[1]

Photo 8: UN-approved 110 Litre Stainless Steel Drum with Epoxy Lining

Box 17: Packaging of Wastes Contaminated with Mercury

**Labelling**: Appropriate labelling is also important, among others to help with the **separation** of mercury wastes from other wastes and ensure that the **hazards of the waste are clearly communicated** during transport. This means that the containers have the relevant hazard pictograms of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS)[66] (see Box 18) and have a distinctive mark indicating, among others:

- Contains ‘toxic’ mercury
- Type of mercury waste
- Origin
- Weight
- Shock resistance

Photo 9: GHS06 – Acute Toxicity

Photo 10: GHS08 – Health Hazard

Photo 11: GHS09 – Environmental Hazard

Photo 12: Example of Product Labelling

Box 18: Labelling

**Transport**: Case Study 5 illustrates the environmentally sound transport of mercury wastes. Prior to transportation, **contingency plans** need to be developed and implemented in order to prevent/minimize environmental impacts associated with spills, fires and other potential emergencies. **Waste shipment acceptance procedures and consistency controls** are keys to successful transport of mercury wastes (Box 19).

### Transport of Wastes Consisting of Mercury (US)

- pallets inspected; drums and pallets banded for stability; loads blocked and braced in carrier‘s conveyance
- all shipments complied with U.S. Department of Transport requirements for shipment of hazardous materials
- certified hazardous material haulers
- stringent reception control, incl. vapour measurement[71]

Photo 13: Transport of Wastes Consisting of Mercury (courtesy: Defense Logistics Agency)

Case Study 5: Transport of Wastes Consisting of Mercury (US)

## Acceptance and Consistency Control

Upon arrival at treatment, storage or disposal facilities, mercury wastes undergo inspection. This includes vapour measurement and chemical analysis. If acceptance criteria are not fulfilled, (e.g. because undeclared substances are present in the waste) the waste is sent back to the owner. Workers should use personal protective equipment (respirators and protective clothing).[10]

Photo 14: Acceptance Control
(courtesy: K+S Entsorgung GmbH)

Box 19: Acceptance and Consistency Control

For an overview of relevant documents for transport and transboundary movement of mercury wastes, see the Basel Technical Guidelines.

### 3.2 Traceability

Throughout the logistics chain, it is important to ensure the traceability of mercury wastes. This will help to ensure that they are not diverted for **illegitimate uses or inadequately disposed**.

Traceability is an approach which identifies and records every activity of hazardous waste management from generation to disposal. Ideally, **mercury wastes are traceable throughout the lifecycle**, including after disposal. Traceability applies to relevant parties upstream (e.g. waste generators) and downstream (e.g. transporters, recyclers, disposers). When a comprehensive traceability approach is implemented, important information on the characteristics, concentration, and quantity of the mercury waste in question as well as the risks associated with its management are available to the relevant local and/or national authorities at all times. It is suggested to request detailed reports and tracking records from dealers, transporters, recyclers, disposers and others involved.[8, 67]

A traceability chain is summarized in Figure 14. Each person/entity involved in the ESM of mercury wastes would reports at least the information presented in Table 3 in its tracking records. This information allows:

- any competent authority to audit/inspect the traceability chain and enforce the **liability** of the different holders of the mercury waste; and
- each person/entity involved to provide a **mass balance** of the mercury wastes held (taking into account the emissions/losses; when significant, with justifications).

The tracking records are kept by each of the involved actors upstream and downstream to allow of the local and/or national authorities to inspect the traceability chain from the initial holder to the final destination.

## The Traceability Chain

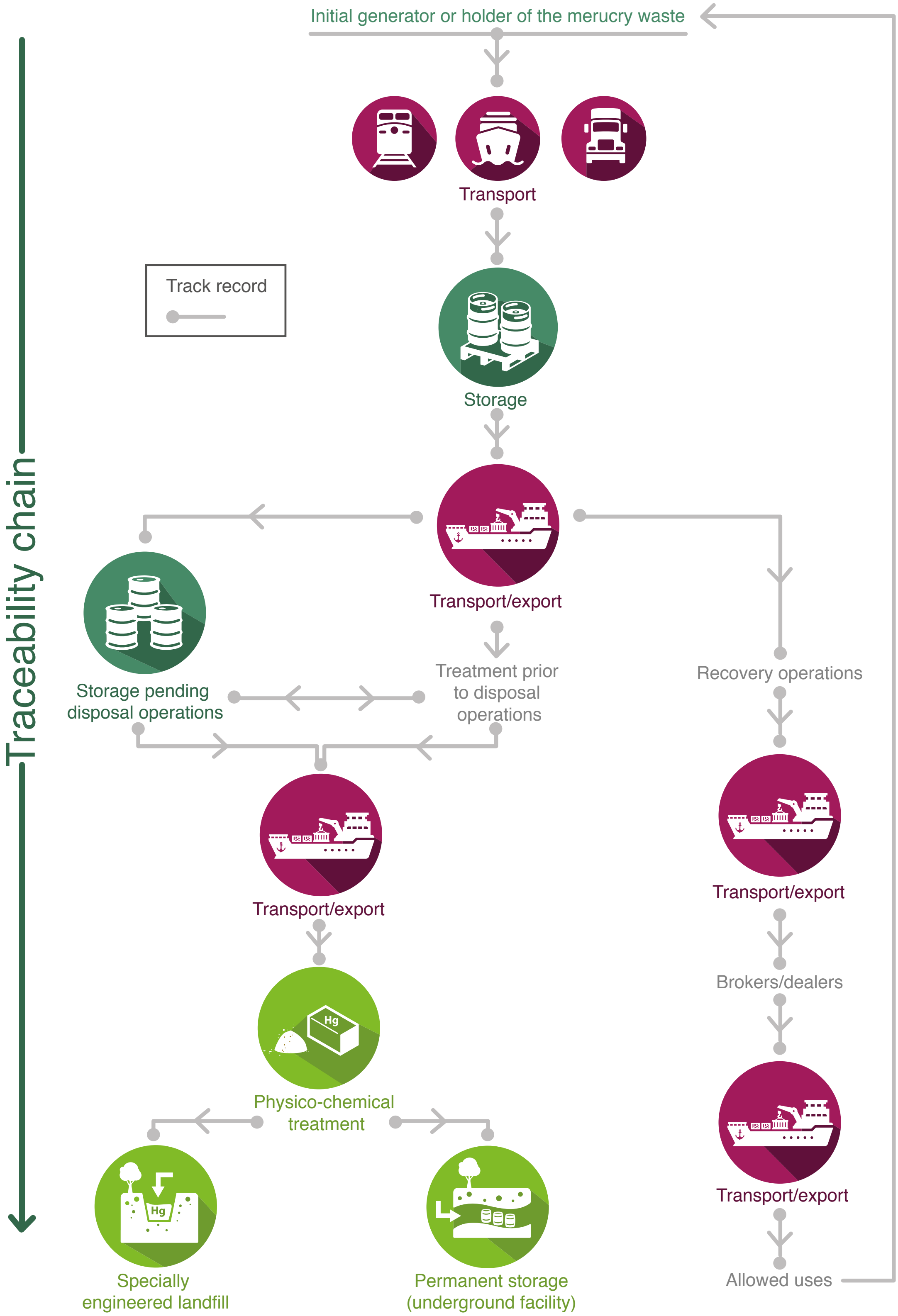


Figure 14: The Traceability Chain

| At the entrance, for each delivery | At the exit, for each shipment departure |
|---|---|
| Identification of the shipment (including notification identification (ID) in case of export) | Identification of the shipment (including notification ID in case of export) |
| Date of delivery | Date of departure |
| Person in charge of the transport | Person in charge of the transport |
| Person in charge of the transfer (import/export) | Person in charge of the transfer (import/export) |
| Previous holder and origin | Next holder and description of the destination/purpose |
| Description of waste (with relevant identification code, if applicable) | Description of waste (with relevant identification code, if applicable) |
| Quantity of the mercury waste | Quantity of the mercury waste |
| Quantity/concentration of mercury in the waste | Quantity/concentration of mercury in the waste/recovered from the waste |
| Location of the storage in the facility | List of the ID of all the flasks for waste mercury/recovered from the waste |
| | Estimated date of arrival at the destination |

Table 3: Information to be Provided in the Tracking Records

ESM of mercury wastes encourages that a **special license/permit** be issued from the competent authority which authorizes a facility to hold the mercury waste. In the case of reuse of mercury derived from mercury wastes for uses allowed under national and international law, including the Minamata Convention, where applicable, it can be important for the community and regulators to know the final destination of the recovered mercury in order to allow **verification of the intended use** and to avoid any illegal use of the recovered mercury. Each transport/export of the mercury waste is ideally followed by a movement document.

In case of transboundary movements of mercury wastes, where appropriate, the Basel Convention requirements apply for the Parties to the Basel Convention. In circumstances where the Basel Convention does not apply to transport across international boundaries, such transboundary movements should be conducted only after taking into account relevant international rules, standards, and guidelines. The text of the Convention can be consulted for more information on legal considerations related to the transboundary movement of mercury wastes.

## 3.3 Storage Options

Mercury wastes often need to be stored somewhere where they can be easily moved/retrieved before they are submitted for recovery operations or disposal operations. Such storage may be **limited in time**, as allowed by national standards. It needs to be undertaken in an environmentally sound manner to avoid contamination of the environment.[1, 8, 65] Storage should be done in compliance with the requirements stipulated by relevant national and international law, including the Minamata Convention, where applicable.

**Useful criteria for siting and design of storage facilities** include, among others, the following:

- not built in sensitive locations (floodplains, earthquake zones etc.), unless technical and legal conditions are sufficient to ensure the ESM of facilities in the area in question
- floors covered with mercury-resistant material
- constant, low temperature
- storage area clearly marked with warning signs (see Photo 15)[1, 65]

Photo 15: Storage Site for Spent Mercury Contaminated Catalysts from Natural Gas Production (courtesy: Ministry of Environment, Indonesia)

**General criteria for operation and safety** include, among others:

- Mercury wastes stored separately from other wastes
- Full inventory; regular monitoring, audits and inspections
- Keep facility locked and secure from theft; restricted access
- Trained personnel; fire alarm and suppression system; emergency plan; vapour detection instruments etc.[1, 65]

More information is available in the Basel Technical Guidelines, and the United Nations Development Programme (UNDP), Global Environment Facility (GEF) 'Guidance on the Cleanup, Temporary or Intermediate Storage, and Transport of Mercury Waste from Healthcare Facilities'.[65]

Storage of mercury wastes may fulfil different functions and be undertaken in varying locations. This may include the following:

i) **on-site at industrial facilities** pending collection, recovery operations or disposal operations
ii) **on-site in public institutions** pending collection, recovery operations or disposal operations
iii) **off-site in suitable centralized hazardous waste management facilities** pending recovery operations or disposal
iv) **off-site in dedicated facilities** specially equipped for storage of mercury for a long period of time pending disposal

Storage may occupy a central position for countries wishing to export mercury wastes for disposal should they currently lack the necessary infrastructure to ensure environmentally sound recovery/recycling, physico-chemical treatment, and/or disposal in SELs or permanent storage in underground facilities.

i) **On-site at industrial facilities pending collection, recovery operations or disposal operations** (see Case Study 6): Wastes contaminated with mercury or mercury compounds generated by industry are typically stored on-site, e.g. in tanks or containers, and are often then placed in on-site warehouses[50]. If on-site storage is practiced in an environmentally sound manner and downstream management options are available, emissions and releases can be prevented or minimized.

## Storage of Sludge Contaminated with Mercury at a NFM plant (Japan)

**Packaging**: The sludge is put in a double plastic bag, placed in a stainless steel drum and properly labelled.[8]

Photo 16: Packaging of Sludge (courtesy: Japan Mining Industry Association)

**Storage and transportation**: The labelled drums are kept and collected in an indoor warehouse until they are sent to a dedicated mercury treatment facility by truck and a railroad container.[8]

Photo 17: Transport of Drums (courtesy: Japan Mining Industry Association)

Case Study 6: Storage of Sludge Contaminated with Mercury at a NFM plant (Japan)

ii) **On-site in public institutions pending collection, recovery operations or disposal operations** (e.g. hospitals) (see Case Study 7): End-of-life mercury-added products may be stored for a short period of time, before transport to centralized facilities or directly to treatment facilities. Boxes or containers for wastes containing mercury or mercury compounds should be monitored to avoid any other waste being deposited in them. The boxes or containers should also be labelled and placed inside buildings where they can be monitored in a well-ventilated area, or, for example, outside the building in a covered and protected area.[1, 65]

iii) **Off-site in suitable centralized storage facilities or treatment plants pending disposal**: Mercury wastes from households, public institutions and industry can be collected and stored in centralized facilities where different types of hazardous wastes or hazardous wastes from different producers are stored (see Case Study 8). Where available, mercury wastes should be directly sent to treatment facilities.

### Storage of Mercury-added Products in the San Lazaro Hospital (Philippines)

In response to an administrative order mandating gradual phase-out of mercury in the Philippine health care sector, the San Lazaro Hospital established a mercury management team, among others responsible for the safe storage of spent mercury-added measuring devices and fluorescent lamps. Safety measures were implemented to comply with the Department of Health's 'Guidelines on Interim Storage of Mercury Devices'.[68, 69]

**STEP 1**

Photo 18:
Placed in the original box and sealed with duct tape

**STEP 2**

Photo 19:
Wrapped in a labelled plastic bag as primary container

**STEP 3**

Photo 20:
Placed in a labelled secondary container and sealed with duct tape

**STEP 4**

Photo 21:
Stored in a dedicated facility in distance of patients' area and offices

Courtesy all pictures: Karen Abejar, Arago

Case Study 7: Storage of Mercury-added Products in the San Lazaro Hospital (Philippines)

### Off-site Storage of Hazardous Waste in a Dedicated Facility (Germany)

A typical example for off-site storage in German communities is the hazardous waste storage facility in Göppingen, operated by a local waste management service provider. The facility accepts hazardous waste, including mercury wastes, from private individuals and local companies/institutions. The waste is stored for a limited period of time until it is collected by specialized and certified waste recyclers or transported to disposal facilities.

- → only for small amounts of waste
- → exclusion of radioactive, infectious and explosive wastes
- → waste is categorized and placed in separate storage sections
- → well-chosen site not threatened by natural disasters and not posing a risk to vulnerable environments and communities
- → technically equipped to reduce risk of releases of hazardous substances into soil, water and air
- → well-trained personnel and availability of protective clothing[8]

Photo 22: Hazardous Waste Storage Facility (courtesy: ETG Entsorgung + Transport GmbH)

Case Study 8: Off-site Storage of Hazardous Waste in a Dedicated Facility (Germany)

iv) **Off-site in dedicated facilities specially equipped for storage of mercury for a long period of time pending disposal**: dedicated facilities can be built for collection and storage of mercury wastes, especially for larger quantities from industry. Such facilities should be (a) located close to large waste generators (provided population density around the site is low) and (b) not be located in environmentally sensitive locations (such as flood zones or wetlands) unless technical and legal conditions are sufficient to ensure the ESM of facilities in the area in question).

Some countries may wish to store mercury wastes for longer periods of time until other disposal options are available. Such temporary storage can be realized in an aboveground facility that is specially designed for this purpose. Many countries may have sites that could be retrofitted for this purpose. In doing so, countries may rely on existing experience. However, **special precautions may need to be taken to allow safe storage for longer periods of time**, as shown in. Case Study 9 Because the untreated mercury wastes remains in the biosphere, it must be actively managed. A high degree of **financial and institutional commitment** is required to manage long term temporary storage.[70]

## Storage of Mercury in Warehouses (US)

In order to identify options for the management of the U.S. Department of Defense's excess stocks of mercury, a Mercury Management Environmental Impact Statement was conducted by the Defense National Stockpile Center. The options included no action, i.e. to continue storage at existing sites, treatment for disposal in dedicated facilities, treatment for storage, and selling the stocks. Following thorough assessment of the various options, long-term storage in a single consolidated facility was identified as the preferred choice.[71, 72, 73]

Photo 23: Mercury Drums Staged in Hawthorne (courtesy: Defense Logistics Agency)

### Mercury Overpacking Project

During the EIS, first preparatory actions were taken. 128,660 flasks were inspected, cleaned, tightened and then overpacked. The flasks were placed in epoxy-coated steel drums with layered protection (absorbent pads, plastic liners, locking ring etc.).[74, 75]

Photo 24: Overpacking (courtesy: Defense Logistics Agency)

Prior to shipment, the selected warehouse was retrofitted to comply with regulatory storage requirements. Training was conducted and the operating permit issued.[75]

### Warehouse Improvements and Safety Measures

- installation of fire suppression and security systems
- installation of flooring sealant and ramped containment dikes
- stringent emergency protocol
- a ventilation system exerts control on mercury vapour emissions
- safety and storage equipment includes mercury vapour detection instruments and spill response kits[74, 75, 76]

Photo 25: Warehouse for the Storage of Mercury (courtesy: Defense Logistics Agency)

Eventually the mercury was transported to Hawthorne, Nevada in compliance with the requirements for the shipment of hazardous materials. A stringent inspection and reception protocol was followed. The Defense Logistics Agency Strategic Materials (DLA-SM) now safely manages ca. 4,400 metric tons (more than 130,000 flasks) of commodity grade mercury in currently 14 well-maintained storage buildings. The storage is six 3 litre flasks per 30 gallon drum, with 5 drums per pallet, all on a catch pan.[8, 74, 75, 76]

The DLA-SM is working with Nevada state environmental regulators and Hawthorne Army Depot to permit a new facility to re-containerize the flasks into new metric ton containers. The storage footprint will be reduced by half, direct container inspection will be realized, and the container welds will be highly qualified for multiple decades safe storage. A 'Mobile Mercury Transfer System', developed by the Oak Ridge National Laboratory safely handles and transfers the mercury.[8]

Case Study 9: Storage of Mercury in Warehouses (US)

Specially designed containers may facilitate safe storage of waste consisting of mercury for long periods of time (see Case Study 10).

## Specially Designed Storage Container (Spain)

The container has been constructed by Minas de Almadén y Arrayanes, S.A. (MAYASA) for the purpose of storing and isolating waste consisting of mercury from the biosphere for a period of over 50 years. The container has a capacity of 50 t, a double shell of stainless steel and a permanent and remote monitoring system. The mercury can easily be removed for future disposal operations A study attested good performance to the stainless steel under static and isothermal conditions.[77, 78]

Photo 26: MERSADE Container (courtesy of MAYASA)

Case Study 10: Specially Designed Storage Container (Spain)


Hg
Cu
Zn
65.38
29
30
Zinc
Hg
Hg
Hg

# CHAPTER 4:
# Recovery Operations for Mercury Wastes

The Basel Technical Guidelines address recovery operations as an inherent part of disposal as noted in Annex IV, Section B and suggest permitting the following operations for mercury wastes:

- R4 – Recycling/reclamation of metals and metal compounds (see the 'Technical guidelines on the environmentally sound recycling/reclamation of metals and metal compounds'[79])
- R5 – Recycling/reclamation of other inorganic materials
- R8 – Recovery of components from catalysts
- R12 – Exchange of wastes for submission to operations R4, R5, R8 or R13
- R13 – Accumulation of material intended for operations R4, R5, R8 or R12

Recovery operations are those operations which may lead to resource recovery, recycling, reclamation, direct re-use or alternative uses. Recovery/recycling of mercury wastes is an essential component of ESM. This Chapter starts with an explanation of the basic steps involved in the separation of mercury from the waste matrix. Next, some examples of the various technologies available for the different waste streams are presented. The Chapter concludes with an overview of important considerations for ensuring that treatment of mercury wastes, including residues, is done in an environmentally sound manner.

**Treatment of Mercury Wastes**: containing or contaminated with mercury or mercury compounds are treated in dedicated facilities to:

i) **extract and purify the mercury contained in the waste for re-use or disposal operations**, and to

ii) **decontaminate the waste to recover the components or to make it eligible for disposal operations**.

Where the mercury is recovered for subsequent re-use, this is referred to as a recovery operation. By contrast, where the mercury is extracted for subsequent disposal operations, this is referred to as physico-chemical treatment. The same or similar processes are used in both cases. For simplicity, it is summarized here.

The process may yield mercury-free, sometimes **valuable raw materials** (e.g. glass from the recycling of lamps, zinc and iron from the recycling of batteries or silver from the recycling of dental amalgam), as well as mercury. As noted previously, recovered mercury can only be used for the purposes allowed under national and international law, including the Minamata Convention, where applicable. An additional advantage of recovery/recycling is that it may help to decrease the waste volume.

Mercury recovery/recycling often involve the three steps shown in Box 20. It should be noted that non-thermal processes are also being used for recovery/recycling of mercury wastes, such as chemical oxidation, chemical precipitation, or adsorption treatment. If crushing of mercury added products is a necessary part of recovery, crushing should be conducted to prevent or minimize worker exposure and releases of mercury into the environment.[1, 8, 80]

## Basic Steps in the Recovery/recycling of Mercury Wastes through Thermal Treatment

### 1. Pre-treatment

Pre-treatment serves to increase the efficiency of subsequent steps by removing materials other than those containing mercury. It is only necessary for some mercury wastes, particularly spent products, which are crushed or disassembled to facilitate the separation of mercury from other components. Some types of waste contaminated with mercury also require pre-treatment. Examples for pre-treatment include mechanical crushing of fluorescent lamps, removal of impurities from batteries, dewatering of sewage sludge or dismantling of electric switches.[1, 8, 79]

Photo 27: Example of Pre-treatment (courtesy: SARP Industries)

### 2. Thermal treatment

The mercury is separated by heating it above its vaporization temperature. Due to its low boiling point (ca. 356.73°C), most of the mercury in the waste enters the off-gas/stream and is separated from other components (e.g. zinc). Flue gas treatment devices can effectively capture mercury and mercury compounds generated during thermal treatment. A number of thermal treatment processes and technologies are available, such as rotary kilns, multiple hearth furnaces, or indirect heated vacuum dryers. Thermal treatment is used for many types of mercury wastes, e.g. to recycle button-cell batteries, reactivate spent carbon, or decontaminate sludge and soil.[1, 8, 79]

Photo 28: Example of Thermal Treatment (courtesy: Nomura Kohsan Co., Ltd.)

### 3. Purification

After having entered the exhaust gas system, mercury vapour emitted during waste treatment is washed out via indirect cooled condensers and condensed in the cooling area. The mercury remains in a liquid slurry. It is then purified by several steps of successive distillation to render it re-usable as a commodity or eligible for disposal.[1, 8, 79]

Photo 29: Example of Refining (courtesy: Nomura Kohsan Co., Ltd.)

Box 20: Basic Steps in the Recovery/recycling of Mercury Wastes

The recycling methods used for wastes containing mercury are often very specific and multi-stage, whereas methods applied for wastes contaminated with mercury often are used for other hazardous wastes as well. A number of different technologies are available for the environmentally sound recovery and recycling of wastes contaminated with mercury as well as mercury-added products. Box 21, Box 22, Box 23, Box 24 and Box 25 illustrate some examples of recycling and recovery.

### Example of a Recovery/recycling Process for Linear Fluorescent Lamps: End-cut/air-push

The aluminum end caps of linear fluorescent lamps are cut by heat. Air push nozzles blow the mercury-phosphor powder adsorbed from the tube. The metals, glass and mercury-containing phosphor powder are then collected in different vessels via a dry separation technology. Where necessary, the method also allows for separation of the different types of powder. Unlike in other processes, the mercury is not extracted; instead, the powder is sent to lamp manufacturers for re-use. The closed system operates under negative pressure.[8]

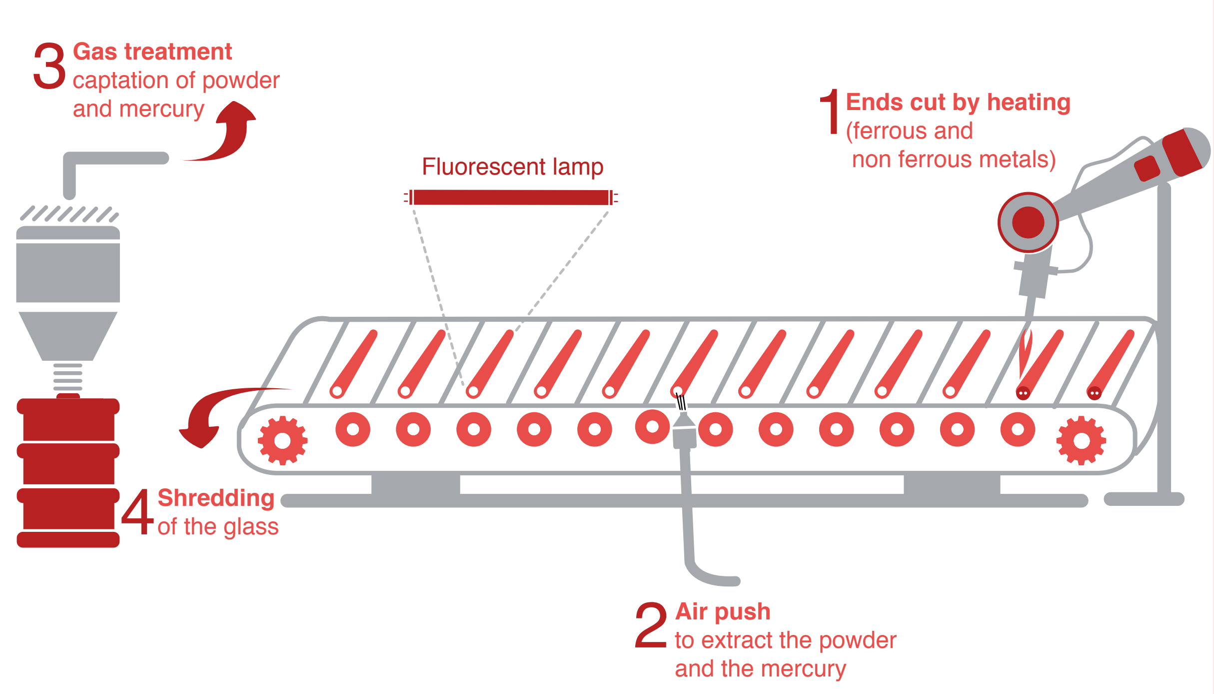


Figure 15: End-cut/air-push Fluorescent Lamp Recycling (courtesy: SARP Industries)

Box 21: Example of a Recovery/recycling Process for Linear Fluorescent Lamps: End-cut/air-push

## Example of Thermal Treatment in a Multiple Hearth Furnace

The multiple hearth furnace has 6 floors to process the mercury waste. Stirring paddles rotating around the centre shaft push the waste from the upper to the lower floors until a heater vaporizes the mercury content. The mercury enters the furnace with the exhaust gas.

The exhaust gas is cooled down and condensed through the cooling tower. It is then collected as a mixture of mercury and smoke dust. At this stage, most of the mercury is collected.

Next, the gas is treated with a scrubber and electrical dust collector to remove any remaining dust. Finally, activated carbon in the adsorption tower collects mercury residues. Once the activated carbon is saturated with mercury, it is replaced and treated with the same process. Residues which have mercury concentrations well below the acceptance standards, are disposed in a SEL.[8]

Photo 30: Multiple Hearth Furnace
(courtesy: Nomura Kohsan Co., Ltd.)

Box 22: Example of Thermal Treatment in a Multiple Hearth Furnace

## Example of Recovery/recycling of Mercury-added Batteries via Pyrolysis

Following manual separation, the mercury-added batteries are pyrolized at high temperatures (700—800°C). In the exhaust gas purification plant, mercury is washed out and condensed as a metal in a sludge. The sludge is sent for further processing in the mercury distillation plant, where mercury of high purity is recovered. Apart from mercury, the process produces mercury-free ferro-manganese, zinc and slag.[8]

Photo 31: Pyrolysis
(courtesy: Batrec Industrie AG)

Box 23: Example of Recovery/recycling of Mercury-added Batteries via Pyrolysis

## Example of a Vacuum Distillation Process

First, the mercury wastes are transferred into a bucket which is subsequently put into a retort. The retort is heated under vacuum condition to about 600°C for an extended period until the majority of the mercury, including moisture and hydrocarbons, are vaporized out from the materials. Vapours generated from the retort are then cooled and condensed under vacuum condition into receiving vessels where pure mercury, water and hydrocarbons are separated. Due to the air-tightness of the process, the production of waste gas and the risk of spontaneous combustion is minimized.[8]

Photo 32: Retorts
(Begemann Milieutechniek (BMT) bv)

Box 24: Example of a Vacuum Distillation Process

## Example of an Indirect Heated Vacuum Dryer (Vacuum Mixer)

A vacuum evaporator chamber uses heat and controlled vacuum (< 50 mbar (abs)) to evaporate contaminants with boiling points up to 450°C. To heat up the evaporator, temperature resistant synthetic oil is circulated inside the evaporator´s heating jacket and its central shaft. The rotating shaft inside the still-standing cylindrical evaporator vessel ensures intensive mixing during the process. Due to the mixing, the heat transfer and the mercury removal is higher than in stationary processes.

The evaporation process is divided in several phases and ensures a defined evaporation of water, hydrocarbons and mercury.  Vaporized compounds enter the off-gas stream, which is led into a heat exchanger, separating the vaporized compounds from the off-gas stream by indirect condensation. The remaining vapour passes through a vacuum unit and is cleaned of residual contaminants by an activated carbon filter, before finally being discharged into the atmosphere. Water, hydrocarbons and mercury are recovered as separate fractions.[8]

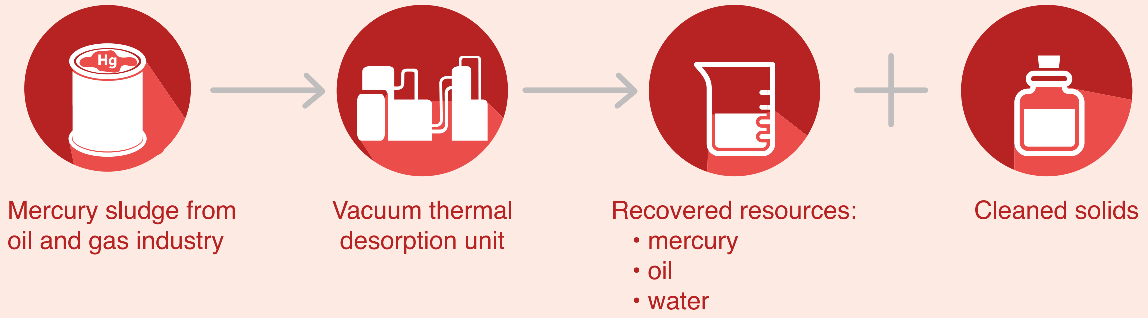


Figure 16: Vacuum Thermal Desorption

Box 25: Example of an Indirect Heated Vacuum Dryer (Vacuum Mixer)

**Management of residues, emissions and releases from recovery operations**: Environmentally sound treatment includes the following steps:

- To the extent feasible, **establish a mass balance**, i.e. monitor the amount of mercury entering on one end and captured on the other and, if possible, investigate where mercury is lost during the process.
- Treatment steps during which mercury may be emitted should take place in a **closed system under negative pressure** to prevent vapour emissions to the atmosphere.
- **Mercury in the exhaust air is captured** (for example by indirect condensation combined with sulphur impregnated activated carbon filters).
- **Mercury in the wastewater is isolated** using various physico-chemical treatment steps (for example precipitation, ion exchange).
- **Mercury emissions and releases are** preferably continuously **monitored**.[1, 8, 80]

It is often not possible to extract all mercury contained in the waste. Moreover, a small, but significant proportion will be ‘lost’ during treatment processes. Some mercury will vaporize during pre-treatment, remain in the fly/bottom ash during thermal treatment or may contaminate wastewater. **Mercury residuals from processing of wastes** either undergo further treatment or are disposed in SELs or permanently stored. The same applies for wastes contaminated with mercury that are generated during gas and wastewater mercury recovery and treatment (e.g. saturated carbon).[1, 8, 80]


Hg
Cu
29
opper
65.38
Zn
30
Zinc
Hg
Hg
Hg

# CHAPTER 5:
# Disposal Operations for Mercury Wastes

The Basel Technical Guidelines address disposal operations as an inherent part of disposal as noted in Annex IV, Section A and suggest permitting the following operations for mercury wastes:

- D5 – Specially-engineered landfill
- D9 – Physico-chemical treatment
- D12 – Permanent storage
- D13 – Blending or mixing prior to submission to D5, D9, D12, D14 or D15
- D14 – Repackaging prior to submission to D5, D9, D12, D13 or D15
- D15 – Storage pending any of the operations D5, D9, D12, D13 or D14

Disposal operations are those operations which do not lead to the possibility of resource recovery, recycling, reclamation, direct re-use or alternative uses

## 5.1. Physico-chemical Treatment (Stabilization/Solidification)

One of the means of reducing the risk of emissions and releases from mercury is physico-chemical treatment: Mercury wastes can be **chemically stabilized and/or physically solidified using commercially available technologies**. In many cases, a combination of both is used. This is referred to as stabilization/solidification (S/S) (see Box 26 and Box 27).[81]

## Stabilization

In stabilization processes, mercury is brought into reaction with chemical agents that convert it into a substance that is thermodynamically more stable, less soluble and less volatile, making it less mobile and thereby reducing release and exposure potential.[81, 82, 83]

Box 26: Stabilization

## Solidification

In solidification processes mercury wastes are embedded in a solid and stable matrix. **Micro-encapsulation** means mixing the waste with the encasing material. **Macro-encapsulation** means pouring the encasing material over and around the waste mass, thus enclosing it in a solid block.[81, 82, 83]

Box 27: Solidification

S/S can be used for wastes consisting of mercury or mercury compounds as well as wastes contaminated with mercury to reduce the risk factor associated with such wastes. The objective is to **immobilize the mercury in a solid and low permeable matrix so that the waste complies with the acceptance criteria for disposal in SELs or permanent storage in underground facilities.** S/S provides an additional barrier and thus increases the safety of these disposal operations.[1, 8, 81, 83, 84, 85]

Box 28 and Box 29 describe two of the most commonly used approaches.

## Sulphur Stabilization of Mercury (Germany)

Sulphur and mercury are mixed under heat in a vacuum mixer, thus reacting to form mercury sulphide.

Reported characteristics of the final product:

- Product is a powder with no detectable releases of mercury vapour
- Complies with applicable leaching standard
- Weight increases by approximately 16%, volume approximately 6-fold[8, 83, 77, 81]

Photo 33: Commercial Stabilization Plant (courtesy: NQR Nordische Quecksilber Rückgewinnung GmbH)

Box 28: Sulphur Stabilization of Mercury (Germany)

## Sulphur Polymer Stabilization and Solidification (SPSS) of Mercury and Mercury Containing Wastes (Spain)

Mercury is stabilized with sulphur as mercury sulphide and then incorporated and microencapsulated in a polymeric sulphur matrix. Characteristics of the final products:

- High compressive strength; very low porosity
- Difficult to reverse the process
- Final product after treatment of metallic mercury contains about 70% of mercury by weight
- Monolithic and crushed samples comply with applicable EU leaching acceptance criteria for inert solid waste landfills[8, 77, 78, 86, 87]

Photo 34: Monolithic Block after the Treatment of Metallic Mercury from the Chlor-alkali Sector

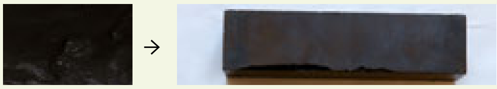


Photo 35: Monolithic Block after the Treatment of Zinc Production Waste

Photo 36: Monolithic Block after the Treatment of Fluorescent Lamp Dust

(all photos courtesy of MAYASA, National Technological Centre for Mercury Decontamination, CTNDM, Spain)

Box 29: Sulphur Polymer Stabilization and Solidification (SPSS) of Mercury and Mercury Containing Wastes (Spain)

Japan has developed a technology similar to SPSS, which stabilizes mercury with sulphur powder to form mercury sulphide and the second step is to solidify the mercury sulphide with modified sulphur. Results of Japanese Leaching Test-13 applied to the final product are below the elution test standard (0.005mg/L).

Another form of S/S is Stabilization and solidification with sulphur microcements (see Box 30).

## S/S with Sulphur Microcements (Spain)

The treatment of mercury wastes with sulphur microcements results in a solid matrix that ensures the confinement of mercury because of its precipitation in the form of very insoluble compounds, as oxides, hydroxides and sulphides. The process includes the mixture of mercury contaminated waste with the sulphur microcement and water. The mixture is then discharged into the desired mould and is matured for 24 to 48 hours in watertight and leak-protected areas.

- Technology tested in wastes with low mercury contamination levels (Hg ≤ 2% by weight)
- Final product can take different forms, including large cubic blocks to minimize surface exposure
- High compressive strength
- Final product complies with applicable EU leaching acceptance criteria for inert solid waste landfills[1, 8]

Box 30: S/S with Sulphur Microcements (Spain)

A number of S/S processes have undergone laboratory testing at small and large scale. Some are now commercially available or are expected to be so in the near future. **Prior to using a new technology, there should be careful review of pilot or commercial operational test data for performance and quality assurance/ quality control to assure that treated wastes meet national or international criteria**. For up-to-date information, please consult the Basel Technical Guidelines or visit the website of the Global Mercury Partnership areas on supply and storage and waste management.[5]

It is suggested to evaluate physico-chemical treatment methods in pilot-scale tests before commercial use. This includes:

- a **verification of the quality of the stabilization process** by determining the conversion rate and the mercury vapour release from the stabilized waste;
- an **evaluation of the leaching potential** over a range of plausible disposal conditions (especially over a range of pH values); and
- an **evaluation of plausible changes to the treated waste in the long-term** due to exposure to the environment and biological activity at disposal sites.

There remains some concern that information regarding the long term stability of S/S wastes may not be fully understood. The performance of S/S products is usually tested with procedures such as the US EPA TCLP/LEAF leaching tests (see Box 5) or the compliance test for leaching of granular waste materials and sludges (EN 12457) before disposal. For more information on the different methods, see the Basel Technical Guidelines.

| Challenges Related to Physico-chemical Treatment (S/S) |
|---|
| • Increased storage/disposal costs due to additional treatment and waste volume should be considered |
| • Measures to prevent decomposition of stabilized mercury wastes in the long term should be identified |
| • Completeness of the reaction between mercury and treatment chemicals should be established |
| • Further research and steps towards large-scale commercialization needed [8, 81, 83, 84, 85] |

Table 4: Challenges Related to Physico-chemical Treatment (S/S)

| Opportunities Related to Physico-chemical Treatment (S/S) |
|---|
| • Reduces vapour pressure, solubility and mobility; enhances physical strength |
| • Enhances safeguards against illegal use |
| • Stabilized/solidified mercury wastes are relatively easy and safe to handle |
| • Allows safe storage and disposal in SELs or permanent storage underground [8, 81, 83, 84, 85] |

Table 5: Opportunities Related to Physico-chemical Treatment (S/S)

A decision adopted by the COP to the Basel Convention at its twelfth meeting invites parties and others to submit comments on any developments regarding methods for environmentally sound disposal of mercury wastes, including the long-term effectiveness of the stabilization and solidification of wastes consisting of mercury. Despite some remaining challenges, **S/S processes reflecting the latest science offer important benefits** with regard to human health and the environment. It is therefore suggested to consider this option in any mercury waste management strategy.

## 5.2. Specially Engineered Landfill

A specially engineered landfill (SEL) is **an environmentally sound system for solid waste disposal and is a site where solid wastes are capped and isolated from each other and from the environment.**[1] The waste is stored aboveground or near the surface below ground.[85] SELs may be used for the environmentally sound disposal of treated mercury wastes.

There are concerns that the placement of treated wastes consisting of mercury or mercury compounds in SELs may lead to the **leaching of contaminants** since it may not yet be proven that such treatment can effectively stabilize mercury over long periods of time. Mercury wastes are **tested to assure their long-term stability in SELs**. In addition, when wastes containing mercury or mercury compounds is disposed of in a SEL, special considerations should be given to the combination of S/S and final disposal methods of such wastes.[1, 8]

**Eligible mercury wastes: The following wastes that meet the acceptance criteria defined by domestic regulations** may be disposed of in SELs.

- wastes contaminated with mercury or mercury compounds
- wastes containing mercury or mercury compounds that result from a stabilization and solidification of wastes consisting of mercury or mercury compounds with additional measures to minimize releases and methylation of mercury (such as prevention of rainwater/groundwater inflow, separate storage of wastes, leachate collection, monitoring etc.); waste mercury-added products are treated to remove or recover mercury: this treatment results in waste consisting of mercury or mercury compounds and waste contaminated with mercury or mercury compounds.

Most countries specify leaching limit values, concentration and/or content thresholds (see the examples for the EU, the US and Japan in Table 6).

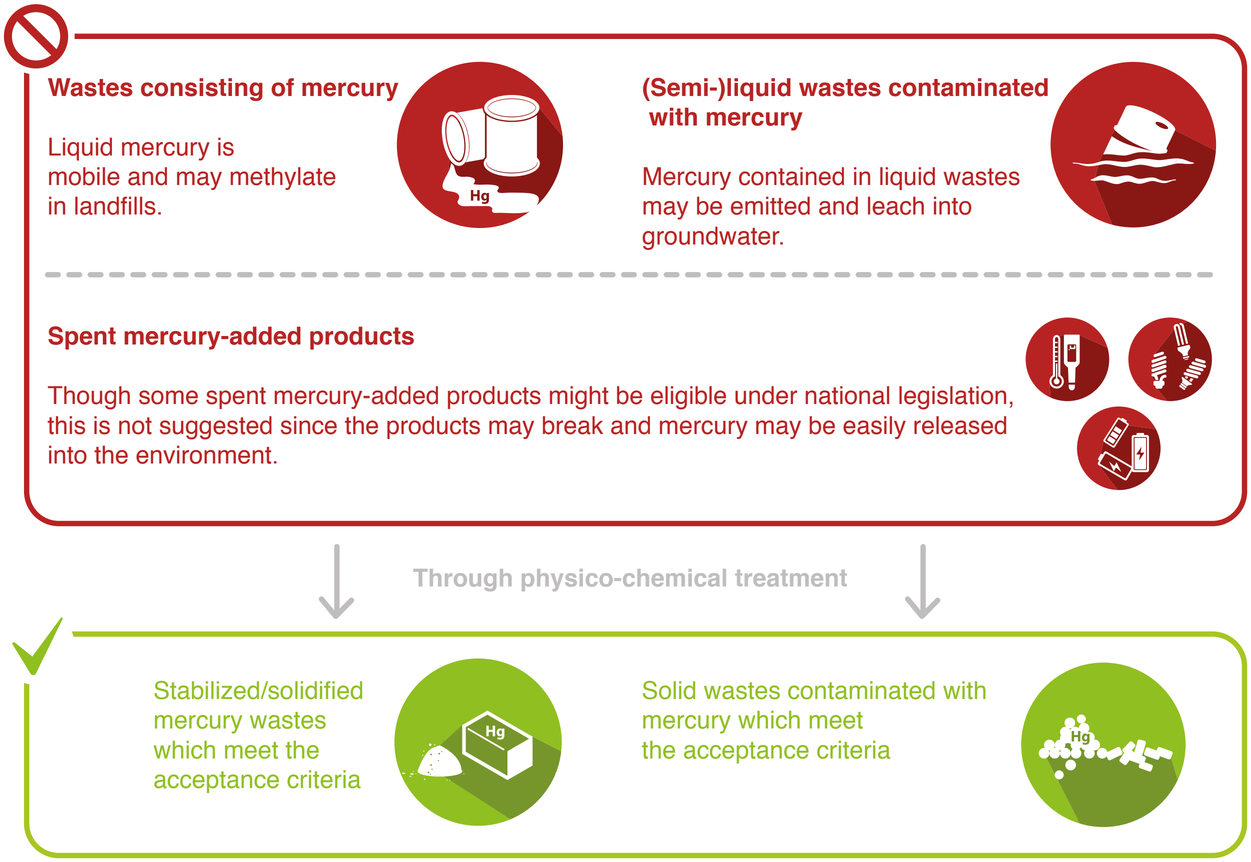
### Eligibility Criteria for Landfill Disposal in the EU, the US and Japan

| EU | US | Japan |
|---|---|---|
| Only wastes with leaching limit values of 0.2 and 2 mg Hg/kg dry substance at a liquid-solid ratio of 10 L/Kg in landfills for non-hazardous and hazardous wastes respectively.86 Some EU member states prohibit aboveground landfill disposal of waste with a mercury content above a certain limit value (e.g. Netherlands, Sweden, Belgium). | Only low concentration mercury wastes can be treated and landfilled; treated mercury wastes must leach less than 0.025 mg/L mercury (by TCLP testing). | Treated wastes with mercury concentration equal to or less than 0.005 mg/L accepted in landfills for domestic and industrial wastes (leachate-controlled type); wastes with mercury concentration in excess of 0.005mg/L disposed at landfills for hazardous industrial wastes (isolated type). |

Table 6: Eligibility Criteria for Landfill Disposal in the EU. the US and Japan

Figure 17 provides suggestions on which types of mercury wastes may be disposed of in SELs and which ones may not.[1, 8, 12, 84, 85, 88, 89, 90]

## Suggestions on the Eligibility of Mercury Wastes for Disposal in a Specially Engineered Landfill



**Wastes consisting of mercury**

Liquid mercury is mobile and may methylate in landfills.

**(Semi-)liquid wastes contaminated with mercury**

Mercury contained in liquid wastes may be emitted and leach into groundwater.

**Spent mercury-added products**

Though some spent mercury-added products might be eligible under national legislation, this is not suggested since the products may break and mercury may be easily released into the environment.

Through physico-chemical treatment

Stabilized/solidified mercury wastes which meet the acceptance criteria

Solid wastes contaminated with mercury which meet the acceptance criteria

Figure 17: Suggestions on the Eligibility of Mercury Wastes for Disposal in a Specially Engineered Landfill

**Duration**: In principle, and for a defined time period, a landfill site can be engineered to be environmentally safe subject to the site being appropriate and with proper precautions and efficient management.[1]

**Site selection**: It is suggested to select sites with favourable natural and artificial containment properties and base the decision on an evaluation of detailed technical, biological, social, economic, and environmental factors. The site selection process may include, among others, consideration of the following:

- Geographical, geological and hydrogeological properties of the site
- Future use of the landfill area
- Degree of urbanization and its proximity to the site.

Where possible, it is suggested to choose sites where the possibility of ground water pollution can be avoided.[1]

**Safety requirements**: In order to minimize risks to human health and the environment, it is suggested to ensure that preparation, management and control of the landfill as well as the process of site selection, design and construction, operation and monitoring, closure and post closure care are of the highest standard.[1, 8]

The site needs to be specially engineered for the purpose of disposal of mercury wastes. Overall engineering should ensure isolation from the environment that is as complete as possible. Key requirements to prevent leakages and contamination of the environment include, among others:

- the waste is disposed of in dedicated cells, separate from other wastes
- control and oversight procedures are in place; periodic monitoring and evaluation is undertaken
- bottom (operating phase) and top-liner (closure and post-closure phase) installed[1, 88]

It is suggested to **pay particular attention to the measures required to protect groundwater resources from leachate infiltration into the soil**. For examples of SELs, see Box 31 and Box 32. For detailed information on safety measures and specific site criteria, it is recommended to consult the Basel Technical Guidelines and the Basel Technical Guidelines on Specially Engineered Landfills.[88]

## Example (A) of a Specially Engineered Landfill

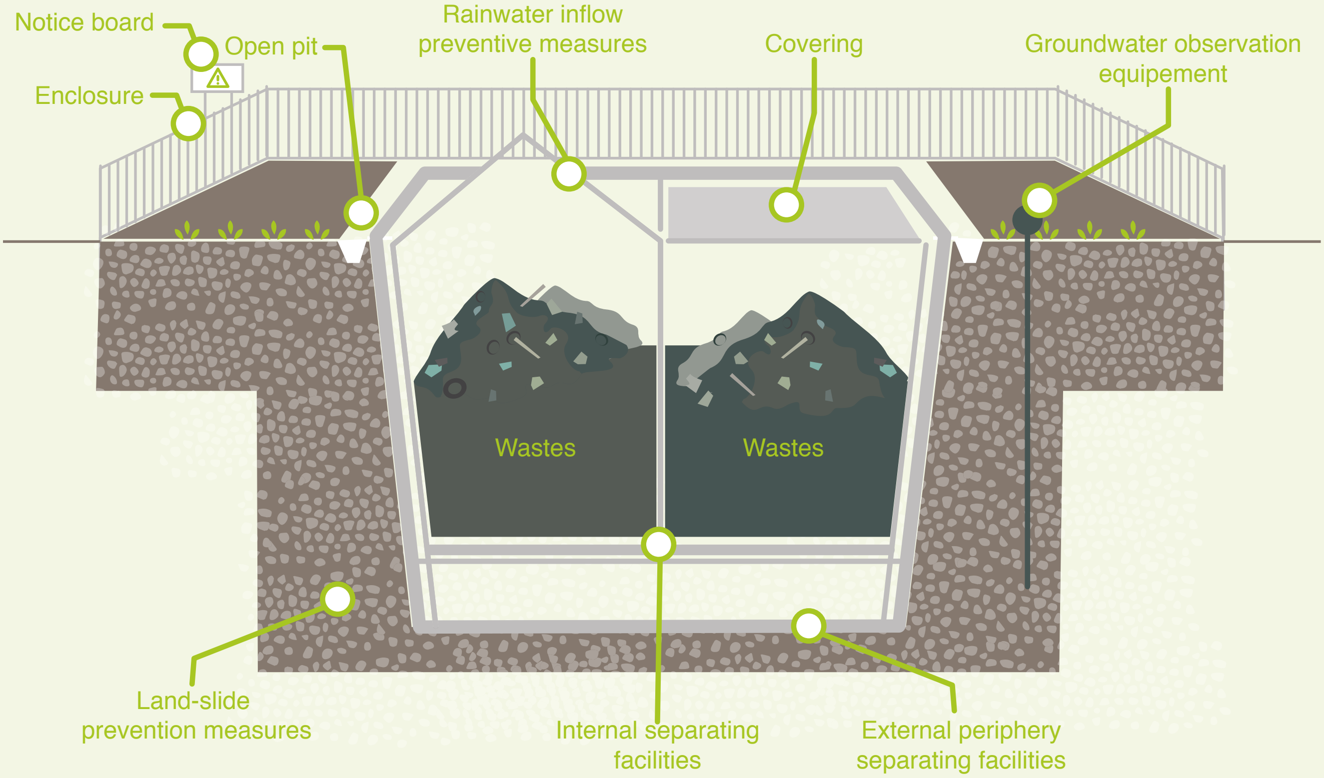


Figure 18: Example (A) of a Specially Engineered Landfill

This example shows a model of a SEL that is designed to isolate the waste from the environment. It is enclosed in watertight and reinforced concrete and covered with equipment preventing rainwater inflow such as a roof and a rainwater drainage system.[1]

Box 31: Example (A) of a Specially Engineered Landfill

## Example (B) of a Specially Engineered Landfill

- Double water-sealing structure
- Reinforced concrete on the premises
- Only residues with Hg concentrations well below the acceptance standard
- Capacity of about 100,000 $m^3$
- Discharged water and groundwater regularly analysed[8]

Photo 37: Example (B) of a Specially Engineered Landfill (courtesy: Nomura Kohsan Co., Ltd.)

Box 32: Example (B) of a Specially Engineered Landfill

| Challenges Related to Specially Engineered Landfills |
|---|
| Long-term stability of treated mercury wastes in SELs should be examined and methods to evaluate such long-term stability should be established |
| SELs where treated mercury wastes are disposed of should be continuously managed and monitored to prevent mercury releases to the environment [1, 8, 24, 25, 27, 36, 37, 77, 78, 81, 85, 89, 90] |

Table 7: Challenges Related to Specially Engineered Landfills

| Opportunities related to Specially Engineered Landfills |
|---|
| Well established concept in many countries; experience with other hazardous wastes |
| Relatively low investment costs |
| Mercury wastes are isolated for a defined period of time |
| SELs could be a solution to countries that do not have natural underground facilities/options [1, 8, 24, 25, 27, 36, 37, 77, 78, 81, 85, 89, 90] |

Table 8: Opportunities Related to Specially Engineered Landfills

Special attention may be necessary when disposing treated mercury wastes in SELs. Mercury sulphide is thermally decomposed at fire temperatures and can be oxidised by atmospheric oxygen at approx. 250°C-300°C to gaseous mercury and sulphur dioxide. **The surface sealing of a landfill may be permeable to air in the long-term.** Mercury can then come into contact with atmospheric oxygen and become oxidised to mercury and sulphate. The formation of methylmercury may occur under suitable geochemical conditions. Both mercury as well as methylmercury may leave the landfill via the gas circuit (landfill gas).[1, 27]

In addition to fire prevention, methods to stabilize/solidify wastes consisting of mercury or mercury compounds as well as the structure and sealing of the landfill accepting them should respond to such mechanism to ensure mercury releases from the disposed wastes are minimized.[1]

Despite such challenges, S/S processes offer important benefits with regard to human health and the environment. It is therefore suggested to consider this option in any mercury management strategy.

**Important ESM landfill considerations include the following:**

- **Examine the long-term stability** of treated mercury wastes in SELs and establish methods to evaluate such long-term stability, including examination of leachate and off-gassing;
- **establish a permit system**, stipulating leachate and gas control systems, closure and post-closure measures etc.;
- **identify existing landfills that could be retrofitted** for the disposal of stabilized mercury;

- **make thorough environmental impact assessments** and analyse the long-term behaviour of stabilized mercury wastes in the specific settings of the facility; and
- **continuously manage and monitor** SELs in which treated mercury wastes have been disposed.

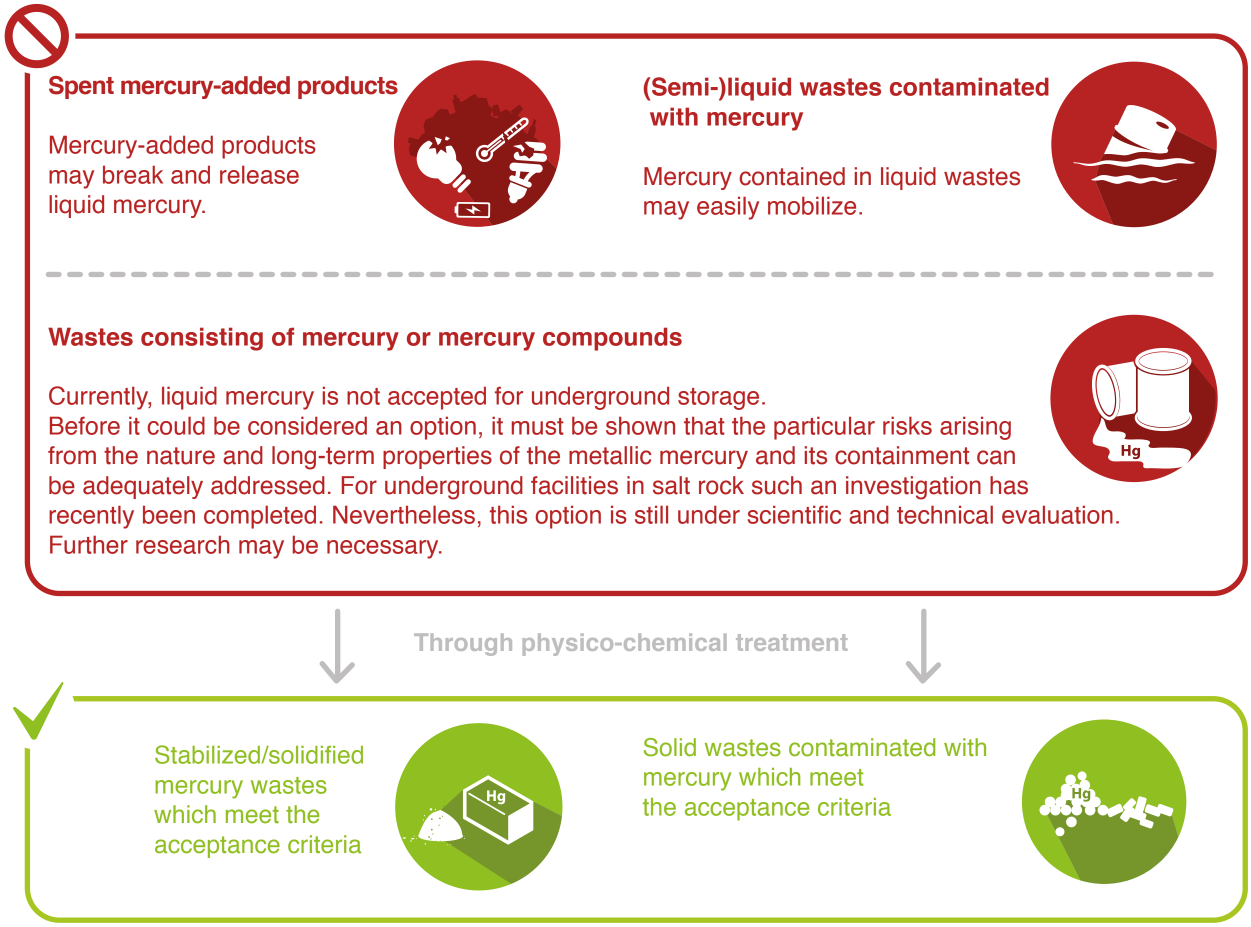
## 5.3 Permanent Storage (Underground Facilities)

Mercury wastes can be permanently stored in deep geological cavities (e.g. in an underground mine). The intent is to **permanently isolate mercury wastes from the biosphere** by including it as completely and permanently as possible in a suitable host rock via several natural and artificial barriers. A detailed case-by-case evaluation of the suitability of any such facility is critical to its effectiveness.

**Eligible mercury wastes**: Mercury wastes, after having been solidified or stabilized, where appropriate, which meet the acceptance criteria for permanent storage (disposal operation D12) may be permanently stored in special containers in designated areas in an underground storage facility such as in salt rock.[1]

Figure 19 provides suggestions in terms of which wastes may or may not be disposed of underground.[1, 8, 24, 25, 27, 36, 37, 81, 84, 85, 90, 91, 92]

**Suggestions on the Eligibility of Mercury Wastes for Disposal in a Specially Engineered Landfill**



**Spent mercury-added products**

Mercury-added products may break and release liquid mercury.

**(Semi-)liquid wastes contaminated with mercury**

Mercury contained in liquid wastes may easily mobilize.

**Wastes consisting of mercury or mercury compounds**

Currently, liquid mercury is not accepted for underground storage.
Before it could be considered an option, it must be shown that the particular risks arising from the nature and long-term properties of the metallic mercury and its containment can be adequately addressed. For underground facilities in salt rock such an investigation has recently been completed. Nevertheless, this option is still under scientific and technical evaluation.
Further research may be necessary.

Through physico-chemical treatment

Stabilized/solidified mercury wastes which meet the acceptance criteria

Solid wastes contaminated with mercury which meet the acceptance criteria

Figure 19: Suggestions on the Eligibility of Mercury Wastes for Underground Disposal

**Duration**: Permanent storage in deep rock facilities aims at finding solutions that do not rely on long-term maintenance or repair of an engineered structure. It is nevertheless important that retrievability of the disposed waste is ensured, in case future generations would find this necessary or desirable. If safety requirements are fulfilled, this option may serve to isolate mercury wastes from the biosphere for geological periods of time.[1, 8, 24, 25, 27, 90, 91, 92]

**Site selection**: Potential sites could be underground mines that are no longer used and have suitable geological conditions, once they have been specifically adapted for the purpose. Potential host rocks include the following:

i) **Salt rock**: Considered impermeable to liquids and gases and a very effective barrier for long-term storage of hazardous waste. A minimum thickness of the salt layer, however is needed to ensure safe encapsulation. Few countries have suitable formations.

ii) **Clay formations**: Also considered as very good barrier. Although not impermeable, migration of pollutants is considered to be extremely slow. Many deposits can be found worldwide.

iii) **Hard rock formations**: Although typically fractured, may provide sufficient long-term safety if combined with technical barriers. This type may be found in many regions worldwide.

Other rock formations may be suitable as well, assuming that the overall geological situation provide for a sufficient long-term isolation of the hazardous substances. All **potential sites have to be carefully assessed and additional technical barriers must be in place**.

The choice of a site is governed by a number of factors, including geological conditions, permitting procedures, construction, operation, financial considerations and the prospects of gaining local consent). It may be advisable to examine the possibility of using existing mines to keep the cost at a reasonable level.[91, 92, 93, 94, 95, 96]

**Safety requirements**: The sealing and permanent isolation from the biosphere may be achieved through a **multi-barrier system**.[93, 94] Thus, the isolating potential is safeguarded by geological (e.g. host rock formation of practically impermeable formations, overlaying clay layer) and engineered (e.g. chemical properties of the waste, packaging) elements. In order to ensure environmentally sound permanent storage, mercury wastes are stored:

- in accident-proof containers;
- properly sealed off from old or active mine passages and shafts;
- in geological formations that are well below zones of available groundwater and/or completely isolated from water-bearing zones ;
- in geological formations that are extremely stable; and
- not in areas subject to earthquakes.[1, 8, 24, 25, 27, 90, 91, 92]

## Prototype Container Potentially Suited for Permanent Storage (Argentina)

During a UNEP project on mercury storage and disposal, engineers of the National Institute for Industrial Technology Argentina adapted a proposal initially developed for radioactive waste to explore the possibility of permanently storing mercury wastes. The idea: A permanent underground storage structure based on the use of steel reinforced concrete cells in which drums containing solidified waste are stored.[97]

Photo 38: Prototype Container
(courtesy: INTI Argentina)

Case Study 11: Prototype Container Potentially suited for Permanent Storage

A long-term, thorough and holistic **site-specific risk and safety assessment** is necessary to provide firm evidence on the isolation potential offered by the barriers and to identify a potential need for additional action. Technical and natural barriers as well as possible unexpected events (e.g. accidents, earthquakes) must be assessed.[1, 8, 24, 25, 27, 90, 91, 92]

Further information on site selection criteria and safety measures can be found in the following resources developed by the International Atomic Energy Agency (IAEA):

- 'Geological Disposal Facilities for Radioactive Waste'[98];
- 'Planning and Design Considerations for Geological Repository Programmes of Radioactive-Waste'[99]; and
- 'Geological Disposal of Radioactive Waste: Technological Implications for Retrievability'[93].

Experience from nuclear waste management may be of value for the establishment of a safeguarding system.

## Permanent Storage of Mercury Wastes from Mining in Crystalline Rock (Sweden)

In Sweden, plans for construction of a permanent storage facility in deep crystalline rock are in advanced planning stages by a mining and smelter company.

The facility will be located at a depth of approximately 350 m., with a capacity of around 50,000 tons per year. It will receive a total of 400,000 tons of mercury waste and other toxic industrial waste from the company's operation. Some waste types will be stabilized prior to permanent storage.[8]

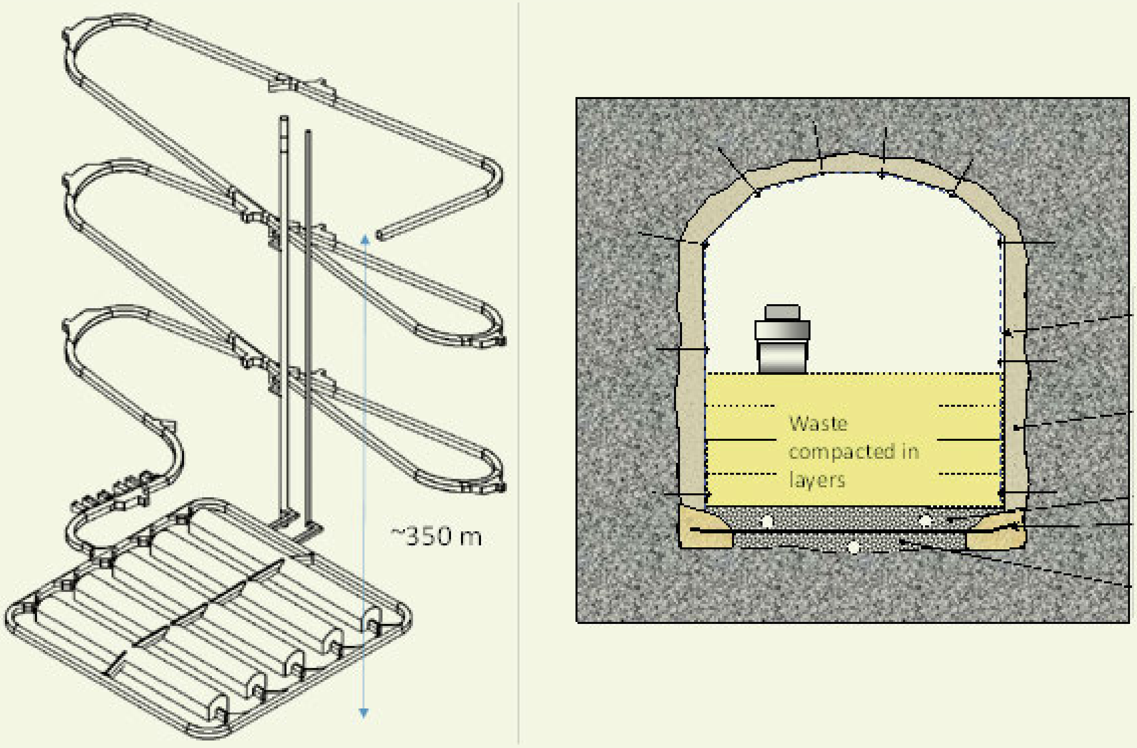


Figure 20: Layout of the Planned Deep Rock Disposal Facility

Case Study 12: Permanent Storage of Mercury Wastes from Mining in Crystalline Rock (Sweden)

## Permanent Storage in Salt Mines (Germany)

In Germany, one option to dispose of mercury containing waste is to permanently store it in underground salt mines. An example is the underground landfill in Herfa Neurode, where mercury-contaminated soils and components, mercury-contaminated demolition waste from the chlor-alkali sector, and contaminated glass breakage were disposed. The disposal area is located at depths of 500 to 800 m. and thus far below the groundwater.[8, 91]

### Operation

- Samples taken at entrance
- Acceptance control (chemical analysis)
- Information pertaining to storage time and location recorded
- Implementation monitored by authorities

### Multi-barrier system

Natural barriers:

- Salt (gastight): 300m
- Clay (watertight): 100m
- Bunter stone: 500m

Artificial barriers:

- Waste packaging
- Brick walls
- Field dams
- Watertight shaft sealing

Photo 39: Placement of big bags in the salt mine (courtesy: K+S Entsorgung GmbH)

Photo 40: Storage arrangement of drums in the salt mine (courtesy: K+S Entsorgung GmbH)

### Storage arrangement

- Stored in disused, excavated areas of the mine, remote from the extraction area.
- Different waste types placed in dedicated storage sections, separated and sealed by brick walls and salt dams
- Frequent monitoring of mercury vapour (and other hazardous substances).[8, 91]

Case Study 13: Permanent Storage in Salt Mines (Germany)

| Challenges Related to Permanent Storage |
|---|
| • Diligent selection processes and assessments should be undertaken, including to determine whether the conditions required to host an underground site (geographic, legal, political etc.) are fulfilled |
| • Steps should be taken to ensure that significant financial resources are available |
| • Safeguards should be in place to ensure retrievability of the waste in case of accidents[1, 8, 24, 25, 27, 36, 37, 81, 84, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99] |

Table 9: Challenges Related to Permanent Storage

| Opportunities Related to Permanent Storage |
|---|
| • Little aftercare needed (low post-closure costs) |
| • Allows isolation from the biosphere for geological period of time |
| • Existing experience with hazardous wastes, including mercury wastes[1, 8, 24, 25, 27, 36, 37, 81, 84, 85, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99] |

Table 10: Opportunities Related to Permanent Storage

Important ESM permanent disposal steps include the following:

- Develop site selection criteria, identify sites and conduct long-term site-specific risk and safety assessments;
- engage in public consultation and carefully handle the local consultative process to achieve local approval;
- put engineered barriers in place to complement geological barriers, and ensure safety requirements and safeguards are in place (experience from nuclear waste management may be of value); and
- secure financing and ensure private sector involvement (polluter-pays and EPR approaches).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# CHAPTER 6:
# Export of Mercury Wastes

The export of mercury wastes for environmentally sound disposal is **a particularly important option for countries without the necessary infrastructure** (see Case Study 14, Case Study 15 and Case Study 16). It may also be the preferred choice for countries with relatively small amounts of mercury waste or where the establishment and operation of dedicated facilities is considered too costly. Some countries may see export as an interim solution, until domestic facilities become available.

### Export of Catalysts Contaminated with Mercury for Recovery/recycling (Indonesia)

Indonesia has a significant gas extraction industry. This sector generates large amounts of wastes contaminated with mercury, including catalysts. No recovery/recycling facility was domestically available. The spent catalysts, contaminated with up to 15% of mercury, are exported to companies in Switzerland and the Netherlands for recovery/recycling.[8]

Photo 41: Recycling of Catalysts (courtesy of Batrec Industrie AG)

Case Study 14: Export of Catalysts Contaminated with Mercury (Indonesia)

### Export of Mercury-added Fluorescent Lamps for Recovery/recycling (Philippines)

A mercury recycler from Japan and a collection company from the Philippines established a cooperative arrangement for the shipment of fluorescent lamps for recovery/recycling. In order to avoid transport costs (and the associated risks), the company is currently investigating the commercialization of a plant in the Philippines.

- transported in 40 ft. containers
- plastic stuffing to prevent breakage
- in compliance with the Basel Convention and applicable national laws
- in total, more than 50 t. exported to date[8]

Photo 42: Storage of Fluorescent Lamps (courtesy: Nomura Kohsan Co., Ltd.)

Photo 43: Transport of Fluorescent Lamps (courtesy: Nomura Kohsan Co., Ltd.)

Case Study 15: Export of Mercury-added Fluorescent Lamps for Recovery/recycling (Philippines)

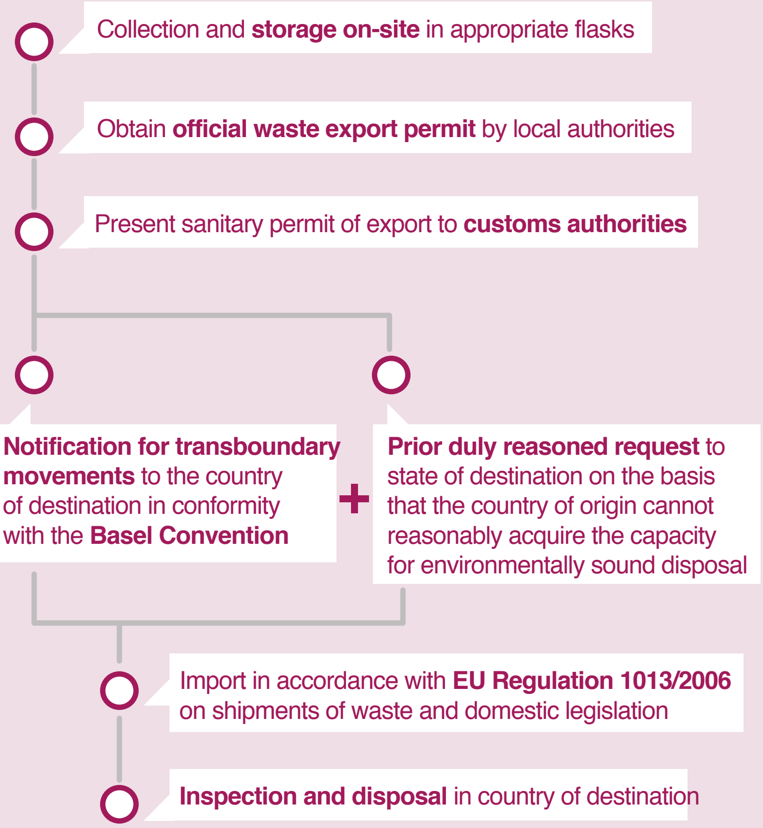
### Export of Mercury Waste from a Gold Mine for Stabilization and Permanent Storage (Peru)

In the past, mercury from Peru's gold mines was recovered and sold for processing and re-use. Currently, it has been decided to retire it from the market for environmentally sound disposal.[8]

Photo 44: The Yanacocha Mine in Peru

**Challenge**:
No facilities domestically available; hazardous waste landfills not considered an option, since S/S not available.

**Solution**:
Export for stabilization and permanent storage in underground facilities; 30t retired to date.



Collection and **storage on-site** in appropriate flasks

Obtain **official waste export permit** by local authorities

Present sanitary permit of export to **customs authorities**

**Notification for transboundary movements** to the country of destination in conformity with the **Basel Convention**

\+

**Prior duly reasoned request** to state of destination on the basis that the country of origin cannot reasonably acquire the capacity for environmentally sound disposal

Import in accordance with **EU Regulation 1013/2006** on shipments of waste and domestic legislation

**Inspection and disposal** in country of destination

Case Study 16: Export of Mercury Waste from a Gold Mine for Stabilization and Permanent Storage (Peru)

**Legal considerations**: Where applicable, all shipments should be made in accordance with the Minamata Convention (see Box 33) as well as the rules and procedures of the Basel Convention. Under the Basel Convention, Parties shall take the appropriate measures to ensure that the transboundary movement of hazardous wastes and other wastes only be allowed under certain circumstances (see Box 34).

**Transport across International Boundaries under the Minamata Convention: Art. 11, Para. 3 (c)**

*"Each Party shall take appropriate measures so that mercury waste is*

*[….]*

*(c) For Parties to the Basel Convention, not transported across international boundaries except for the purpose of environmentally sound disposal in conformity with this Article and with that Convention. In circumstances where the Basel Convention does not apply to transport across international boundaries, a Party shall allow such transport only after taking into account relevant international rules, standards, and guidelines."*

Box 33: Transport across International Boundaries under the Minamata Convention: Art. 11, Para. 3 (c)

**Transport across International Boundaries under the Basel Convention: Art. 9**

*"Parties shall take the appropriate measures to ensure that the transboundary movement of hazardous wastes and other wastes only be allowed if:*

*(a) The State of export does not have the technical capacity and the necessary facilities, capacity or suitable disposal sites in order to dispose of the wastes in question in an environmentally sound manner; or*
*(b) The wastes in question are required as a raw material for recycling or recovery industries in the State of import; or*
*(c) The transboundary movement in question is in accordance with other criteria to be decided by the Parties, provided those criteria do not differ from the objective of this Convention."*

Box 34: Transport across International Boundaries under the Basel Convention: Art. 9

**The importing country should have the infrastructure to manage the waste in an environmentally sound manner** according to its national legislation. If the transboundary movement is not done in compliance with the requirements, it could be considered an illegal shipment and may be sent back to the owner.

**Costs**: Whether export might be a cheaper solution than the alternatives depends on a number of factors, e.g. the volume of mercury wastes. It is difficult to give general cost estimates, as they vary greatly (e.g. due to energy prices). Main cost factors include insurance, packaging, customs, freight and shipment fees, and the costs or treatment/storage/disposal in the country of destination.

**Important ESM export steps** include the following:

- Seek regional solutions in order to avoid unnecessary risks associated with transportation of mercury wastes;

- address issues of ownership, liability and traceability; and

- ensure that the rules and procedures of the Minamata and Basel Conventions and/or relevant international rules, standards and guidelines are observed.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# CHAPTER 7:
# Management of Sites Contaminated with Mercury Wastes

The management of sites contaminated with mercury is a complicated, time consuming and often costly effort. The management and remediation of mercury contaminated sites is often different from the management of more conventional contaminants since mercury wastes or methyl mercury act differently in the environment. Furthermore the options to clean large volumes of mercury waste contaminated soils are costly.

Regardless of these concerns, it is suggested for governments to identify and inventory sites contaminated with mercury, ensure that the source of the contamination is contained to prevent any further contamination and remediate the site as soon as feasible to reduce exposure to humans and the environment.[1, 8, 54] Management of sites contaminated with mercury, once identified, often involve the following general steps:

1. **Preliminary Assessment** which identifies the nature and scope of contamination, including contamination by other toxic chemicals that may be present

2. **Site Investigation** which identifies the area of contamination and assesses the surface and subsurface extent of contamination

3. **Feasibility Studies** which determine what technical options are available to manage or remediate the site including evaluating how each alternative can best reduce or eliminate contamination from the site, and the cost of each option

4. **Final Decision** document which presents the best approach to managing or remediating the site

Each step in this process should be made available to all interested parties and be available for public comment prior to their finalization. [8]

At contaminated sites the surface and sub-soil, sediment, surface and ground water may need to be adequately treated. A number of processes are available for on– and off-site treatment (see for example the EU‘s relevant Best Available Techniques Reference Document (BREFs)[51] or the US EPA‘s ‘Treatment Technologies for Mercury in Soil, Waste and Water’[80].

**Contaminated Stes under the Minamata Convention: Art. 12, Para. 1 and 2**

> *“1. Each Party shall endeavour to develop appropriate strategies for identifying and assessing sites contaminated by mercury or mercury compounds.*
>
> *2. Any actions to reduce the risks posed by such sites shall be performed in an environmentally sound manner incorporating, where appropriate, an assessment of the risks to human health and the environment from the mercury or mercury compounds they contain.”*

Box 35: Contaminated Sites under the Minamata Convention: Art. 12, Para 1 and 2

## Treatment of Soil Contaminated with Mercury through a Combination of Wet Screening and Vacuum Distillation (France)

Mercury contaminated soil and building rubble was treated by a combination of soil washing and using a vacuum thermal desorption unit (vacuum mixer). In order to reduce the amount of material that has to be treated in the vacuum mixer, a soil washing process was utilized. Coarse material, which is generally less contaminated, was separated from fine material, which contains the bulk of the contamination, by a washing process. The fine material was sent to the vacuum mixer. Coarse material was tested and declared as cleaned solid if it met the quality criteria. If not, it was crushed and treated in the vacuum mixer.

The material treated by the vacuum mixer achieved a final mercury content of less than 1 ppm and leached less than 0.001 mg/l. After the treatment, stabilization was used to reduce the leachability of other heavy metals and the clean material was used for backfilling on-site.

Photo 45: Indirectly Heated Discontinuous Vacuum Mixer for Mercury Recovery, Including Solidification Mixer (courtesy: econ industries GmbH)

Before adopting a soil washing approach, it may be advisable to determine if the concentration of mercury in the contaminated soils is amenable to this type of treatment.

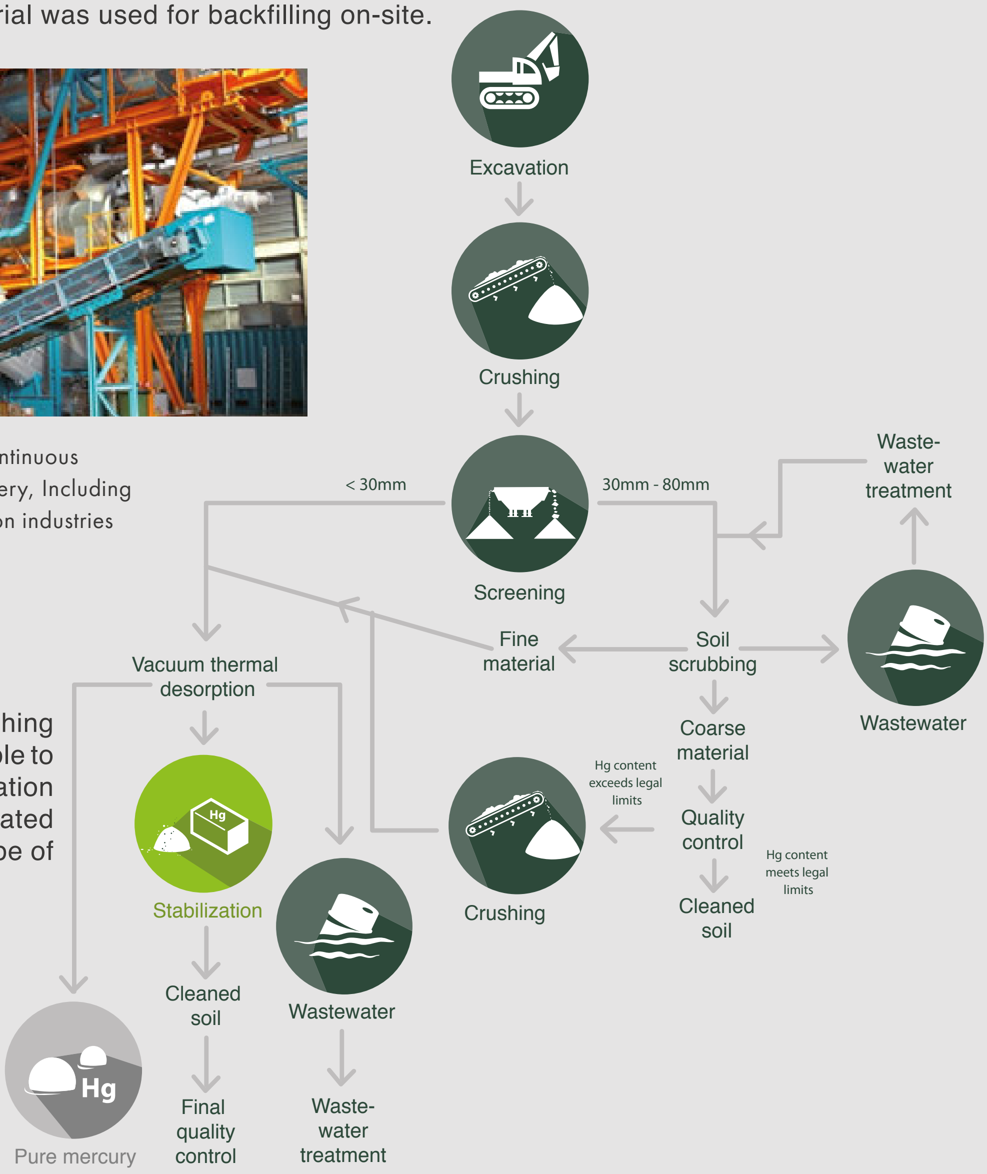

Figure 21: Combination of Wet Screening and Vacuum Distillation Flow Chart (courtesy: econ industries GmbH)

Case Study 17: Treatment of Soil Contaminated with Mercury through a Combination of Wet Screening and Vacuum Distillation (France)

For additional information regarding the management and remediation of contaminated sites, see:

- ‘Technical and Economic Criteria for Processing Mercury-Containing Tailings’[54]
- ‘Remediation of mercury contaminated sites – A review’[100]
- ‘Remcosite – Remediation of Mercury Contaminated Sites’[101]
- ‘Treatment Technologies for Mercury in Soil, Waste, and Water’[80]
- ‘International Experience in Policy and Regulatory Frameworks for Brownfield Site Management’[102]
- ‘Management of Mercury Contaminated Sites’[61]
- ‘Network for Industrially Contaminated Land in Europe’[103]
- ‘Initiatives in Europe for the remediation in contaminated soil’[104]
- ‘Remedial Design/Remedial Action’[105]
- ‘Federal Remediation Technologies Roundtable’[105]

# KEY MESSAGES AND ACTION POINTS

This section provides an overview of the factors that can be considered in choosing management options. **Optimally, this means that mercury wastes are treated to extract the mercury or to immobilize it in an environmentally sound manner. After stabilization/solidification, the extracted mercury is then disposed of at a permanent storage site or a specially engineered landfill (SEL) site** (alternatively, it may be used for uses in products or industrial processes allowed under national and international law, including the Minamata Convention, where applicable, in order to prevent/reduce the need for primary mining). **Mercury wastes may be securely stored, for example for further treatment until facilities are available or for export for disposal**.

## Types and sources of mercury wastes:

- Identify domestic sources of mercury wastes , the types of mercury wastes; and the amounts of waste from each source and for each type;
- Determine whether excess mercury is or may become available and decide on a management strategy to ensure that sufficient domestic capacity is available: and
- Establish clear rules and definitions for mercury wastes, including when it is to be classified as waste, and ensure that sampling and analysis are subject to quality assurance and quality control.

## ESM of mercury wastes:

- Prioritize avoidance/prevention/reduction of industrial processes and other activities which generate mercury wastes;
- Ensure mercury wastes are not mixed with other wastes, not discarded in uncontrolled landfills, not (co-) incinerated without dedicated flue gas cleaning and controls, and treated to extract or immobilize mercury;
- Manage in accordance with national and international law, including the Minamata and Basel Conventions, where applicable, and other relevant rules and obligations;
- Ensure that S/S, encapsulation or other treatment methods are conducted under control measures to ensure the quality of treatment, and that the effectiveness of treatment in immobilizing mercury is tested (i.e., for leaching and vapour release) before final disposal
- Take measures so that wastes consisting of mercury are treated and disposed of in a SEL or sent for permanent storage in underground facilities following S/S;
- Ensure that mercury-added products are collected, safely stored and, if appropriate, recovered/recycled; consider implementing ESM;
- Take steps so that solid and liquid wastes contaminated with mercury from industrial processes with mercury in the raw material or intentional uses of mercury are subjected to ESM, including on-site or off-site treatment ; and
- Adopt a clear regulatory framework for the downstream management of mercury recovered from industrial processes as well as of excess mercury from intentional uses.

## Storage, handling, transport and traceability:

- Encourage the establishment of dedicated storage facilities at locations where mercury wastes are generated;
- Implement measures to guarantee that on– and off-site storage is done in an environmentally sound manner;
- Ensure that mercury wastes are labelled, packaged and transported in appropriate containers with adequate labelling;

- Enforce the traceability of mercury wastes throughout the logistics chain; and
- Consider retrofitting existing facilities for the safe storage of mercury wastes.

### Recovery/recycling of mercury wastes:

- Use environmentally sound recovery/recycling processes to extract and purify the mercury contained in the waste for re-use or disposal operations and to decontaminate the waste; and
- Ensure the following in facilities: a mass balance is established; the system operates under negative pressure; mercury in the exhaust air and wastewater is captured; emissions and releases are monitored.

### Disposal Operations:

- If available, use proven commercially available S/S processes to immobilize the mercury; where not available, consider export of mercury wastes for ESM treatment and disposal;
- Where applicable, submit eligible mercury wastes for disposal in SELs or permanent storage in underground facilities;
- Where necessary, establish site selection criteria, secure financing, conduct an environmental impact assessment and implement necessary siting, design, and operational safeguards; and
- Where applicable, ensure that the export of mercury wastes is done in compliance with the Basel Convention.

### In practical terms, it is of utmost importance to engage in outreach and training activities:

- Ensure that relevant information on the ESM of mercury wastes is provided to those involved in its management; directly address relevant institutions, facilities and companies;
- Instruct responsible persons at identified sources that mercury wastes are collected and managed separately;
- Offer guidance on how to deal with mercury wastes (covering identification, collection, handling, storage, disposal operations etc.) that is easy to understand and use; and
- Develop, document and distribute concepts and solutions that can be implemented against the background of domestic circumstances.

Figure 22 shows the various steps suggested to be taken in the development of a comprehensive strategy for the environmentally sound storage and disposal of mercury wastes. The figure is partially based on the 'Suggested Framework for Decision-Making for the Safe Management of Surplus Mercury'[25], which can be consulted for further information and guidance.

## Key Steps in the Environmentally Sound Storage and Disposal of Mercury Wastes

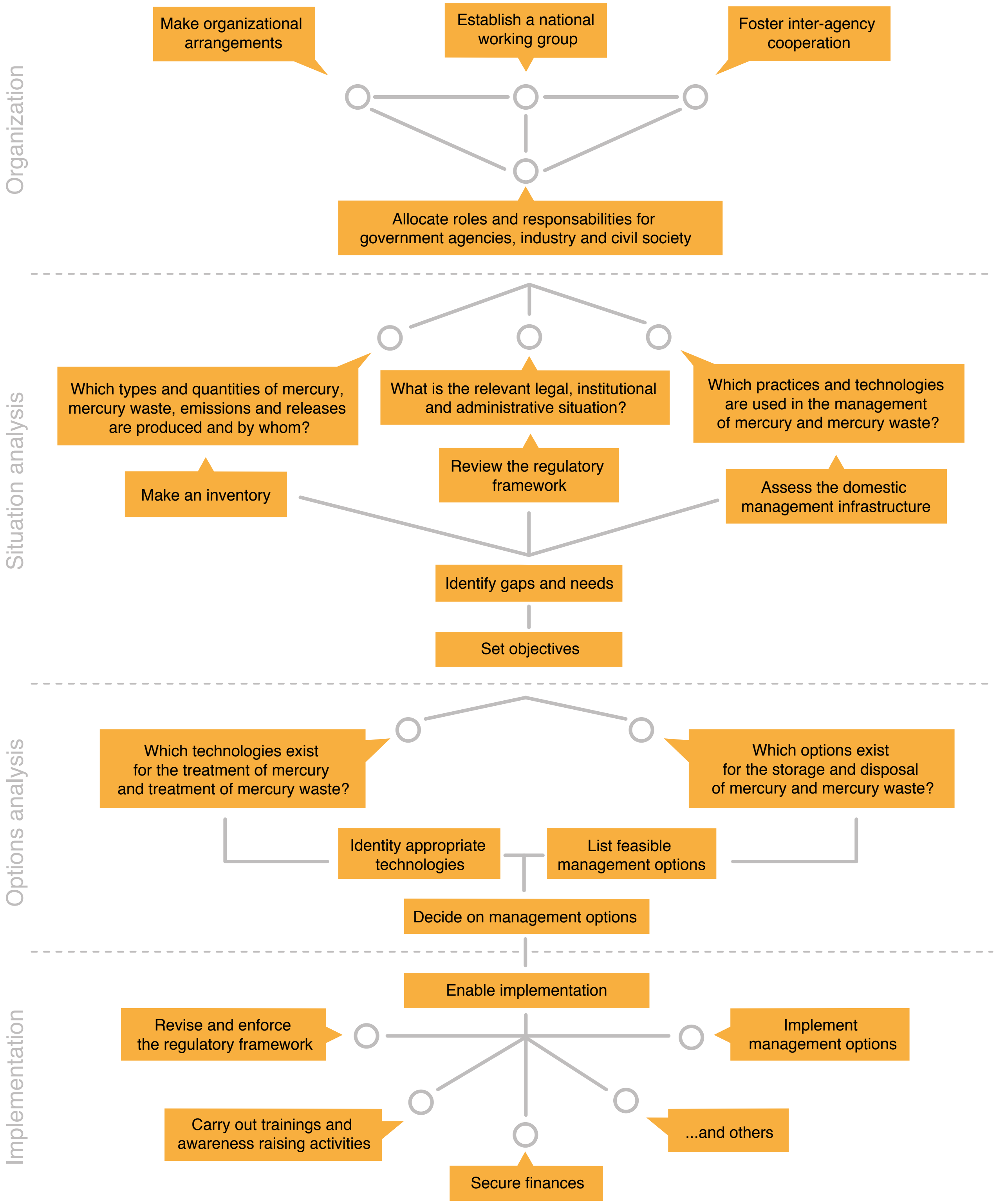

Figure 22: Key Steps in the Environmentally Sound Storage and Disposal of Mercury Wastes

# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **ASGM** | Artisanal and small-scale gold mining |
| **COP** | Conference of the Parties |
| **DLA-SM** | Defense Logistics Agency - Strategic Materials |
| **DTIE** | Division of Technology, Industry and Economics |
| **EPA** | Environment Protection Agency |
| **EPR** | Extended producer responsibility |
| **ESM** | Environmentally sound management |
| **EU** | European Union |
| **GC** | Governing Council |
| **GEF** | Global Environment Facility |
| **GHS** | Globally Harmonized System of Classification and Labelling of Chemicals |
| **IAEA** | International Atomic Energy Agency |
| **IETC** | International Environmental Technology Centre |
| **IGOs** | Intergovernmental organizations |
| **ISWA** | International Solid Waste Association |
| **LEAF** | Leaching Environmental Assessment Framework |
| **MAYASA** | Minas de Almadén y Arrayanes, S.A. |
| **NFM** | Non-ferrous metals |
| **SEL** | Specially engineered landfill |
| **Sourcebook** | Practical Sourcebook on Mercury Waste Storage and Disposal |
| **SPSS** | Sulphur polymer stabilization and solidification |
| **S/S** | Stabilization/solidification |
| **TCLP** | Toxicity Characteristic Leaching Procedure |
| **UNDP** | United Nations Development Programme |
| **UNEP** | United Nations Environment Programme |
| **UNITAR** | United Nations Institute for Training and Research |
| **US** | United States |
| **VCM** | Vinyl chloride monomer |
| **WEEE** | Waste electrical and electronic equipment |
| **XRF** | X-ray Fluorescence |

# REFERENCES

1 Secretariat of the Basel, Rotterdam and Stockholm Conventions. (2015). Updated technical guidelines for the environmentally sound management of wastes consisting, containing, or contaminated with mercury. Final version soon available at: http://www.basel.int/Implementation/MercuryWastes/TechnicalGuidelines/tabid/2380/Default.aspx.

2 UNEP. (2013). Minamata Convention on Mercury. Available at: http://www.mercuryconvention.org/Convention/tabid/3426/Default.aspx.

3 Ministry of the Environment of Japan. (n.d.). Lessons from Minamata Disease and Mercury Management in Japan. Available at: http://www.env.go.jp/chemi/tmms/pr-m/mat01/en_full.pdf.

4 UNEP. (2013).Global Mercury Assessment 2013 – Sources, Emissions, Releases and Environmental Transport. Available at:http://www.unep.org/PDF/PressReleases/GlobalMercuryAssessment2013.pdf.

5 UNEP. (2015). UNEP Global Mercury Partnership. Available at: http://www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/tabid/1253/Default.aspx.

6 UNEP. (2013). Time to Act. Available at: http://www.unep.org/PDF/PressReleases/Mercury_TimeToAct.pdf.

7 SEPA (1997): Final disposal of mercury – Mercury containing waste in Sweden – Inventory, characterization and prioritizing. Pers, K.; Karlsson, L. G.; Höglund, L. O. Kemakta Konsult AB. Swedish Environmental Protection Agency. Rapport 4768 (in Swedish).

8 UNEP. (n.d.). Interviews with, and submissions and presentations of, the members of an expert group composed of representatives from industry, governments, NGOs, academia and research as part of the Sourcebook project, including a face-to-face meeting.

9 US EPA. (n.d.). Toxicity Characteristic Leaching Procedure. Available at: http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1311.pdf.

10 US EPA. (2015). Resource Conservation and Recovery Act. Available at: http://www.epa.gov/agriculture/lrca.html.

11 US EPA. (2010). Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods. Available at: http://nepis.epa.gov/Adobe/PDF/P1009TQ9.pdf.

12 EU. (2002). Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills. Official Journal of the European Communities, L 11/27. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:011:0027:0049:EN:PDF.

13 US EPA. (2015). Land Disposal Restrictions for Hazardous Wastes. Available at: http://www.epa.gov/waste/hazard/tsd/ldr/index.htm.

14 Zero Mercury Working Group. (n.d.). Global Mercury Supply. INC 2 Briefing Paper Series. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/INC2/ZMWG3_Supply_FS0111_03.pdf.

15 European Commission. (2006). Mercury Flows and Safe Storage of Surplus Mercury. Available at: http://ec.europa.eu/environment/chemicals/mercury/pdf/hg_flows_safe_storage.pdf.

16 UNEP. (2006). Summary of supply, trade and demand information on mercury. Available at: http://www.chem.unep.ch/mercury/PM-HgSupplyTradeDemand-Final-Nov2006-PMformat19Jan07.pdf.

17 Sprl concorde. (2009). Assessment of Excess Mercury in Asia, 2010-2050. Available at http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/supplystorage/Assessment%20of%20Excess%20Mercury%20in%20Asia%202010-2015_Final%20Draft_May%202009.pdf.

18 UNEP. (2009). Excess Mercury Supply in Latin America and the Caribbean, 2010-2050 – Assessment Report. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Supply%20and%20Storage/LAC%20Mercury%20Storage%20Assessment_Final_1July09.pdf.

19 UNEP. (2010). Excess Mercury Supply in Eastern Europe and Central Asia, 2010-2050 – Assessment Report. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/supplystorage/EECA%20Excess%20Mercury_Final%20Draft_Apr2010.pdf.

20 Secretariat of the Basel, Rotterdam and Stockholm Conventions. (2015). 'Methodological guide for the development of inventories of hazardous wastes and other wastes under the Basel Convention'. Final version soon available at: http://www.basel.int/Implementation/LegalMatters/Compliance/GeneralIssuesActivities/Activities201415/Guidanceoninventories/tabid/3560/Default.aspx.

21 UNEP. (2015). Toolkit for Identification and Quantification of Mercury Releases. Available at: http://www.unep.org/chemicalsandwaste/Mercury/MercuryPublications/GuidanceTrainingMaterialToolkits/MercuryToolkit/tabid/4566/language/en-US/Default.aspx.

22 UNEP, UNITAR. (2015). MercuryLearn. Available at: http://mercurylearn.unitar.org/.

23 UNEP. (2011). Introduction to terms relevant to the discussion of mercury storage and disposal. 9th draft. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/SupplyandStorage/Reports/tabid/4508/language/en-US/Default.aspx.

24 Hagemann, S. (2011). Concepts for the environmentally sound management of surplus mercury. Presentation held during the Asia Pacific Regional Mercury Storage Projec, Executive Committee Meeting, 29-30.07.2011, Surabaya, Indonesia.

25 Integrating Knowledge to Inform Mercury Policy Initiative. (2010). A suggested framework for decision making for the safe management of surplus mercury. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/SupplyandStorage/Reports/tabid/4508/language/en-US/Default.aspx.

26 US EPA. (2007). Mercury Storage Cost Estimates. Available at: http://www.epa.gov/mercury/archive/stocks/Storage_Cost_Draft_Updated_11-6-final.pdf.

27 Umwelbundesamt. (2014). Behaviour of mercury and mercury compoudns at the underground disposal in salt formations and their potential mobilisations by saline solutions. Available at: http://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_07_2014_behaviour_of_mercury_and_mercury_compounds_at_the_underground_disposal_in_salt_formations.pdf.

28 UNEP. (2012). Business Plan of the Partnership Area on Supply and Storage. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/SupplyandStorage/tabid/3546/Default.aspx.

29 UNEP. (n.d.). Module 1 – Mercury in Products and Wastes. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/AwarenessPack/English/UNEP_Mod1_UK_Web.pdf.

30 US EPA. (2015). Consumer and Commercial Products. Available at: http://www.epa.gov/mercury/consumer.htm.

31 Northeast Waste Management Officials Association. (2015). Mercury Legacy Products. Available at: http://www.newmoa.org/prevention/mercury/projects/legacy/index.cfm.

32 Secretariat of the Basel, Rotterdam and Stockholm Conventions. (1989). Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal. Available at http://www.basel.int/Portals/4/Basel%20Convention/docs/text/BaselConventionText-e.pdf.

33 UNEP. (2006). Guide for Reducing Major Uses and Releases of Mercury. Available at: http://www.chem.unep.ch/mercury/Sector%20Guide%202006.pdf.

34 UNEP. (n.d.). List of Alternatives to Mercury-Added Products. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Products/flyer%20final1%20%20mercury-free%20alternatives.pdf.

35 UNEP, WHO. (2008). Guidance for Identifying Populations at Risk from Mercury Exposure. Available at http://www.who.int/foodsafety/publications/chem/mercuryexposure.pdf.

36 Brasser, T and Hagemann, S. (2010). Metallic Mercury Long-Term Storage Possibilities/Options. Presentation held in Tokyo, Japan, 09-10.03.2010. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Waste%20management/S1_15_Germany.pdf.

37 Hagemann, S. (2011). Technical Concepts for Storage and Disposal of Elemental Mercury. Presentation held during the Asia Pacific Regional Mercury Storage Project Executive Committee Meeting, 29-30.07.2011, Surabaya, Indonesia.

38 OECD. (2001) Extended Producer Responsibility: A Guidance Manual for Governments. Paris, France: OECD

39 European Commission (2012). European Commission Directive 2012/19/EU on waste electrical and electronic equipment (WEEE). Official Journal of the European Union L197/38. Available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019.

40 UNEP. (2012). Achieving the Global Transition to Energy Efficient Lighting Toolkit. Available at: http://www.thegef.org/gef/sites/thegef.org/files/publication/Complete%20EnlightenToolkit_1.pdf.

41 Ministry of the Enviornment of Japan. (2010). Good Practices for Management of Mercury Releases from Waste. First draft. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/INC2/Good_practices_Oct2010.pdf.

42 Maxson, P. (2007). Mercury in dental use: Environmental implications for the European Union. Report for the European Environmental Bureau. Available at: http://www.zeromercury.org/phocadownload/Events/Maxson%20Dental%2014May2007%20-%20A5colour.pdf.

43 WHO. (2011). Future Use of Materials for Dental Restoration. Available at http://www.who.int/oral_health/publications/dental_material_2011.pdf.

44 UNEP. (2015). East Africa Dental Amalgam Phase Down Project. Project information, presentations and reports. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/Products/Activities/EastAfricaDentalAmalgamPhase-DownProject/tabid/105844/Default.aspx.

45 US EPA. (2015). Mercury in Dental Amalgam. Available at: http://www.epa.gov/hg/dentalamalgam.html.

46 UNEP. (2010). Study on mercury sources and emissions, and analysis of cost and effectiveness of control measures – 'UNEP Paragraph 29 Study'. Available at http://www.unep.org/hazardoussubstances/Portals/9/Mercury/Documents/Paragraph29Study/Final%20Report%20Para29_5%20Nov%202010.pdf.

47 OECD; IAEA. (2008). Clean Coal Technologies – Accelerating Commercial and policy Drivers for Deployment. Available at: http://www.iea.org/publications/freepublications/publication/Clean_Coal_CIAB_2008.pdf.

48 European Commission. (2003). Integrated Pollution Prevention and Control (IPPC) – Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries. Available at: http://eippcb.jrc.ec.europa.eu/reference/BREF/ref_bref_0203.pdf.

49 European Commission. (2006). Integrated Pollution Prevention and Control (IPPC) – Reference Document on Best Available Techniques for Large Combustion Plants. Available at: http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf.

50 European Commission. (2001). Integrated Pollution Prevention and Control (IPPC) – Reference Document on Best Available Techniques in the Non Ferrous Metals Industries. Available at http://eippcb.jrc.ec.europa.eu/reference/BREF/nfm_bref_1201.pdf.

51 European Commission. (2015). Reference documents. Joint Research Centre, Institute for Prospective Technological Studies. Available at: http://eippcb.jrc.ec.europa.eu/reference/.

52 UNEP. (2011). Mercury and the Non-Ferrous Metals Sector. Draft Report.

53 European Commission. (2004). Integrated Pollution Prevention and Control (IPPC) – Reference Document on best Available Techniques for Management of Tailings and Waste Rock in Mining Activities. Available at: http://ec.europa.eu/environment/ippc/brefs/mtwr_final_0704.pdf

54 UNEP. (2010). Technical and Economic Criteria for Processing Mercury-Containing Tailings. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/PartneshipsAreas/Technical%20and%20economic%20criteria-2010.pdf.

55 Hylander, L. D. and Herbert, R. B. (2008). Global Emission and Production of Mercury during the Pyrometallurgical Extraction of Nonferrous Sulfide Ores. Environmental Science & Technology, 42 (16), p. 5971-5977.

56 Zero Mercury Working Group (n.d.). Vinyl Chloride Monomer (VCM). Available at: http://www.zeromercury.org/index.php?option=com_content&view=article&id=214&Itemid=102.

57 UNEP. (2015). Vinyl Chloride Monomer Production. Information, reports and presentations. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/VinylChlorideMonomerProduction/tabid/4523/Default.aspx.

58 Ministry of Environment of China. (2010). Project Report on the Reduction of Mercury Use and Emission in Carbide PVC Production. Available at http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/VCM%20Production/Phase%20I%20Final%20Report%20-%20PVC%20Project%20Report%20for%20China.pdf.

59 Euro Chlor. (2009). Guideline for Decommissioning of Mercury Chlor-Alkali Plants. Environmental Protection 3, 5th Edition. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/chloralkali/Updates%20from%20Eurochlor/Env%20Prot%203%20Edition%205.pdf.

60 Euro Chlor. (2006). Guideline for the minimization of mercury emissions and wastes from mercury chlor-alkali plants. Environmental Protection 13, 2nd Edition. Available at: http://www.chem.unep.ch/mercury/Sector-Specific-Information/Docs/ENV%20PROT%2013%20Edition%202.pdf.

61 Euro Chlor. (2009). Management of Mercury Contaminated Sites. Environmental Protection 15, 2nd Edition. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/chloralkali/Updates%20from%20Eurochlor/ENV%20PROT%2015%20Edition%202.pdf.

62 Euro Chlor. (2007). Guidelines for the preparation for permanent storage of metallic mercury above ground or in underground mines. Environmental Protection 19, 1st Edition. Available at: http://www.chem.unep.ch/mercury/Sector-Specific-Information/Docs/Env%20Prot%2019%20Edition%201.pdf.

63 UNEP. (2015). World Chlorine CounciL Publications and Guidelines. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/ChloralkaliSector/Reports/tabid/4495/language/en-US/Default.aspx.

64 Euro Chlor. (2015). Mercury. Available at: http://www.eurochlor.org/chlorine-industry-issues/mercury.aspx.

65 UNDP; GEF. (n.d.). Guidance on the Cleanup, Temporary or Intermediate Storage, and Transport of Mercury Waste from Healthcare Facilities. Available at: https://noharm-global.org/sites/default/files/documents-files/1030/GEF_Guidance_Cleanup_Storage_Transport_Mercury.pdf.

66 UNECE. (2015). About the GHS. Available at: http://www.unece.org/trans/danger/publi/ghs/ghs_welcome_e.html.

67 Capra, A. Presentation on traceability developed as part of the TRP + workshop.

68 Abejar-Arago, K. (n.d.). Storage of Phased-Out Mercury Containing devices – The San Lazaro Hospital experience in compliance to the Department of Health Administrative Order No. 2008-0021. Available at: http://www.mercuryfreehealthcare.org/Asia_Conf/Session_5-Storage_Mercury_Devices-San_Lazaro_Hospital.pdf.

69 Health Care Without Harm. (2013). From the Backyard to the Frontline – Initiatives of Philippine Hospital Workers on Best Environmental Practices. Asia, Global Healthcare Waste Project, UNDP, GEF, available at: http://web.undp.org/gef/document/From%20the%20Backyard%20to%20the%20Frontline.pdf.

70 Hagemann, S. (2011). Aboveground Storage of Elemental Mercury in Warehouses. Presentation during the Asia-Pacific Mercury Storage Project, Surabaya, Indonesia, 29.30.07.2011.

71 US DoE. (2011). Final Long-Term management and Storage of Elemental Mercury – Environmental Impact Statement – Summary and Guide for Stakeholders. Available at http://energy.gov/sites/prod/files/2013/09/f3/EIS-0423-S1-FEIS-Summary-2013.pdf.

72 US DoE. (2013). Final Long-Term Management and Storage of Elemental Mercury, Supplemental Environmental Impact Statement – Summary and Guide for Stakeholders. Available at http://energy.gov/sites/prod/files/2013/09/f3/EIS-0423-S1-FEIS-2013.pdf

73 US DoE. (2013). Final Long-Term Management and Storage of Elemental Mercury, Supplemental Environmental Impact Statement – Comment Response Document. Available at http://energy.gov/sites/prod/files/2013/09/f3/EIS-0423-S1-FEIS-Summary-2013.pdf

74 Lynch, D. M. (2007). Mercury Storage Site Hawthorne, Nevada. Presentation during the Commodity-Grade Mercury Stakeholder Meeting, 24.07.2007, Denver, Colorado. US: Defense National Stockpile Center.

75 Lynch, D. M. (2007). Meeting DNSC's Mercury Challenge. Presentation during the Mercury Stakeholder Meeting, 24.07.2007. US: Defense Logistics Agency.

76 Cripps, C. (2007). Mercury Storage in Nevada. Presentation during the Mercury Stakeholder Meeting, 24.07.2007. US: Defense Logistics Agency. Nevada Division of Environmental Protection.

77 MAYASA. (2010). Mersade Stabilization Technique and Proposals for the Safe Storage of Metal Mercury. Available at: http://www.mayasa.es/img/MERSADEESTABILIZATION.pdf

78 MAYASA. (n.d.). Mersade Project: Layman's Report. Available at: http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=LIFE06_ENV_PREP_E_000006_LAYMAN.pdf.

79 Secretariat of the Basel, Rotterdam and Stockholm Conventions. (2004). Technical guidelines on the environmentally sound recycling/reclamation of metals and metal compounds (R4). Available at: http://archive.basel.int/pub/techguid/r4-e.pdf

80 US EPA. (2007). Treatment Technologies for Mercury in Soil, Waste, and Water. Available at: http://www.epa.gov/tio/download/remed/542r07003.pdf

81 GRS. (2009). Technologies for the stabilization of elemental mercury and mercury-containing wastes. Available at http://www.grs.de/en/content/grs-252-technologies-stabilization-elemental-mercury-and-mercury-containing-wastes.

82 European Commission. (2000). Decision 200/532/EC of 3 May 2000. OJ 226.

83 UNEP. (n.d.). Update on mercury stabilization technologies. Available at: http://www.unep.org/chemicalsandwaste/Mercury/PrioritiesforAction/SupplyandStorage/tabid/3546/Default.aspx.

84 Bipro; European Comission. (2010). Requirements for facilities and acceptance criteria for the disposal of metallic mError! Bookmark not defined.ercury. Available at: http://ec.europa.eu/environment/chemicals/mercury/pdf/bipro_study20100416.pdf.

85 Höglund, L. O. (n.d.). Technical options for storage and disposal of mercury. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/supplystorage/Technical_options_for_storage_and_disposal_of_mercury.pdf.

86 Kalb et al. (2001). Treatment of Mixed-Wasre Mercury Recovered from Environmental Restoration Activities at BNL. Brookhaven National Laboratory. Available at: http://webmail.awinet.at/src/download.php?startMessage=1&passed_id=374&mailbox=INBOX&ent_id=2&passed_ent_id=0&where=FROM&what=paul.

87 Kalb et al. (2003). Using the Sulfur Polymer Stabilization/Solidification Process to Treat Residual Mercury Wastes from Gold Mining Operations. Available at: http://webmail.awinet.at/src/download.php?startMessage=1&passed_id=374&mailbox=INBOX&ent_id=3&passed_ent_id=0&where=FROM&what=paul.

88 Secretariat of the Basel Convention. (1995). Basel Convention Technical Guidelines on Specially Engineered Landfills. Available at: http://www.basel.int/TheConvention/Publications/TechnicalGuidelines/tabid/2362/Default.aspx.

89 Laboratorio Technologico del Uruguay; UNEP. (2010). Options analysis and feasibility study for the long-term storage of mercury in Latin America and the Caribbean. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/supplystorage/Final_Draft_LAC%20Hg%20Options_Chile.pdf.

90 GRS. (2011). Analysis of options for the environmentally sound management of surplus mercury in Asia and the Pacific. Available at: http://www.unep.org/chemicalsandwaste/Portals/9/Mercury/Documents/supplystorage/Analysis%20of%20options%20for%20the%20environmentally%20sound%20management%20of%20surplus%20Hg%20in%20AP%20R2.pdf.

91 Baart, A. Underground Waste Disposal. Presentation. K+S Entsorgungsgesellschaft. Available at: http://www.mercurynetwork.org.uk/wp-content/uploads/2009/10/Baart.pdf.

92 IAEA. (2009). Geological Disposal of Radioactive Waste: Technological Implications for Retrievability Available at: http://www-pub.iaea.org/MTCD/publications/PDF/Pub1378_web.pdf.

93 IAEA; 2009; Geological Disposal of Radioactive Waste: Technological Implications for Retrievability (http://www-pub.iaea.org/MTCD/publications/PDF/Pub1378_web.pdf

94 Miller, W.; Alexander, R.; Chapman, N.; McKinley, I. and Smellie, J. (2000): Geological Disposal of Radioactive Wastes and Natural Analogues – Lessons from Nature and Archaeology. Waste Management Series, Volume 2. Pergamon Press. ISBN 0 008 043853 9.

95 SEPA (2003): A Safe Mercury Repository. English translation of the Swedish Government. Swedish Environmental Protection Agency. Report 8105.

96 US DOE (2014). Evaluation of Options for Permanent Geologic Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste in Support of a Comprehensive National Nuclear Fuel Cycle Strategy. Volume I. FCRD-UFD-2013-000371, Revision 1, SAND2014-0187P (Vol. I).

97 UNEP. (2014). Mercury Storage and Disposal Project in Two Selected Countries in South America. Available at: http://www.unep.org/chemicalsandwaste/Mercury/GlobalMercuryPartnership/SupplyandStorage/Activities/LACMercuryStorageProject/MercuryStorage2CountriesProject/tabid/79070/Default.aspx.

98 IAEA. (2011). Geological Disposal Facilities for Radioactive Waste – Specific Safety Guide. IAEA Safety Standards Series SSG-14. Available at: http://www-pub.iaea.org/books/IAEABooks/8535/Geological-Disposal-Facilities-for-Radioactive-Waste-Specific-Safety-Guide.

99 IAEA. (2014). Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste. IAEA TECDOC 1755. Available at: http://www-pub.iaea.org/books/IAEABooks/10585/Planning-and-Design-Considerations-for-Geological-Repository-Programmes-of-Radioactive-Waste.

100 Wang, J.; Feng, X.; Anderson, C. W. N.; Xing, Y. and Shang, L. (2012). Remediation of mercury contaminated sites – A review. Journal of Hazardous Materials, 221-222, pp. 1-18.

101 GRS. (2008). REMCOSITE – Remediation of Mercury Contaminated Sites. Sino-German Workshop 2008, Guiyang, May 27 – 30, 2008. Available at: http://www.grs.de/sites/default/files/pdf/Remcosite_2008_Chemieabfaelle_0.pdf.

102 World Bank. (2010). International Experience in Policy and Regulatory Frameworks for Brownfield Site Management. Discussion Papers. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/2927/578900ESW0P11910BOX353785B01PUBLIC1.pdf?sequence=1.

103 Network for Industrially Contaminated Land in Europe. (2015): Welcome to NICOLE. Available at: http://www.nicole.org/.

104 US EPA. (2015). Initiatives in Europe for the remediation in contaminated soil. Available at: http://www.epa.gov/oswer/international/factsheets/200906_eu_soils_contamination.htm#initiatives.

105 US EPA. Remedial Design/Remedial Action. Available at: http://www.epa.gov/superfund/cleanup/rdra.htm.

106 Federal Remediation Technologies Roundtable. (2015). Available at: http://www.frtr.gov/.


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