INVENTORY OF MERCURY RELEASES IN SOUTH AFRICA

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by

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Greening the environment through consultancy

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ABBREVIATIONS

AMAP:	The Arctic Monitoring and Assessment Programme;
EU:	European Union;
FAO:	Food and Agriculture Organization;
FGD:	Flue gas desulfurization; process of/equipment for primarily minimizing emissions of sulphur from combustion flue gases;
GEF:	Global Environment Facility;
Hg:	Mercury;
Hg^0:	Elemental mercury;
Hg^{2+}:	Divalent mercury - the dominating mercury form in organic and inorganic mercury compounds. In the atmosphere, mercury species with divalent mercury are more easily washed out of the air with precipitation and deposited than elemental mercury;
Hg_p:	Particulate mercury - mercury bound in, or adsorbed on, particulate material. In the atmosphere, particulate mercury is deposited much faster than elemental mercury;
IARC:	International Agency for Research on Cancer;
ILO:	International Labor Organization;
IPCS:	International Programme on Chemical Safety;

Kg: kilogram;

l or L : litre;

LC_{50}: Lethal concentration, 50%; concentration of toxic substance in a medium (for example water) at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example fish;

LD_{50}: Lethal dose, 50%; dose (intake) of a toxic substance at which 50% of the individuals in the toxicity test sample die; a unit used to describe the level of toxicity of a substance to a specific species, for example in laboratory tests on mice, birds or other animals;

Life-time: In atmospheric physio-chemistry: Time during which the first order processes (or totality of the first order processes) of scavenging results in mercury species mass reduction in **e** times in a geophysical reservoir; for a reservoir with homogeneous mercury species distribution the life-time is equal to the ratio of the mass contained in the reservoir to scavenging rate. Since the mass of mercury in the reservior left to be reacted or removed decreases over time, the amount reacted or removed per unit of time decreases in a natural logarithmic fashion. For example, a lifetime of mercury of one year, does not mean that it would all be gone in one year if emissions were zero. It means that the rate of removal at the start of the time period in terms of mass per unit time would remove it all in one year, but since the rate of removal decreases as the mass of mercury left decreased, the amount of mercury left after one year would be (1/e) times the initial mass, where "e" is 2.71828183 defined to 8 decimals. In descriptions of life-cycles of products: The time span from when the product is put into use (usually time of purchase) until it is no longer used or discarded;

Load The intensity of input of pollutants to a given ecosystem from the environment; atmospheric load - the intensity of input from the atmosphere;

LOEL: Lowest observed effect level (also called **LOAEL** – lowest observed adverse effect level); for toxic or other effects imposed on organisms or experienced by humans;

LRTAP Convention: Convention on Long-Range Transboundary Air Pollution;

M: meter;

MethylHg or **MeHg**: methylmercury;

metric ton: 1000 kg;

mg: Milligram (10^{-3} gram);

MSC-E: Meteorological Synthesizing Centre – East (associated with the

	LRTAP Convention);
MSW:	Municipal solid waste;
MW:	Megawatt;
MWC:	Municipal waste combustor;
MWh:	Megawatt-hour;
Natural emission:	Mercury input to the atmosphere, which is not connected with current or previous human activity;
NEMA:	National Electrical Manufacturers Association (in the USA)
Ng:	Nanogram (10^{-9} gram);
NGO:	Non-governmental organization;
NRC:	National Research Council of the United States of America;
OECD:	Organization for Economic Cooperation and Development;
Pg:	Picogram (10^{-12} gram);
PM:	Particulate matter
POPs:	Persistent Organic Pollutants;
Ppb:	Parts per billion;
Ppm:	parts per million;
PS:	Particle scrubber; equipment designed to reduce emissions of particles from combustion flue gases
Re-emission:	Secondary input of mercury to the atmosphere from geochemical reservoirs (soil, sea water, fresh water bodies) where mercury has been accumulating as a result of previous and current human activity;
RfD:	Reference dose; term used in evaluation of risk of toxic effects various chemicals (such as methylmercury) on humans; the RfD is defined by US EPA as an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.
SCR:	Selective catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;
SDA:	Spray dryer adsorber system; equipment designed to reduce emissions of certain pollutants from combustion flue gases;
Slag:	Waste material produced when coal is dug from the earth, or a substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.
SNCR:	Selective non-catalytic reduction; equipment designed to reduce emissions of certain pollutants from combustion flue gases;

TLV:	Threshold limit value;
TWA:	Time weighted average;
UN:	United Nations;
UNCED:	United Nations Conference on Environment and Development;
UNEP:	United Nations Environment Programme;
US EPA:	Environmental Protection Agency of the United States of America;
USA:	United States of America;
Wet deposition -	Flux of substance from the atmosphere onto the underlying surface with atmospheric precipitation;
WHO	World Health Organization;

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PART ONE

EXECUTIVE SUMMARY

Introduction

Mercury is a potent neurotoxin, bio-accumulative and persists in the environment. Therefore, it is extremely important to properly handle and dispose of mercury-containing products. Moreover, the responsible use and end-of-life management of mercury-containing products (i.e., recycling rather than landfilling) can actually help to reduce the overall amount of mercury entering the environment. The benefits of undertaking a situation analysis of mercury in South Africa, and the development of an inventory of mercury use, sources, availability of safer and effective and affordable alternatives where applicable in South Africa include:

- protecting the environment from releases of mercury and
- preparation for effective participation of the South African delegation in the Intergovernmental Negotiating Committee (INC IV) on mercury, and priority setting for the country.

OBJECTIVES

The objectives of this study were to:

- develop a situation analysis of mercury in South Africa;
- develop an inventory of mercury use and sources, mercury containing products, availability of safer, effective and affordable alternatives where applicable in South Africa;
- identify whether business and industry have undertaken voluntary programs to reduce mercury use and/or emissions in South Africa;
- identify and propose NGOs/research institutions in the country addressing /studying mercury related or chemical related environmental problems for continued monitoring of intentional mercury introduction into the environment;
- identify, if any, vulnerable populations that require awareness raising about the mercury issue to protect human health and the environment;

recommend a comprehensive information system for tracking/tracing/monitoring mercury;

- come up with recommendations on mitigation and decontamination and

In pursuance of these goals, the scientists available in AJUA Environmental Consultants CC, applied their expert knowledge on toxic metal analysis as well as the successful completion of Rotterdam Convention Prior Informed consent (PIC) final regulatory action on chemicals and pesticides currently banned and severely restricted in South Africa for DEA in 2008-2009, to achieve aforementioned goals. The study was approached using the following methods namely:

METHODS

INDICATIVE METHOD INCLUDE:

- desk research of existing information;
- focus group meetings;
- questionnaire surveys
- postal communication
- life cycle product identification (supply chain)
- Relevant stakeholder consultation
- telephone interviews
- email/Web based information sourcing
- face to face interviews
- statistical methods

- **UNEP Toolkit level 1** (revised January 2011)

The mass balance principle, inputs and outputs

The mercury release calculations used in this Toolkit are based on the mass balance principle: All the mercury fed into the system (say, an industrial sector) with materials and fuels are expected to come out again, either as releases to the environment or in some kind of product stream. In other words: "Sum of inputs = sum of outputs".

Inputs: Therefore, the quantity of mercury inputs is obtained from the amount of mercury containing material fed into the system (called "**activity rate**") and general data on the mercury concentration in the feed material (called "**input factor**").

Outputs: The mercury releases from the system are calculated by distributing this mercury amount on the relevant release pathways based on available data on how the releases (or

"outputs") are generally distributed in this sector. For calculating this distribution, we use general "output distribution factors".

On inventory Level 1, these calculations are automatic, and are based on default input factors and default output distribution factors, which are already entered in the electronic calculation spreadsheet [UNEP TOOLKIT, 2008].

The generalized formula used in the calculations is:

Estimate mercury released to pathway X = activity rate * input factor * output distribution factor for pathway X

RESULTS

A summary of the results obtained in the study is shown in the table below. As can be seen from the table, the following source categories contributed the major mercury inputs: energy consumption and fuel production, domestic production of metals and raw materials and waste handling and recycling. The individual mercury release sub-categories contributing with the highest mercury inputs were: coal combustion and other coal uses, primary metal production and other material production. Waste deposition also constitutes a significant flux of mercury, but the majority of the mercury in the waste stream originates from products and processes with intentional mercury use. The individual mercury release sub-categories with the highest mercury releases to the atmosphere were coal combustion and other coal uses, primary metal production (excluding gold production by amalgamation), other material production and waste deposition.

Other contributors to the release of mercury into the environment include: disposal of dental amalgam and crematoria and cemeteries.

SUMMARY OF MERCURY RELEASES FROM MAIN GROUP SOURCES

Source category	Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, kg Hg/y					
		Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Coal combustion and other coal use	44,826.5	40,343.8	0.0	0.0	0.0	4,482.6	0.0
Other fossil fuel and biomass combustion	343.1	343.1	0.0	0.0	0.0	0.0	0.0
Oil and gas production	139.7	19.0	27.8	0.0	37.4	43.8	0.0
Primary metal production (excl. gold production by amalgamation)	2,197,727.9	91,955.4	43,664.3	1,964,804.2	92,148.6	333.0	4,822.3
Gold extraction with mercury amalgamation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other materials production	4,027.2	2,459.4	0.0	0.0	783.9	783.9	0.0
Chlor-alkali production with mercury-cells	-	-	-	-	-	-	-
Other production of chemicals and polymers	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Production of products with mercury content	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Use and disposal of dental amalgam fillings	7,588.0	151.8	2,519.2	0.0	273.2	1,456.9	1,456.9
Use and disposal of other products	14,388.8	1,117.6	2,045.2	708.2	0.0	9,657.9	860.0
Production of recycled metals	41.8	13.8	0.0	14.2	0.0	13.8	0.0
Waste incineration and open waste burning*1	0.7	0.6	0.0	0.0	0.0	0.0	0.1
Waste deposition*1	100,000.0	1,000.0	10.0	0.0	-	-	-
Informal dumping of general waste *1*2	1,000.0	100.0	100.0	800.0	-	-	-
Waste water system/treatment *3	39.9	0.0	35.9	0.0	0.0	4.0	0.0
Crematoria and cemeteries	1,561.5	93.7	0.0	1,467.8	0.0	0.0	0.0
TOTALS	**2,371,685.1**	**137,598.2**	**48,402.4**	**1,967,794.2**	**93,243.1**	**16,775.9**	**7,139.2**

CONCLUSION

The aforementioned objectives have been achieved in this study by:

- Providing a situation analysis of mercury in South Africa;
- Developing an inventory of mercury use and sources, mercury containing products, in South Africa;
- Identifying NGOs/research institutions in the country addressing/studying mercury related or chemical related environmental problems for continued monitoring of

intentional mercury introduction into the environment. Those identified are contained in the reference section of this report;

- Identifying business and industry who have undertaken voluntary programs to reduce mercury use and/or emissions in South Africa. For example, during the cause of this study, it was found out that the dental practitioners have embarked on providing alternatives to the mercury amalgam for filling. Furthermore, there is a national campaign by the energy sectors on the use of low mercury containing compact fluorescent lamps (CFL) instead of the high mercury containing long fluorescent lamps.

- Women using skin lightening creams and soaps which may contain mercury have been identified as the vulnerable populations and they require awareness raising about the mercury issue to protect human health and the environment. Also people using mercury amalgam for dental fillings as well as those living within the vicinity of power generating plants and illegal gold miners have been identified as vulnerable.

- Recommend the need for tracking/tracing/monitoring mercury as well as some recommendations on mitigation and decontamination.

The present study has shown that energy consumption and waste disposal are the major contributors of mercury releases to the atmosphere and land so far in South Africa. However, information on other sources of mercury still need to be collected and added to the present results in order to give an overview of mercury releases within the South African environment. By examining the steps and strategies other countries are taking to reduce the releases of mercury into the environment, South Africa's drive to undertake a situation analysis and develop inventories of monitoring mercury and coming up with recommendations and mitigation measures to control the releases of mercury into the South African environment will be achieved. However, the present study was not able to provide information on mercury releases from some source categories as contained in the UNEP toolkit level 1. This was attributed to either lack of available information or the non-cooperation of the identified users/consumers to give out information.

PART TWO

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

1.1.1 UNEP INITIATIVE ON MERCURY RELEASES

The UNEP Governing Council decision GC 24/3 IV identified seven priority areas for action to reduce the risks from releases of mercury, two of which are:

i. To reduce the global mercury supply, including considering curbing primary mining and taking into account a hierarchy of sources; and
i. To find environmentally sound storage solutions for mercury.

Even more recently, the UNEP Governing Council decision GC 25/5 (paragraph 34) mandated member governments to take further international measures including the elaboration of a legally binding instrument on mercury, which could include both binding and voluntary approaches, as well as a range of interim activities, to reduce risks to human health and the environment. For South Africa to evaluate its status in global mercury emission, it is necessary to look at the mercury inventory and the models used to determine such data. Such situation analysis could be of significant importance in coming up with a national inventory based UNEP toolkit developed in 2005 [UNEP, 2005].

In view of the mercury poisoning incidences reported throughout the world, the United Nations Environmental Programme (UNEP)'s Governing Council (GC) initiated global assessment of mercury at its twenty-first session held in 2001. Since then, UNEP through its wings has undertaken to increase the understanding of mercury emission sources to the atmosphere as it is critical for the development of relevant and cost-effective strategies towards the reduction of this global pollutant. An inventory of the global anthropogenic emissions of mercury for 2005 was prepared in a joint UNEP/AMAP project in 2008. This inventory was based on nationally reported emissions, and emissions estimated for other countries based on activity data and relevant emission factors. The UNEP regions of Asia and Central America and the Caribbean have already developed their mercury assessment projections for the period of 2015-2050 according to some models. However, the African region is yet to complete its mercury inventory by its member states.

Mercury (Hg) pollution is a global concern, given its toxicity, persistence and ability to bioaccumulate in the environment [Pacyna et al., 2006a; Feng and Qiu, 2008; Zhang et al., 2008]. Over the last century, there has been an increase in Hg emissions into the environment, which has largely been attributed to anthropogenic sources [Streets et al., 2005; Zhang et al., 2008]. This has prompted many studies on Hg emissions from various sources in Europe [Pacyna et al., 2006a], China [Streets et al. 2005; Wu et al., 2006; Niksa and Fujiwara, 2009; Zhang et al., 2008] and India [Mukherjee et al., 2008]. In addition to these, countries such as Canada are conducting national inventories that attempt to track trends in Hg emissions from anthropogenic and/or natural activities. Mercury emissions inventories in most developing countries, particularly countries in Africa, are lacking. This is particularly true for South Africa, where only recently some Hg emissions estimates have been published [Dabrowski et al., 2008; Leaner et al., 2009; Masekoameng et al. 2010]. Table 1-1 shows the production and use phase of life cycle of mercury (UNEP, 2002 = Global mercury Assessment).

Table 1-1 Production and use phases of life cycle of mercury [UNEP 2002]

TYPE AND AIM OF MEASURE		STATE OF IMPLEMENTATION
Production and use phases of life cycle		
Point Sources	Prevent or limit the intentional use of mercury in processes	General bans implemented in very few countries
	Prevent or limit mercury from industrial processes (such as chlor-alkali and metallurgic industry) from being released directly to the environment	Implemented in many countries, especially OECD countries
	Apply emission control technologies to limit emissions of mercury from combustion of fossil fuels and processing of mineral materials	Implemented in some OECD countries
	Prevent or limit the release of mercury from processes to the wastewater treatment system	Implemented in some OECD countries
	Prevent or limit use of obsolete technology and/or require use of best available technology to reduce or prevent mercury releases	Implemented in some countries, especially OECD countries
Products	Prevent or limit products containing mercury from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as batteries, lighting, clinical thermometers
	Prevent products containing mercury from being exported	Only implemented in a few countries
	Prevent or limit the use of already purchased mercury and mercury-containing products	Only implemented in a few countries
	Limit the allowable content of mercury present as impurities in high-volume materials	Only implemented in a few countries
	Limit the allowed contents of mercury in commercial foodstuffs, particularly fish, and provide guidance (based on same or other limits values) regarding consumption of contaminated fish	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.
Disposal phase of life cycle		
Prevent mercury in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent mercury in products and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment		Implemented in many countries, especially OECD countries
Prevent or limit mercury releases to the environment from incineration and other treatment of household waste, hazardous waste and medical waste by emission control technologies		Implemented or implementation ongoing in some countries, especially OECD countries.
Set limit values for allowable mercury contents in sewage sludge spread on agricultural land		Implemented in a number of countries
Restrict the use of solid incineration residues in road building, construction and other applications		Implemented in some OECD countries
Prevent the re-marketing of used, recycled mercury		Only implemented in a few countries

Mercury pollution has significant impacts at local, national, regional and global levels. These impacts can be addressed through a range of actions at each of these levels, targeting reductions in uses, releases and exposures. Numerous actions implemented in Europe, North America and elsewhere have successfully reduced uses and releases of mercury. However, inventories are still incomplete in these regions, and some releases are still significant. The extent of decreases in environmental levels and ecosystem improvements in response to decreased releases of mercury will vary considerably depending on local ecosystem characteristics and other factors, and in some cases may take several decades. South Africa being a mineral rich country has several challenges related to mercury release from mineral processing and utilization. More than 98% of South Africa's electricity come from coal fired thermal power stations which have the potential of being the major mercury point sources if processing technologies to reduce mercury releases from coal are not applied.

The source of mercury emission in South Africa do not differ significantly from other countries except that no mercury mining is being carried out locally and all mercury in its environment is from natural resources utilisation and from imported goods containing mercury. Apart from specific applications, however, mercury use for most other regions has only roughly been estimated in the past. As of 1995 global atmospheric releases from a number of major anthropogenic sources is shown in Table 1-2. A significant number of countries did not have inventories by the year 1995.

Table 1-2 Estimates of global atmospheric releases of mercury (metric tons/year) from a number of major anthropogenic sources in 1995 (Releases to other media are not accounted for here *1)

Continent	Stationary combustion	Non-ferrous metal production *5	Pig iron and steel production	Cement production	Waste disposal *2	U	Sum, quantified sources *3
Europe	186	15	10	26	12		250
Africa	197	7.9	0.5	5.2			210
Asia	**860**	**87**	**12**	**82**	33		1070
North America	105	25	4.6	13	**66**		210
South America	27	25	1.4	5.5			60
Australia and Oceania	100	4.4	0.3	0.8	0.1		100
Sum, quantified sources, 1995 ***3**,**4**	1470	170	30	130	110	300	1900 +300
Based on references:	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Pirrone *et al.* (2001)	Lacerda (1997)	

1 Note that releases to aquatic and terrestrial environments - as well as atmospheric releases from a number of other sources - are not included in the table, because no recent global estimates have been made. See chapter 6 for description of this issue.
2 Considered underestimated by authors of the inventory,
3 Represents total of the sources mentioned in this table, not all known sources. Sums are rounded and may, therefore, not sum up precisely.
4 Estimated emissions from artisanal gold mining refer to late 1980's/early 1990's situation. A newer reference (MMSD, 2002) indicates that mercury consumption for artisanal gold mining - and thereby most likely also mercury releases - may be even higher than presented here.
5 Production of non-ferrous metals releasing mercury, including mercury, zinc, gold, lead, copper, nickel.

The nature and extent of mercury pollution and its impacts in South Africa have not been extensively studied. In the 1980s and early 1990s, Thor Chemicals, received thousands of tons of chemical waste from the Americas and Europe, to be reprocessed. The effluent spill containing mercury contaminated the Umgeni River in July 1988. The mercury levels in the Umgeni River, 15 km downstream where THOR's facility was located, were reported to be 1000 times higher than WHO standards for drinking water. No incident of death was reported. The case of stockpile of mercury waste in KwaZulu-Natal Province of South Africa has remained unresolved [GroundWork, 2005]. Several studies have also been conducted on mercury emissions in South Africa but no national mercury inventory exercise has been conducted.

1.2 OBJECTIVE

The main objective of this study was, therefore, to carry out a situational analysis of mercury in South Africa, particularly on the uses, sources with recommendations on safer, effective and affordable alternatives where applicable in South Africa, in preparation for effective participation of the South African delegation in the upcoming intergovernmental negotiating committee (INC IV) on mercury, and priority setting for the country.

1.3 TERMS OF REFERNCE (ToR)

The terms of reference of the present study was to appoint a suitable independent Service provider (s) that can support DEA with the situational analysis of mercury in South Africa, particularly to develop an inventory of mercury use, sources, availability of safer, effective and affordable alternatives where applicable, in South Africa in preparation for effective participation of the South African delegation in the upcoming intergovernmental negotiating committee (INC III) on mercury, and priority setting for the country.

CHAPTER 2: LITERATURE REVIEW

2 IDENTITY AND PHYSICAL/CHEMICAL PROPERTIES

2.1 MERCURY

Mercury is a chemical element with the symbol Hg and atomic number 80. It is also known as quicksilver or hydrargyrum (from "hydr-" *water* and "argyros" *silver*). A heavy, silvery d-block element, mercury is the only metal that is liquid at standard conditions for temperature and pressure [Ehrlich and Newman 2008]. As compared to other metals, it is a poor conductor of heat, but a fair conductor of electricity. Due to its high reactivity, mercury is rarely found in pure state in nature. The common ore in which mercury has a viable concentration suitable for mining is mercuric sulphide (cinnabar) ore. Generally, mercury compound have low melting and evaporation temperatures when compared to inorganic salts of other transition metals [Ehrlich and Newman, 2008].

2.1.1 OCCURRENCE

Mercury is an extremely rare element in the Earth's crust, having an average crustal abundance by mass of only 0.08 parts per million (ppm) [Ehrlich and Newman, 2008]. However, because it does not blend geochemically with elements that constitute the majority of the crustal mass, mercury ores can be extraordinarily concentrated considering the element's abundance in ordinary rock. The richest mercury ores contain up to 2.5% mercury by mass, and even the leanest concentrated deposits are at least 0.1% mercury (12,000 times average crustal abundance). It is found either as a native metal (rare) or in cinnabar, corderoite, livingstonite and other minerals, with cinnabar (HgS) being the most common ore [Rytuba, 2003]. Mercury ores usually occur in very young orogenic belts where rock of high density are forced to the crust of the Earth, often in hot springs or other volcanic regions [USGS, 2009]. Mercury is commonly found in three general forms namely:

- Elemental mercury, which is a shiny liquid metal sometimes referred to as “metallic mercury;
- Inorganic mercury, which is most often bound to particulates and, therefore, not readily available for uptake by organisms and
- Organic mercury, which is found mainly in the form of methylmercury.

2.1.2 ELEMENTAL MERCURY

Elemental mercury is the most volatile form of mercury. It has a vapour pressure of 0.3 Pa at 25 °C and transforms into the vapour phase at typical room temperatures. It is relatively insoluble in water (56 μg/litre at 25°C) and hydrochloric acid, but soluble in lipids, nitric acid, pentane (2.7 mg/litre) and sulphuric acid upon boiling. Mercury in its elemental form, like any other heavy metals, is persistent and the major releases of mercury pollution are emissions to air because of its volatility [Rytuba, 2003]. However, mercury if released into water and soil can attenuate to form inorganic and organic mercury compounds. Once mercury is released into the environment, it persists by circulating between air, water, soil and biota in various chemical forms. The species of mercury released into the environment depends on the forms present in the source and generally, major species found in the air is elemental mercury, which is transported globally to regions far from emissions source [AMAP/UNEP, 2008].

Elemental mercury can react with some organic compounds such as alkyl halides compounds to form alkylmercury halides. The most common of these organomercuric compounds is methylmercury which is formed by microbial metabolism of mercury and its compounds. Recent studies have shown that methylmercury can be released from directly from municipal landfills [Lindberg et al., 2001] and sewage treatment plants [Sommar et al., 1999]. However, the significance of these sources to local emissions is still uncertain.

2.1.3 INORGANIC MERCURY

Inorganic mercury occurs as salts of its divalent and monovalent cationic forms such as mercuric chloride ($HgCl_2$), mercurous chloride (Hg_2Cl_2), mercuric sulphide (HgS) and mercuric acetate ($HgC_4H_6O_4$). Inorganic mercury in the form of mercury chloride (Hg_2Cl_2) is another volatile species of mercury with an atmospheric mobility between 100 and1000 km before it deposits to land or water bodies. When mercury and its inorganic compounds are deposited in water and or on soil, they undergo microbial metabolism, attenuating into methyl mercury which has the capacity to bio-accumulate and concentrate up the food chain (bio-magnify), especially in fish and marine mammals [Huheey et al., 1993].

2.1.4 ORGANIC MERCURY

Organic mercury compounds are historically important but are of little industrial value. Organomercury compounds are always divalent and usually two-coordinate and linear geometry. Organomercury compounds do not react with water and they usually have the

formula HgR_2, which are often volatile, or HgRX, which are often solids, where R is aryl or alkyl and X is usually halide or acetate. Methylmercury, a generic term for compounds with the formula CH_3HgX is a toxic family of compounds that is found in some polluted water and they arise by a process known as biomethylation [USNRC, 2000].

2.2 SOURCES OF HUMAN EXPOSURE

Over geological time, mercury has been distributed throughout the environment by natural processes, such as volcanic activity; fires; movement of rivers, lakes, and streams; oceanic upwelling; and biological processes. Since the industrial revolution of the late 18th and 19th centuries, anthropogenic sources have become a significant contributor to the environmental distribution of mercury and its compounds [Rytuba, 2003].

As with other components of the lithosphere, natural global cycling has always been a primary contributor to the presence of chemical elements in water, air, soils, and sediments.

The emissions of mercury have been classified into four major sources namely:

i. Natural source-releases due to natural mobilisation of naturally occurring mercury from the earth's crust, such as volcanic eruptions and rock weathering [UNEP 2002];

ii. Current anthropogenic (associated with human activity) releases from the mobilisation of mercury impurities in raw materials such as fossil fuels in particularly coal in the case of South Africa;

iii. Current anthropogenic releases resulting from mercury used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases;

iv. Re-mobilisation of historic anthropogenic mercury releases previously deposited in soils, sediments, water bodies, landfills and waste/tailings piles [Streets et al., 2005; Niksa &Fujiwara, 2009; UNEP 2002].

The natural component of the mercury is difficult to quantify and even the UNEP toolkit for 2011 does not incorporate the contribution of natural emission to the overall global environmental mercury load. The Oceanic activities are the major contributors of mercury emission. The global mercury emissions from natural sources and their proportional contribution are shown in Figure 2.1.

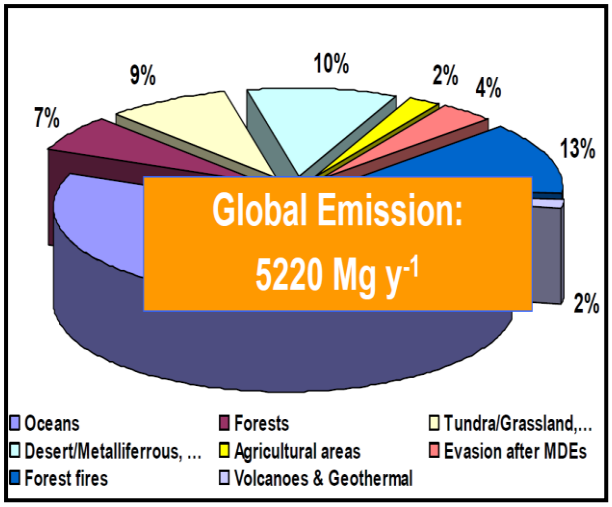

Figure 2.1 Mercury Emissions from Natural Sources [Rytuba, 2003]

The major contributor to global mercury load has been identified as the current anthropogenic sources and any remedial steps taken to curtail mercury release should encompass its reduction from these sources. Major anthropogenic sources of mercury in the environment include the following [Brito & Guimaraes, 1999; Grandjean et al., 1999; Pacyna et al., 2006].

2.2.1 Extraction and use of Fuels/Energy Sources

These include power stations, industrial furnaces, and extraction of natural gas, mineral oil, fossil fuels and installations for providing space heating. The main pathway of mercury release is air and accounts for the largest quantity of mercury emissions. Coal is used for home heating and in certain areas where it is burned in unvented household stoves; people may be exposed directly to emissions of mercury and other toxic substances and organic compounds. The major anthropogenic mercury emission sources by sector globally are shown in Figure 2.2 as revised by UNEP in 2008. The combustion of coal in power stations, artisanal gold mining and combustion of fossil fuel by other sectors contribute the largest to mercury emission into the air.

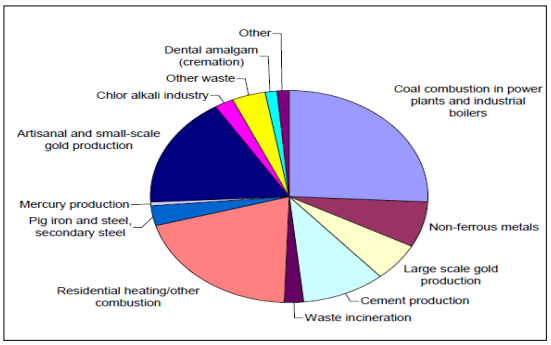

Figure 2.2 Proportion of global anthropogenic emissions of mercury to air in 2005 from various sectors [revised from UNEP/AMAP, 2008]

2.2.2 Primary metal production

The main pathways for the release of mercury from primary metal production include:

- Primary extraction and processing of mercury, i.e., dedicated primary mercury mining;
- Gold and silver extraction with mercury-amalgamation process; and
- Zinc, copper, lead, aluminium, non-ferrous and ferrous metals extraction and processing where mercury impurities are present in the ores;

2.2.3 Production of other minerals & materials with mercury impurities

The main pathways for the release of mercury from the production of other minerals and materials with mercury impurities include [Pacyna et al., 2003]:

- Cement production, including mercury in lime, waste as fuel and other feedstock materials;
- Pulp and paper production, including mercury impurities in wood;
- Lime production and light weight aggregate kilns;
- Production and processing of other raw materials, including production and use of lime, light weight aggregates, mineral fertilizers, and others.

2.2.4 Intentional use of mercury in industrial processes [Pacyna et al., 2003]

The following industrial processes have been identified as one of the several pathways for the releases of mercury from intentional use of mercury in industrial processes:

- Chlor-alkali production with mercury-technology;
- Vinyl-chloride-monomer production with mercury-dichloride ($HgCl_2$) as catalyst;

- Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst;
- Other production of chemicals and polymers with mercury compounds as catalysts.

2.2.5 Consumer products with intentional use of mercury [Pacyna et al., 2003]

The following sources are one of the main consumer products with intentional use of mercury:

- Thermometers containing mercury, including medical thermometers, other glass thermometers used in laboratories for educational purposes, mercury thermometers for industrial and marine diesel engines;
- Electrical and electronic switches, contacts and relays with mercury;
- Light sources with mercury, in particular compact fluorescent bulbs;
- Batteries containing mercury, in particular mercury oxide batteries (cylindrical and button);
- Biocides and pesticides;
- Paints;
- Pharmaceuticals for human and veterinary uses, including vaccines, eye drops, some herbal medicines and disinfectants and
- Cosmetics and related products, including skin lightening creams and soaps, preservation in eye cosmetics, etc. For mercury containing consumer products, safe disposal is also generally an issue.

2.2.6 Other intentional product/process uses [Skare, 1995; Health Canada, 1997; UNEP, 2002]

Other intentional products and processes that make use of mercury include:

- Dental amalgam fillings;
- Manometers and blood pressure gauges;
- Laboratory chemicals and equipment;
- Ethnic/cultural/ritualistic uses, including mercury metal use in religious/ethnic/cultural rituals and practices and folklore medicine;
- Other mercury metal uses, including educational uses, gyroscopes with mercury, vacuum pumps with mercury, marine navigation lights in light houses (in some types the lens/lamp unit floats on mercury, mercury in large bearings of rotating mechanic part in for example older waste water treatment plants;

- Miscellaneous products, including infra-red detection semiconductors, tanning, pigments, browning and etching steel, certain colour photograph paper types, recoil softeners in rifles, explosives (mercury-fulminate), fireworks, executive toys. For mercury containing consumer products, safe disposal is also generally an issue.

2.2.7 **Production of recycled metals** [Pacyna et al., 2003]

The following pathways are the major sources via which mercury is released from production of recycled metals:

v. Production of recycled mercury ("secondary" metal production), including the collection and processing involved in recycling of mercury;

vi. Production of recycled ferrous metals (iron and steel), scrap yard handling, scrap auto smelting, shredder and re-melting furnace.

2.2.8 **Waste incineration** [Pacyna et al., 2003]

The following sources contribute to the release of mercury from waste incineration:

vii. Incineration of municipal/general waste - mainly domestic (household and institution) waste;

viii. Incineration of hazardous waste - usually combustible wastes collected separately, which may contain mercury from intentional uses (e.g. pesticides, paints, pharmaceuticals, organic mercury compounds) as well as general mercury impurities;

ix. Incineration of medical waste;

x. Sewage sludge incineration and

xi. Informal waste incineration - private or local informal waste incineration in open fire, barrels, domestic heating ovens, etc.

2.2.9 **Waste deposition/land filling and waste water treatment** [Pacyna et al., 2003]

The following sources are the main pathways for the release of mercury from waste deposition/landfilling and wastewater treatment:

xii. Controlled landfills/deposits;

xiii. Diffuse deposition such as deposition of incineration residues and other solid residues;

xiv. Informal local deposition of industrial production waste, such as chlor-alkali production waste, chemicals production waste;

xv. Informal dumping of waste, i.e., uncontrolled, informal dumping of general waste diffusely or at informal waste dumps;

xvi. Wastewater system/treatment, - where any mercury in wastewater originating from all sorts of mercury uses such as dental amalgam wastes ends up in the sewage sludge, and to a lesser degree in the output water.

2.2.10 Crematoria

Mercury may be released during cremation of corpses. Most of the mercury released is due to the presence of dental amalgam fillings that contain mercury.

2.3 ENVIRONMENTAL TRANSPORT, DISTRIBUTION AND TRANSFORMATION

2.3.1 Environmental transformation

Generally, it is essential to understand the speciation products of mercury which predominate in certain environmental conditions. Each species has its own limit of concentration (LC_{50}) and the species influence:

i. The physical availability of exposure;
ii. The internal transport inside the organism tissue to target organelles;
iii. Its toxicity;
iv. Its accumulation, bio-modification, de-toxification and
v. Its bio-magnification.

The nature of the species determines its capacity to move from one environmental compartment to the other and its life span when it is airborne. The air, river and ocean currents are media for long-range mercury transport. Some fish species have the tendency to migrate between hemispheres depending on climatic seasonal conditions. This behavour tends to expose migratory fish to mercury contamination in such region. Therefore, mercury contamination of air, rivers, lakes and especially oceans is actually global in nature, affecting the fishing industries and fish consumers around the globe.

2.3.2 Air

In the atmosphere, mercury speciation products reaction kinetics is non-homogenous and some of the possible reaction includes:

i. Gas phase reactions which may include free radical reactions;
ii. Aqueous phase reactions which usually occur at water/clouds droplets;
iii. Partitioning reactions of elemental mercury and oxidised species between the gas phase and the solid which is usually ice/clouds in the atmosphere;

iv. Partitioning between solid and aqueous phases especially for volatile insoluble; and inorganic mercury speciation products [UNEP, 2000].

However, the predominant species at particular time is heavily dependent on the atmospheric conditions. A dry atmosphere will favour the existence of elemental mercury or its oxides, while the presence of moist conditions will favour the formation of inorganic salts or oxides. Hence, rainy water despite the belief that it is naturally clean, it might reach the ground with significant amount of mercury if local pollution predominates in a particular area like those close to coal fired power stations. Figure 2-3 shows the mercury cycle in terms of oxidation states and state functions.

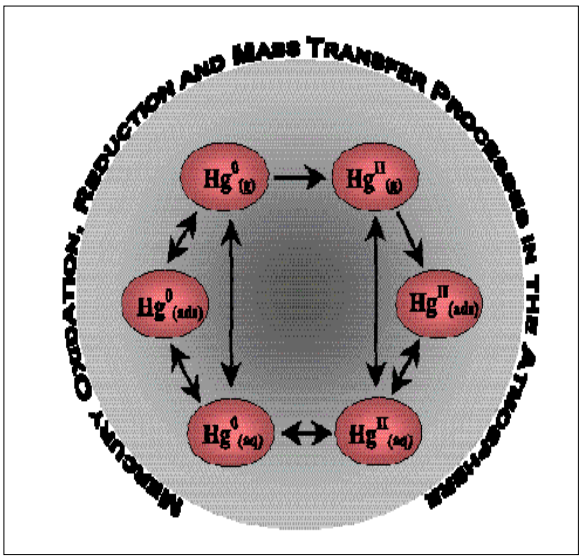

Figure 2.3 Model of interactions between mercury species in the atmosphere [Pirrone et al., 2001]

2.3.3 Aquatic system

Elemental mercury is the major species released into the environment in most anthropogenic releases. When mercury gets into aquatic environment, several reaction pathways can then transform it into inorganic and or organomercuric compounds. However, methylmercury salts are the common compounds of mercury which are formed through chemical or biochemical processes catalysed by certain bacteria found naturally in aqueous environments [Dipasquale et al., 2000; Bailey et al., 2001]. It has been reported that some algae naturally use methylmercury as their carbon source, thus demethylation in the process can convert methylmercury into its elemental form or hydroxide [Ullrich et al., 2001]. Methylmercury is

the worst toxic speciation product of mercury as it is easily absorbed by aquatic life such as fish where it bio-accumulates. The presence of dimethylmercury and phenylmercury speciation products in lake and ocean waters has been investigated and methylmercury was found to be the dominant species [Mason and Fitzgerald, 1996, 1997]. Mason and Fitzgerald, (1996), summarised the dynamics of mercury in ocean waters as shown in Figure 2.4.

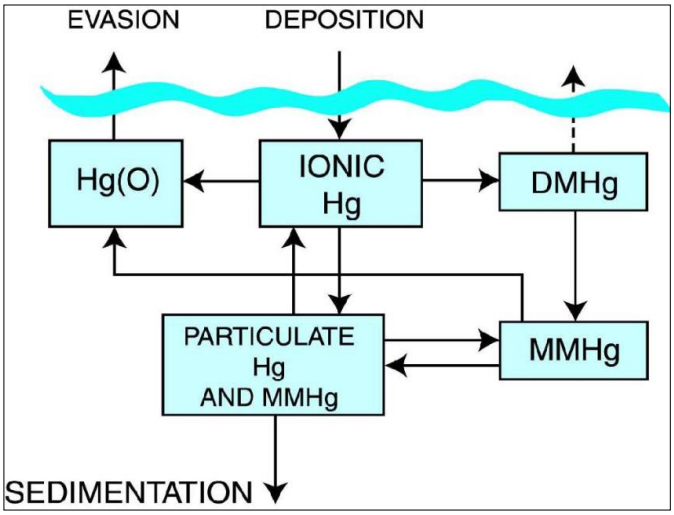

Figure 2.4 **Dynamic interactions between the various mercury species in ocean waters** [Mason & Fitzgerald, 1996]

2.3.4 Soil

Mercury in soil is subjected to a variety of chemical and biological reactions, determining concentrations and composition of species and their complexes. These reactions depend on soil conditions such as redox potential, dissolved and solid phase organic substances, soil pH, mineral content and composition, temperature and moisture content [Revis et al., 1990; Warfvinge, 1997]. Mercury in soil is effectively bound to soil organic matter (SOM) pertaining to both aqueous and solid phases in the upper soil horizons. Away from local pollution sources, metal levels in soils depend on the type of bedrock, soil pH, cation exchange capacity, movement of water, weathering and biological processes. Suggested permissible levels of mercury in soil were found to be 17 mg kg^{-1} on calcareous and 6 mg kg^{-1} on acidic soil [Wang et al., 1982]. The critical value of mercury is 0.5 mg kg^{-1}. High pH values, high lime content, and accumulated salt in soil reduce its uptake by plants [Xuexum and Linhai, 1991]. Considerable amounts of mercury may be added to agricultural land with fertilisers, lime, and manure [Andersson, 1979].

The use of metal contaminated sludge or fertilisers as soil treatments may cause significant contamination of agricultural soils and crops. Important sources of contamination of agricultural soil include the use of organic mercurials as a seed-coat dressing to prevent fungal diseases in seeds, the use of mercury sulphate as a root dip, and the use of phenyl mercuric acetate (PMA) for the treatment of apple scab [Frank et al., 1976a, 1976b]. Organomercury compounds are highly effective in treating apple scab but directly contaminate the soil, as mercury complexes with the soil's organic humic acid component. In general, the effect of the treatment on germination is favourable when recommended dosages are used. The use of mercury compounds as agricultural seed dressing has resulted in mercury accumulation and toxicity in avian and mammalian seed eaters and in avian predators of these herbivores [Fimreite, 1970; Johnels et al., 1979].

Because of the way mercury is transported when emitted into the environment, it has the potential to impact significantly at local, national, regional and at global levels. Interventions steps have been taken by the developed countries of North America and Western Europe and elsewhere to reduce the use and releases of mercury [Kindbom & Munthe, 2007]. These countries have even gone further to develop inventories of mercury releases which are essential for any country to know it status as a mercury emitter. However, because of the unique metallic properties of mercury, it is still widely used as an essential component in the manufacture of electronic and medical equipment. There are several industrial processes whereby mercury is used as a catalyst in the manufacture of drugs and as an extractant in artisanal gold and silver mining. Elaborate studies in Sweden have shown that, by reducing mercury releases, environmental levels of mercury, such as in freshwater fish may be reduced significantly in specific locations within one to two decades [UNEP, 200; 2005]. However, the origins of atmospheric mercury are due to global activities, hence the effort by one nation or regions to reduce mercury emissions may not be enough to reduce atmospheric mercury load.

2.4 THE TOXICOLOGICAL EFFECTS OF MERCURY

As alluded to in previous sections, mercury exists in mainly three speciation products categories viz:

i. Elemental mercury (Hg(0);
ii. Inorganic salts Hg(I) and Hg(II); and

iii. Organomercuric salts, RHgX, where X is a monovalent anion and R an alkyl group.

These species affect humans and animals in different ways and thus the symptoms and signs observed after exposure vary widely. For alkyl compounds, methylmercury is by far of the major concern as its exposure to humans and animals is through diet, especially fish and other seafood [UNEP, 2000]. Elemental mercury is widely used in dental amalgams which is the important source of exposure for the general population. Occupational to elemental mercury is also a possibility to individuals working in the virgin metal processing. Illicit facial skin-lightening creams and soaps containing elemental mercury have been finding their way into the cosmetic markets especially in third world countries. Studies show that the percentages of women using such products regularly in Senegal, Mali, Togo, South Africa and Nigeria are 27%, 25%, 59%, 35%, 77%, respectively [http://www.chem.unep.ch/mercury/awareness_raising_package/C_01-24_BD.pdf].

In 2004, more than one third (38%) of women surveyed in Hong Kong, Korea, Malaysia, the Philippines and Taiwan use skin lightening products, up from 34% in 2002. In a survey carried out in June 2004, 61% of respondents in Hong Kong, Malaysia, the Philippines, South Korea and Taiwan said they felt they looked younger with a fair complexion and this also results in substantial exposures to elemental mercury [http://www.chem.unep.ch/mercury/awareness_raising_package/C_01-24_BD.pdf].

Mercury, in all forms, is a neurotoxin. The health effects associated with exposure to mercury include permanent brain damage, central nervous system disorders, memory loss, heart disease, kidney failure, liver damage, loss of vision, loss of sensation and tremors. The severity of the health effect depends on the level of mercury exposure. In its methylated form, Hg tends to accumulate in marine life eventually bio-accumulates, and biomagnifies up the food chain, reaching levels that can be toxic to humans. Human exposure to elemental mercury occurs primarily from industrial processes and mercury-containing products.

Hence, methylmercury is of greatest concern in terms of human and animal exposure. The adverse impacts of mercury exposure on human health and the environment globally are well documented. All mercury speciation products are highly toxic as they interfere with the development of nervous systems in unborn babies. Methylmercury due to its methyl organic moiety is easily absorbed into the bloodstream and can readily diffuse through the placental barrier and the blood-brain barrier. Foetus and young children are the most vulnerable to

methylmercury exposure due to the sensitivity of their nervous system development. Hence, pregnant women should avoid or minimize fish in their diet, particularly if they are not sure of the quality of the fish in terms of possible mercury contamination. Fish eating birds are equally vulnerable to mercury exposure, hence, the impact of mercury in the environment have a far reaching impacts to human health and the environment [USNRC, 2000].

The first evidence of gross mercury poisoning came into light in Minamata city in Kumamoto prefecture, Japan in 1956 [MEGJ, 2002]. It was caused by the release of methylmercury in the industrial wastewater from the Chisso Corporation's chemical factory. This highly toxic chemical bio-accumulated in shellfish and fish in Minamata Bay which was eaten by the local populace and this resulted to mercury poisoning. Victims were diagnosed as having a degeneration of their nervous systems. Numbness occurred in their limbs and lips. Their speech became slurred, and their vision constricted. After the Minamata incidence, mercury poisoning has been reported in other parts of the world such as Iraq [Bakir et al., 1973]. The awareness of the toxicity of mercury created a global concern. Hence, mercury has been included in a number of the global conventions such as Rotterdam Convention on Persistence Toxic Substances.

2.4.1 Methylmercury toxicity

Among the speciation products of mercury, methylmercury has the largest range of adverse effects on human health and the environment. The adverse neurological effects of methylmercury on the development of nervous system of unborn and newborn babies are well document based on human and animal studies [WHO/IPCS, 1990; NCR, 2000]. Methylmercury which could be in some food products when consumed can rapidly get absorbed into the gastrointestinal tract and rapidly enters the brain. Observations from the victims of Minamata, Japan and Iraq methylmercury poisoning showed that severe effects take place in the development of the brain and the nervous system of the foetus [NRC, 2000].

A series of large epidemiological studies have provided evidence that methylmercury in pregnant women's seafood diet-even at low mercury concentrations (0.1-0.2 ppm) of effects observed in adults)-appears to have subtle, persistent effects on the children's mental development as observed at about the start of the school age (so-called cognitive deficits; [NRC, 2000]. The adverse effects of methylmercury on human health based on the symptoms and health effects as observed in Minamata victims include:

i. Sensory disorders in the four extremities (loss of sensation, in the hands and feet);
ii. Ataxia (difficulty in coordinating movement of hands and feet);

iii. Narrowing of the field of vision;
iv. Hearing impairment;
v. Speech impediments;
vi. Trembling of hands and feet; and
vii. Disorder of the occur movement.

Severe exposure to methylmercury can result in madness, loss of consciousness and may even cause death to victims. Other toxicological effects which may be observed in methylmercury poisoning victims include cancer [IARC, 1993] (neo-plastic effects), renal effects [Tamashiro, 1986], cardiovascular effects [Sorensen, 1999] and genotoxicity [Franchi et al., 1994]. The health impacts caused by methylmercury exposure proved to be lethal and are long term. Hence, governments need to take steps to monitor the generation, use and disposal of this substance as a way minimising the chances of population exposure.

2.4.2 Elemental and inorganic mercury toxicity

The main route of exposure for elemental mercury is by inhalation of the vapours. About 80 % of inhaled vapours are absorbed by the lung tissues. This vapour also easily penetrates the blood-brain barrier and is a well-documented neurotoxin. Intestinal absorption of elemental mercury is low. Elemental mercury can be oxidized in body tissues to the inorganic divalent form [WHO (WHO/IPCS, 1990; IARC, 1993; US EPA, 1997; 200; Pirrone, et al., 2001].

Neurological and behavioural disorders in humans have been observed following inhalation of elemental mercury vapour. Specific symptoms include tremors, emotional lability, insomnia, memory loss, neuromuscular changes, and headaches. In addition, there are effects on the kidney and thyroid. High exposures have also resulted in death. With regard to carcinogenicity, the overall evaluation, according to IARC (1993), is that metallic mercury and inorganic mercury compounds are not classifiable as to carcinogenicity to humans. A critical effect on which risk assessment could be based is, therefore, the neurotoxic effects, for example, the induction of tremor. The effects on the kidneys (the renal tubule) should also be considered; they are the key endpoint in exposure to inorganic mercury compounds. The effect may well be reversible, but as the exposure to the general population tends to be continuous, the effect may still be relevant.

2.4.3 Mercury exposures and risk evaluation for humans

As mentioned earlier, the general population is primarily exposed to methylmercury through diet (especially fish) and to elemental mercury vapours due to dental amalgams [USA Public

Health Service, 1993]. Depending on local mercury pollution load, substantial additional contributions to the intake of total mercury can occur through air and water. Also, personal use of skin-lightening creams and soaps, mercury use for religious, cultural and ritualistic purposes, the presence of mercury in some traditional medicines (such as certain traditional Asian remedies) and mercury in the home or working environment can result in substantial elevations of human mercury exposure. For example, elevated air levels in homes have resulted from mercury spills from some old gas meters and other types of spills. Also, elevated mercury levels in the working environment have been reported in chlor-alkali plants, mercury mines, thermometer factories, refineries and dental clinics, as well as in mining and manufacturing of gold extracted with mercury.

Additional exposures can result from the use of Thimerosal/Thiomersal (ethylmercury thiosalicylate) as a preservative in some vaccines and other pharmaceuticals. The relative impacts of mercury from local pollution, occupational exposure, certain cultural and ritualistic practices and some traditional medicines may today vary considerably between countries and regions in the world, and are significant in some regions. In South Africa, the use of skin-lightening creams usually banned by Department of Health is common practice among women. These skin-lightening creams are usually marketed by street vendors and informal shops such as flea-markets.

2.5 ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

The most significant factor of mercury impacts to the environment is its ability to bio-accumulate in organisms and up along the food chain. Although all forms of mercury can bio-accumulate to some degree, methylmercury is absorbed and accumulates to a greater extent than other forms. Inorganic mercury can also be absorbed, but is generally taken up at a slower rate and with lower efficiency than is methylmercury. The bio-magnification of methylmercury has most significant influence on animals and humans. Fish appear to bind methylmercury strongly, nearly 100% of mercury that bio-accumulates in predator fish is methylmercury. Most of the methylmercury in fish tissue is covalently bound to protein sulfhydryl groups. This covalent bond is strong and non reversible causing a long half-life for elimination. As a consequence, there is a selective enrichment of methylmercury (relative to inorganic mercury) from one trophic level to the next higher trophic level [Andren and Nriagu, 1979].

2.5.1 Levels in fish

In contrast to other mercury compounds the elimination of methylmercury from fish is very slow. Given steady environmental concentrations, mercury concentrations in individuals of a given fish species tend to increase with age as a result of the slow elimination of methylmercury and increased intake due to changes in trophic position that often occur as fish grow to larger sizes (i.e., the increased fish-eating and the consumption of larger prey items). Therefore, older fish typically have higher mercury concentrations in the tissues than younger fish of the same species. The mercury concentrations are lowest in the smaller, non-predatory fish and can increase many-fold on the way up the food chain. Apart from the concentration in food, other factors affect the bioaccumulation of mercury [UNEP, 2002; US-EPA, 2001a; 2001b].

Data on mercury concentrations in fish have been submitted from a number of nations and international organisations. Additionally, many investigations of mercury levels in fish are reported in the literature. The mercury concentrations in various fish species are generally from about 0.05-1.4 mg of mercury per kilogram of fish tissue (mg/kg) depending on factors such as pH and redox potential of the water, and species, age and size of the fish [UNEP, 2002; US-EPA, 2001a; 2001b]. For example, in a study of a representative group of about 1700 women in the USA (aged 16-49 years) for 1999-2000, about 8 % of the women had mercury concentrations in their blood and hair exceeding the levels corresponding to the USEPA's reference dose (an estimate of a safe dose) [US-EPA, 2001a; 2001b].

Since mercury biomagnifies in the aquatic food web, fish higher on the food chain (or of higher trophic level) tend to have higher levels of mercury. Hence, large predatory fish, such as king mackeral, pike, shark, swordfish, walleye, barracuda, large tuna (as opposed to the small tuna usually used for canned tuna), scabbard and marlin, as well as seals and toothed whales, contain the highest concentrations. The available data indicate that mercury is present all over the globe (especially in fish) in concentrations that adversely affect human beings and wildlife. These levels have led to consumption advisories (for fish, and sometimes marine mammals) in a number of countries, warning people, especially sensitive subgroups (such as pregnant women and young children), to limit or avoid consumption of certain types of fish from various water bodies. Moderate consumption of fish (with low mercury levels) is not likely to result in exposures of concern. However, people who consume higher amounts of contaminated fish or marine mammals may be highly exposed to mercury and are therefore at risk (UNEP, 2002; US-EPA, 2001a; 2001b).

2.5.2 Mammalian predators

At the top levels of the aquatic food web are fish-eating species, such as humans, seabirds, seals and otters. The larger wildlife species (such as eagles, seals) prey on fish that are also predators, such as trout and salmon, whereas smaller fish-eating wildlife such as kingfishers tends to feed on the smaller forage fish. In a study of fur-bearing animals in Wisconsin, the species with the highest tissue levels of mercury were otter and mink, which are top mammalian predators in the aquatic food chain. Top avian predators of aquatic food chains include raptors such as the osprey and bald eagle. Thus, mercury is transferred and accumulated through several food web levels [US EPA, 1997]. Aquatic food webs tend to have more levels than terrestrial webs, where wildlife predators rarely feed on each other, and therefore, the aquatic bio-magnification typically reaches higher values.

It has been reported that mercury was responsible for the reduction of micro-biological activity vital to the terrestrial food chain in soils over large parts of Europe – and potentially in many other places in the world with similar soil characteristics. Preliminary critical limits to prevent ecological effects due to mercury in organic soils have been set at 0.07-0.3 mg/kg for the total mercury content in soil [Rundgren, 1992]. The same food web characteristics and a similar dependence on a mercury contaminated food source are found in specific ecosystems and human communities in many countries of the world, particularly in places where a fish diet is predominant. Rising water levels associated with global climate change may also have implications for the methylation of mercury and its accumulation in fish. For example, there are indications of increased formation of methylmercury in small, warm lakes and in many newly flooded areas [Anderssen and Nriagu, 1979].

2.6 GLOBAL MERCURY EMISSION AND CONSUMPTION

Global mercury levels have been on the increase since the industrial revolution which started in the Western countries in the 18th century [Pacyna et al., 2006]. The global consumption of mercury from various UNEP regions is shown in Figure 2.5. The emission from sub-Saharan Africa, particularly South Africa has artisanal gold mining as the major consumption of mercury imported into the region. However, South Africa's large gold producers use cyanidation process instead the mercury amalgam extraction process [Pacyna et al., 2006].

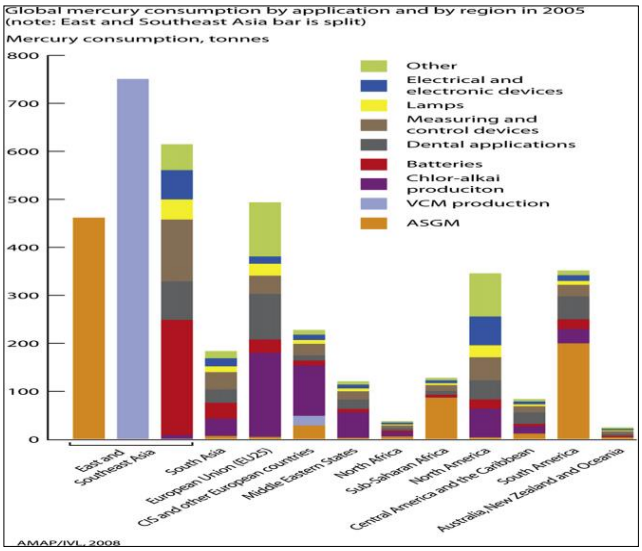

Figure 2.5 Global Hg consumption in the year 2005 (3798 tonnes) by application and by region [AMAP/UNEP, 2008]

Pig-Iron & Steel is one of the major virgin metal processing industries. Most of the ore where iron is extracted contain traces of mercury. However, because of the large quantities of ore extracted each year, the amount of mercury emitted into the atmosphere from these sources is significant. The overall mercury global emission was estimated to be 43 Mg y^{-1} [UNEP/AMAP, 2008]. According to UNEP/AMAP report 2008, in 2005, South Africa was contributed 3% of total global emission to the atmosphere from 43 Mg y^{-1} coming from pig-iron and steel industries. The world's major producers of iron and steel are shown in Figure 2.6 and their proportional contribution to mercury emissions.

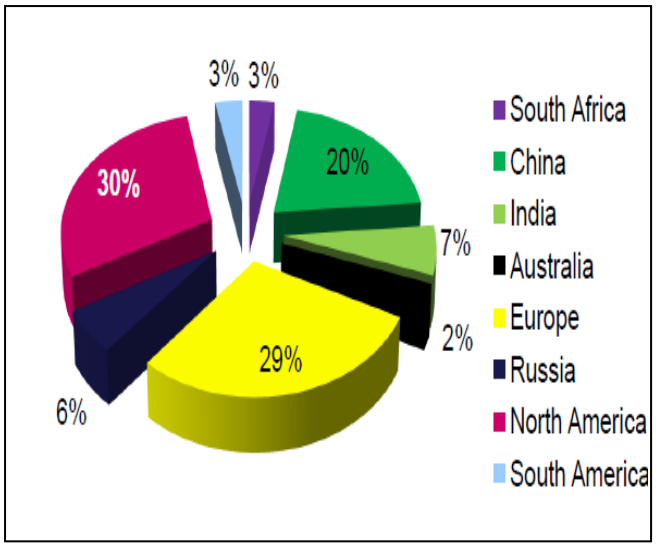

Figure 2.6 Global emissions from Pig-Iron and Steel industries in 2005 [UNEP/AMAP, 2008]

The contribution of global emission of mercury from non-ferrous metal extraction is shown in Figure 2.7. The proportion produced by South Africa was insignificant.

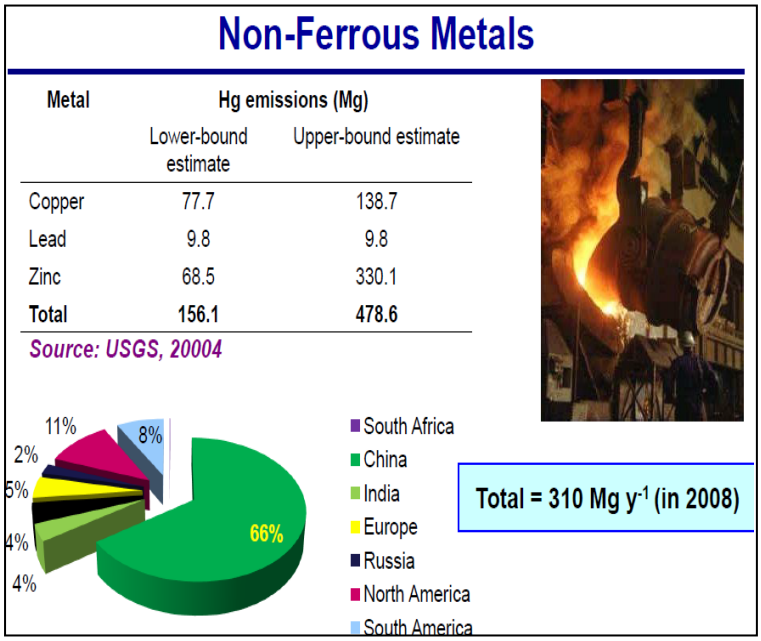

Figure 2.7 Global mercury emissions into the atmosphere in 2005
[UNEP/AMAP, 2008]

Waste incineration has been identified as one of the major contributor to global mercury. Medical waste is generally a combination of spent medical equipment and sanitary materials which are microbial active. Spent apparatus such as thermometers, pressure gauges, manometers and others contain mercury which is then lost to the atmosphere during incineration. Incineration of waste at global level has been estimated to have produced 187 M g y^{-1} [UNEP, 2008]. Figure 2.8 shows the emission percent of the major waste incinerators.

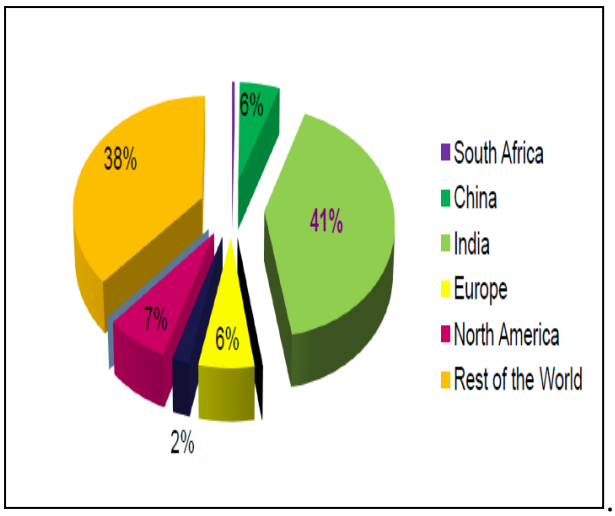

Figure 2.8 Global emissions of mercury from waste incineration [UNEP/AMAP, 2008]

The overall anthropogenic mercury emissions globally considering all possible sources which could be estimated using the toolkit [UNEP, 2005] expressed as a percentage are shown in Figure 2.9 and the emissions from various countries are shown in Figure 2.10.

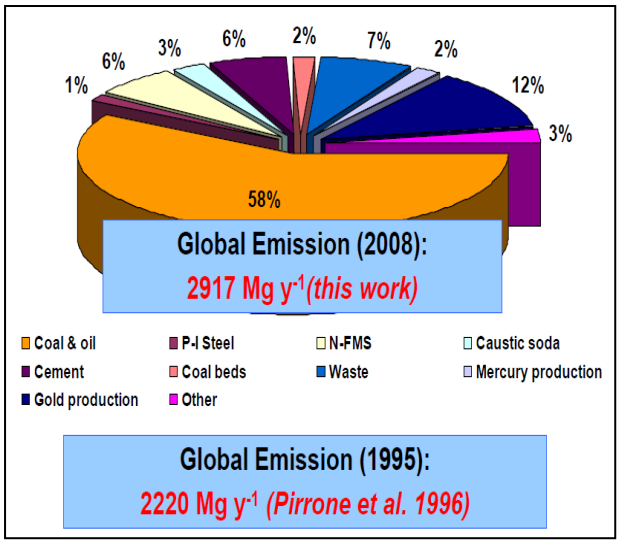

Figure 2.9 Global Anthropogenic emissions [UNEP, 2008]

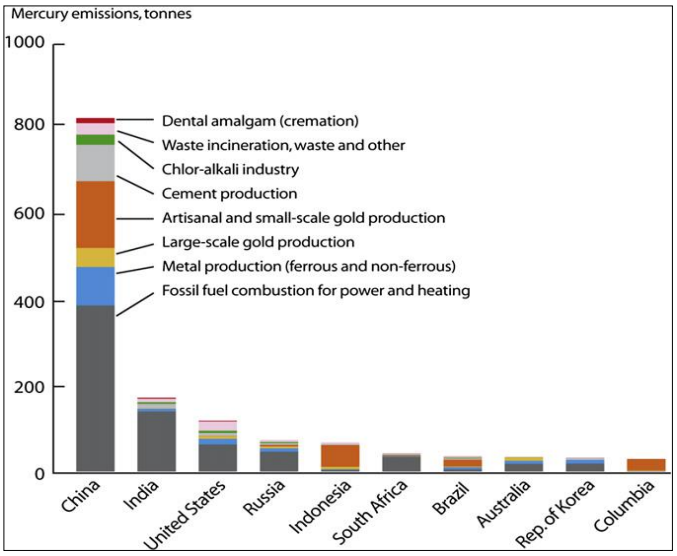

Figure 2.10 Emissions of mercury to air in 2005 from various anthropogenic sectors in the ten largest emitting countries [UNEP/AMAP, 2008]

The quantities of mercury used by different sectors which require mercury for the raw materials and or operations are shown in Figure 2.11. Products such as batteries, lighting, electrical and electronic equipment and dental amalgams are commonly imported into South Africa. There are no regulations covering the importation or disposal of spent material from these products. Hence, mercury is imported indirectly into South Africa through these products.

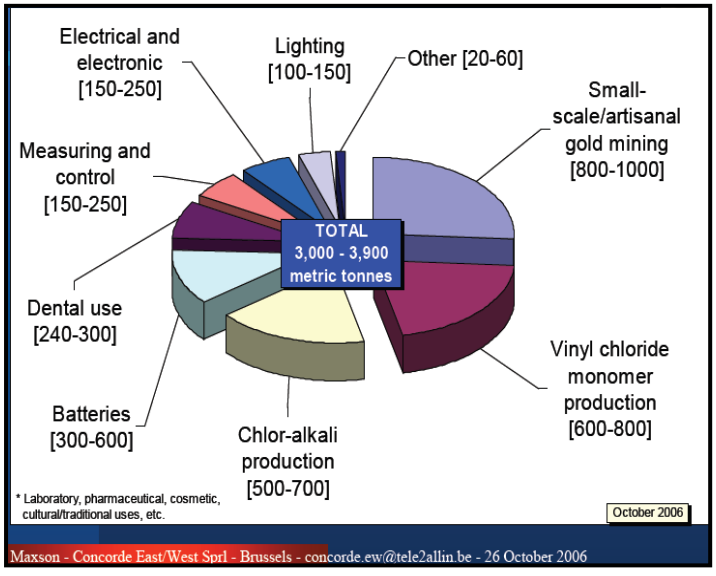

Figure 2.11 Major global mercury uses – 2005 [UNEP/AMAP, 2008]

The contribution of mercury emissions by the burning of fossil fuel on a global scale is shown in Figure 2.12. South Africa contributes 2% according to this estimate. However,

significant amount of coal is burnt outside the establishment of Eskom and the emission from such coal was not factored in.

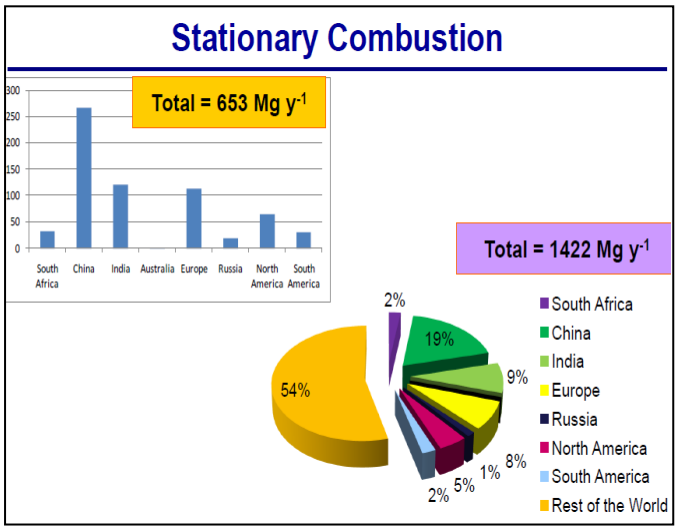

Figure 2.12 Proportion of South Africa in stationary combustion of fossil fuels [UNEP/AMAP, 2008]

Cement production is one of the identified processes which contribute to global mercury emission. The global emission of mercury from cement production is shown in Figure 2.13.

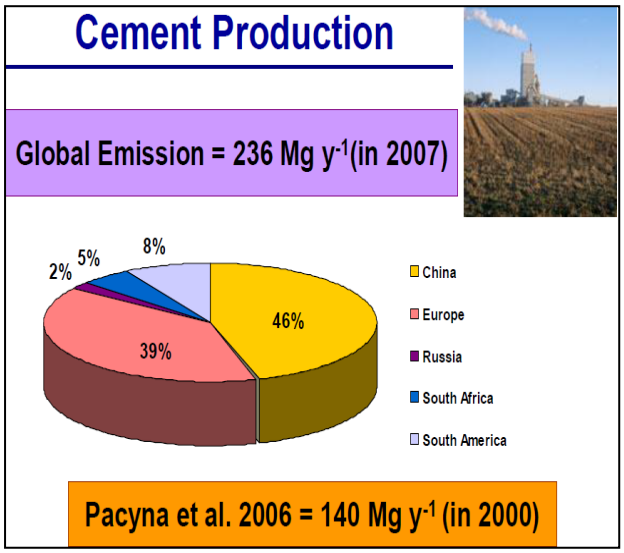

Figure 2.13 Global emissions from Cement production in 2007 [UNEP/AMAP, 2008].

Figure 2.14 contains estimates of global mercury emissions from natural and anthropogenic sources. The cycling of mercury in the environment is also illustrated.

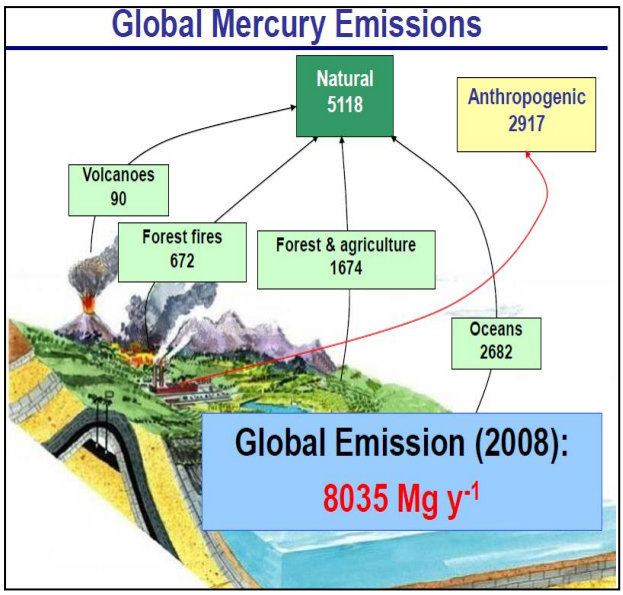

Figure 2.14 Global mercury emissions as of 2008 [UNEP/AMAP, 2008].

Tables 2-1 to 2-6 show the consumption and emission of mercury from different industrial applications and sources respectively.

Table 2.1 Global Mercury Consumption 1990-2005 [UNEP/AMAP, 2008]

	VCM and acetaldehyde processes				Mercury cell chlor-alkali process*			
Region	1990	1995	2000	2005	1990	1995	2000	2005
East and Southeast Asia	200	300	500	750	25	20	10	6
South Asia	0	0	0	0	250	150	75	38
European Union (25 countries)	30	10	0	0	750	450	250	178
CIS and other European countries	40	30	30	20	300	200	150	105
Middle Eastern States	0	0	0	0	70	80	75	53
North Africa	0	0	0	0	50	45	25	9
Sub-Saharan Africa	0	0	0	0	3	3	2	1
North America (excl. Mexico)	15	0	0	0	280	190	110	75
Central America and the Caribbean	0	0	0	0	30	25	15	10
South America	0	0	0	0	100	80	50	30
Australia New Zealand and Oceania	0	0	0	0	6	5	0	0
TOTAL	285	340	530	770	1864	1248	762	504

* Although an intentional-use, emissions from this sector are estimated as part of the by-product inventory data compilations

Table 2.2 Global Mercury Consumption 1990-2005

	Measuring devices				Electrical and electronic switches and relays			
Region	1990	1995	2000	2005	1990	1995	**2000**	***2005***
East and Southeast Asia	140	160	150	129	60	70	**70**	***61***
South Asia	50	60	55	36	25	30	**25**	***17***
European Union (25 countries)	130	80	50	18	80	60	**20**	***4***
CIS and other European countries	40	40	30	24	15	18	**14**	***11***
Middle Eastern States	25	25	20	17	11	13	**10**	***8***
North Africa	7	8	7	6	3	4	**4**	***4***
Sub-Saharan Africa	15	15	14	12	7	8	**7**	***6***
North America (excl. Mexico)	125	72	48	45	77	88	**72**	***60***
Central America and the Caribbean	25	25	18	13	11	12	**9**	***6***
South America	40	40	30	24	15	18	**14**	***12***
Australia New Zealand and Oceania	7	7	6	6	5	4	**4**	***3***
TOTAL	604	532	428	328	309	325	**249**	***189***

Table 2.3 Global Mercury Consumption 1990-2005 [AMAP 2010]

	Batteries				Lamps			
Region	1990	1995	2000	2005	1990	1995	2000	2005
East and Southeast Asia	350	400	350	240	35	40	42	42
South Asia	150	130	90	33	9	10	11	12
European Union (25 countries)	400	200	60	28	40	40	23	20
CIS and other European countries	100	90	60	10	7	7	8	8
Middle Eastern States	60	50	30	7	5	5	6	6
North Africa	20	13	7	3	1	1	2	2
Sub-Saharan Africa	40	30	15	5	3	3	4	4
North America (excl. Mexico)	450	110	30	14	41	45	20	17
Central America and the Caribbean	60	50	30	5	3	3	4	4
South America	80	80	60	20	6	7	8	8
Australia New Zealand and Oceania	10	6	4	3	2	2	2	2
TOTAL	1720	1159	736	365	152	163	130	122

Table 2.4 Global Mercury Consumption 1990-2005: Artisanal and small-scale gold mining [AMAP, 2010]

Region	1990	1995	2000	2005
	300	360	450	516
East and Southeast Asia				
South Asia	2	4	6	8
European Union (25 countries)	3	3	4	5
CIS and other European countries	25	28	31	33
Middle Eastern States	1	1	2	2
North Africa	3	4	5	6
Sub-Saharan Africa	50	60	80	100
North America (excl. Mexico)	20	12	6	3
Central America and the Caribbean	10	14	18	23
South America	180	160	190	227
Australia New Zealand and Oceania	2	2	3	3
TOTAL	596	648	795	925

Table 2.5 Global Mercury Consumption 1990-2005: Dental amalgam [AMAP, 2010]

Region	1990	1995	2000	2005
East and Southeast Asia	55	60	65	70
South Asia	13	15	20	25
European Union (25 countries)	90	105	105	95
CIS and other European countries	20	20	15	11
Middle Eastern States	18	20	20	17
North Africa	3	4	5	5
Sub-Saharan Africa	4	5	6	6
North America (excl. Mexico)	55	48	38	36
Central America and the Caribbean	14	16	18	18
South America	25	30	35	35
Australia New Zealand and Oceania	5	5	4	4
TOTAL	302	328	331	321

2.7 MERCURY CONSUMPTIONS, EMISSIONS AND LEVELS IN SOUTH AFRICA

In South Africa, potential anthropogenic sources of Hg include coal combustion, crude oil, ferrous and non-ferrous metals production, artisanal gold mining and consumer products. These sources as well as the levels of Hg in environmental media are shown in Table 2.6.

Table 2.6 Emission factors for mercury, used to estimate the 2005 emissions [Pacyna et al., 2010]

Category	Unit	Emission factor
Coal combustion	g tonne^{-1} coal	
Power plants		0.1–0.3
Residential and commercial boilers		0.3
Oil combustion	g tonne^{-1} oil	0.001
Non-ferrous metal production		
Copper smelters	g tonne^{-1} Cu produced	5.0
Lead smelters	g tonne^{-1} Pb produced	3.0
Zinc smelters	g tonne^{-1} Zn produced	7.0
Cement production	g tonne^{-1} cement	0.1
Pig iron & steel production	g tonne^{-1} steel	0.04
Waste incineration	g tonne^{-1} wastes	
Municipal wastes		1.0
Sewage sludge wastes		5.0
Mercury production (primary)	kg tonne^{-1} ore mined	0.2
Gold production (large-scale)	g g^{-1} gold mined	0.025–0.027
Caustic soda production	g tonne^{-1} produced	2.5

2.7.1 Coal combustion in power stations

The potential anthropogenic sources of Hg in South Africa include coal combustion, ferrous and non-ferrous metals production, artisanal gold mining and from consumer products. According to NERSA, (2005), approximately 93% of South Africa's electricity is produced from coal. This is of concern since coal contains 3-5 mg of Hg which is released during combustion. The amounts of Hg released from coal power stations in South Africa are given in Figure 2.15

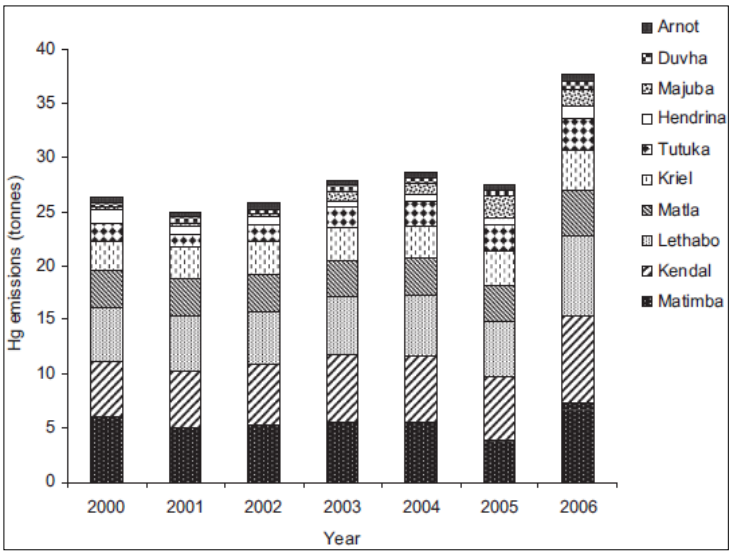

Figure 2.15 Atmospheric Hg emissions estimated for coal-fired power plants in South Africa during 2000-2006 [Masekoameng et al, 2009]

2.7.2 Coal combustion in coal gasification process

South Africa uses a significant amount of coal as a feedstock for the production of viable alternative fuels and chemicals. A large facility located near Secunda in the Mpumalanga Province produces about 30% of South Africa's liquid fuels requirements and amounts to 180 000 barrels of fuels and chemicals per day. In 2004, the total coal consumption for the production of alternative fuels and chemicals in South Africa amounted to about 41 Tg [DME, 2008]. About 70% of coal is used for the gasification process, while the remaining 30% is combusted to produce process steam and electricity [Wagner et al., 2008]. During this process, Hg is released into the environment and it has been estimated that 1.68 Mg Hg was emitted from coal based petrochemical process in 2004 [Van Dyk et al., 2006]. This amount of Hg emitted (1.68 Mg in 2004) is comparable to the estimate of Hg emissions (1.25 Mg per year) reported by Wagner et al. (2008).

2.7.3 Crude oil refining

The presence of Hg is not limited to coal, but also to crude oil which contains Hg at varying degrees, depending on the origin [Pacyna et al., 2006b]. Since South Africa imports more than 80% of its crude oil requirements, Hg emissions from this source are considered not to vary significantly. A total of 0.45 Mg Hg is estimated to have been released during crude oil refining and minerals processing in South Africa in 2004. Of this, crude oil refining is

estimated to emit about 0.16 Mg Hg, while coal combustion during minerals processing accounts for the remaining fraction of 287 kg Hg.

2.7.4 Cement production

Coal for firing cement kilns and producing clinker are the major sources of Hg in cement production since information on the use of waste as source fuel is not available. Using the annual cement production data, the annual coal consumption was estimated, considering that approximately 15 Mg of coal is burned in order to produce 100 Mg of cement clinker [DME, 2005]. Using appropriate emission reduction factors, approximately 3.77 Mg of Hg was released to the South African environment during this period in 2005. It has been reported that Hg emissions for cement production in Africa were 5.3 Mg in 2000 [Pacyna et al. 2006]. Cement production is most likely to increase in future as new infrastructure is required to support the growing South African economy. Thus, Hg emissions for South Africa and the continent will increase.

2.7.5 Ferrous metal (iron and steel) production

In addition to coal combustion, crude oil processing, cement production, the ferrous and non-ferrous metal industries [Hylander and Meili, 2005; ECDGE, 2006] are also potential Hg emissions sources, particularly during the processing of new iron and steel ores, melting of scrap iron and steel as well as during gold, lead, copper and zinc production. Compared to other sectors, a small amount of coal is used for iron and steel industry in South Africa. The major source of Hg emissions from this activity is from coke production [Pacyna et al., 2006]. Using appropriate emission reduction factors, the combustion of approximately 7.62 Tg of coal for coke production and scrap smelting in the iron and steel industry during 2004 is estimated to have released about 1 Mg of Hg to the environment [DME, 2008]. About one-third of the Hg emitted is from coke production, with the remaining two-thirds attributed to scrap smelting. South Africa is the world's leading producer of primary metals, ranking first in gold, lead and copper production, and 22nd in Zn production [DME, 2006]. Therefore, Hg emissions from these sources can be substantial and will increase in future. Figure 2.16 shows the total mercury emissions in South Africa during the period 2000-2006.

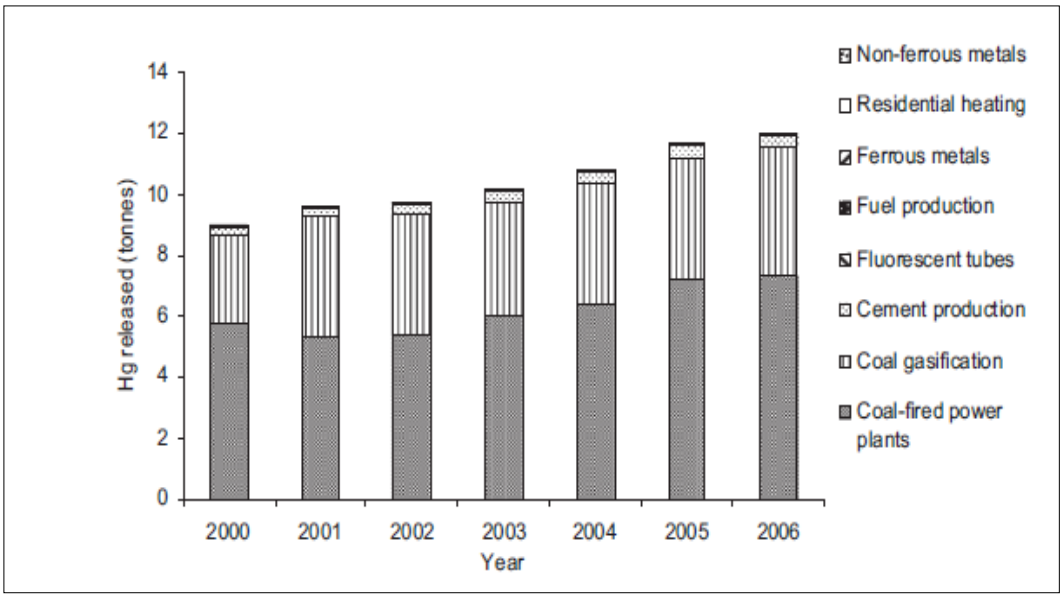

Figure 2.16 The total atmospheric Hg emissions estimated for different activities in South Africa during 2000-2006 [Masekoameng et al, 2009]

2.7.6 Coal combustion for residential heating

Coal is generally regarded as inexpensive form of energy and, therefore, it is used for heating and cooking in many low-income households, particularly during winter [Engelbrecht et al., 2002]. The use of coal for this purpose contributes to Hg emissions to the environment. It has been estimated that about 0.75 Mg Hg may have been emitted to the atmosphere in 2004. About 90% of Hg emitted from this source is gaseous Hg^0 and Hg^2, and the users of coal for this purpose have been estimated to be exposed to 0.66 Mg of Hg during heating or cooking in their homes [Pacyna et al., 2003].

2.7.7 Production of primary metals (non-ferrous)

Mercury emissions from different primary metal ores vary according to the technology used to process the ore, the content of Hg in the ore and the type of emission control devices employed during processing. Generally, an estimated average of 0.64 Mg Hg was emitted during non-ferrous metal production in 2004. The order of Hg emissions was estimated from the following productions: gold>copper>zinc>lead. In South Africa, the Witwatersrand ores reportedly have gold (Au) and mercury (Hg) concentrations ranging between 80.9–92.9 wt.%, and 0.6–5.8 wt.%, respectively [Frimmel and Gartz, 1997]. Gold from these ores was traditionally extracted using mercury-gold amalgam method, until it was replaced with a

cyanide-based process in 1890 when mining operations reached greater depths [Naickera et al., 2003]. Earlier, Schröder et al. (1982) estimated that mercury (Hg) emissions from the gold-mining industry in South Africa, was less than 0.2 Mg per year. Others have suggested a 6% Hg loss to the atmosphere during gold recovery [Jones and Miller, 2005]. The Hg emission estimates from this industry, which uses cyanidation and not Hg amalgamation to extract gold from the ore, are based on limited information and require Hg emission measurements at the source(s). The production processes for other primary (virgin) metals were estimated to emit a total of approximately 0.32 Mg Hg per year from the production of 0.240 Tg Zn, 0.346 Tg Cu and 0.042 Tg Pb [DME, 2006].

2.7.8 Artisanal and small-scale gold mining activities

It is a known fact that artisanal gold miners operate in some provinces, particularly Mpumalanga and Limpopo Provinces in South Africa [CoMSA, 2006]. However, the extent to which artisanal and small-scale gold mining activities contribute to Hg emissions in South Africa is unknown. This activity is illegal in South Africa, and it has been estimated that between 8 000 to 20 000 small-scale gold miners are operating in the country. For South Africa, the Hg emissions from these activities are likely to be lower, except where Hg-amalgam method is still being practised.

2.7.9 Mercury in other environmental media

2.7.9.1 General waste

Hg-containing products such as batteries, lamps, and electric switches are most often discarded as general waste to landfills or incinerated. Therefore, waste deposition, landfilling and incineration are important sources of Hg emissions to the environment. Although the Hg content of municipal waste streams is thought to be decreasing in the developed countries, little is known about the situation for developing countries [Van Veizen et al., 2002]. In South Africa, about 95% of waste was disposed of in landfills prior to 2000 [DWAF, 1998]. Landfills generally release landfill gas that contains varying quantities of heavy metals, including Hg [Lindberg et al., 2005 ; de la Rosa, 2006 ; Nguyen et al., 2007; Ilgen et al., 2007]. Total Hg levels in landfill gas have not yet been measured in South Africa.

2.7.9.2 Medical waste

Medical waste is reported to be the fourth largest contributor of Hg to the global environment [Zimmer and McKinley, 2008]. South Africa's National Waste Management Strategy requires medical waste to be sorted prior to disposal or incineration; and that the disposal of potentially hazardous medical waste to landfills should be avoided (DEAT, 1999). The authorised medical waste treatment capacity in South Africa was approximately 0.028 Tg of medical waste in 2005 [DEAT, 2006b]. Using the amount of medical waste incinerated in 2004, and using the relevant emission factors, approximately 0.70 kg of Hg is estimated to have been released to the South African environment. Poor on-site incinerators in public hospitals or clinics, if present; and the burning or illegal dumping of waste in residential areas will likely increase Hg emissions to the South African environment.

2.7.9.3 Consumer products

Currently, consumer products such as Hg-containing fluorescent light sources (double end tubes) and compact fluorescent lamps (CFLs) are not separated from general waste and are assumed to be land filled in South Africa. A total of 1,829,066 fluorescent light tubes (double end) were imported into South Africa during 2004 [DTI, 2004]; assuming an average Hg content of 10 mg per item [NEWMOA, 2006], this yields an estimated 0.018 Mg Hg produced by this source. It has been estimated that approximately 0.46 kg Hg (0.0005 Mg Hg) may have been released from this source in 2004. A survey was conducted in three provinces in South Africa to identify skin lightening creams and soaps. The results indicated that there are a range of skin lightening creams and soaps sold in South Africa. It was, however, difficult to quantify the amount available since they are sold illegally and to confirm whether the identified creams and soaps contain Hg and not other skin lightening substances such as hydroquinone or some steroids.

2.7.9.4 Mercury in hair

Hair locks of at least 100 strands of hair from 86 study participants were cut from the root of the occipital region of the scalp with stainless-steel scissors and stored at room temperature until analysis. The concentrations of mercury in the 86 hair samples ranged from <0.1 to 54.8 mg g^{-1}. Mercury concentrations in 17% of samples exceeded the World Health Organisation (WHO) guideline level of 7 mg g^{-1}. The concentrations of mercury in the hair of two study participants exceeded 50 mg g^{-1}, which is the WHO guideline level for methyl-mercury

intoxication. The difference in median hair total mercury levels between the three villages, Mshazi, Nqetho and Madimeni in KwaZulu-Natal was significant. The ratio of methyl-mercury to total mercury in nine participants selected from the three villages was 75–100%, suggesting mercury contamination through diet. Bivariate analysis showed that vegetable consumption, fish consumption and low levels of education were risk factors for elevated hair mercury levels in the study sample.

2.7.9.5 Mercury in fish

Ten fish (catfish and carp species) of varying sizes and lengths (weight range: 0.08–5.5 kg; length range: 29–68 cm), were captured from the Inanda Dam by a local fisherman using fishing nets. Cyprinus Carpio Linnaeus, the most common species of Carp in the region, is omnivorous, and thus consumes a wide range of plants and animal matter, mainly by grubbing in sediment. The total mercury concentration level in the ten fish samples ranged from 0.26-1.78 mg g^{-1}, with the mean and median equalling 0.67 and 0.55 mg g^{-1}, respectively. Furthermore, three fish samples were also analysed for methylmercury content and the results ranged from 0.83-1.77 mg g^{-1}, with the mean and median equalling 1.25 and 1.15 mg g^{-1}, respectively [Papu-Zamxaka et al, 2009]. About 50% of the fish samples were found to have mercury concentrations that exceeded the World Health Organization (WHO) guideline level of 0.5 mg g^{-1}.

2.7.9.6 Mercury in sediment

About 37 sediment samples were collected along a path from the source of the Mngceweni River, along the uMgeni River and Inanda Dam. Sample collection was commenced at the Inanda Dam and continued in an upstream direction in order to minimise disturbance of the sediment bed, and prevent sample contamination. A small stainless-steel spade was used to collect each sample (500 g) into a plastic sampling bag (acid-cleaned and dried) and sealed. Immediately after sample collection, labels, with the sample code and date of collection written using a waterproof pen, were firmly attached to the plastic sample bags. The bagged samples were placed in plastic storage crates and transported to the laboratory. The concentrations of mercury in the sediment samples ranged from <0.1-897.5 mg g^{-1}, with the mean and median concentrations respectively equalling 52.83 and 0.09 mg g^{-1}. Twenty-two percent of the sediment samples had mercury concentrations that exceeded the Severe Effect Level (SEL) of 2 mg g^{-1} adopted by the Ontario Ministry of the Environment, while 20

samples contained mercury concentrations which exceeded 50 mg g^{-1} (the level used in The Netherlands to designate soil or sediment as chemical waste) in 19% of the sediment samples. Sixty-two percent of the thirteen Mngceweni River sediment samples exceeded mercury concentration levels of 2 mg g^{-1} and 10 mg g^{-1}, respectively, compared with none in either the uMgeni River or the Inanda Dam samples. The concentration of 10 mg g^{-1} in sediments is a level at which remedial action is required. Fifty-four percent of the Mngceweni River sediment samples exceeded 50 mg g^{-1} [Fatoki and Awofolu, 2003].

2.7.9.8 Mercury in surface water

The levels of Hg detected in water samples ranged from trace to 0.003 ± 0.001 mg/l in the Buffalo River, were trace in the Keiskamma and Umtata Rivers and varied between trace and 0.003 ± 0.001 mg/l in the Tyume River [Fatoki and Awofolu, 2003]. The levels of Hg detected in water samples from the dams varied from trace to 0.004 ± 0.001 mg/l in the Sandile Dam and were trace in the Umtata Dam. The South African guideline for Hg in water for domestic use, use of ecosystem and aquaculture use is 0.001 mg/l [DWAF, 1996a, b&d]. Based on this guideline, the levels of Hg are considered generally low in the rivers and dams and would not pose a problem in water for the above uses.

2.7.9.9 Monitoring Hg emissions in South Africa

Atmospheric monitoring of Hg concentrations in South Africa to date has mostly been made at Cape Point's Global Atmospheric Watch (GAW) Station in the Western Cape. There have been measurements of total gaseous Hg since 1995 at the Cape Point GAW Station [Baker et al., 2002; Slemr et al., 2006] and these have recently been supplemented with additional atmospheric Hg sampling. The average yearly concentrations of total gaseous Hg in the atmosphere between 1995 and 2004 ranged between 1-1.5 ng m^{-3}, and this range is similar to those measured on board ship in the South Atlantic, and only slightly elevated compared to those measured at Neumayer on the Antarctic Peninsula [Baker et al., 2002 ; Slemr et al., 2006]. These concentrations, therefore, represent the regional background signal and do not show enhanced concentrations that are predicted by modelling studies that use the Pacyna et al. (2006) emission scenarios [Selin et al., 2007; Strode et al., 2007]. Atmospheric Hg studies have been conducted at the CSIR in Pretoria in the Gauteng Province [Trüe et al., 2010]. While this study is one of the several studies to be conducted in Pretoria, there is evidence that the concentrations of total gaseous Hg are occasionally elevated (~2 ng m^{-3}), especially

during the day, and there is some indication of some variation (lower concentrations at night). Such concentrations and variations may reflect local and regional sources in the vicinity, and are not surprising given the high level of urban and industrial activity in the Gauteng Province.

More recently, rainfall collections have been made (weekly bulk phase) at Cape Point's GAW station. Because the collector is continuously open, the device collects both wet deposition and some fraction of the dry deposition. The average Hg concentration in rainfall for seven weeks of weekly rain sampling (July and August 2007) was 6.3 ± 3.0 ng L^{-1}. While this preliminary data should not be over-extrapolated, they are not substantially elevated for what may be expected from a coastal location on the South Atlantic Ocean, and are consistent with the air measurements. Scaling this data to a yearly flux suggests that wet deposition could amount to around 3 m g m^{-2} yr^{-1}, a value that is consistent with the estimates of Mason et al. (1994) for the remote southern Hemisphere, and lower than that of similar locations in the North Atlantic Bermuda, for example, is 8 m g m^{-2} yr^{-1}, or most locations on the east coast of the USA [Mason et al., 2000]. Overall, the Hg concentrations in precipitation and atmospheric air samples measured at Cape Point are inconsistent with the predictions of modelling studies that use the Pacyna et al. (2006) emission scenarios [Selin et al., 2007; Strode et al., 2007]. Weekly rain collections in Pretoria in Gauteng Province are also now underway and the preliminary results from these collections (August 2007 to February 2008) suggest higher concentrations (21 ±18 ng L^{-1}; volume weighted mean concentration 16.5 ng L^{-1}). The associated annual flux is 8.8 m g m^{-2} yr^{-1} (for an annual rainfall of approximately 0.5 m yr^{-1}). Thus, there is a contrast in Hg concentrations and fluxes between Pretoria and Cape Point, which reinforces the notion of more extensive anthropogenic emissions in the northern-most provinces of South Africa. The current data support the re-evaluation that while there are substantial Hg emissions for South Africa, their extent is lower than previously thought. True et al (2010), employed Carulite C300 sorbent tubes to ambient air to absorb mercury for a period of five months in Pretoria area. The mean mercury concentration during four months of measurements with the Opsis analyser was 1.7±1.9 ng m^{-3} mercury, while 1.6±0.4 ng m^{-3} was determined by sorbent tube/CVAAS analysis.

2.8 INCIDENCE OF MERCURY CONTAMINATION IN SOUTH AFRICA

In the eastern province of KwaZulu-Natal, South Africa, Thor Chemicals, Inc. of Great Britain (Thor) received shipments of mercury wastes from the United States and other countries as part of the company's mercury recycling programme. As one of the few facilities in the world to form a large-scale mercury reclaiming process, In 1988 mercury levels in the Umgeni River, 15 km downstream where Thor's facility was located, were reported to be 1000 times higher than WHO standards for drinking water. Water samples, contained 1.5 million parts per billion (ppb) of mercury–1500 times higher than the US limit for "sediment to be declared toxic" [Lambrecht, 1989]. Mercury levels in the river were found to be still 20 times the US limit as far as 40 miles downstream, near the coastal city of Durban, the second most populous city of South Africa with a population of 3.2 million [DEAT,1997; 2007; GroundWork 2005].

CHAPTER 3: METHODOLOGY

3.1 METHODOLOGY AND DESIGN

The ultimate goal of DEA's call on the documentation of mercury inventory in South Africa was to develop an inventory of mercury use and sources.

3.2 RESEARCH DESIGN

This research was focused on the activities which were presumed to be the major mercury source releases according to UNEP Toolkit level 1. The sub-categories which were considered in this study are as following:

3.2.1 Extraction and use of Fuels/Energy Sources

Under this sub-category, the quantities of coal, gas and other oil products used in South Africa per annum were identified and their contribution to mercury releases were computed using the UNEP toolkit Level 1.

3.2.2 Primary (Virgin) metal production

South Africa being a high mineral rich resource country has a lot of virgin metal processing taking place. The production of gold, silver and platinum group of elements (PGMs) was considered in terms of total quantities produced per annum in South Africa. Non- ferrous metals which were considered in this study included zinc, lead, copper and aluminium in terms of the concentrates. The ferrous metals investigated in this study were iron, nickel, chromium and cobalt. However, the last three metals' input towards mercury production is not considered by the Level 1 Toolkit from UNEP which was used in this study. The primary extraction and processing of mercury i.e., dedicated primary mercury mining never took place in South Africa and hence, no further information was collected on it.

3.2.3 Production of other minerals & materials with mercury impurities

The materials considered under this categories included cement production, pulp and paper and lime production and processing.

3.2.4 Intentional use of mercury in industrial processes

The processes which follow under this categories were identifies as Chlor-alkali production with mercury technology, VCM (vinyl-chloride-monomer) production with mercury chloride ($HgCl_2$), Acetylaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst and other production of chemicals and polymers compounds as catalysts. These processes were identified as not taking place in South Africa and no further methods were designed to collect information on the quantities of products produced by these processes.

3.2.5 Consumer products with intentional use of mercury

In this sub-category, information was collected on the availability and quantities of products whose functioning was dependent on the addition in their make-up. Thermometers of all categories were considered with sub-groups such as medical, laboratory, industrial and other forms of thermometers in use in South Africa. Electrical devices such electrical and electronic switches, contacts and relays with mercury, light sources with mercury, compact fluorescent bulbs and many forms of dry cells. Pharmaceuticals for humans and veterinary uses are burned in South Africa and responsible Government department such as Agriculture and Veterinary Services confirmed this. Hence, no further procedures were developed to investigate their presence. Cosmetics and related products containing mercury are not manufactured in South Africa. The presence of some illicit skin lighting creams and eye cosmetics on the South African market prompted the researchers in this study to develop protocols for data collection.

3.2.6 Other intentional products/processes uses

In this sub-category of the contribution of dental amalgam fillings, manometers and blood pressure gauges was considered. The use of mercury for ethnic/cultural/ritualistic uses or folklore medicine was presumed to be non-existent in the Black African majority population of South Africa. The use of mercury for educational purposes is still a common practice in South Africa and necessary steps were taken to collect information on the mercury sales and utilisation by stakeholders. Other mercury metal uses were considered and unavailability of information led to the assumption that there was very little activity on mercury use in that area. The use of mercury is some miscellaneous products, such as infra-red detection semiconductors, tanning, pigments, browning and etching steel, certain colour photograph

paper types, recoil softeners in rifles, explosives and fireworks was investigated but due not the non availability of information no further data collection procedures were taken.

3.2.7 Production of recycled metals

There is no production of mercury through secondary metal production taking place in South Africa. However, there is a lot of ongoing scrap metal recycling to recover ferrous and non-ferrous metals. Protocols to carry out data collection were then developed under this sub-category which is also a potential mercury release source.

3.2.8 Waste Incineration

Generally, incineration of waste by municipalities is no longer taking place in South Africa and the only waste being incinerated is bioactive medical waste. However, incineration of informal waste was investigated.

3.2.9 Waste deposition/landfilling and wastewater treatment

This sub-category was identified as one of the common mercury source as all municipalities in South Africa have controlled landfills. Low level illegal waste incineration does occur in some areas in South Africa in a haphazard manner such that it was difficult to develop any protocol to determine their quantification. The treatment of wastewater was identified as a major activity listed under UNEP sub-categories which are also responsible for mercury emission. Protocols were designed to get information on mercury releases from wastewater treatment.

3.2.10 Crematoria

The cremation of bodies for the period 2003-2004 was the last national data on cremation collected. The mercury input from crematoria was then computed based on the information obtained for this period. Some Metropolitan such as Tshwane Metro keeps a good record of dead bodies buried and cremated. Efforts to collect data from other provinces failed. Therefore, the data collected from Tshwane could not be used to reflect the national trend. Consequently, data for the 2003-2004 was used in the absence of updated data. Hence, the statistics on mercury releases from cremation contained in the present report is highly approximate as it is based on previous trends which are almost a decade old by 2011.

3.2.11 Potential Hotspots

The only place close to the hotspot in South Africa is the former THOR Chemical Factory in the province of KwaZulu-Natal. No sampling procedures were developed to determine the current mercury activity on the site as this was beyond the scope of this study.

3.2.12 Mercury levels in fish

The information on contamination of fish by mercury was obtained from various literature sources. No attempts were made to sample fish and analysed them for mercury as this was deemed to be beyond the scope of this study.

3.3 DATA COLLECTION PLAN

The ultimate goal of DEA's call for situation analysis with regards to mercury in South Africa, and the development of an inventory of mercury use and sources, in preparation for the intergovernmental negotiating committee to prepare a globally legally binding instrument on mercury, is to protect human and ecosystem health in South Africa, by reducing and/or eliminating the use and release of mercury from human sources to the environment. This inventory draws the experience of AJUA Environmental Consultants technical team on toxic metal analysis as well as literature review and internet scan on programmes that deal with collection, recycling and phase out activities of mercury in various countries.

The two methods employed in the present study were (i) indicative and (ii) UNEP TOOL Kit Level 1.

3.3.1 Indicative method

This method provided the data which were used in the UNEP Tool Kit level 1. Indicative methodologies used included:

- desk research of existing information;
- focus group meetings;
- questionnaire surveys;
- postal communication;
- life cycle product identification (supply chain);
- Relevant stakeholder consultation;
- telephone interviews;
- email/Web based information sourcing;

- face to face interviews and
- statistical methods

3.3.2 UNEP Toolkit level 1 **(revised January 2011)**

The mass balance principle, inputs and outputs

The mercury release calculations used in the UNEP Toolkit 1, are based on the mass balance principle: All the mercury fed into the system (say, an industrial sector) with materials and fuels are expected to emerge, either as releases to the environment or in some kind of product stream. In other words: "Sum of inputs = sum of outputs".

Inputs: Therefore, quantification of mercury is based on the mercury inputs from the amount of mercury containing material fed into the system (called "**activity rate**") and general data on the mercury concentration in the feed material (called "**input factor**").

Outputs: The mercury releases from the system are calculated by distributing this mercury amount on the relevant release pathways based on available data on how the releases (or "outputs") are generally distributed in this sector. For calculating this distribution, we use general "output distribution factors".

On Inventory Toolkit Level 1, these calculations are automatic, and are based on default input factors and default output distribution factors, which are already entered in the electronic calculation spreadsheet.

The generalized formula used in the calculations is:

Estimated mercury release to pathway X	=	**activity rate * input factor * output distribution factor for pathway X**

where activity rate = quantity of mercury containing product; Input factor = concentration of mercury in product (default values); Output distribution factor = releases via air, water or land.

3.3.3 Simplifications and limitations in the design of Inventory Level 1

Mercury concentrations in raw materials, fuels or products used vary depending on their type and origin and this naturally affects the amount of mercury being released. Production

set-ups and pollution reduction equipment configurations may also influence the distribution of mercury releases among the release output pathways (air, water, land, waste, etc.). These factors are incorporated in the Toolkit. Simplification and standardisation of the inventory development was prioritized in Inventory Level 1 and, therefore, input and release scenarios predominant in developing countries and countries with economies in transition were prioritised here.

In Inventory Level 1, the Toolkit spreadsheet uses medium input and release factors (here called output distribution factors) for the calculation of the mercury inputs and releases, and presents the results as "standard estimates" with no uncertainty intervals. These calculated “standard estimates” are simplified results of inputs and releases and may as such be above or below the actual inputs and releases in a country. These simplified results aim at providing a useful first insight into a country’s situation as regards mercury inputs and releases. Generally, it may be useful to produce refined inventories at later stages, as the work with national management of mercury develops further.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

A comprehensive introduction of this study is given in the literature review section. Consequently, it was deemed not necessary to repeat a detailed introduction as outlined in earlier report.

This mercury release inventory was prepared using the "Toolkit for identification and quantification of mercury releases" made available by the United Nations Environment Programme's Chemicals division (UNEP Chemicals). The Toolkit is available at UNEP Chemicals' website:

http://www.unep.org/hazardoussubstances/Mercury/MercuryPublications/GuidanceTrainingMaterialToolkits/MercuryToolkit/tabid/4566/language/en-US/Default.aspx.

This inventory was developed on the Toolkits Inventory Level 1. The Toolkit is based on mass balances for each mercury release source type. Inventory Level 1 works with pre-determined factors used in the calculation of mercury inputs to society and releases, the so-called default input factors and default output distribution factors. These factors were derived from data on mercury inputs and releases from such mercury source types from available literature and other relevant data sources.

The presentation of results of this study is as prescribed by the revised Toolkit Level 1. Briefly, the results are presented as follows: summary of the mercury releases from the main group sources followed by mercury releases from different sources and sub-categories within each source, definitions of mercury release pathways (air, water and land) and finally data acquisition sources and gaps.

4.2 Data collection Plan

Data collection was done through several electronic means such as internet search on websites of various organisations and institutions, telephonic interviews, e-mailing, oral interviews and government gazettes. A summary of the results for main groups of mercury release sources is presented in Table 4.1.

Table 4-1 Summary of mercury releases from main group sources

Source category	Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y					
		Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Coal combustion and other coal use	44,826.5	40,343.8	0.0	0.0	0.0	4,482.6	0.0
Other fossil fuel and biomass combustion	343.1	343.1	0.0	0.0	0.0	0.0	0.0
Oil and gas production	139.7	19.0	27.8	0.0	37.4	43.8	0.0
Primary metal production (excl. gold production by amalgamation)	2,197,727.9	91,955.4	43,664.3	1,964,804.2	92,148.6	333.0	4,822.3
Gold extraction with mercury amalgamation	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other materials production	4,027.2	2,459.4	0.0	0.0	783.9	783.9	0.0
Chlor-alkali production with mercury-cells	-	-	-	-	-	-	-
Other production of chemicals and polymers	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Production of products with mercury content	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Use and disposal of dental amalgam fillings	7,588.0	151.8	2,519.2	0.0	273.2	1,456.9	1,456.9
Use and disposal of other products	14,388.8	1,117.6	2,045.2	708.2	0.0	9,657.9	860.0
Production of recycled metals	41.8	13.8	0.0	14.2	0.0	13.8	0.0
Waste incineration and open waste burning*1	0.7	0.6	0.0	0.0	0.0	0.0	0.1
Waste deposition*1	100,000.0	1,000.0	10.0	0.0	-	-	-
Informal dumping of general waste *1*2	1,000.0	100.0	100.0	800.0	-	-	-
Waste water system/treatment *3	39.9	0.0	35.9	0.0	0.0	4.0	0.0
Crematoria and cemeteries	1,561.5	93.7	0.0	1,467.8	0.0	0.0	0.0
TOTALS	**2,371, 685.1**	**137,598.2**	**48,402.4**	**1,967,794.4**	**93,243.1**	**16,775.9**	**7,140.0**

*1: To avoid double counting of mercury inputs from waste and products in the input TOTAL, only 10% incineration sources, waste deposition and informal dumping was included in the total for mercury input approximately the mercury input to waste from materials which were not quantified individually in Inve

See Appendix 1 to the Inventory Level1 Guideline for more explanation.
*2: The estimated quantities included mercury in products which has also been accounted for under each product category.
To avoid double counting, the release to land from informal dumping of general waste has been subtracted automatically from the TOTAL.
*3: The estimated input and release to water include mercury amounts which have also been accounted for under each source category.
To avoid double counting, input to, and release to water from, wastewater system/treatment have been subtracted automatically from the TOTAL.

As shown in Table 4-1, the following source groups contribute the major mercury inputs: energy consumption and fuel production, domestic production of metals and raw materials and waste handling and recycling. In the individual mercury release sub-categories, the order of contributions to mercury inputs was: coal combustion and other coal uses>primary metal production (excluding gold production by amalgamation)>and other material production. Waste deposition also constitutes a significant flux of mercury, but the majority of the mercury in the waste stream originated from products and processes with intentional mercury use. Detailed presentation of mercury inputs and releases for all mercury release source types present in the country are shown in the following report sections.

4.3 Mercury release source types present

Table 4-2 shows which mercury release sources were identified as present, absent or not sure respectively, in the country. Only source types positively identified as present are included in the quantitative assessment.

Table 4-2 Identification of mercury release sources in the country (INVENTORY LEVEL 1 - MERCURY SOURCES IDENTIFIED)

Source category	Source present?
	Y/N/?
Energy consumption	
Coal combustion in large power plants	y
Other coal uses	y
Combustion/use of petroleum coke and heavy oil	y
Combustion/use of diesel, gasoil, petroleum, kerosene	y
Use of raw or pre-cleaned natural gas	Y
Use of pipeline gas (consumer quality)	Y
Biomass fired power and heat production	y
Charcoal combustion	Y
Fuel production	
Oil extraction	Y
Oil refining	y
Extraction and processing of natural gas	Y
Primary metal production	
Mercury (primary) extraction and initial processing	N
Production of zinc from concentrates	Y
Production of copper from concentrates	Y
Production of lead from concentrates	Y
Gold extraction by methods other than mercury amalgamation	Y
Alumina production from bauxite (aluminium production)	Y
Primary ferrous metal production (iron, steel production)	Y

Gold extraction with mercury amalgamation - without use of retort	N
Gold extraction with mercury amalgamation - with use of retorts	N
Other materials production	
Cement production	Y
Pulp and paper production	Y
Production of chemicals	
Chlor-alkali production with mercury-cells	N
VCM production with mercury catalyst	N
Acetaldehyde production with mercury catalyst	N
Production of products with mercury content	
Hg thermometers (medical, air, lab, industrial etc.)	Y
Electrical switches and relays with mercury	Y
Light sources with mercury (fluorescent, compact, others: see guideline)	Y
Batteries with mercury	Y
Manometers and gauges with mercury	Y
Biocides and pesticides with mercury	N
Paints with mercury	N
Skin lightening creams and soaps with mercury chemicals	Y
Use and disposal of products with mercury content	
Dental amalgam fillings ("silver" fillings)	Y
Thermometers	Y
Electrical switches and relays with mercury	Y
Light sources with mercury	Y
Batteries with mercury	Y
Polyurethane (PU, PUR) produced with mercury catalyst	N
Paints with mercury preservatives	N
Skin lightening creams and soaps with mercury chemicals	Y
Medical blood pressure gauges (mercury sphygmomanometers)	Y
Other manometers and gauges with mercury	Y
Laboratory chemicals	Y
Other laboratory and medical equipment with mercury	Y
Production of recycled of metals	
Production of recycled mercury ("secondary production")	N
Production of recycled ferrous metals (iron and steel)	Y
Waste incineration	
Incineration of municipal/general waste	N
Incineration of hazardous waste	N
Incineration of medical waste	Y
Sewage sludge incineration	N
Open fire waste burning (on landfills and informally)	N
Waste deposition/landfilling and waste water treatment	
Controlled landfills/deposits	Y
Informal dumping of general waste *1	Y
Waste water system/treatment	Y
Crematoria and cemeteries	
Crematoria	Y
Cemeteries	Y

It should be noted, however, that the presumably minor mercury release source types shown in Table 4-3 were not included in the detailed source identification and quantification work.

Table 4-3 Miscellaneous potential mercury sources not included in the quantitative inventory with preliminary indication of possible presence in South Africa

Source category	Source present?	
	Y/N/?	
Combustion of oil shale	N	
Combustion of peat	N	
Geothermal power production	N	
Production of other recycled metals	Y	
Production of lime	Y	
Production of light weight aggregates (burnt clay nuts for building purposes)	Y	
Chloride and sodium hydroxide produced from mercury-cell technology	N	
Polyurethane production with mercury catalysts	N	
Seed dressing with mercury chemicals	Y	
Infra red detection semiconductors	Y	
Bougie tubes and Cantor tubes (medical)	Y	
Educational uses	Y	
Gyroscopes with mercury	Y	
Vacuum pumps with mercury	Y	
Mercury used in religious rituals (amulets and other uses)	N	
Mercury used in traditional medicines (ayurvedic and others) and homeopathic medicine	N	
Use of mercury as a refrigerant in certain cooling systems	N	
Light houses (levelling bearings in marine navigation lights)	Y	
Mercury in large bearings of rotating mechanic parts in for example older waste water treatment plants	N	
Tanning	?	
Pigments	Y	
Products for browning and etching steel	?	
Certain colour photograph paper types	?	
Recoil softeners in rifles	?	
Explosives (mercury-fulminate a.o.)	?	
Fireworks	?	
Executive toys	?	

4.4 Summary of mercury inputs to society

Mercury inputs to society should be understood here as the mercury amounts made available for potential releases through economic activity in the country. This includes mercury intentionally used in products such as thermometers, blood pressure gauges, fluorescent light bulbs and others. It also includes mercury mobilised via extraction and use of raw materials which contains mercury in trace concentrations. It can be seen from Table 4-4, that the

following source sub-categories made the largest contributions to mercury releases to the atmosphere: coal combustion in large power plants, other coal uses, primary ferrous metal production (iron and steel production) and cement production.

Table 4-4 Summary of mercury inputs to society

Source category	Source present?			Estimated Hg input, kg Hg/y
	Y/N/?	Activity rate	Unit	Standard estimate
Energy consumption				
Coal combustion in large power plants	y	124,580,000	t coal combusted/y	33,637
Other coal uses	y	41,444,000	t coal used/y	11,190
Combustion/use of petroleum coke and heavy oil	y	2,717,000	t oil product combusted/y	149
Combustion/use of diesel, gasoil, petroleum, kerosene	y	7,270,000	t oil product combusted/y	40
Use of raw or pre-cleaned natural gas	Y	1,415,384,615	Nm3 gas/y	142
Use of pipeline gas (consumer quality)	Y	292,333	Nm3 gas/y	0
Biomass fired power and heat production	y	4,996	t biomass combusted/y (dry weight)	0
Charcoal combustion	Y	100,000	t charcoal combusted/y	12
Fuel production				
Oil extraction	Y	254,184	t crude oil produced/y	14
Oil refining	y	18,096	t oil refined/y	1
Extraction and processing of natural gas	Y	1,247,435,897	Nm3 gas/y	125
Primary metal production				
Mercury (primary) extraction and initial processing	N	0	t mercury produced/y	-
Production of zinc from concentrates	Y	50,909	t concentrate used/y	5,345
Production of copper from concentrates	Y	331,614	t concentrate used/y	2,653
Production of lead from concentrates	Y	78,014	t concentrate used/y	7,879
Gold extraction by methods other than mercury amalgamation	Y	39,600,000	t gold ore used/y	2,178,000
Alumina production from bauxite (aluminium production)	Y	1,024,768	t bauxit processed/y	512
Primary ferrous metal production (iron, steel production)	Y	66,753,757	t pig iron produced/y	3,338
Gold extraction with mercury amalgamation - without use of retort	N	0	kg gold produced/y	-
Gold extraction with mercury amalgamation - with use of retorts	N	0	kg gold produced/y	-
Other materials production				
Cement production	Y	14,252,000	t cement produced/y	3,919
Pulp and paper production	Y	3,595,000	t biomass used in production/y	108
Production of chemicals				
Chlor-alkali production with mercury-cells	N	0	t Cl2 produced/y	-
VCM production with mercury catalyst	N	0	t VCM produced/y	-
Acetaldehyde production with mercury catalyst	N	0	t acetaldehyde produced/y	-
Production of products with mercury content				

Hg thermometers (medical, air, lab, industrial etc.)	Y	0	kg mercury used for production/y	0
Electrical switches and relays with mercury	Y	0	kg mercury used for production/y	0
Light sources with mercury (fluorescent, compact, others: see guideline)	Y	0	kg mercury used for production/y	0
Batteries with mercury	Y	0	kg mercury used for production/y	0
Manometers and gauges with mercury	Y	0	kg mercury used for production/y	0
Biocides and pesticides with mercury	N	0	kg mercury used for production/y	-
Paints with mercury	N	0	kg mercury used for production/y	-
Skin lightening creams and soaps with mercury chemicals	N	0	kg mercury used for production/y	-
Use and disposal of products with mercury content				
Dental amalgam fillings ("silver" fillings)	Y	50,586,750	number of inhabitants	7,588
Thermometers	Y	80,767	items sold/y	521
Electrical switches and relays with mercury	Y	50,586,750	number of inhabitants	7,082
Light sources with mercury	Y	8,899,066	items sold/y	117
Batteries with mercury	Y	2,500	t batteries sold/y	625
Polyurethane (PU, PUR) produced with mercury catalyst	N	50,586,750	number of inhabitants	-
Paints with mercury preservatives	N	0	t paint sold/y	-
Skin lightening creams and soaps with mercury chemicals	Y	2	t cream or soap sold/y	60
Medical blood pressure gauges (mercury sphygmomanometers)	Y	40,767	items sold/y	3,261
Other manometers and gauges with mercury	Y	50,586,750	number of inhabitants	253
Laboratory chemicals	Y	50,586,750	number of inhabitants	506
Other laboratory and medical equipment with mercury	Y	50,586,750	number of inhabitants	2,023
Production of recycled of metals				
Production of recycled mercury ("secondary production")	N	0	kg mercury produced/y	-
Production of recycled ferrous metals (iron and steel)	Y	38,000	number of vehicles recycled/y	42
Waste incineration				
Incineration of municipal/general waste*1	N	0	t waste incinerated/y	-
Incineration of hazardous waste*1	N	0	t waste incinerated/y	-
Incineration of medical waste*1	Y	28	t waste incinerated/y	1
Sewage sludge incineration*1	N	0	t waste incinerated/y	-
Open fire waste burning (on landfills and informally)*1	N	0	t waste burned/y	-
Waste deposition/landfilling and waste water treatment				
Controlled landfils/deposits *1	Y	20,000,000	t waste landfilled/y	100,000
Informal dumping of general waste *1*2	Y	200,000	t waste dumped/y	1,000
Waste water system/treatment *3	Y	7,600,000	m3 waste water/y	40
Crematoria and cemeteries				
Crematoria	Y	37,475	corpses cremated/y	94
Cemeteries	Y	587,116	corpses buried/y	1,468
TOTAL of quantified inputs *5				**2,371,745.0**

*1: To avoid double counting of mercury inputs from waste and products in the input TOTAL, only 10% of the mercury input to

waste incineration sources, waste deposition and informal dumping is included

in the total for mercury inputs. These 10% represent approximately the mercury input to waste from materials which were not quantified individually in Inventory Level 1 of this Toolkit.

See Appendix 1 to the Inventory Level1 Guideline for more explanation.
*2: The estimated quantities included mercury in products which has also been accounted for under each product category.
To avoid double counting, the release to land from informal dumping of general waste has been subtracted automatically in the TOTAL.
*3: The estimated input and release to water include mercury amounts which have also been accounted for under each source category.
To avoid double counting, input to, and release to water from, waste water system/treatment have been subtracted automatically in the TOTAL.
*4 The cremation percent of 3.38% for 2010 for Tshwane Metropolitan was used to calculate the total national cremation from the average of 615,255 deaths/year for 2008-2010.
*5 The total amount includes major and minor sources.

4.5 Summary of mercury releases

In Table 4-5, a summary of mercury releases from all source categories present is given. The key mercury releases here were releases to air (the atmosphere), to water (marine and freshwater bodies, including via wastewater systems), to land, to general waste, and to sectors specific waste. An additional output pathway was "by-products and impurities" designated as mercury flow back into the market with by-products and products where mercury does not play an intentional role. A more detailed description and definition of the output pathways is given in Table 4-6.

Table 4-5 Summary of mercury releases

Source category	Estimated Hg releases, standard estimates, kg Hg/y					
	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Energy consumption						
Coal combustion in large power plants	30,272.9	0.0	0.0	0.0	3,363.7	0.0
Other coal uses	10,070.9	0.0	0.0	0.0	1,119.0	0.0
Combustion/use of petroleum coke and heavy oil	149.4	0.0	0.0	0.0	0.0	0.0
Combustion/use of diesel, gasoil, petroleum, kerosene	40.0	0.0	0.0	0.0	0.0	0.0
Use of raw or pre-cleaned natural gas	141.5	0.0	0.0	0.0	0.0	0.0
Use of pipeline gas (consumer quality)	0.0	0.0	0.0	0.0	0.0	0.0
Biomass fired power and heat production	0.1	0.0	0.0	0.0	0.0	0.0
Charcoal combustion	12.0	0.0	0.0	0.0	0.0	0.0
Fuel production						
Oil extraction	0.0	2.8	0.0	0.0	0.0	0.0
Oil refining	0.2	0.0	0.0	0.0	0.1	0.0

Extraction and processing of natural gas	18.7	24.9	0.0	37.4	43.7	0.0
Primary metal production						
Mercury (primary) extraction and initial processing	-	-	-	-	-	-
Production of zinc from concentrates	534.5	0.0	1,603.6	1,603.6	0.0	1,603.6
Production of copper from concentrates	265.3	53.1	636.7	1,061.2	0.0	636.7
Production of lead from concentrates	787.9	0.0	2,363.8	2,363.8	0.0	2,363.8
Gold extraction by methods other than mercury amalgamation	87,120.0	43,560.0	1,960,200.0	87,120.0	0.0	0.0
Alumina production from bauxite (aluminium production)	76.9	51.2	0.0	0.0	333.0	51.2
Primary ferrous metal production (iron, steel production)	3,170.8	0.0	0.0	0.0	0.0	166.9
Gold extraction with mercury amalgamation - without use of retort	-	-	-	-	-	-
Gold extraction with mercury amalgamation - with use of retorts	-	-	-	-	-	-
Other materials production						
Cement production	2,351.6	0.0	0.0	783.9	783.9	0.0
Pulp and paper production	107.9	0.0	0.0	0.0	0.0	0.0
Production of chemicals						
Chlor-alkali production with mercury-cells	-	-	-	-	-	-
VCM production with mercury catalyst	-	-	-	-	-	-
Acetaldehyde production with mercury catalyst	-	-	-	-	-	-
Production of products with mercury content						
Hg thermometers (medical, air, lab, industrial etc.)	0.0	0.0	0.0	0.0	0.0	0.0
Electrical switches and relays with mercury	0.0	0.0	0.0	0.0	0.0	0.0
Light sources with mercury (fluorescent, compact, others: see guideline)	0.0	0.0	0.0	0.0	0.0	0.0
Batteries with mercury	0.0	0.0	0.0	0.0	0.0	0.0
Manometers and gauges with mercury	0.0	0.0	0.0	0.0	0.0	0.0
Biocides and pesticides with mercury	-	-	-	-	-	-
Paints with mercury	-	-	-	-	-	-
Skin lightening creams and soaps with mercury chemicals	-	-	-	-	-	-
Use and disposal of products with mercury content						
Dental amalgam fillings ("silver" fillings)	151.8	2,519.2	0.0	273.2	1,456.9	1,456.9
Thermometers	52.1	156.2	0.0	0.0	312.5	0.0
Electrical switches and relays with mercury	708.2	0.0	708.2	0.0	5,665.7	0.0
Light sources with mercury	5.9	0.0	0.0	0.0	111.4	0.0
Batteries with mercury	0.0	0.0	0.0	0.0	625.0	0.0
Polyurethane (PU, PUR) produced with mercury catalyst	-	-	-	-	-	-

Paints with mercury preservatives	-	-	-	-	-	-
Skin lightening creams and soaps with mercury chemicals	0.0	57.0	3.0	0.0	0.0	0.0
Medical blood pressure gauges (mercury sphygmomanometers)	326.1	978.4	0.0	0.0	1,956.8	0.0
Other manometers and gauges with mercury	25.3	75.9	0.0	0.0	151.8	0.0
Laboratory chemicals	0.0	166.9	0.0	0.0	166.9	172.0
Other laboratory and medical equipment with mercury	0.0	667.7	0.0	0.0	667.7	688.0
Production of recycled of metals						
Production of recycled mercury ("secondary production")	-	-	-	-	-	-
Production of recycled ferrous metals (iron and steel)	13.8	0.0	14.2	0.0	13.8	0.0
Waste incineration						
Incineration of municipal/general waste	-	-	-	-	-	-
Incineration of hazardous waste	-	-	-	-	-	-
Incineration of medical waste	0.6	0.0	0.0	0.0	0.0	0.1
Sewage sludge incineration	-	-	-	-	-	-
Open fire waste burning (on landfills and informally)	-	-	-	-	-	-
Waste deposition/landfilling and waste water treatment						
Controlled landfills/deposits	1,000.0	10.0	0.0	-	-	-
Informal dumping of general waste *1	100.0	100.0	800.0	-	-	-
Waste water system/treatment *2	0.0	35.9	0.0	0.0	4.0	0.0
Crematoria and cemeteries						
Crematoria	93.7	0.0	0.0	-	0.0	0.0
Cemeteries	0.0	0.0	1,467.8	-	0.0	0.0
TOTAL of quantified releases	**137,598.2**	**48,402.4**	**1,967,794.2**	**93,243.1**	**16,775.9**	**7,140.0**

Notes:
*1: The estimated quantities included mercury in products which had also been accounted for under each product category.
To avoid double counting, the release to land from informal dumping of general waste was subtracted automatically from the TOTAL.
*2: The estimated release to water included mercury amounts which had also been accounted for under each source category.
To avoid double counting, input to, and release to water from, wastewater system/treatment was subtracted automatically from the TOTAL.

Table 4-6 provides general descriptions and definitions of the output pathways.

Table 4-6 Description of the types of results

Calculation result type	Description
Estimated Hg input, kg Hg/y	The standard estimate of the amount of mercury entering this source category with input materials, for example, calculated mercury amount in the amount of coal used annually in the country for combustion in large power plants.
Air	Mercury emissions to the atmosphere from point sources and diffuse sources from which mercury may be spread locally or over long distances with air masses; for example from: • Point sources such as coal fired power plants, metal smelter, waste incineration; • Diffuse sources as small scale gold mining, informally burned waste with fluorescent lamps, batteries, thermometers.
Water	Mercury releases to aquatic environments and to waste water systems: Point sources and diffuse sources from which mercury will be spread to marine environments (oceans), and freshwaters (rivers, lakes, etc.). for example releases from: • Wet flue cleaning systems from coal fired power plants; • Industry, households, etc. to aquatic environments; • Surface run-off and leachate from mercury contaminated soil and waste dumps
Land	Mercury releases to soil, the terrestrial environment: General soil and ground water. For example releases from: • Solid residues from flue gas cleaning on coal fired power plants used for gravel road construction;. • Uncollected waste products dumped or buried informally • Local un-confined releases from industry such as on site hazardous waste storage/burial • Spreading of sewage sludge with mercury content on agricultural land (sludge used as fertilizer) • Application on land, seeds or seedlings of pesticides with mercury compounds
By-products and impurities	By-products that contain mercury, which are sent back into the market and cannot be directly allocated to environmental releases, for example: • Gypsum wallboard produced from solid residues from flue gas cleaning on coal fired power plants. • Sulphuric acid produced from desulphurization of flue gas (flue gas cleaning) in non-ferrous metal plants with mercury trace concentrations • Chlorine and sodium hydroxide produced with mercury-based chlor-alkali technology; with mercury trace concentrations • Metal mercury or calomel as by-product from non-ferrous metal mining (high mercury concentrations)
General waste	General waste: Also called municipal waste in some countries. Typically household and institution waste where the waste undergoes a general treatment, such as incineration, landfilling or informal dumping. The mercury sources to waste are consumer products with intentional mercury content (batteries, thermometers, fluorescent tubes, etc.) as well as high volume waste like printed paper, plastic, etc., with small trace concentrations of mercury.
Sector specific waste treatment /disposal	Waste from industry and consumers which is collected and treated in separate systems, and in some cases recycled; for example. • Confined deposition of solid residues from flue gas cleaning on coal fired power plants on dedicated sites. • Hazardous industrial waste with high mercury content which is deposited in dedicated, safe sites • Hazardous consumer waste with mercury content, mainly separately collected and safely treated batteries, thermometers, mercury switches, lost teeth with amalgam fillings etc. • Confined deposition of tailings and high volume rock/waste from extraction of non-ferrous metals

4.6 DATA AND INVENTORY ON ENERGY CONSUMPTION AND FUEL PRODUCTION

4.6.1 Data description

Coal is a major fossil fuel in South Africa and it is used for power generation and production of synthetic fuels. All South Africa's twelve large power stations are owned by ESKOM, a public power utility. Hence, coal combustion in large power stations consumed an average of 124 M tons per annum for the period 2008-2010 [ESKOM, 2010]. Coal being one of the major mineral resources of the South African economy, all information pertaining to coal production, local sales and exports is supplied to the Department of mineral Resources (DMR) by stakeholders such as mining houses and coal merchants. Coal is also utilised by other uses of coal (41.4 M tons/year) [DMR, 2011b], combustion /use of petroleum coke and heavy oil used 7.3 M tons/year [SASOL, 2011] and combustion/use of diesel, gasoil, petroleum, kerosene used 2.7 M tons/year [DMR, 2009a]. No data was found indicating the use of biomass fired power and heat production plants. Charcoal is generally sold in several retail shops in South Africa but the industry is not regulated since most of the product found on the market is from small scale dealers. There is no regulation governing the production and sale of charcoal, hence, no official data is available from government departments.

The information reported in this document was based on the data posted by various national charcoal producers and dealers. Data values for oil extraction, oil refining and extraction and processing of natural gas was obtained from the DMR, [DMR, 2009a].

4.6.2 Background calculations and approximations

Most of the data obtained for various sub-categories of energy consumption and fuel production was directly processed by the Toolkit Level 1 without further calculations. Only data for natural gas was supplied in kilograms/year and had to be converted into Nm^3/year [Bio-Energy Producers Association, 2009].

4.6.3 Data gaps and priorities for potential follow up

The lack of audited information or official data on charcoal production and utilisation was the only sub-category that still requires further verification. Other data sources were presumed reliable as they could be cross-referenced between data kept by DMR and stakeholders.

4.7 DATA AND INVENTORY ON DOMESTIC PRODUCTION OF METALS AND RAW MATERIALS

4.7.1 Data description

South African is a major producer of precious metals, ferrous and non-ferrous metals, diamonds and coal. Large volumes of Platinum group of metals which includes, platinum, palladium and nickel (PGMs) ores are processed in South Africa and their contribution to mercury releases is unknown as this data is not covered by the Toolkit Level 1 as proposed by UNEP. Under the primary metal production, there is no mercury (primary) extraction and initial processing taking place in South Africa according to the records on Mineral Economics [DMR, 2008]. The following sub-categories of primary metal production were found to be in operation in South Africa: production of zinc from concentrates of 28,000 ton/year [DMR, 2008], production of copper from concentrates of 92,852 tons/year [DMR, 2008], production of lead of 49149 tons/year [DMR, 2008], gold extraction by methods other than mercury amalgamation of 198 tons/year [DMR, 2009c], aluminium production from bauxite (aluminium production of 1024768 tons/year [DMR, 2008] and primary ferrous metal production (iron and steel production) of 66 753737 tons/year [DMR, 2011a]. Other ferrous metals produced in South Africa in large quantities not discussed by the current UNEP Toolkit level 1 are Nickel (384.1 kt/y in 2006), cobalt (238 t/y in 2009) [DMR, 2011].

4.7.2 Background calculations and approximations

The data on metal production was obtained from DMR as the official figures supplied by the various mining houses extracting mineral resources in South Africa. No further calculations and approximations were made before processing the data by the Toolkit Level 1.

4.7.3 Data gaps and priorities for potential follow up

The data for metal production in South Africa is well regulated and there is a system for data movement from the producers to responsible departments such as DMR and South African Revenue Services (SARS). Hence, it can be said that no data gaps were identified in this category.

4.8 DATA AND INVENTORY ON DOMESTIC PRODUCTION AND PROCESSING WITH INTENTIONAL MERCURY USE

4.8.1 Data description

Mercury is not mined in South Africa and there are no industry still using mercury in metal production. Hence, this category was of no significance in the South African scenario in terms of mercury releases.

4.8.2 Background calculations and approximations

No calculations and approximations were made under this category and, therefore, this category was considered not applicable to the South African situation.

4.8.3 Data gaps and priorities for potential follow up

No data gaps were observed under this category as the assumption was that no mercury processing activities were taking place in South Africa.

4.9 DATA AND INVENTORY ON WASTE HANDLING AND RECYCLING

4.9.1 Data description

The sub-category on waste handling and recycling which represented the largest flux of mercury was waste land filled on formal dumpsites which amounted to 20 Mt/y with an estimated mercury amount of 100000 kg Hg/y. Other sub-categories which were found to contribute to mercury releases included wastes which are dumped on informal dumpsites, vehicles crushed and recycled to produce steel and about 7.6 MM^3/y of wastewater [DEA, 2006; 2010]. The incineration of general waste by municipalities is no longer a practice in South Africa. Mercury production has never been done in South Africa and hence, the issue of production of recycled mercury is not applicable.

With respect to recycling, for the calculations to work, the number of recycled cars needs to be known. However, information on the number of recycled car could not be obtained and, therefore, estimate was obtained from the average weight of steel in cars of 1t/vehicle and assumed roughly that cars were the dominant source of recycled iron and steel. The estimated turnover for the production of ferrous metals from scrap metals was about 3 Mt

per annum for South Africa and 400 000 t/y of non-ferrous metals [Reclaim Group, 2011]. The total amount of medical waste incinerated in South Africa was approximately 28tonne/yr.

4.9.2 Background calculations and approximations

Information obtained under the sub-categories of waste processing is quite insufficient. There are several players in the waste processing in South Africa. Industrial wastes depending on their classification are either processed through municipal facilities or by private companies. The processing of waste is loosely regulated such that it was quite difficult to get precise figures on the amounts of waste processed by most waste handling facilities. Most municipal facilities especially those covering rural areas have no weigh bridges to quantify the amount of waste they handle. It was quite difficult to come up with reasonable calculations and approximations for determining waste processing in South Africa. There is also a problem of dumping of waste in undesignated areas, hence, all these sources could be potential mercury release sources unaccounted for.

4.9.3 Data gaps and priorities for potential follow up

A lot of data gaps were identified in this area of waste handling due to the large numbers of players in waste processing and handling. Regulations should be introduced whereby all players in waste handling and processing should be in a position of supplying information on the volumes and quantities of wastes they are handling on monthly basis to authorities such as Department of Environment Affairs (DEA) or any designated authority. Some small waste handling facilities do not have weighing equipment for wastes brought to the sites by their clients. It is necessary that any registered waste handling facility should have a weighing bridge if the exact amount of waste produced in South Africa going to formal dumpsites is to be determined with better approximation.

4.10 DATA AND INVENTORY ON GENERAL CONSUMPTION OF MERCURY IN PRODUCTS, AS METAL MERCURY AND AS MERCURY CONTAINING SUBSTANCES

4.10.1 Data description

The consumption of mercury in products, as metal mercury and mercury containing substances in South Africa has been identified and the following categories are of hence forth discussed.

4.10.2 Dental amalgam fillings

Although substitute materials without mercury are now available on the South African market, mercury based amalgam formulations are still available. However, dental fillings with mercury are still being marketed in South Africa. Available information indicated that the total amount sold amounted to 70-100 kg dental amalgam per year for the past 3 years (2009-2011) which contains 41 to 60 kg silver and 23 kg to 30 kg mercury. Furthermore, approximately 50 kg of mercury not in amalgam form is sold to dental practitioners who make their own formulations.

4.10.3 Manometers

There is a large variety of thermometers on the South African market ranging from traditional bulb mercury thermometers and more modern digital thermometers which do not contain mercury. The use of digital thermometers is limited by the high cost of these thermometers compared to bulb mercury thermometers. The manufacture, importation of mercury thermometers is unregulated in South Africa. The major consumers of mercury thermometers are educational institutions, hospital and clinics, industry, research institutions and agricultural industry. For medical uses, there are about 40,767 registered medical practitioners in South Africa and the number of clinical thermometers consumed per year is approximated to be a total of 150 767 based on the fact that each practitioner is expected to have a thermometer plus each medical students with a population 110,000/yr. The units sold per year are assumed to be equivalent to the number of medical practitioners registered. Hence, standard estimate of mercury releases from medical thermometers is estimated to be 3,514 kg per year. There is a number of other medical equipment containing mercury which is still widely used in South Africa's health facilities. However, there is no national record on the number of mercury containing equipment which is disposed after reaching their end of life. Some of the commonly used equipment containing mercury includes blood pressure measuring equipments and pressure gauges.

4.10.4 Light sources with mercury

Fluorescent discharge lamps (FDLs) are the major light sources which contain mercury as it is necessary for their operation. Among the light sources, FDLs are generally 5 times more efficient than incandescent lamps i.e., those lamps with usually tungsten filaments. In South Africa the government through if state power utility, ESKOM, have rolled out free compact fluorescent lamps (CFLs) amounting to 4.5 million units between 2004 and 2010 [ESKOM, 2010]. During the 2005/2006 financial year high intensity discharge lamps (186,900 units), linear fluorescent/double end two pin fluorescent lamps (16,330,000 units) and CFLs (19,095,000 units) were imported into South Africa [Finlay, A., 2008]. It has been reported that 1,829,066 units of double end fluorescent tubes and 7,000,000 units of CFLs are sold per year in South Africa. The mercury releases from fluorescent lamps is estimated to be 117.0kg.y^{-1}. There is no legislation governing the disposal of used fluorescent lamps and most of those which have reached their end of life end up being in general waste dumpsites.

4.10.5 Batteries

Estimates indicate that about 50 million batteries sold in South Africa each year which equates to 2500 tonnes/year [DEA, 2010c; http://www.uniross.co.za/battery_recycling.html]. Whilst some are rechargeable batteries, the majority are alkaline and zinc oxide batteries which are not rechargeable. Various heavy metals including mercury and cadmium are present in these batteries, resulting in their classification as hazardous waste. From the Toolkit calculations, 625.0 kg Hg y^{-1} is estimated to be released into the environment from the dumping of used batteries.

4.10.6 Biocides and Pesticides

South Africa has about 700 tons of pesticides accumulated in farms and containers which require disposal. However, it is not clear whether these pesticides residues include pesticides with mercury based formulation which are already banned in South Africa.

4.10.7 Paints

Reports from South African Paint Manufacturers Association (SAPMA) a board with represent 90% of paint manufacturers in South Africa is that the is no production of paints

whose formulation including mercury. They are in the process of recalling of paints which contain lead.

4.10.8 Pharmaceuticals for human and veterinary uses

There are no veterinary or pharmaceutical products containing mercury being sold on the South African market according to South African Veterinary Council (SAVC) and Health Professional Council of South Africa (HPCSA).

4.10.9 Cosmetics and related products

An assortment of soaps and creams for skin lightening is available on the South African informal market. Some of the products which were indentified included skin lightening creams such as Movate, Top Cream, Ambi. These products did not have ingredients labels even the manufacturer except a description of the skin lightening creams. It is, therefore, possible that there may be other skin lightening chemicals such as hydroquinone and hydrocortisones. Hence, there is a need to conduct proper investigation on the chemical compositions of the skin lightening cosmetic products. In order to confirm this, analysis of these skin lightening creams need to be carried out.

4.10.10 Data gaps and priorities for potential follow up

The national departments like the Trade and Industry (dti) did not have information on electrical switches sold in South Africa annually. The skin lightening cosmetics found on the informal market are not registered by relevant boards and they come as contrabands products into the country. There is a great need to make some follow-ups on how the trafficking of illicit cosmetics into the country can be curtailed.

Mercury is not a controlled substance in terms of its trade, use and disposal after use. Mercury because of its unique properties as the only liquid heavy metal at room temperature and it reactivity is widely used in research, especially in the area of catalysis. There is a need to develop a chain of custody procedures for proper handling, collection and disposal of stockpiles of mercury in research institution, dental clinics and the waste produced thereafter.

4.11DATA AND INVENTORY ON CREMATORIA AND CEMETERIES

4.11.1 Data description for crematoria and cemeteries

Under these sub-categories only the data on total death per annum was obtained nationally [Stats SA, 2010]. The average number of deaths between 2003 and 2004, and between 2001 and 2010 was 62,459 and 635581 per annum respectively [The Cremation Society of Great Britain, 2009]. The average percent of cremation for the period of 2003 to 2004 was about 6%. The difference between the two averages for the period under discussion was a 2% deviation which indicated that there was no significant difference in deaths rates over ten years. The total estimated Hg emitted into the air and land from crematoria and cemeteries were 93.7 and 1,467.8 kg/yr respectively.

4.11.2 Background calculations and approximations

In this study it was assumed that there was no significant change in cultural behaviour in terms of patterns of disposing the deceased bodies. The average of deaths over a period of 10 years that is from 2001 to 2010 was used in the toolkit calculations. The number of cremated bodies was calculated by assuming a 6% cremation rate for all deaths occurred.

4.11.3 Data gaps and priorities for potential follow up

The cremations taking place in South Africa are mainly based on ethnicity and religious background. Cremation is generally common among Indians who follow Hindu religion and some members of the White community. Cremations are also done by municipalities as a form of pauper disposal of unclaimed bodies from hospitals. As of now, the Home Affairs department which is issues birth and deaths certificates does not request information from relatives taking death certificates of the deceased person the way the body is going to be disposed. It is recommended that the Home Affairs Department should start correcting data on the forms of body disposal as this will enable STATS SA to get information on cremations. Hence, the mercury releases from cremation activities will remain highly approximate until national collection of such viable data by relevant SA government department is re-started again.

4.12POTENTIAL HOTSPOTS

Findings from this study showed that mercury manufacturing /processing was not taking place in South Africa. Most of the mercury releases were from anthropogenic sources except at the defunct THOR Chemicals in KwaZulu Natal. However, anthropogenic sources of mercury releases such as coal combustion is quite significant since almost all of South Africa's power comes from thermal power station which are coal powered. Hence, the Vaal Triangle Air-shed Priority Area and the Highveld Priority Area have been identified as 'hot spots' because of intensive industrial and mining activities in the coal and steel industries which have increased significantly the local levels of mercury in air.

4.13MERCURY LEVELS IN FISH

A study of the presence of mercury in fish from South African rivers showed that mercury was in the range 0.2-1.78 µg g^{-1} in cat fish samples obtained from Inanda Dam [Papu-Zamxaka,et al., 2010]. The upper limit of this range is higher than the US FDA limit of 1.0 mg kg^{-1}. There are quite limited studies in this area and further studies are recommended in order to safe guard the health of the fresh water fish consumers in South Africa.

4.14LEGISLATION

Some of the legislations promulgated at International and National levels meant to control the movement of toxic wastes including mercury containing wastes are listed in the following sub-sections.

4.14.1 International response

- Basel Convention on the Control of Transboundary Movement of
- Hazardous Wastes and their Disposal, 1989
- Fourth ACP-EEC Convention, 1989
- Bamako Convention on the Ban of the Import and Control of
- Transboundary Movement of Hazardous Wastes within Africa

4.14.2 National Response

- National Constitution 1996
- National Environmental Management: Waste Management Bill (2000)
- Environment Conservation Act (73 of 1989)
- National Water Act (36 of 1998)
- Atmospheric Pollution Prevention Act (45 of 1965). Pending update.

- Hazardous Substances Act (15 of 1973)
- Fertilizers, Farm Feeds and Agricultural Remedies (36 of 1947)
- Minimum Requirements for Waste Disposal by Landfill 1998
- Polokwane Declaration 2001
- Recycling Initiatives
- National Waste Management Strategy 2011

CHAPTER 5: CONCLUSIONS AND GAPS

5.1 CONCLUSION

This study has shown that the total estimated Hg input, in South Africa was 2, 371, 685.1 kg Hg/yr which was distributed as follows: 137, 598.2 kg Hg/yr, 48,402.4 kg Hg/yr, 1,967,794.2 kg Hg/yr, 93,243.1 kg Hg/yr, 16,775.9 kg Hg/yr and 7, 139.2 kg Hg/yr releases via air, water, land, by-products and impurities, general waste and sector specific waste treatment/disposal respectively. Energy consumption and primary metal production are the major contributors of mercury releases to the atmosphere and land so far in South Africa. The major contributors of mercury atmospheric emissions identified were coal combustion in large power plants and other coal use (44, 826.5 kg Hg/year), primary metal production (excluding gold production by amalgamation (2, 197, 727.9 kg Hg/year), other materials production (4,027.2 kg Hg/year), waste deposition (100,000 kg Hg/year) . Production of lead, copper and zinc from concentrates was found to contribute 7,879, 2,653 and 5,345 kg Hg/year respectively. Cement production contributed approximately 3,919 kg Hg/year based on cement production in 2005. Emissions from the production of iron and steel from primary ferrous metal production was 3,338 kg Hg/year. No evidence of gold production by amalgamation in South Africa was found. From the national annual deaths recorded, crematoria and cemetery represented 94 kg and 1,468 kg Hg/year of estimated mercury respectively. Data on mercury-containing skin lightening creams and soaps was difficult to obtain since a large number of these products that are in use are not properly labelled with respect to their chemical ingredients composition. Data on mercury contents in dental fillings is not conclusive because of the unwillingness of dental amalgam practitioners and suppliers to give out information. However, the very few information obtained suggested that mercury is supplied to dental practitioners who formulate their own dental amalgam as well as in pre-weighed capsules with amalgam ingredients. In this case, the issue of handling of wastes from this practise becomes a big concern. Mercury containing health equipment was estimated to give 3,514 kg Hg/year.

The objectives of the present study have been achieved by:

- Providing a situation analysis of mercury in South Africa;
- Developing an inventory of mercury use and sources, mercury containing products, in South Africa;
- Identifying NGOs/research institutions in the country addressing/studying mercury related or chemical related environmental problems for continued monitoring of

intentional mercury introduction into the environment. Those identified are contained in the reference section of this report;

- Identifying business and industry who have undertaken voluntary programs to reduce mercury use and/or emissions in South Africa. For example, during the cause of this study, it was found out that the dental practitioners have embarked on providing alternatives to the mercury amalgam for filling. Furthermore, there is a national campaign by the energy sectors on the use of low mercury containing compact fluorescent lamps (CFL) instead of the high mercury containing long fluorescent lamps.

- Women using skin lightening creams and soaps which may contain mercury have been identified as the vulnerable populations and they require awareness raising about the mercury issue to protect human health and the environment. Also people using mercury amalgam for dental fillings as well as those living within the vicinity of power generating plants and illegal gold miners have been identified as vulnerable.

- Recommend the need for tracking/tracing/monitoring mercury as well as some recommendations on mitigation and decontamination.

The present study has shown that energy consumption and waste disposal are the major contributors of mercury releases to the atmosphere and land so far in South Africa. However, information on other sources of mercury still need to be collected and added to the present results in order to give an overview of mercury releases within the South African environment. By examining the steps and strategies other countries are taking to reduce the releases of mercury into the environment, South Africa's drive to undertake a situation analysis and develop inventories of monitoring mercury and coming up with recommendations and mitigation measures to control the releases of mercury into the South African environment will be achieved.

However, the present study was not able to provide information on mercury releases from some source categories as contained in the UNEP toolkit level 1. This was attributed to either lack of available information or the non-cooperation of the identified users/consumers to give out information.

5.2 DATA INFORMATION GAPS

5.2.1 National

The following gaps have been identified:

- Need to evaluate the contribution of biomass burning as a potential source of Hg to the

South African environment since total gaseous Hg at Cape Point suggests that biomass burning could be a significant source of Hg in the southern Hemisphere. The impacts of Hg from these sources have not been characterised in South Africa;

- Detailed examination of Hg levels in artisanal gold mining areas in South Africa is needed to evaluate the potential impact that such activities may have on human health and the surrounding terrestrial and aquatic ecosystems. Although these are potential sources of Hg, no information is available on the Hg content of emissions from these sources;

- Although there has been ongoing campaign by the energy sector to replace mercury containing long fluorescent lamps, with compact fluorescent lamps, efforts should be geared towards use of mercury free alternatives in the future since the CFL also contain some mercury vapour in small quantity; Mercury free LED bulbs are available in the trade but do still not give adequate light quality for some uses;

- Information on the use and management of mercury spillages from broken thermometers and other hospital equipment is still outstanding;

- Major data gaps were the following: use and disposal of dental fillings and use and disposal of other products. No quantitative data could be found from national bodies or government departments who are supposed to regulate the import and export of these products;

- The fate and transport processes of gaseous Hg through the entire electricity generation process require further investigation;

- Major gaps on the Hg content of raw materials used in industry (i.e. in iron and base metal ores, limestone in the cement industry and others and the type and efficiency of control devices used in various industrial sectors;

- Hg in landfill gas, leachates, sediments, ecosystem and skin lightening creams and soap still needs to be determined;

- Inventories of other uses, consumption and environmental releases of mercury that are not captured in the Toolkit;

- Monitoring of current levels of mercury in various media (such as air, air deposition, surface water) and biota (such as fish, wildlife and humans) and assessment of the impacts of mercury on humans and ecosystems, including impacts from cumulative exposures to different mercury forms;

- Data and evaluation tools for human and ecological risk assessments;

- Knowledge and information on possible prevention and reduction measures relevant to

the national situation;

- Public awareness-raising on the potential adverse impacts of mercury and proper

handling and waste management practises;

- Appropriate tools and facilities for accessing existing information relevant to mercury

and mercury compounds at national, regional and international levels;

- Capacity building and physical infrastructure for safe management of hazardous

substances, including mercury and mercury compounds, as well as training of personnel handling such hazardous substances;

- There is an urgent need to embark on UNEP Tool Kit level 2, in combination with

quantitative national data on the concentrations of Hg from various sources

5.2.2 Global

Although mercury is probably among the best-studied environmental toxicants, there are data gaps in the basic understanding of a number of general, global issues relevant to mercury. Based on submitted information and the compilation and evaluation hereof, a possible division of current data gaps of global relevance on mercury could be as follows (not in order of priority):

- Understanding and quantification of the **natural mechanisms affecting the fate of**

mercury in the environment, such as mobilisation, transformation, transports and intake. In other words, the pathways of mercury in the environment, and from the environment to humans;

- Understanding and quantification – in a global perspective – of the **human conduct in**

relation to mercury releases, and the resulting human contributions to the local, regional and global mercury burden. In other words, the pathways of mercury from humans to the environment and

- Knowledge expansion base on mercury to improve risk assessment and ensure effective

risk management. Some of the needs include, among others;

CHAPTER 6: RECOMMENDATIONS

6.1 PREVENTION AND CONTROL TECHNOLOGIES AND PRACTICES

As noted in previous sections, the sources of releases of mercury to the biosphere can be grouped in four major categories. Two of these categories (releases due to natural mobilisation of mercury and re-mobilisation of anthropogenic mercury previously deposited in soils, sediments and water bodies) are not well understood and largely beyond human control.

The other two are current anthropogenic mercury releases. Reducing or eliminating these releases will require:

- Investments in controlling releases from and substituting the use of mercury-contaminated raw materials and feedstocks, the main source of mercury releases from "unintentional" uses; and

- Reducing or eliminating the use of mercury in products and processes, the main source of releases caused by the "intentional" use of mercury.

The specific methods for controlling mercury releases from these sources vary widely, depending upon local circumstances, but fall generally under the following four groups:

- Reducing mercury consumption of raw materials and products that generate mercury releases;

- Substitution (or elimination) of products, processes and practices containing or using mercury with non-mercury alternatives;

- Controlling mercury releases through end-of-pipe techniques;

- Introducing mercury waste management.

The first two of these are "preventive" measures – preventing some uses or releases of mercury from occurring at all. The latter two are "control" measures, which reduce (or delay) some releases from reaching the environment. Within these very general groupings are a large number of specific techniques and strategies for reducing mercury releases and exposures. Whether or not they are applied in different countries depends upon government and local priorities, information and education about possible risks, the legal framework, enforcement, implementation costs, perceived benefits and other factors.

6.1.1 REDUCING CONSUMPTION OF RAW MATERIALS AND PRODUCTS THAT GENERATE MERCURY RELEASES

Reducing consumption of raw materials and products that generate mercury releases is a preventive measure that is most often targeted at mercury containing products and processes, but may also result from improved efficiencies in the use of raw materials or in the use of fuels for power generation. This group of measures could potentially include the choice of an alternative raw material such as using natural gas for power generation instead of coal, or possibly by using a coal type with special constituents (such as more chlorine), because the mercury emissions from burning this type of coal might be easier to control than other coal types.

Another possible approach in some regions might be the use of coal with lower trace mercury content (mercury concentrations appear to vary considerably in some regions depending on the origin of the raw materials). However, there are some limitations and potential problems with this approach. For example, as in the case of the utility preference for low-sulphur crude oil, it is likely that some utilities might be willing to pay more for low-mercury coal, which effectively lowers the market value of all high-mercury coal, which in turn might lead to higher consumption of high-mercury coal in regions where utilities have less rigorous emission controls. Moreover, data collected recently in the US indicate that coal supplies in the US do not vary significantly in mercury content.

Nonetheless, such preventive measures aimed at reducing mercury emissions are generally cost-effective, except in cases where an alternative raw material is significantly more expensive or where other problems limit this approach.

6.1.2 SUBSTITUTION OF PRODUCTS AND PROCESSES CONTAINING OR USING MERCURY

Substitution of products and processes containing or using mercury with products and processes without mercury may be one of the most powerful preventive measures for influencing the entire flow of mercury through the economy and environment. It may substantially reduce mercury in households (and reduce accidental releases, as from a broken thermometer), the environment, the waste stream, incinerator emissions and landfills. Substitutions are mostly cost-effective, especially as they are demanded by a larger and

larger market. This group of measures would also include the conversion of a fossil-fuelled generating plant to a non-fossil technology.

At the same time, it would be a mistake to assume that substitution is always a clear winner. For example, in the case of energy-efficient fluorescent lamps, as long as there are no competitive substitutes that do not contain mercury, it is generally preferable from a product-life-cycle perspective to use a mercury-containing energy-efficient lamp rather than to use a less efficient standard incandescent lamp containing no mercury, as a result of current electricity production practises.

6.1.3 Controlling mercury emissions through end-of-pipe techniques

Controlling mercury emissions through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to raw materials with trace mercury contamination, including fossil-fuelled power plants, cement production (in which the lime raw material often contains trace mercury), the extraction and processing of primary raw materials such as iron and steel, ferromanganese, zinc, gold and other non-ferrous metals and the processing of secondary raw materials such as iron and steel scrap. Existing control technologies that reduce SO_2, NO_x and PM for coal-fired boilers and incinerators, while not yet widely used in many countries, also yield some level of mercury control. For coal-fired boilers, reductions range from 0-96 %, depending on coal type, boiler design, and emission control equipment. On average, the lower the coal rank, the lower the mercury reductions; however, reductions may also vary within a given coal rank. Technology for additional mercury control is under development and demonstration, but is not yet commercially deployed. In the long run, control strategies that target multiple pollutants, including SO_2, NO_x, PM and mercury, may be a cost-effective approach. However, end-of-pipe control technologies, while mitigating the problem of atmospheric mercury pollution, still result in mercury wastes that are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner.

6.1.4 Mercury waste management

Mercury wastes, including those residues recovered by end-of-pipe technologies, constitute a special category of mercury releases, with the potential to affect populations far from the initial source of the mercury. Mercury waste management, the fourth “control” measure mentioned above, may consist of rendering inert the mercury content of waste, followed by

controlled landfill, or it may not treat the waste prior to landfill. In Sweden, the only acceptable disposal of mercury waste now consists of "final storage" of the treated waste deep underground, although some technical aspects of this method are yet to be finalised.

Mercury waste management has become more complex as more mercury is collected from a greater variety of sources, including gas filtering products, sludges from the chlor-alkali industry, ashes, slags, and inert mineral residues, as well as used fluorescent tubes, batteries and other products that are often not recycled. Low concentrations of mercury in waste are generally permitted in normal landfills, while some nations only allow waste with higher mercury concentrations to be deposited in landfills that are designed with enhanced release control technologies to limit mercury leaching and evaporation. The cost of acceptable disposal of mercury waste in some countries is such that many producers now investigate whether alternatives exist in which they would not have to produce and deal with mercury waste. Mercury waste management, as it is most commonly done today, in accordance with national and local regulations, increasingly requires long-term oversight and investment. Proper management of mercury wastes is important to reduce releases to the environment, such as those that occur due to spills (i.e. from broken thermometers and manometers) or releases that occur over time due to leakage from certain uses (e.g., auto switches, dental amalgams). In addition, given that there is a market demand for mercury; collection of mercury-containing products for recycling limits the need for new mercury mining.

6.1.5 Emission prevention and control measures

A well thought-out combination of emission prevention and control measures is an effective way to achieve optimal reduction of mercury releases. If one considers some of the more important sources of anthropogenic mercury releases, one may see how prevention and control measures might be combined and applied to these sources:

- Mercury emissions from **municipal and medical waste incinerators** may be reduced

by separating the small fraction of mercury containing waste before it is combusted. For example, in the USA, free household mercury waste collections have been very successful in turning up significant quantities of mercury-containing products and even jars of elemental mercury. Also, separation programmes have proved successful in the hospital sector and a number of hospitals have pledged to avoid purchasing mercury-containing products through joint industry-NGO-Government programmes. However, separation programmes are sometimes difficult or costly to implement widely, especially when dealing with the general public. In such cases a better long-term

solution may be to strongly encourage the substitution of non-mercury products for those containing mercury. As a medium term solution, separation programmes may be pursued, and mercury removed from the combustion stack gases. Mercury emissions from medical and municipal waste incineration can be controlled relatively well by addition of a carbon sorbent to existing PM and SO_2 control equipment, however, control is not 100% effective and mercury-containing wastes are generated from the process;

- Mercury emissions from **utility and non-utility boilers**, especially those burning coal,

may be effectively addressed through pre-combustion coal cleaning, reducing the quantities of coal consumed through increased energy efficiency, end-of-pipe measures such as stack gas cleaning and/or switching to non-coal fuel sources, if possible. Another potential approach might be the use of coal with lower mercury content. Coal cleaning and other pre-treatment options can certainly be used for reducing mercury emissions when they are viable and cost-effective. Also, additional mercury capture may be achieved by the introduction of a sorbent prior to existing SO_2 and PM control technologies. These technologies are under development and demonstration, but are not yet commercially deployed. Also, by-products of these processes are potential sources of future emissions and must be disposed of or reused in an environmentally acceptable manner;

- Mercury emissions due to **trace contamination of raw materials or feedstocks** such

as in the cement, mining and metallurgical industries may be reduced by end-of-pipe controls, and sometimes by selecting a raw material or feedstock with lower trace contamination, if possible;

- Mercury emissions during **scrap steel production**, scrap yards, shredders and

secondary steel production, result primarily from convenience light and anti-lock brake system (ABS) switches in motor vehicles; therefore a solution may include effective switch removal/collection programmes;

- Mercury releases and health hazards from **artisanal gold mining** activities may be

reduced by educating the miners and their families about hazards, by promoting certain techniques that are safer and that use less or no mercury and, where feasible, by putting in place facilities where the miners can take concentrated ores for the final refining process. Some countries have tried banning the use of mercury by artisanal miners, which may serve to encourage their use of central processing facilities, for example, but enforcement of such a ban can be difficult;

- Mercury releases and occupational exposures during **chlor-alkali production** may be

substantially reduced through strict mercury accounting procedures, "good housekeeping" measures to keep mercury from being dispersed, properly filtering exhaust air from the facility and careful handling and proper disposal of mercury wastes. There are a number of specific prevention methods to reduce mercury emissions to the atmosphere. The US chlor-alkali industry invented the use of

ultraviolet lights to reveal mercury vapour leaks from production equipment, so that they could be plugged. Equipment is allowed to cool before it is opened, reducing mercury emissions to the atmosphere. A continuous mercury vapour analyser can be employed to detect mercury vapour leaks and to alert workers so that they can take remedial measures. The generally accepted long-term solution is to encourage the orderly phase-out of chlor-alkali production processes that require mercury, and their substitution with technologies that are mercury free;

- Mercury releases and exposures related to mercury-containing **paints, soaps, various**

switch applications, thermostats, thermometers, manometers, and barometers, as well as **contact lens solutions, pharmaceuticals and cosmetics** may be reduced by substituting these products with non-mercury products;

- Mercury releases from **dental practices** may be reduced by preparing mercury

amalgams more efficiently, by substituting other materials for mercury amalgams, and by installing appropriate traps in the wastewater system;

- Mercury emissions from dental amalgams during **cremation** may only be reduced by

removing the amalgams before cremation, which is not a common practice, or by filtering the gaseous emissions when the practice takes place in a crematorium. Since a flue gas cleaner is an expensive control technique for a crematorium, prevention by substituting other materials for mercury amalgams during normal dental care might be a preferred approach;

- In cases of **uncontrolled disposal of mercury-containing products or wastes**,

possible reductions in releases from such practises might be obtained by making these practices illegal and adequately enforcing the law, by enhancing access to hazardous waste facilities, and, over the longer term, by reducing the quantities of mercury involved through a range of measures encouraging the substitution of non-mercury products and processes.

6.2 INITIATIVES FOR CONTROLLING RELEASES, LIMITING USES AND EXPOSURE

6.2.1 National initiatives

The environmental authorities in a number of countries consider mercury to be a high-priority substance with recognised adverse effects. They are aware of the potential problems caused by use and release of mercury and mercury compounds, and therefore, have implemented measures to limit or prevent certain uses and releases. Types of measures that have been implemented by various countries include:

i. Environmental quality standards, specifying a maximum acceptable mercury concentration for different media such as drinking water, surface waters, air and soil and for foodstuffs such as fish;

ii. Environmental source actions and regulations that control mercury releases into the environment, including emission limits on air and water point sources and promoting use of best available technologies and waste treatment and disposal restrictions;

iii. Product control actions and regulations for mercury-containing products, such as batteries, cosmetics, dental amalgams, electrical switches, laboratory chemicals, lighting, paints/pigments, pesticides, pharmaceuticals, thermometers and measuring equipment;

iv. Other standards, actions and programmes, such as regulations on exposures to mercury in the workplace, requirements for information and reporting on use and releases of mercury in industry, fish consumption advisories and consumer safety measures.

Although legislation is the key components of most national initiatives, safe management of mercury also includes efforts to reduce the volume of mercury in use by developing and introducing safer alternatives and cleaner technology, the use of subsidies to support substitution efforts and voluntary agreements with industry or users of mercury. A number of countries have through implementation of this range of measures obtained significant reductions in mercury consumption, and corresponding reductions of uses and releases.

6.3 REGIONAL AND INTERNATIONAL INITIATIVES

It is also apparent that because of mercury's persistence in the environment and the fact that it is transported over long distances by air and water, crossing borders and often accumulating in the food chain far from its original point of release, a number of countries have concluded that national measures are not sufficient. There are a number of examples where countries have initiated measures at regional, sub-regional and international levels to identify common reduction goals and ensure coordinated implementation among countries in the target area.

Three regional, legally binding instruments exist that contain binding commitments for parties with regards to reductions on use and releases of mercury and mercury compounds:

- LRTAP Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (for Central and Eastern Europe and Canada and the USA);

- OSPAR Convention for Protection of the Marine Environment of the North-East

Atlantic; and

- Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea.

All these three instruments have successfully contributed to substantial reductions in use and releases of mercury within their target regions. However, no such instruments exist in Africa.

The regional and sub-regional cooperation is, however, not limited to legally binding agreements. Six initiatives exist at regional or sub-regional levels that inspire and promote cooperative efforts to reduce uses and releases of mercury within the target area without setting legally binding obligations on the countries/regions participating. The initiatives are: the Arctic Council Action Plan, the Canada-US Great Lakes Bi-national Toxics Strategy, the New England Governors/Eastern Canada Premiers Mercury Action Plan, the North American Regional Action Plan, the Nordic Environmental Action Programme and the North Sea Conferences. Important aspects of these initiatives are the discussion and agreement on concrete goals to be obtained through the cooperation, the development of strategies and work plans to obtain the set goals and the establishment of a forum to monitor and discuss progress. Although these initiatives are not binding on their participants, there is often a strong political commitment to ensure that the agreements reached within the initiative are implemented at national/regional level.

There are also a number of examples of national/regional initiatives being taken by the private sector in the form of voluntary commitments that can be seen as an adjunct to public sector initiatives and as having a good chance of success as they have, by definition, the support of the primary stakeholders. All these voluntary initiatives are valuable supplements to national regulatory measures and facilitate awareness raising, information exchange and the setting of reduction goals that benefit the target region.

At the international level, two multilateral environmental agreements (MEAs) exist that are of relevance to mercury and mercury compounds:

- the Basel Convention on Control of Transboundary Movements of Hazardous Wastes and their Disposal and
- the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Chemicals and Pesticides in International Trade. These instruments regulate trade in

unwanted chemicals/pesticides or hazardous wastes. However, they do not contain specific commitments to reduce uses and releases of mercury directly. The most recently negotiated agreement relevant to chemicals, the Stockholm Convention on POPs, does not cover mercury. In addition, a number of international organizations have ongoing activities addressing the adverse impacts of mercury on humans and the environment.

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APPENDIX 1: INVENTORY LEVEL 1 CALCULATION SPREADSHEETS

Appendix1.1: Energy consumption and fuel production

Source category	Source present?	Activity rate		Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y						
Energy consumption	**Y/N/?**	Annual consumption/production	Unit	Standard estimate	Air	Water	Land	**By-products and impurities**	**General waste**	Sector specific waste treatment /disposal	Cat. no.
Coal combustion in large power plants	y	124,580,000	t coal combusted/y	33,637	30,272.9	0.0	0.0	0.0	3,363.7	0.0	5.1.1
Other coal uses	y	41,444,000	t coal used/y	11,190	10,070.9	0.0	0.0	0.0	1,119.0	0.0	5.1.2
Combustion/use of petroleum coke and heavy oil	y	2,717,000	t oil product combusted/y	149	149.4	0.0	0.0	0.0	0.0	0.0	5.1.3
Combustion/use of diesel, gasoil, petroleum, kerosene	y	7,270,000	t oil product combusted/y	40	40.0	0.0	0.0	0.0	0.0	0.0	5.1.3
Use of raw or pre-cleaned natural gas	Y	1,415,384,615	Nm3 gas/y	142	141.5	0.0	0.0	0.0	0.0	0.0	5.1.4
Use of pipeline gas (consumer quality)	Y	292,333	Nm3 gas/y	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1.4
Biomass fired power and heat production	y	4,996	t biomass combusted/y (dry weight)	0	0.1	0.0	0.0	0.0	0.0	0.0	5.1.6
Charcoal combustion	Y	100,000	t charcoal combusted/y	12	12.0	0.0	0.0	0.0	0.0	0.0	5.1.6
Fuel production											
Oil extraction	Y	254,184	t crude oil produced/y	14	0.0	2.8	0.0	0.0	0.0	0.0	5.1.3
Oil refining	y	18,096	t oil refined/y	1	0.2	0.0	0.0	0.0	0.1	0.0	5.1.3
Extraction and processing of natural gas	Y	1,247,435,897	Nm3 gas/y	125	18.7	24.9	0.0	37.4	43.7	0.0	5.1.4

Appendix 1.2: Domestic production of metals and raw materials

Source category	Source present?	Activity rate		Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y					
	Y/N/?	Annual consumption/production	Unit	Standard estimate	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Primary metal production										
Mercury (primary) extraction and initial processing	N	0	t mercury produced/y	-	-	-	-	-	-	-
Production of zinc from concentrates	Y	50,909	t concentrate used/y	5,345	534.5	0.0	1,603.6	1,603.6	0.0	1,603.6
Production of copper from concentrates	Y	331,614	t concentrate used/y	2,653	265.3	53.1	636.7	1,061.2	0.0	636.7
Production of lead from concentrates	Y	78,014	t concentrate used/y	7,879	787.9	0.0	2,363.8	2,363.8	0.0	2,363.8
Gold extraction by methods other than mercury amalgamation	Y	39,600,000	t gold ore used/y	2,178,000	87,120.0	43,560.0	1,960,200.0	87,120.0	0.0	0.0
Alumina production from bauxite (aluminium production)	Y	1,024,768	t bauxit processed/y	512	76.9	51.2	0.0	0.0	333.0	51.2
Primary ferrous metal production (iron, steel production)	Y	66,753,757	t pig iron produced/y	3,338	3,170.8	0.0	0.0	0.0	0.0	166.9
Gold extraction with mercury amalgamation - without use of retort	N	0	kg gold produced/y	-	-	-	-	-	-	-
Gold extraction with mercury amalgamation - with use of retorts	N	0	kg gold produced/y	-	-	-	-	-	-	-
Other materials production										
Cement production	Y	14,252,000	t cement produced/y	3,919	2,351.6	0.0	0.0	783.9	783.9	0.0
Pulp and paper production	Y	3,595,000	t biomass used in production/y	108	107.9	0.0	0.0	0.0	0.0	0.0

Appendix 1.3: General waste management setup in the country

Source category	Source present?	Activity rate		Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y					
Production of recycled of metals	**Y/N/?**	Annual production /waste disposal	Unit	Standard estimate	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Production of recycled mercury ("secondary production")	N		kg mercury produced/y	-	-	-	-	-	-	-
Production of recycled ferrous metals (iron and steel)	Y	38,000	number of vehicles recycled/y	42	13.8	0.0	14.2	0.0	13.8	0.0
Waste incineration										
Incineration of municipal/general waste	N		t waste incinerated/y	-	-	-	-	-	-	-
Incineration of hazardous waste	N		t waste incinerated/y	-	-	-	-	-	-	-
Incineration of medical waste	Y	28	t waste incinerated/y	1	0.6	0.0	0.0	0.0	0.0	0.1
Sewage sludge incineration	N		t waste incinerated/y	-	-	-	-	-	-	-
Open fire waste burning (on landfills and informally)	N		t waste burned/y	-	-	-	-	-	-	-
Waste deposition/landfilling and waste water treatment										
Controlled landfills/deposits	Y	20,000,000	t waste landfilled/y	100,000	1,000.0	10.0	0.0	-	-	-
Informal dumping of general waste *1	Y	200,000	t waste dumped/y	1,000	100.0	100.0	800.0	-	-	-
Waste water system/treatment	Y	7,600,000	m3 waste water/y	40	0.0	35.9	0.0	0.0	4.0	0.0

Source category	Source present?	Activity rate		Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y					
	Y/N/?	Annual consumption/population	Unit	Standard estimate	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
			NOTE: Selection regarding waste management:		More than 2/3 of the waste is collected and treated under public control					
Use and disposal of products with mercury content										
Dental amalgam fillings ("silver" fillings)	***Y***			***7,588***	***151.8***	***2,519.2***	***0.0***	***273.2***	***1,456.9***	***1,456.9***
Preparations of fillings at dentist clinics		50,586,750	number of inhabitants		151.8	1,062.3	0.0	0.0	910.6	910.6
Use - from fillings already in the mouth		50,586,750	number of inhabitants		0.0	91.1	0.0	0.0	0.0	0.0
Disposal (lost and extracted teeth)		50,586,750	number of inhabitants		0.0	1,365.8	0.0	273.2	546.3	546.3
Thermometers	***Y***	***80,767***		***521***	***52.1***	***156.2***	***0.0***	***0.0***	***312.5***	***0.0***
Medical Hg thermometers	Y	40,767	items sold/y	41						
Other glass Hg thermometers (air, laboratory, dairy, etc.)	Y	40,000	items sold/y	480						
Engine control Hg thermometers and other large industrial/speciality Hg thermometers	?		items sold/y	?						
Electrical switches and relays with mercury	Y	50,586,750	number of inhabitants	7,082	708.2	0.0	708.2	0.0	5,665.7	0.0
Light sources with mercury	***Y***	*8,899,066*	items sold/y	***117***	***5.9***	***0.0***	***0.0***	***0.0***	***111.4***	***0.0***
Fluorescent tubes (double end)	Y	1,829,066	items sold/y	46						
Compact fluorescent lamp (CFL single end)	Y	7,000,000	items sold/y	70						

	Y/N/?	Annual consumption/population	Unit	Standard estimate	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal
Other Hg containing light sources (see guideline)	Y	70,000	items sold/y	2						
Batteries with mercury	***Y***	***2,500***	***t batteries sold/y***	***625***	***0.0***	***0.0***	***0.0***	***0.0***	***625.0***	***0.0***
Mercury oxide (button cells and other sizes); also called mercury-zinc cells	?		t batteries sold/y	?						
Other button cells (zinc-air, alkaline button cells, silver-oxide)	N	0	t batteries sold/y	-						
Other batteries with mercury (plain cylindrical alkaline, permanganate, etc., see guideline)	Y	2,500	t batteries sold/y	625						
Polyurethane (PU, PUR) produced with mercury catalyst	N	50,586,750	number of inhabitants	-	-	-	-	-	-	-
Paints with mercury preservatives	N		t paint sold/y	-	-	-	-	-	-	-
Skin lightening creams and soaps with mercury chemicals	Y	2	t cream or soap sold/y	60	0.0	57.0	3.0	0.0	0.0	0.0
Medical blood pressure gauges (mercury sphygmomanometers)	Y	40,767	items sold/y	3,261	326.1	978.4	0.0	0.0	1,956.8	0.0
Other manometers and gauges with mercury	Y	50,586,750	number of inhabitants	253	25.3	75.9	0.0	0.0	151.8	0.0
Laboratory chemicals	Y	50,586,750	number of inhabitants	506	0.0	166.9	0.0	0.0	166.9	172.0
Other laboratory and medical equipment with mercury	Y	50,586,750	number of inhabitants	2,023	0.0	667.7	0.0	0.0	667.7	688.0

Appendix 1.4: Crematoria and cemeteries

Source category	Source present?	Activity rate		Estimated Hg input, Kg Hg/y	Estimated Hg releases, standard estimates, Kg Hg/y						
Crematoria and cemeteries	**Y/N/?**	Annual numbers dead	Unit	Standard estimate	Air	Water	Land	By-products and impurities	General waste	Sector specific waste treatment /disposal	Cat. no.
Crematoria	Y	37,475	corpses cremated/y	94	93.7	0.0	0.0	-	0.0	0.0	5.10.1
Cemeteries	Y	587,116	corpses buried/y	1,468	0.0	0.0	1,467.8	-	0.0	0.0	5.10.2

Appendix 1.5: Miscellaneous mercury release sources not quantified on Inventory level 1

Source category	Source present?
	Y/N/?
Combustion of oil shale	N
Combustion of peat	N
Geothermal power production	N
Production of other recycled metals	Y
Production of lime	Y
Production of light weight aggregates (burnt clay nuts for building purposes)	Y
Chloride and sodium hydroxide produced from mercury-cell technology	N
Polyurethane production with mercury catalysts	N
Seed dressing with mercury chemicals	Y
Infra red detection semiconductors	Y
Bougie tubes and Cantor tubes (medical)	Y
Educational uses	Y
Gyroscopes with mercury	Y
Vacuum pumps with mercury	Y
Mercury used in religious rituals (amulets and other uses)	N
Mercury used in traditional medicines (ayurvedic and others) and homeopathic medicine	N
Use of mercury as a refrigerant in certain cooling systems	N
Light houses (levelling bearings in marine navigation lights)	Y
Mercury in large bearings of rotating mechanic parts in for example older waste water treatment plants	N
Tanning	?
Pigments	Y
Products for browning and etching steel	?
Certain colour photograph paper types	?
Recoil softeners in rifles	?
Explosives (mercury-fulminate a.o.)	?
Fireworks	?
Executive toys	?

Source category	Source present?	
	Y/N/?	
Combustion of oil shale	N	
Combustion of peat	N	
Geothermal power production	N	
Production of other recycled metals	Y	
Production of lime	Y	
Production of light weight aggregates (burnt clay nuts for building purposes)	Y	
Chloride and sodium hydroxide produced from mercury-cell technology	N	
Polyurethane production with mercury catalysts	N	
Seed dressing with mercury chemicals	Y	
Infra red detection semiconductors	Y	
Bougie tubes and Cantor tubes (medical)	Y	
Educational uses	Y	
Gyroscopes with mercury	Y	
Vacuum pumps with mercury	Y	
Mercury used in religious rituals (amulets and other uses)	N	
Mercury used in traditional medicines (ayurvedic and others) and homeopathic medicine	N	
Use of mercury as a refrigerant in certain cooling systems	N	
Light houses (levelling bearings in marine navigation lights)	Y	
Mercury in large bearings of rotating mechanic parts in for example older waste water treatment plants	N	
Tanning	?	
Pigments	Y	
Products for browning and etching steel	?	
Certain colour photograph paper types	?	
Recoil softeners in rifles	?	
Explosives (mercury-fulminate a.o.)	?	
Fireworks	?	
Executive toys	?	