MERCURY RISING

Kamuzu Central Hospital incinerator – Lilongwe, Malawi

Photo credit: Murray (Picasa)

Reducing global emissions from burning mercury-added products

Mercury Policy Project

February 2009

zero Hg mercury working group

BAN TOXICS!

gaia

Global Alliance for Incinerator Alternatives
Global Anti-Incinerator Alliance

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Disclaimer

[1] The **Mercury Policy Project** (www.mercurypolicy.org) coordinated this report,. Co-releasers include the following:

The **Zero Mercury Working group** is an international coalition of more than 40 public-interest non-governmental organizations from around the world, formed in 2005 by the European Environmental Bureau and the Mercury Policy Project/Ban Mercury Working Group. The aim of the group is to continually reduce emissions, demand and supply of mercury, from all sources we can control, with the goal of eliminating mercury in the environment within the EU and globally. For further information, please see www.zeromercury.org.

Ban Toxics! is an independent non-profit Asian regional environmental non-governmental organization that is focused on empowering local communities on the issue of toxics in order to reform national and regional toxics policy, making it more responsive and respectful to the needs of people and the environment. Ban Toxics! is an active member of Zero Mercury Working Group (ZMWG) and is the Asia-Pacific node of the Basel Action Network. For more information, please consult www.bantoxics.multiply.com.

GAIA is a worldwide alliance of more than 600 grassroots groups, non-governmental organizations, and individuals in over 80 countries whose ultimate vision is a just, toxic-free world without incineration. The GAIA alliance works against incinerators and for safe, sustainable and just alternatives. Further information may be found at www.no-burn.org.

Executive summary

This assessment has been prepared for the Mercury Policy Project/Tides Center and is being co-released by the Zero Mercury Working Group (ZMWG), Ban Toxics! and the Global Alliance for Incinerator Alternatives (GAIA).

Project objective

The atmospheric mercury (Hg) emissions from waste have long been inadequately understood and seriously underestimated. This report scrutinizes the largest contributor to mercury in the waste stream – mercury-added products – and greatly improves our global understanding of this source of emissions.

Report recommendations

The magnitude of mercury releases to air from sources involving the combustion, both controlled and uncontrolled, of mercury-added products attests to the need for globally coordinated actions to phase out the manufacture, sale and use of such products. Toward that end, it is recommended that the United Nations Environment Program Governing Council take the following steps at its February 2009 meeting in Nairobi:

1) Establish an Intergovernmental Negotiating Committee (INC) for the purpose of negotiating a free-standing legally binding instrument on mercury that shall include, in part, provisions to phase out as soon as possible the use of mercury in the manufacture of products for which viable non-mercury alternatives are available, such as measuring devices, batteries, and switches, recognizing that the time frames for such phase-outs may differ depending upon the product and the circumstances of the different countries.
2) Request that UNEP, in the interim period before such an instrument becomes effective, assume responsibility for the awareness-raising, analytical, technical and legal support activities necessary to encourage manufacturers of mercury-added products, and countries where such manufacturers are located, to identify and implement the actions needed to shift production toward mercury-free alternative products.
3) Recognize that combustion of mercury-added products in incinerators, landfill fires and open burning of domestic waste is a significant contributor of mercury and other toxics to both local and global ecosystems, and urge countries to take steps to stop these practices and to move expeditiously towards safe, just, sustainable and more environmentally-sound alternatives.
4) Request that UNEP take account of the additional emissions identified in this report in its revision of the draft AMAP/UNEP (2008) Technical Background Report to the Global Atmospheric Mercury Assessment.

Report findings

In this report, the main burning processes investigated were medical waste incineration, municipal and hazardous waste incineration, municipal wastewater sludge incineration, and landfill fires and open burning. For these four categories, the global mercury releases to the air from the burning of wastes containing mercury-added products[2] are estimated as follows.

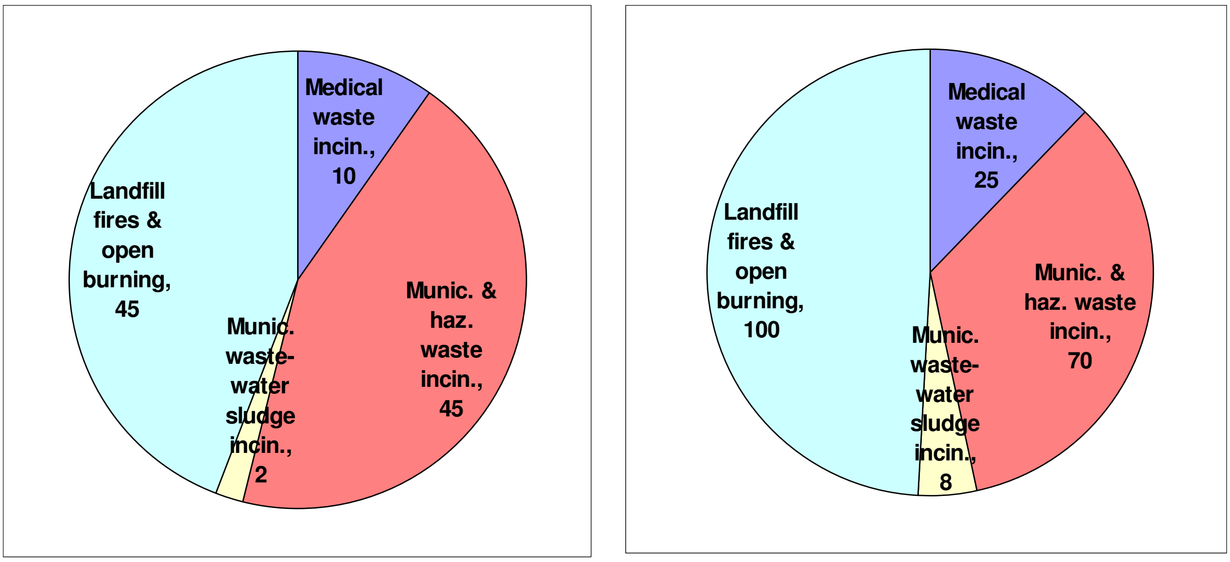
Global mercury emissions (tonnes) to air from burning mercury-added products (2005)

Key waste stream burning processes	Atmospheric mercury emissions tonnes)
Medical waste incineration	10-25
Incineration of mercury-added products in municipal and hazardous waste	45-70
Incineration of municipal wastewater sludge from products	2-8
Landfill fires and open burning of mercury-added products in domestic waste	45-100
Total	**~100-200**

The distribution of emissions among these burning processes is presented graphically in the following figure.

Global mercury emissions (tonnes) to air from burning mercury-added products (2005)

Lower end of range | *Upper end of range*



[2] A "mercury-added product" is defined as any product (e.g. batteries, thermometers, dental amalgam) to which mercury is intentionally added in order to perform the function for which the product is intended. For example, coal is not a mercury-added product since the mercury occurs as a trace contaminant and is not intentionally added. Caustic soda is not a mercury-added product since the mercury occurs as incidental contamination in plants using the mercury cell chlor-alkali process.

While others have estimated mercury releases to air from the combustion of wastes containing mercury-added products, none have looked carefully at the substantial emissions contributed by landfill fires and open burning of domestic waste.

Focusing solely on the presence of mercury-added products in the waste stream, the following table compares our calculation with three other recent estimates of emissions to the atmosphere from waste burning processes.

"Best estimates" of mercury emissions (tonnes) to air from burning mercury-added products

Key waste stream burning processes	**Mercury Policy Project, "Mercury Rising" (this report)**	***Ambio*, Socioeconomic Consequences (Swain *et al.* 2007)**	**Hg Air Transport & Fate Research Partnership (UNEP 2008b)**	**Global Atmospheric Mercury Assessment (AMAP/UNEP 2008)**
Reference year	*2005*	*2005*	*2007*	*2005*
Medical waste incineration	15	13	20[a]	[b]
Incineration of mercury-added products in municipal and hazardous waste	58	37	50[a]	57
Incineration of municipal wastewater sludge from products	4	0	0	0
Landfill fires and open burning of mercury-added products in domestic waste	64	0	0	0
Total	**141**	**50**	**70[a]**	**57**

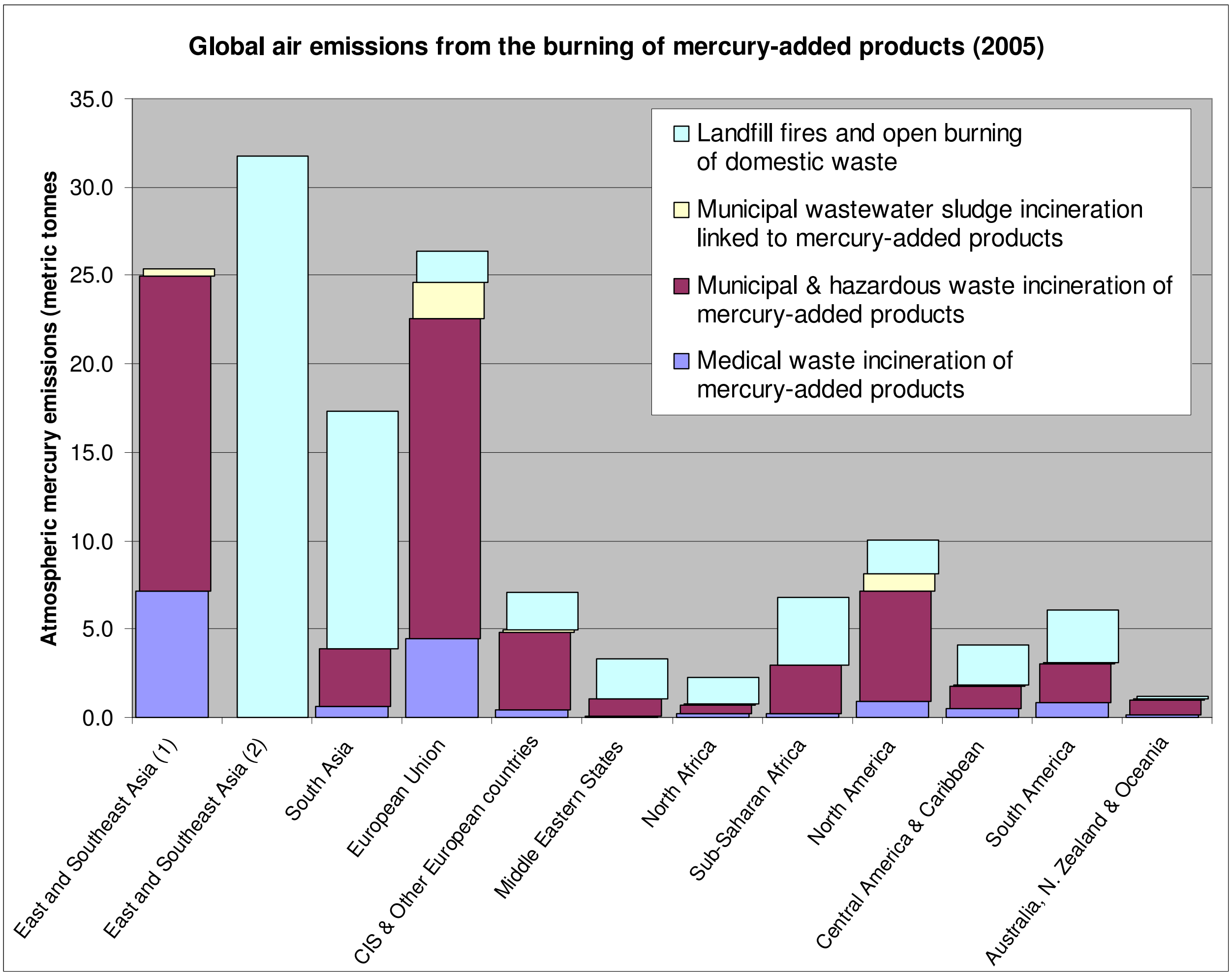
a) A certain (undefined) percentage of these emissions should be attributed to the disposal of mercury process or other wastes not specifically linked to mercury-added products. Therefore, a somewhat lower number should be used for comparative purposes.

b) These emissions are included in the category for municipal waste incineration.

While the different categories of combustion emissions are associated with different levels of uncertainty (e.g., less uncertainty related to municipal waste incineration, and more uncertainty related to uncontrolled burning of waste), this assessment has calculated a total of about 140 tonnes mercury emissions (not including burning of manufacturing wastes), which is our "best estimate" within a wider range of some 100-200 tonnes.

The regional distribution of mercury releases to air from these four main sources of combustion of mercury-added products is shown below.

Regional distribution of mercury emissions (tonnes) to air from burning mercury-added products



The magnitude of emissions in East and Southeast Asia (and South Asia, to a lesser extent) due to landfill fires and open burning of domestic waste reflects a combination of significant open burning, especially in rural areas, a large amount of mercury consumed in products in this region, and very low recycling rates.

Likewise with regard to incineration, even though formal incineration of municipal waste is not common in most countries in Asia, the generation of large volumes of waste, the relatively high use and disposal of mercury-added products, and the fact that Japan, in particular, incinerates a very high percentage of its waste help to explain the magnitude of regional atmospheric mercury emissions from incineration.

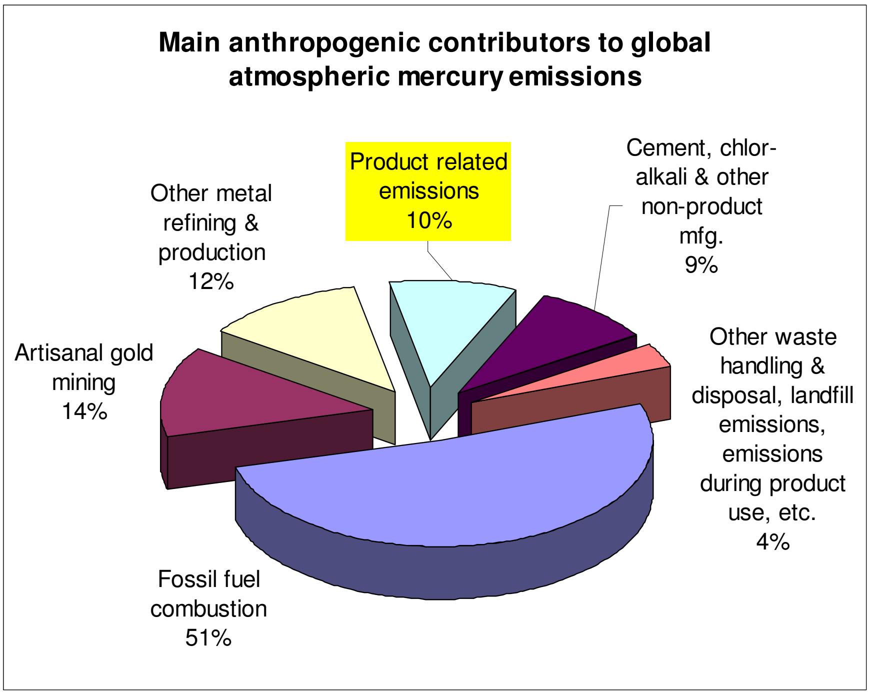
With regard to other regions, the European Union incinerates a large fraction of its municipal waste but has limited controls on mercury emissions from incinerators, while the US also has a high rate of incineration but has recently mandated stricter incinerator controls. All other regions have low incineration rates, and also relatively lower total volumes of municipal waste.

There are other product waste related sources of air emissions not investigated in this analysis, and not included in the tables and figures above, but estimated by other researchers, including cremation (20-30 tonnes Hg), industrial incineration of product manufacturing wastes and sludges (10-25 t Hg), non-combustion landfill emissions (10-45 t Hg), emissions during waste handling (3-8 t Hg), emissions from the wastewater treatment process (4-8 t Hg) and emissions from products that go through metal scrap processing (5-10 t Hg). Together these additional sources come to 50-125 t mercury.

Finally, product-related sources not linked to waste disposal, such as product manufacturing emissions, product breakage during use, etc., have been estimated by other researchers at 15-40 t mercury. When added to all of the above sources, global product-related mercury emissions are in the range of 165-365 t, with a best estimate around 250 t mercury, or about 10% of all anthropogenic mercury emissions.

The combined estimates of global anthropogenic emissions of the three recent research reports cited above are shown in the following figure, relative to total product-related emissions. It should be noted that product-related emissions are of the same general magnitude as major industrial process emissions and metal refining emissions, both of which are already subject to particular scrutiny.

Relative contribution of main anthropogenic sources of mercury emissions to air (~2005)



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MERCURY RISING:

Reducing global emissions from burning mercury-added products

1 Project overview

This assessment has been prepared for the Mercury Policy Project/Tides Center and is being co-released by the Zero Mercury Working Group (ZMWG), Ban Toxics! and the Global Alliance for Incinerator Alternatives (GAIA).

1.1 Objectives

The atmospheric mercury (Hg) emissions from waste have long been inadequately understood and seriously underestimated. As written recently by the Nordic Council of Ministers (Norden 2007):

> *Waste treatment is a major mercury release source. Some countries have waste management systems that reduce releases from mercury containing waste, but many countries worldwide do not have such waste management systems, and practices like open waste burning and informal dumpsites are not uncommon.*

This report scrutinizes the largest contributor to mercury in the waste stream – mercury-added products – and greatly clarifies our global understanding of this source of emissions. The report examines and quantifies mercury emissions to the air related to the burning of wastes containing “mercury-added” products.[1]

The main goal of this study is to develop a better understanding and more detailed modelling of the global life-cycle and fate of mercury-added products discarded to waste. Since the municipal, medical and hazardous waste streams are more commonly studied, this assessment makes a special effort to examine other common waste disposal practices, including uncontrolled or open burning, landfill fires, and other burning of mercury-added products that takes place in many parts of the world.

This study focuses on atmospheric mercury emissions related to burning. However, it is important to note that mercury captured by air pollution control devices, and thereby prevented from directly reaching the atmosphere, is retained in incinerator ashes and/or

[1] A “mercury-added product” is defined as any product (e.g. battery, thermometer, dental amalgam) to which mercury is intentionally added in order to perform the function for which the product is intended. Coal is not a mercury-added product since the mercury occurs as a trace contaminant and is not intentionally added. Caustic soda is not a mercury-added product since the mercury occurs as incidental contamination in plants using the mercury cell chlor-alkali process.

other residues, and may be released to air, soil or water during subsequent handling or disposal.

Already in the Global Mercury Assessment (UNEP 2002), it was emphasized: “Special attention should be paid to diffuse emissions from … household and uncontrolled waste incineration, as well as improvement of data from main point source categories … [including] waste incinerators and power plants using fossil fuel.” Since that time, there has been virtually no progress in our understanding of mercury emissions from landfill fires and open burning, and relatively little progress with regard to our understanding of emissions from other waste combustion processes.

Previous studies of waste emissions of mercury have been labelled with an uncertainty of up to a factor of five. Through an improved focus on burning practices around the world, and the experience gained during this investigation, it is estimated that the uncertainty in mercury emission estimates related to waste combustion processes could be improved to ±50% with relatively little effort, as compared to the ± 25% accuracy reported for recent estimates of mercury emissions from coal-fired power plants.

1.2 General approach

Based upon the extensive research carried out by UNEP and others, there is enough data now available about the consumption and disposal of mercury-added products in different countries, and enough information available about the composition of waste streams, that reasonable emission estimates can be derived from an analysis of the quantities of mercury contained in mercury-added products, the fraction of those products discarded to different waste pathways, the fraction of those wastes incinerated or burned, and the percentage of total mercury content released during burning.

This analysis has used previous research findings on mercury products in the waste stream, as well as additional data gathered for this study, to quantify the volumes of waste generated by different geographical regions (e.g., UN regions – North America, South America, Europe, Africa, East Asia, South Asia, Arab States, etc.) and sub-regions; to characterise waste disposal practices for each region; and to identify typical incinerator characteristics (or emission factors), as available, by region.

1.3 The mercury problem

Global deposition of mercury circulating in the atmosphere – much of it the result of human activities – has increased 3-fold since the Industrial Revolution, with some locations experiencing upwards of a 10-fold increase due to local or regional sources of mercury emissions. While atmospheric emissions are finally on the decline in North America and most of Europe, they continue to increase in Asia and Africa.

Atmospheric mercury emissions linked to human activities have been shown to come from a variety of sources, including coal combustion, non-ferrous metals processing, and small-scale gold mining. However, as documented in this report, the intentional use of mercury in a range of products is also a significant source of eventual mercury emissions.

Products to which mercury is intentionally added, or “mercury-added” products, include thermometers, other medical devices such as blood pressure cuffs, laboratory chemicals, batteries (particularly button cells), dental amalgams, certain electrical switches (in a variety of products such as thermostats and pumps), paints, and more recently, energy-efficient fluorescent lamps, or bulbs. Some 1400-1900 tonnes of mercury (or about 50% of global mercury consumption) are consumed in the manufacture of such products every year, and much of this mercury ends up in the waste stream. Typically, a certain part of the global waste stream ends up getting burnt, and that is the focus of this study.

When any waste containing mercury is burned, most of the mercury is vaporized during the combustion process. Depending on the nature of any air pollution control devices, some portion of the mercury is emitted to the atmosphere, and the remainder is retained in the incinerator ashes and/or other combustion residues. The burning of certain fractions of municipal, medical and other wastes is, therefore, a source of atmospheric mercury emissions, which eventually return to the earth through rain or dry deposition. Some of this mercury, especially after transformation into a more biologically available form such as methylmercury, typically finds its way into the food chain, contributing especially to the health risk of eating contaminated fish.

Mercury and its compounds are toxic to humans and the environment, and exposures at levels proven to confer adverse health and environmental effects are present today in many parts of the world. The toxicity to humans and other organisms depends on the chemical form, the amount, the pathway of exposure and the vulnerability of the person exposed. Human exposure to mercury can result from a variety of pathways, including, but not limited to, consumption of fish and other foods, occupational and household uses, dental amalgams and of course, emissions from the burning of coal and mercury wastes. Widespread exposures may be considerably worsened by human-generated sources, and past practices have left an inheritance of mercury in landfills, mine tailings, contaminated industrial sites, soils and sediments. The most significant human-generated releases of mercury pollution are emissions to air, but mercury is also released from various sources directly to water and land (UNEP 2002).

Once released, mercury persists in the environment, where it circulates among air, water, sediments, soil and biota in various forms. Current emissions add to the global pool – mercury that is continuously mobilised, deposited on land and water, and re-mobilised. Once deposited, the mercury form can change (primarily by microbial metabolism) to methylmercury, which has the capacity to bioaccumulate in organisms and to concentrate up through the food chain (biomagnify), especially in the aquatic food chain (fish and marine mammals). Methylmercury is therefore the form of greatest concern. Nearly all of the mercury in fish, for example, is methylmercury (UNEP 2002).

Some populations are especially susceptible to mercury exposure, most notably the foetus, the newborn, and the young child because of the extreme sensitivity of the developing nervous system. Indigenous populations and others who consume higher amounts of contaminated fish or marine mammals, as well as workers who are exposed to mercury, such as artisanal gold miners and dental workers, may be highly exposed to mercury and are therefore especially at risk. There are also particularly vulnerable ecosystems and wildlife populations. These include top predators in aquatic food webs (such as fish-eating birds and mammals), Arctic ecosystems, wetlands, tropical ecosystems and soil microbial communities (UNEP 2002).

The United Nations Environment Program (UNEP), based on expert advice and the consensus of UN member countries, has determined that mercury emissions – globally – need to be significantly reduced in order to lessen the health and environmental impacts. The UNEP Global Mercury Assessment report (UNEP 2002) summarised research that has established a clear link between anthropogenic mercury emissions and levels of mercury in fish, an important global protein source.

Mercury is highly dispersive, but can also lead to concentrated levels of mercury in local hotspots. Exacerbating the mercury contamination of fish in some areas, hotspots have been identified where multiple local sources contribute so much of the locally deposited mercury that they overwhelm the contribution from regional and global sources. The World Health Organization and numerous national governments have issued guidance to limit or ban the eating of certain species of seafood due to high levels of mercury contamination. However, the implementation of policies dealing with mercury-added products lags behind those dealing with mercury in fish.

1.4 The big picture

With regard to the bigger picture, the evaluation of global mercury emissions is often carried out as a part of an evaluation of global mercury budgets and fluxes using global mercury models. Flux estimates based on field measurements exist, but only representing relatively limited geographical areas and limited time scales. Model results based on Lamborg *et al.* (2002), Mason and Sheu (2002), Selin *et al.* (2007), and Mason (2008) have estimated anthropogenic emissions, or direct emissions from human activities, at 2200 to 2600 tonnes of mercury per year. Swain *et al.* (2007) have estimated 2400 tonnes/year, as in Table 1.

Table 1 Global (primary) anthropogenic mercury emissions (data from 1995-2000)

Sector	Atmospheric emissions (tonnes)
Fossil fuel combustion	1500
Ore refining	330
Artisanal gold mining	300
Manufacturing emissions	120
Product use	40
Product disposal, waste	110
Total	2400

Source: Swain *et al.* (2007)

UNEP (2008b) estimated anthropogenic emissions at about 2500 tonnes, as shown in Table 2 below. Moreover, like others previously, UNEP (2008b) estimated that about one-third of the mercury currently emitted to the atmosphere is derived from point and other identifiable anthropogenic sources (2503 tonnes/yr), of which coal combustion is the largest.

The remainder of the global emissions (5207 tonnes/yr), according to UNEP (2008b), are associated with “natural” processes, but many of these processes have been exacerbated by human activity (e.g. biomass burning), and therefore much of the mercury emitted from these sources likewise had an original anthropogenic source. Overall, UNEP (2008b) has estimated that about one-third of the total mercury emissions to the atmosphere from “natural” processes are due to the pre-industrial (natural) emission component, and the remainder are “recycled” (previously deposited) anthropogenic mercury.

Table 2 Global (primary) anthropogenic mercury emissions

Sector	Atmospheric emissions	Base year
Fossil fuel combustion	1422	2000
Pig iron and steel production	31	2000
Mercury production	50	2007
Other non-ferrous metal production	156	2007
Artisanal gold mining	400	2008
Cement production	140	2000
Chlor-alkali production	65	2000
Waste disposal	166	2007
Coal bed fires	6	2008
Other anthropogenic emissions	65	2007
Total	2503	

Source: UNEP (2008b)

Most recently, the AMAP/UNEP draft report prepared for consideration at the February 2009 UNEP Governing Council Meeting has estimated global anthropogenic mercury emissions at less than 2000 tonnes, as seen in Table 3 (AMAP/UNEP 2008).

Table 3 Estimated global anthropogenic emissions of mercury to air (2005)

Sector	Emissions (tonnes)	Low-end estimate	High-end estimate
Fossil fuel combustion for power and heating	878	595	1160
Metal production (ferrous and non-ferrous) excluding gold	200	123	276
Large-scale gold production	111	66	156
Artisanal and small-scale gold production	351	225	475
Cement production	189	114	263
Chlor-alkali industry	46.8	29	64
Waste incineration, waste and other	125	53	473
Cremation	25.7	24	28
Total	**1930**		

Source: AMAP/UNEP (2008)

Each of these global estimates devotes some attention to mercury emissions related to waste disposal. However, in dealing with emissions from waste disposal, previous publications have typically included diverse emissions besides those directly related to incineration or other burning. Depending on the scope and orientation of the research, these other emissions have included some or all of various contributions such as mercury emissions during the manufacturing process, emissions from breakage of products during collection and transport, emissions of landfill gases, emissions during wastewater treatment, emissions from incineration of industrial process wastes containing mercury, emissions during recycling of mercury wastes, etc.

1.5 Rationale

Mercury emissions from waste combustion have received relatively little international attention largely because of the lack of data on the magnitude of these emissions, and the tendency of researchers to avoid estimating such emissions when supporting data is inadequate. This sometimes leads to the impression that a summary of global emissions is comprehensive, when in fact it may not include some significant contributing sources.

Swain *et al.* (2007) noted that global atmospheric emissions from the disposal of mercury in products may be up to five times higher than he and his colleagues had estimated. The AMAP/UNEP (2008) draft report on global mercury emissions has confirmed that the same level of uncertainty still prevails.

This uncertainty is critical because, in recent years, a number of governments, as well as a large network of non-governmental organizations, have focused major efforts on reducing and eliminating mercury use in products – understanding that mercury-added products represent the major source of mercury in the medical waste and municipal solid waste streams, from where mercury releases to the environment are very difficult to control. However, because worldwide mercury emissions from incineration have been "underestimated" and are critically "incomplete," as described in the Global Mercury Assessment (UNEP 2002), this source has gone relatively unnoticed in international and national policy debates, and as a result, the relevance of mercury product contributions to those atmospheric emissions has not been given the attention it deserves.

1.5.1 Contribution to the UNEP process

The next UNEP Governing Council meeting is scheduled to be held in February 2009 in Nairobi, Kenya. At that time, the Governing Council will review the progress of UNEP's Mercury Program, including a specific mandate to review major sources of atmospheric mercury emissions designed to cover the following areas:

- best available data on mercury emissions and trends, including where possible an analysis by country, region and sector;
- modelling on a global scale and contribution of regional emissions to deposition; and
- sector-based best practices for reducing mercury emissions.

As one of the main items on the agenda, the Governing Council will assess the need for further action on mercury, including the possibility of a legally binding instrument and other actions.

The timing of this analysis is important because UNEP is organising a number of key emission related inputs into the deliberations of the UNEP Governing Council. It is intended that this analysis will be taken into account during the UNEP Governing Council deliberations. In fact, a constructive collaboration was established between this research and the UNEP/AMAP research team, as well as the research team working within the UNEP Mercury Air Transport and Fate Research partnership.

2 Methodology

2.1 Definitions

The term "emission" is often used interchangeably with the term "release." It is important to clarify that in this study the term "emission" is used only as defined in the Convention on Long-Range Transboundary Air Pollution (LRTAP) of the UNECE – in the specific sense of a "release to air." This report will, therefore, use the term "emission" interchangeably with “release to air,” “air emission,” “atmospheric emission,” and the like.

“Primary anthropogenic sources” are those where mercury of geological origin is mobilised and released to the environment. The two main source categories of this type are:

1. mining and smelting (either where mercury is the main element extracted, or where mercury is a by-product or contaminant in the mining of other minerals); and
2. extraction and combustion of fossil fuels, where mercury is present as a trace contaminant.

“Secondary anthropogenic sources” are those where mercury emissions occur from the intentional use of mercury in, e.g., industrial processes, products or for artisanal gold mining.

From both primary and secondary sources, emissions to the environment may occur via direct discharges of exhaust gases and effluents during combustion (fossil fuels), smelting (ores), manufacturing (products), or processing (chlor-alkali).

“Municipal waste,” or municipal solid waste (MSW), is typically considered in more industrialised economies to be the waste collected and treated by or for municipalities; in these countries, the main part originates from households, but similar waste from commerce and trade, office buildings, institutions and small businesses is also included. However, for the purpose of this analysis, it is recognised that in many countries no differentiation is made between household waste, commercial waste and supposedly non-hazardous waste from industry. Moreover, one can frequently find hazardous wastes as well, from any of these sources, mixed in with municipal waste.

“Medical waste” is considered to be waste generated by any health or veterinary care facility including hospitals, clinics, doctors’ and dentists’ offices, nursing homes, veterinary facilities, medical laboratories, as well as medical and veterinary schools and research facilities. As in the case of municipal waste, it is common in many countries for household and other waste to be mixed with medical waste and disposed of together.

“Incineration” is regarded in this study as a rather formal process of burning waste in a purpose-built facility. Nevertheless, the range of incinerators across the world varies from highly sophisticated facilities that carefully control their emissions and responsibly manage their ash and residues, to tiny, poorly maintained ovens that may cause more harm by burning wastes than not.

This analysis refers to various groupings of countries around the world as “regions.” The countries grouped in each region, which are listed in Appendix 1, typically reflect geographical proximity and/or other common characteristics that facilitated the analysis.

2.2 “Product-based” approach

Even under controlled conditions, incinerator emissions are difficult to measure and may vary greatly over time, depending on the source and content of the waste, design and operation of the incinerator, and many other variables. Reliable estimates of incinerator emissions depend on competent and frequent (continuous, if possible) measurements, as well as sound knowledge of the quantity of waste incinerated – a combination of data that is rare in most countries. Emissions data related to “open burning” of mercury wastes is even more difficult to find. Lacking sufficiently comprehensive data, therefore, a “product-based” approach has been adopted for this analysis.

This has been supplemented by a range of data and information furnished, in response to a questionnaire, by NGOs and other investigators in a number of countries around the world. Especially in developing countries and countries with economies in transition, the questionnaire sought information on the number and types of incinerators operating in various countries or regions, as well as the quantities and pathways of key types of waste that is incinerated with varying levels of emission controls. With this information, waste stream data can be better linked to potential mercury emissions.

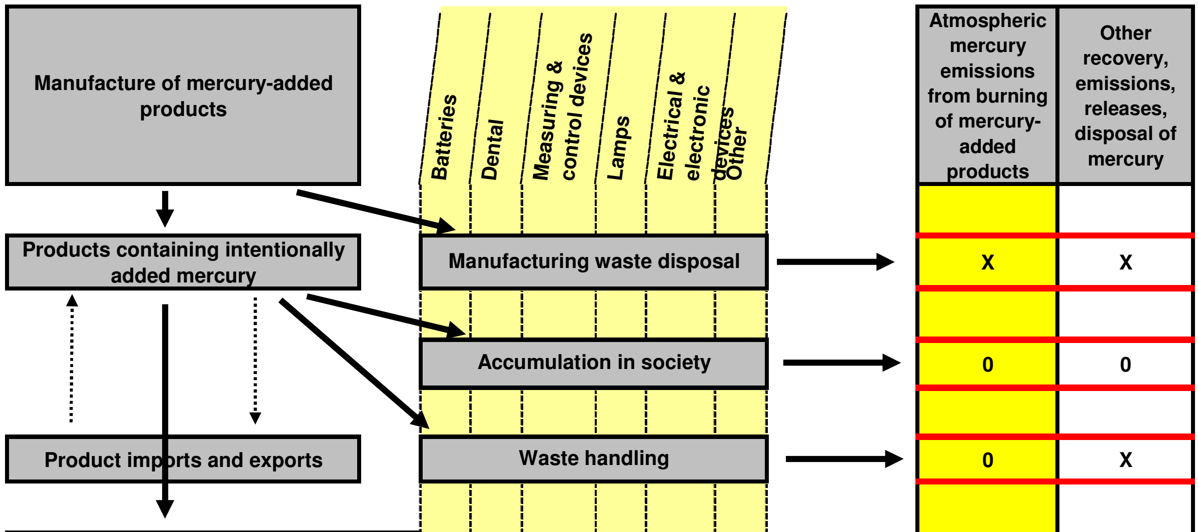
Reasonable estimates of mercury consumption in various product categories have been developed in recent years for the major geographic regions. The rough allocation of this mercury among the diverse life-cycle pathways such as accumulation in society, municipal waste, medical waste, recycling, etc., has been carried out by other researchers for several mass balances at the national level. For this analysis the same approach has been scaled up to the global level and applied to combustion processes.

This analysis begins with the familiar life-cycle perspective, starting with mercury consumption in products in the major world regions, estimating how much of that mercury ends up in the waste stream, and further estimating what part of the different waste fractions is subject to incineration or other burning. Major categories of mercury products considered include batteries, dental uses, measuring and control devices, lamps, electrical and electronic equipment, and a large group of “other products” to which mercury has been intentionally added, such as pesticides, paints, polyurethane elastomers, laboratory chemicals, pharmaceutical products, traditional medicine, cultural and ritual products, etc.

The basic flow model used for this analysis may be seen in Figure 1, and includes all of the following steps:

1. quantify mercury consumed in the major product categories (batteries, dental applications, measuring and control devices, lamps, electrical and electronic equipment, and other) for different world regions, as defined in Appendix 1.
2. identify waste disposal practices for each region, and the various waste pathways for mercury in these product categories in order to determine the quantities of mercury (by region and by product category) going to:
    - breakage and waste handling
    - production losses
    - accumulation in society
    - recycling
    - deep underground or secure disposal
    - hazardous waste treatment
    - municipal solid waste (MSW) treatment
    - medical waste treatment
    - sludge waste treatment
    - managed landfill
    - uncontrolled dumping, unmanaged landfill, unauthorised waste tips and other informal disposal

Figure 1 Methodology for estimating the global atmospheric emissions from burning of mercury-added products in waste



			Atmospheric mercury emissions from burning of mercury-added products	Other recovery, emissions, releases, disposal of mercury
Waste disposal - South Asia				
Separate collection & recycling	Hg released		0	X
	Hg recovered		0	X
Hazardous wastes incinerated	Incineration with controls	x (emission factor)	X	X
	Incineration without controls	x (emission factor)	X	X
Medical wastes incinerated	Incineration with controls	x (emission factor)	X	X
	Incineration without controls	x (emission factor)	X	X
Municipal wastes incinerated	Large-scale incineration with controls	x (emission factor)	X	X
	Large-scale incineration without controls	x (emission factor)	X	X
	Small-scale incineration without controls	x (emission factor)	X	X
Wastewater sludges	Incineration without controls	x (emission factor)	X	X
	Land disposal		0	X
Landfill and open dumping	Hazardous waste landfill		0	X
	Managed landfill	x (emission factor)	X	X
	Open dump & uncontrolled burn (urban)	x (emission factor)	X	X
	Open dump & uncontrolled burn (rural)	x (emission factor)	X	X
Secure disposal	No releases		0	X
Waste disposal - East & SE Asia	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - European Union	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - CIS & Other Europe	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - Middle Eastern States	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - North Africa	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - Sub-Saharan Africa	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - North America	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - C. America & Caribbean	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - South America	[Waste disposal pathways, as above]	[As above]	X	X
Waste disposal - Australia, NZ & Oceania	[Waste disposal pathways, as above]	[As above]	X	X
		Totals	X	X

3. investigate each of the above pathways in order to determine the quantities of product mercury in the waste stream that may be subject to incineration or other burning (note that cremation is not within the scope of this particular analysis)
4. identify emission factors relevant to waste burning in order to determine mercury emissions (by region and by product category) to the atmosphere from:
    - large-scale MSW incineration with emission controls
    - large-scale MSW incineration without emission controls
    - small-scale MSW incineration without emission controls
    - medical waste incineration with emission controls
    - medical waste incineration without emission controls
    - hazardous waste incineration
    - sludge waste incineration
    - burning of wastes in managed landfills
    - open burning of domestic waste, both urban and rural

Finally, the atmospheric emissions from all of the above pathways were added together in order to determine total emissions by region and by product category due to incineration and other burning of mercury-added products.

Each of the main methodological steps will be described in further detail below. But first we will identify the main product groups and describe in further detail the key waste disposal pathways.

2.3 Main product groups

The major categories of mercury products considered include batteries, dental uses, measuring and control devices, lamps, electrical and electronic equipment, and a large group of "other products" to which mercury has been intentionally added, such as pesticides, paints, polyurethane elastomers, research instruments, pharmaceuticals, traditional medicine, cultural and ritual products, etc.

2.3.1 Batteries

The use of mercury in batteries, while still considerable, continues to decline as many nations have implemented policies to deal with the problems related to diffuse mercury releases related to batteries.

2.3.2 Dental amalgams

Denmark, Finland, Japan, Norway and Sweden have implemented measures to greatly reduce the use of dental amalgams containing mercury. In these and some other countries, especially among populations with a reasonably high income, dental use of mercury is now declining. The most common alternatives are composites, followed by glass ionomers and compomers (modified composites). However, the speed of decline varies widely, so that mercury use is still significant in most countries. In developing countries and countries with economies in transition, changing diets and better access to dental care may actually increase mercury use temporarily.

2.3.3 Measuring and control devices

A wide selection of mercury containing measuring and control devices, including thermometers, barometers, manometers, etc., are still marketed, although thermometers and sphygmomanometers dominate with regard to mercury use. As market awareness has improved, most international suppliers now offer mercury-free alternatives. European legislation, among others, is being implemented to phase out such equipment and to promote mercury-free alternatives, which are available for nearly all applications.

2.3.4 Energy-efficient lamps

Mercury containing (fluorescent tubes, compact fluorescent, high-intensity discharge – HID, etc.) lamps remain the standard for energy-efficient lamps, where ongoing industry efforts to reduce the amount of mercury in each lamp are countered, to some extent, by the ever-increasing number of energy-efficient lamps purchased and installed around the world. There is no doubt that mercury-free alternatives such as light emitting diodes (LEDs) will become increasingly available, but for most applications the alternatives are still quite limited and/or expensive.

2.3.5 Electrical and electronic equipment

Following the implementation of the European Union's Restriction on Hazardous Substances (RoHS) Directive, and similar initiatives in Japan, China and California, among others, mercury-free substitutes for mercury switches, relays, etc., are being actively encouraged, and mercury consumption for these applications has declined substantially in recent years. At the same time, the USA-based Interstate Mercury Education and Reduction Clearinghouse (IMERC) database[2] demonstrates that mercury use in these devices remains significant.

2.3.6 Other applications

This category has traditionally included the use of mercury and mercury compounds in such diverse applications as pesticides, fungicides, laboratory chemicals, pharmaceuticals, paints, traditional medicine, cultural and ritual uses, cosmetics, etc. Other uses have been identified, e.g., by officials of the Syrian Arab Republic in a UNEP workshop, including tanneries, textile printing, glass colorants, photography, pigments, sterilization of seeds, timber preservation materials, and fireworks (UNEP 2004). However, there are some further applications that have recently come to light in which the consumption of mercury is especially significant. In particular, the continued use of mercury in the production of specialised plastics is one such use that is rather widespread.[3] Likewise, the use of significant quantities of mercury in some technical devices has until recently escaped special notice.

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[2] All suppliers of mercury containing products to the Northeastern United States are required to file annual reports, as described in http://www.newmoa.org.

[3] Mercury "catalysts" (basically hardening or curing agents) are sometimes used in the fabrication of polyurethane elastomer products, especially castings such as roller blade wheels, etc., in which the catalysts remain in the final product.

2.4 Main waste disposal pathways

This section describes the main pathways that waste mercury-added products travel, that may lead to eventual burning. As identified in the UNEP Toolkit, there are five main waste burning pathways including: incineration of municipal/general waste, incineration of medical waste, incineration of hazardous waste, incineration of wastewater sludge, and informal incineration (referred to in this report as “landfill fires and open burning”) of waste.

In addition to mercury emissions at waste “burning” sites, there are various other stages where mercury may be emitted to the atmosphere prior (or parallel) to disposal, such as product manufacture, emissions during use or separate collection of products, breakage (especially lamps) during waste transport, emissions during recycling, etc.

Since recycling of mercury products is considered to take place in parallel to the “disposal” waste streams, recycling emissions (e.g. during a thermal retorting process) are not included here in the detailed analysis of emissions due to the burning of mercury-added products. Furthermore, as a special case of product “burning,” the emissions of mercury from dental fillings during cremation are not included in the detailed analysis. Independent assessments of those emissions have recently received increased attention by other researchers, and will be noted later in this report. The detailed analysis here focuses on incineration or other burning of mercury-added products in the waste stream – specifically the following pathways:

2.4.1 Municipal waste incinerators

Mercury typically enters the municipal waste stream in the form of discarded products (batteries, old paints, electrical switches or relays, energy-efficient lamps, etc.). Eventual emissions depend on the quantities and types of these products in the waste stream, how many are separated from the waste before final disposal, and how much of the waste is incinerated or otherwise burned – variables that vary dramatically from country to country. Municipal waste incinerators may be roughly classified as large-scale with emission controls, large-scale without emission controls, or small-scale without emission controls. As noted below, since most countries do not effectively separate hazardous wastes from the municipal waste stream, it has been decided to combine them for this presentation. Furthermore, it is impossible to ignore the growing practice of co-combustion of municipal waste (and hazardous waste) in cement kilns and coal-fired power plants, both of which are already significant sources of mercury releases to the air, although beyond the scope of this analysis.

2.4.2 Medical waste incinerators

The medical waste stream often contains mercury from discarded thermometers, blood pressure devices, and other medical products and lab chemicals. Because medical wastes are often incinerated in order to treat biological hazards, the mercury wastes that may be mixed in will also be incinerated, and some part of the mercury emitted to the atmosphere – depending on the air pollution control equipment, if any. Medical waste incinerators may be roughly characterised as those with emission controls – though typically not designed to deal with mercury emissions – and those without. For the purpose of this analysis, the latter category includes all small-scale medical waste incinerators.

2.4.3 Hazardous waste incinerators

Mercury in hazardous wastes originate from industrial processes involving some form of mercury, obsolete pesticides, paints, mercury-contaminated mixed waste, etc., as well as discarded products, such as broken thermometers or dental amalgam waste, that have been separated from other waste for special treatment. Mercury emissions from hazardous waste incinerators depend on the combustion process and the air pollution control equipment. High-tech combustion, combined with sophisticated pollution control equipment, can achieve very low mercury emissions.. Since most countries do not have such sophisticated incinerators, and many do not even effectively separate hazardous wastes from the municipal waste stream, hazardous and municipal waste incineration have been combined in this presentation.

2.4.4 Sewage sludge incinerators

The mercury content of municipal wastewater may be heavily influenced by inflows of mercury product waste from dental clinics, laboratories, etc. Municipal wastewater treatment systems, while not designed specifically to trap mercury, often capture a high percentage of mercury in wastewater sludges, which may subsequently be incinerated or spread on land.

2.4.5 Landfill fires and open burning

Despite gradually improving efforts to separate and recycle mercury-added products from the waste stream, most mercury product waste in every major world region still ends up in some type of land disposal. The manner of land disposal may be extremely varied, including sanitary or regulated landfill, hazardous waste landfill, open dumping, etc. For the purpose of characterising open burning of wastes including mercury-added products, however, two main categories of land disposal are considered: 1) managed landfill and 2) uncontrolled dumping of domestic waste, which may include medical and even industrial wastes that are not segregated from domestic wastes.

Burning may occur in both of these types of land disposal, resulting in substantial mercury emissions.[4] Reliable data on the extent of waste burning in landfills, dumps and backyard piles and barrels is neither readily available nor robust. However, estimates developed for the purpose of calculating dioxin and furan emissions from various burning processes provide some useful guidelines.

While not the focus of this report, it should also be kept in mind that mercury escapes from landfills by various other routes as well. A part is evaporated to the atmosphere either through the gas collection system or by direct volatilisation; a part is leached to the groundwater; and a part is converted into methylmercury in the presence of organic waste (Mukherjee *et al.* 2004; Oman and Junestedt 2008).

2.5 Primary data and information sources

The various data and information sources called upon for this investigation are listed in the “References” section of the report. The primary sources of information on mercury consumption and waste, the allocation of mercury waste among the diverse pathways

[4] Fires at managed landfills are entirely common and are, in fact, widely accepted as a method to reduce the volume of waste. Open or uncontrolled burning of domestic waste (other than managed landfills) includes all instances where waste is burned in the open with no pollution controls, e.g. burning in open piles, in pits, in barrels, or in unmanaged landfills.

leading to burning, and identification of mercury emission factors[5] for each type of burning, etc., are drawn from:

- the Global Mercury Assessment (UNEP 2002),
- the Mercury Toolkit (UNEP 2005),
- the EU mercury product emissions analysis published by IVL (Kindbom *et al.* 2007),
- a number of recent country mercury inventories and/or emissions data including Australia, Burkina Faso, Cambodia, Canada, Chile, Japan, Madagascar, Malaysia, Peru, Philippines, South Africa, Syria, USA, and several countries in Europe,
- the US mercury product emissions analysis by Cain *et al.* (2007),
- several reports produced by the Chinese Chemical Registration Centre (CRC 2006, 2007a, 2007b) together with NRDC,
- the most recent and comprehensive EU-wide assessment of mercury in products, prepared for the European Commission (2008),
- the draft AMAP/UNEP global atmospheric mercury assessment presented at OEWG 2 in Nairobi in October 2008 (AMAP/UNEP 2008), to be finalised after the February 2009 meeting of the UNEP Governing Council,
- the recent report of the UNEP Mercury Air Transport and Fate Research partnership (UNEP 2008b),
- the report prepared for UNEP Chemicals and OEWG 2 on the repercussions of phasing out primary mercury mining (2008a), and
- the country- specific responses to the detailed questionnaire included in Appendix 2.

2.6 Research challenges

Waste incineration is a longstanding practice that is relatively well documented in some regions and countries, e.g., the European Union, United States, Japan, etc. However robust emission inventories are not available for other major regions. Therefore, the highly uncertain contribution of small-scale incineration and open burning have not been well integrated into previous calculations of total product-related atmospheric mercury emissions.

Mercury emissions are considerably influenced by the extent of open burning of waste, which remains common in most regions of the world. The extent of open burning of mercury-added products in the waste stream may be inferred from such observations as one offered by Tsinghua University in a 2006 report:

> *"…no statistical data are available for the amount of waste disposed informally in China. But these sources cannot be negligible, because there were 768.51 million rural population in China in 2003, and the average waste produced in rural area is about 0.9-1.7 kg per person per day, and most rural waste were usually dumped and incinerated informally in recent years. Thus in 2003, the informal general waste in China was 364.66 million tons."*

Similarly, the US and some other countries have estimated the extent of open burning of domestic waste in preparing their dioxin inventories. In this investigation, the

[5] The emission factor determines how much of the mercury content of a given waste stream is actually emitted to the atmosphere during burning.

uncertainties in emissions from disposal options such as open burning were addressed, first, by taking account of the range of indications in the sources listed above, and second, by making sure that not only the quantity of mercury in the waste stream (discussed in section 3.1.4 below), but also the critical burning rates (section 4.4.9) and emission factors (section 4.5) have been estimated conservatively.

3 Global mercury consumption and waste

This section will assess how much mercury is used in different product groups and in different regions of the world, and how much of that mercury goes into the waste stream.

3.1 Clarifications

The following explanations are provided in order to facilitate interpretation of the mercury consumption and waste data that follow.

3.1.1 Mercury "consumption"

In order to maintain the focus of the report on mercury in waste streams, mercury "consumption" is defined here in terms of regional uses of mercury-added products rather than overall regional "demand."

For this assessment, the difference between consumption and demand may be most easily described through the following example. Although most measuring and control devices are manufactured in China (reflecting Chinese regional "demand" for mercury), a large number of these products are exported, "consumed" and disposed of in other countries. In this analysis the country of "consumption" and final disposal is most important since that indicates the appropriate geographic region and waste stream.

3.1.2 "Gross" mercury consumption

Furthermore, unless noted otherwise, mercury consumption will be considered to be "gross" consumption, i.e., before any recycling and recovery operations.

This is another important distinction because, for any sector in which significant recycling of mercury wastes or discarded products occurs, that sector's "net" consumption of mercury will be lower than its "gross" consumption. In the following analysis, gross mercury consumption will be assessed first, after which a certain quantity of mercury will be allocated to recycling, i.e., removed from any eventual waste stream.

3.1.3 Changing patterns of regional mercury consumption

While continuing its long-term decline in most higher income economies, consumption of mercury-added products remains relatively robust in many lower income and transition economies, especially in South and East Asia. The main factors behind the decrease in mercury consumption in higher income economies are the substantial reduction or substitution of mercury content in regulated products (paints, batteries, pesticides, etc.), increasing regulation of hazardous wastes and a shift of mercury product manufacturing operations (thermometers, batteries, etc.) from higher income to lower income countries. Mercury consumption in the major product groups in different world regions is presented in Section 3.2 below.

3.1.4 Correlation between mercury consumption and mercury in waste

Depending on the lifetime of the various products in commercial use, mercury in the waste stream typically reflects the use of mercury in different products over a number of years before the mercury entered the waste stream. For example, batteries may enter the waste stream less than a year after purchase, while a thermostat switch may be in use for 20 years before it is replaced. For a study of the European Union, Kindbom *et al.* (2007) adopted the following convention: "Emissions occurring in the same year but caused by consumption in the previous 10 years were derived using the consumption in 2005 and assuming the same patterns of distribution and emissions."

Considering the overall level of precision of this sort of analysis, it will be assumed here that the quantity of mercury consumed in 2005 by each product group is roughly equivalent to the mercury disposed of in 2005. Therefore, since the consumption of most mercury-added products is in gradual decline, the quantity of mercury actually going to disposal in 2005, for example, will exceed the amount of mercury consumed in 2005. This implies that the calculations presented hereafter are conservative, i.e., suggesting somewhat less mercury going to waste than in reality.

3.1.5 Reference year and geographical regions

For consistency with other recent UNEP analyses, 2005 has been selected as the "reference" year for mercury consumption in this study.

The geographical regions referred to in the analysis are those defined in Appendix 1. They have been defined merely to facilitate analysis, and neither the regional groupings nor any country names or references should be taken to imply this report's endorsement of any political claims, borders, etc.

3.2 Mercury consumption data

The baseline data for global mercury consumption used in this analysis were initially developed for the UNEP Trade Report (UNEP 2006) and revised for the UNEP Mercury Mining Report (UNEP 2008a). Table 4 below summarises mercury consumption by major product category and by world region, while Figure 2 presents graphically the same data. The quantities indicated are average values for the range of quantities reported in each instance.

Among these product categories, it may be seen that batteries, dental applications, measuring and control devices, and "other" applications are all responsible for roughly similar levels of mercury consumption on a global basis. The total consumption of 1665 tonnes represents the best estimate within a larger range of about 1400-1900 tonnes. The major uncertainties are associated with the product categories of batteries and "other" applications.

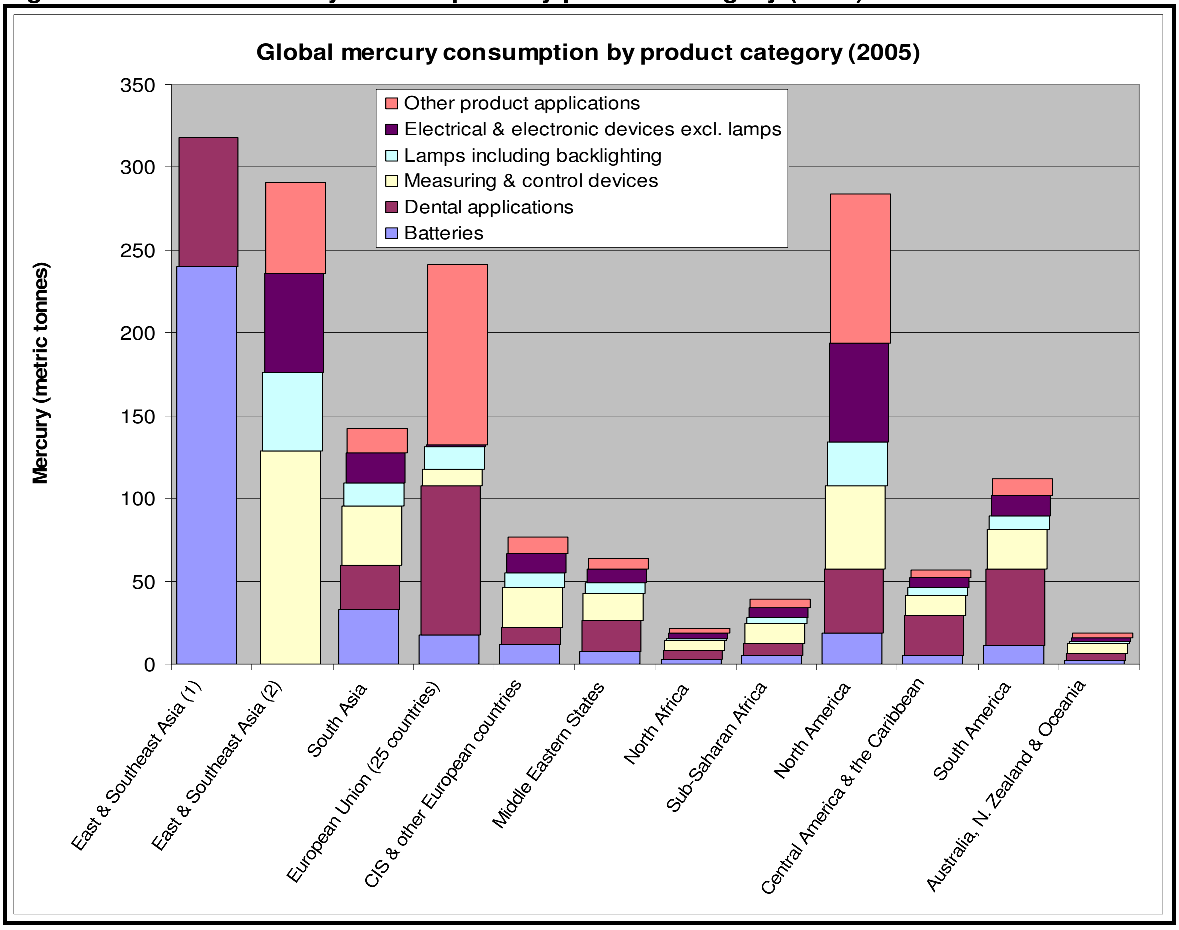
Table 4 Total mercury consumed[1] worldwide by region and by major product category

Elemental mercury 2005 (metric tonnes, average)	Batteries	Dental applications	Measuring & control devices	Lamps	Electrical & electronic equipment	Other[2]	Regional totals
East & Southeast Asia	240	78	129	47	60	55	609
South Asia	33	27	36	14	18	15	143
European Union (25 countries)	18	90	10	14	2	109	241
CIS & other European countries	12	11	24	9	12	10	77
Middle Eastern States	8	19	17	6	9	7	64
North Africa	3	5	6	2	4	3	22
Sub-Saharan Africa	6	7	12	4	6	5	39
North America	19	39	50	27	60	90	284
Central America and the Caribbean	6	24	13	5	6	5	57
South America	11	47	24	8	13	10	112
Australia, New Zealand and Oceania	3	4	6	2	3	3	19
Total per application	**355**	**350**	**325**	**135**	**190**	**310**	**1665**

Note 1 Regional mercury "consumption" is defined here in terms of regional market demand for mercury products. For example, although most measuring and control devices are produced in China, many of them are exported and subsequently "consumed" in other regional markets.

Note 2 "Other" product applications include uses of mercury in pesticides, fungicides, catalysts, paints, laboratory chemicals, research and testing equipment, pharmaceuticals, cosmetics, traditional medicine, certain cultural and ritual uses, etc.

Figure 2 Global mercury consumption by product category (2005)



3.3 Previous estimates of mercury emissions from waste

3.3.1 United States

Cain *et al.* (2007) specifically studied the role of mercury-added products in US waste streams, writing: “Although waste incinerators caused most of the [US] air releases from disposal of mercury-added products in 1990, only 7% of these air releases are estimated to have been caused by incinerators in 2005 [see Table 5]. Most of the 2005 air releases from product disposal resulted from breakage of products in use or while in the solid waste collection system and subsequent evaporation of mercury from homes, trash cans, garbage trucks, and waste transfer stations. These estimates are, of course, highly uncertain.”

Table 5 Emissions from mercury-added products in the United States

Table 5 Air releases of mercury from products by pathway in the United States (tonnes)

	1990	*2000*	*2005*
Incinerators	98	8	1
Other MSW	36	8	6
Steel furnaces	18	15	12
Other iron/steel recycling	5	4	3
Sludge incineration/ land application	2	2	1
Dental office/cremation/ exhaled air	3	3	3
Paint use	57	0	0
Other	2	1	1
Total	**221**	**41**	**27**

Source: Cain *et al.* (2007).

Largely due to the major reductions in mercury emissions from incinerators in the US, and to a lesser extent in other countries, global emissions from large-scale incinerators have clearly declined over the past 10 years (van Velzen *et al.* 2002).

3.3.2 European Union

Kindbom *et al.* (2007) carried out a parallel study of product waste streams in the EU. As in the study by Cain *et al.* (2007), mercury-added product emissions to air were calculated for other sources in addition to the burning of wastes. While the table below shows the best estimates, the total emissions to the air from products in the EU were calculated at 10-18 tonnes for the product categories shown, and at 2-5 tonnes from cremation. Of the mercury releases directly related to mercury-added products, the best estimate was 11% emitted to air, 31% ending up in safe storage, and 58% accumulated in society or disposed of in landfills, as in Table 6.

Table 6 Emissions, accumulation and safe storage of mercury in mercury-added products in the European Union (EU-25) in 2005

	Mercury consumed in one year	Emissions to air	Accumulated and land filled*	Safe storage**
Batteries	20	2	11	7
Measuring & control eq.	35	3	21	11
Electrical equipment	35	5	19	11
Light sources	35	3	21	11
Sum	125	14	72	39
Fraction of consumed amount		*11 %*	*58 %*	*31 %*

* Mercury in products still in use or stored in society, and the fraction of mercury land filled. In these cases additional emissions to air occur on a long term basis.
**Safe storage includes re-collected mercury as well as waste from flue gas cleaning etc, assumed to be stored safely.

Source: Kindbom *et al.* (2007)

3.3.3 Greater Europe

Within greater Europe, and based on different assumptions, a widely cited estimate of emissions from municipal waste incineration suggested it was responsible for 16% (36 tonnes) of all mercury emissions in 1990 (Pacyna *et al.* 1996), and less than 5% in 2000, as shown in Figure 3 below (Pacyna *et al.* 2006).

Figure 3 Anthropogenic mercury emissions in greater Europe (2000)

E.G. Pacyna et al. / Science of the Total Environment 370 (2006) 147–156

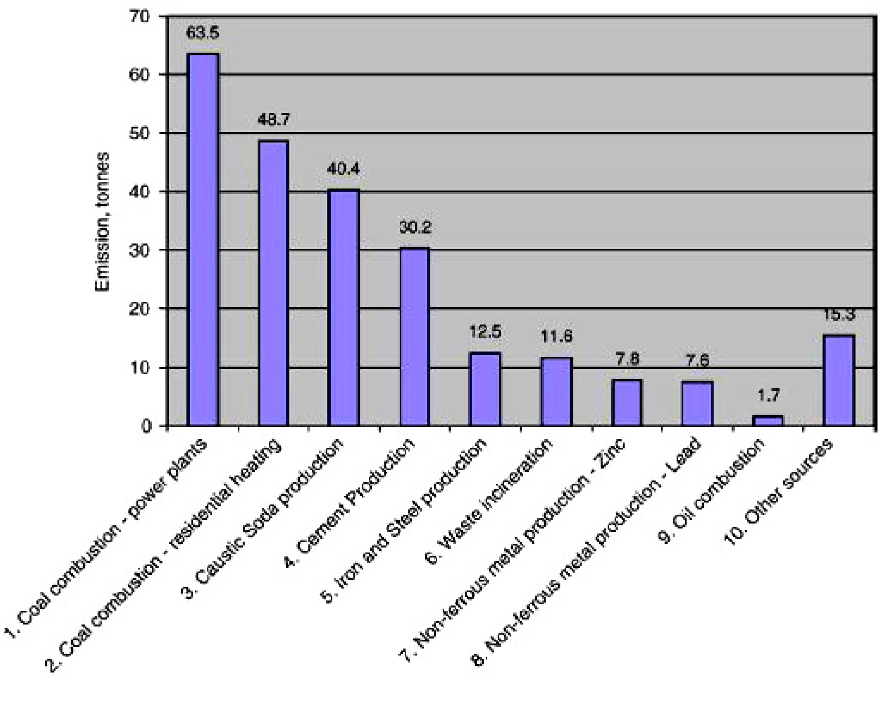


Fig. 2. Emission of Hg from anthropogenic sources in Europe in 2000 (in tonnes).

Source: Pacyna EG *et al.* (2006)

3.3.4 Other studies

Various other studies – some mentioned in Section 3.4 – have attempted to quantify mercury emissions from combustion of various wastes. However, only the most recent analysis (AMAP/UNEP 2008), which is still in draft form until it is reviewed during the UNEP Governing Council meeting in February 2009, has modeled at a global scale the many links from mercury-added products to air emissions. Unfortunately, even the present draft of AMAP/UNEP (2008) does not fully take into account the extent of burning that occurs in landfills and uncontrolled waste dumping.

3.4 Major pathways for mercury waste disposal

In order to determine very simply how much of the mercury in mercury-added products continues on to various waste streams, it has been conservatively assumed, as mentioned in Section 3.1.4, that the amount of mercury consumed (or introduced into the economy) in products each year is roughly the same as the amount coming out of the economy each year – minus mercury releases during production, releases due to breakage during product use or waste transport, and mercury in products stored or accumulated in society.

Based primarily on various reports on the situation in China (CRC 2006; CRC 2007a; CRC 2007b; Tsinghua 2006), in the US (Cain *et al.* 2007), and in the EU (European Commission 2008), mercury releases during production, mercury releases due to breakage during product use and waste handling, and mercury in products stored or accumulated in society were calculated for each product category and geographic region. The remaining mercury destined to recycling and to different waste streams is summarized in Table 7 below, as a percentage of the gross mercury consumption as shown in Table 4.

Table 7 Global mercury output to recycling and waste streams (as % of mercury consumption)

Elemental mercury 2005	Batteries	Dental applications	Measuring and control devices	Lamps	Electrical and electronic equipment	Other[1]	Regional weighted average
East & Southeast Asia	85%	90%	60%	52%	77%	79%	76%
South Asia	85%	90%	60%	52%	77%	79%	75%
European Union (25 countries)	94%	95%	87%	85%	87%	88%	91%
CIS & other European countries	85%	95%	60%	52%	77%	79%	73%
Middle Eastern States	85%	92%	60%	52%	77%	79%	76%
North Africa	85%	90%	60%	52%	77%	79%	75%
Sub-Saharan Africa	85%	90%	60%	52%	77%	79%	73%
North America	94%	95%	87%	85%	88%	91%	90%
Central America and Caribbean	85%	90%	60%	52%	77%	79%	78%
South America	85%	91%	60%	52%	77%	79%	78%
Australia, NZ and Oceania	94%	94%	87%	85%	88%	91%	90%

Note 1 "Other" product applications include uses of mercury in pesticides, fungicides, catalysts, paints, laboratory and clinical applications, research and testing equipment, pharmaceuticals, cosmetics, traditional medicine, certain cultural and ritual uses, etc.

Next it is necessary to determine how much of the mercury described in Table 7 goes to:

- recycling,
- hazardous waste,
- safe storage,
- municipal waste,
- medical waste,
- landfill, or
- other, less formal, disposal, such as uncontrolled dumping.

A variety of (sometimes contradictory) sources all contribute to our understanding and refinement of the general information provided in the references cited above. Some of them are mentioned below.

3.4.1 Malaysia

The following table demonstrates that approximately one-half of Malaysia's consumption of mercury in mercury-added products is discarded to solid waste. A large quantity also goes to wastewater, as in the case of dental waste.

Table 8 Disposal of mercury-added products to solid waste in Malaysia

Product type	Consumption kg Hg	Disposed of with solid waste kg Hg	Reported to scheduled waste kg Hg
Thermometers	40 - 300	20 -180	
Electrical switches and relays	480 - 1,440	380 - 1,150	
Light sources	342 - 1,310	320 - 1,240	5.8
Batteries	100 - 300	100 - 300	
Dental fillings	1,200 - 4,800	290 - 1,150	
Manometers and gauges	20 - 150	20 - 120	
Laboratory chemicals	50 - 300	0	2
Mercury metal use in laboratories and schools	200 - 500	?	
Miscellaneous uses	200 - 1000	160 - 800	
Mercury as trace element in all waste products	?	?	?
Total	**2,432 - 9,600 (+?)**	**1,300-4,950 (+?)**	**7**

Source: Malaysia (2006).

3.4.2 USA – New Jersey

While not entirely due to mercury-added products, the mercury concentration in municipal solid waste (MSW) in New Jersey in 2001 was estimated to be in the range of 1.5 - 2.5 ppm (NJ MTF, 2002). Yet according to the US EPA (2004) there is up to 50 times more mercury in medical waste than in general municipal waste in the USA. That estimate may be compared with a previous assumption of some 20 ppm mercury in medical waste (US EPA 1997).

3.4.3 Mexico

The following describes the status of Mexican healthcare waste management as it was before a couple of hospitals worked with the NGO Health Care Without Harm (HCWH), and as it still is in most Mexican hospitals:

"Regarding mercury management within the hospital, mercury wastes from the dentistry department are discharged into the drainage systems. Regarding broken thermometers, no clean-up protocol is followed and the material used to clean leaked mercury is deposited with either infectious and biological hazardous wastes or with municipal-deposit wastes, and broken fluorescent lamps are also deposited in the municipal trash."

"100% of [dental] fillings applied are made of mercury, and are prepared by the medical personnel at the moment of application. The Pediatric Odontology module has a hermetic amalgam device which avoids mercury loss during preparation. However, the device used in the dental area is manual, and the dentists report mercury spills during use. Regarding the practice followed for filling removal, the equipment has a small trap which captures amalgam fragments (as preventative measure for the equipment), and when the trap is full the residues are removed and deposited with the common trash or are rinsed with water and washed down the drain" (Mexico 2007).

Table 9 Landfill management practices in Latin America and the Caribbean

	Grandes			Medianos			Pequeños			País		
País	Relleno sanitario (%)	Relleno controlado (%)	Vertedero a cielo abierto o cursos de agua (%)	Relleno sanitario (%)	Relleno controlado (%)	Vertedero a cielo abierto o cursos de agua (%)	Relleno sanitario (%)	Relleno controlado (%)	Vertedero a cielo abierto o cursos de agua (%)	Relleno sanitario (%)	Relleno controlado (%)	Vertedero a cielo abierto o cursos de agua (%)
Anguila	..	..	..	..	..	..	99,9	-	-	99,9	-	-
Antigua y Barbuda	..	..	..	95,0	-	-	..	..	..	95,0	-	-
Argentina	97,8	-	1,5	12,2	8,5	32,2	5,8	16,9	67,2	60,7	5,6	22,9
Bahamas	..	..	..	...	...	...	...	...	...	...	...	...
Barbados	35,0	48,0	...	..	..	..	..	..	...	35,0	48,0	...
Belice	..	..	..	-	99,0	1,00	-	95,0	5,0	-	96,8	3,3
Bolivia	70.7	13,5	7,9	55,6	16,1	5,3	-	21,3	39,2	55,5	15,3	13,0
Brasil	...	...	...	...	...	...	...	...	...	12,6	16,8	59,6
Chile	63,5	33,1	-	38,5	47,1	6,2	27,5	29,6	38,4	43,2	38,5	12,6
Colombia*	74,0	6,5	16,6	40,5	8,6	46,5	40,8	4,0	54,0	32,0	15,0	54,0
Costa Rica	96,5	-	-	57,9	17,0	16,0	36,0	24,1	37,4	54,4	17,5	22,4
Cuba	19,4	73,9	6,6	17,7	39,0	42,7	39,5	16,7	42,0	21,4	57,6	20,5
Dominica	..	..	..	-	85,0	-	..	..	..	-	85,0	-
Ecuador	75,8	8,9	-	22,3	31,9	24,7	18,4	28,0	44,5	48,9	7,88	16,8
El Salvador	86,2	-	-	49,1	-	...	8,2	-	...	41,3	-	...
Granada	..	..	..	90,0	-	-	90,0	-	-	90,4	-	-
Guatemala	-	32,2	...	-	-	...	-	-	...	-	22,0	...
Guyana	..	..	..	-	90,0	10,0	-	-	88,1	-	59,1	36,8
Haití	-	-	34,3	-	-	20,3	-	-	3,3	-	-	24,1
Honduras	..	100,0	-	...	...	...	...	...	...	...	...	...
Islas Caimán	..	..	..	..	..	..	95,0	-	4,5	95,0	-	4,5
Islas Vírgenes Británicas	..	..	..	..	..	..	33,4	15,8	-	36,4	15,8	-
Jamaica	-	-	-	-	100,0	-	-	-	-	-	100,0	-
México**	60,0	60,0	15,0	20,0	14,0	56,0	10,0	5,0	63,0	25,0	35,0	40,0
Nicaragua	-	-	-	15,9	-	38,1	20,1	-	56,5	12,6	15,6	33,5
Panamá	84,4	84,4	...	-	-	64,4	-	-	23,8	56,4	-	20,1
Paraguay	20,2	20,2	-	-	43,6	56,4	-	34,4	67,3	6,4	37,2	42,2
Perú	24,6	24,6	18,4	7,1	57,5	20,2	12,8	54,6	17,1	15,0	51,0	18,7
República Dominicana	64,3	64,3	24,8	14,8	-	81,6	0,3	1,2	93,1	35,0	4,1	57,2
San Kitts y Nevis	..	..	..	..	..	..	100,0	-	-	10,0	-	-
Santa Lucía	..	..	..	70,0	17,5	-	..	..	..	70,0	17,5	-
San Vicente y las Granadinas	..	..	..	80,0	-	-	-	-	-	77,6	-	-
Suriname	-	-	99,9	-	-	-	-	-	100,0	-	-	100,0
Trinidad y Tabago	-	100,0	-	-	91,1	8,9	-	100,0	-	-	93,5	6,5
Uruguay	-	70,7	29,3	24,8	29,1	46,1	-	-	100,0	2,6	65,5	31,9
Venezuela	...	40,6	18,9	-	20,8	79,2	-	-	100,0	...	24,3	59,2
Promedio ALC	60,1	14,2	12,4	19,3	23,8	44,1	13,6	12,4	58,8	22,6	23,7	45,3

Grandes: > 200.000 habitantes; medianos: 50.000-200.000 habitantes; pequeños: <50.000 habitantes.
.. Sin núcleo poblacional de ese tamaño.
... Información no disponible.
- Magnitud cero.
Fuente: Evaluación de Residuos
Nota: Los valores de Colombia y México han sido suministrados por los revisores del Informe Regional y no son los datos que los países han ingresado. Se tomó estos valores al ser más coherentes con valores previos de algunos estudios. Las fuentes para los respectivos países son: * República de Colombia. Ministerio de Ambiente, Vivienda y Desarrollo Territorial, Dirección de Agua Potable y Saneamiento Básico y Ambiental. ** Evaluación del desempeño ambiental de México. OCDE, 2003 y La basura en el limbo. Desempeño de gobiernos locales y participación privada en el manejo de residuos urbanos. Comisión Mexicana de Infraestructura Ambiental. México, 2003.

INFORME DE LA EVALUACIÓN REGIONAL DE LOS SERVICIOS DE MANEJO DE RESIDUOS SÓLIDOS MUNICIPALES EN AMÉRICA LATINA Y EL CARIBE

Source: Evaluatión de Residuos, undated.

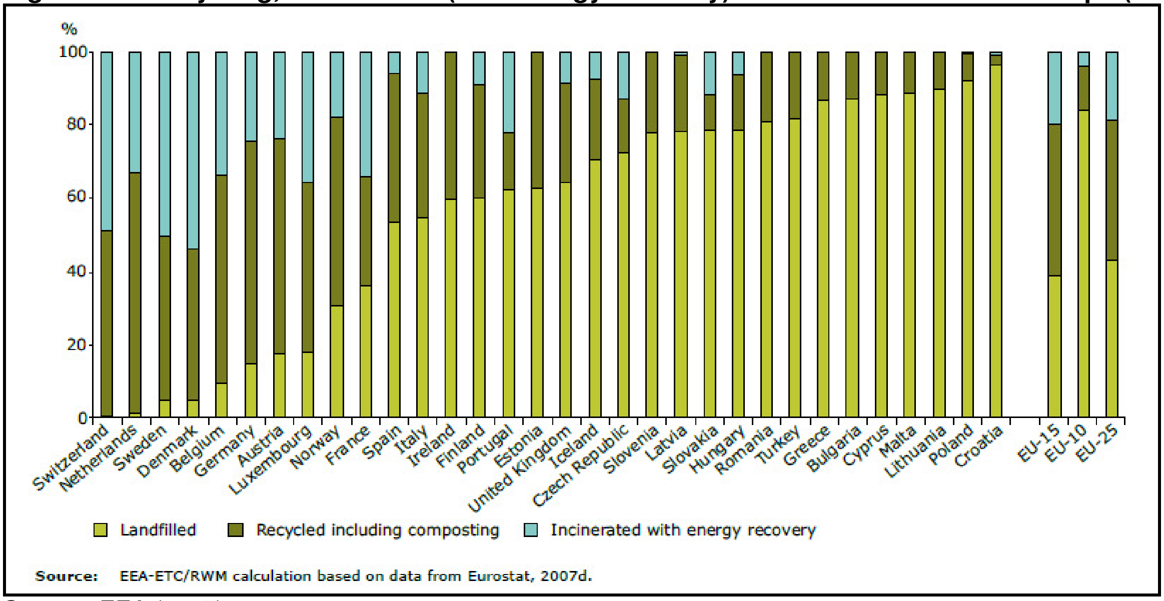
3.4.4 Latin America and the Caribbean

Table 9 above provides interesting detail of estimated waste disposal practices – although only for urban areas – throughout Latin America and the Caribbean. The three main waste disposal options investigated were sanitary landfill, managed landfill and uncontrolled dumping on land and in the water. It may be inferred that uncontrolled dumping is the norm in rural areas.

3.4.5 Europe

Figure 4 and Figure 5 give a detailed breakdown of incineration, landfill and recycling and recovery of municipal waste in Europe. Since the recycling rate applies largely to paper, metal and glass fractions, however, it is not possible to infer from these data a separate collection or recycling rate for mercury-added products.

Figure 4 Recycling, incineration (with energy recovery) and landfill of MSW in Europe (2005)

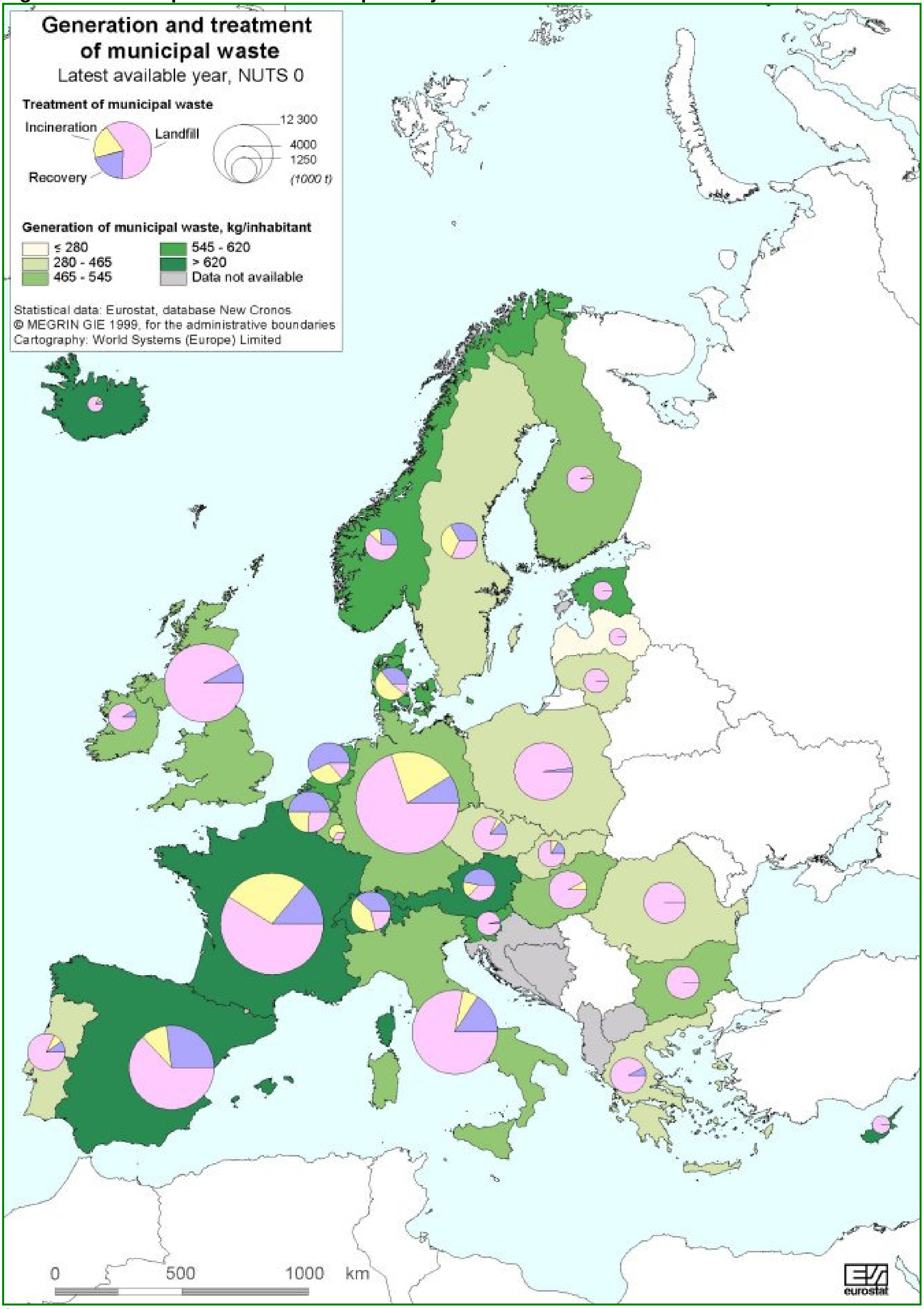


Source: EEA (2007).

With regard to dental waste in particular, much EU dental waste goes to municipal solid waste and medical waste. This is why one needs to include sludge waste incineration in mercury-added product emissions. The EEB dental report (EEB 2007) has estimated that:

- 20-25% of total dental mercury waste (i.e., 28 tonnes of mercury) may end up in the municipal wastewater system,
- up to 20% of total dental mercury waste (i.e., 23 tonnes of mercury) may be emitted to the atmosphere by all pathways, and
- up to 10% of mercury in EU sludge waste may be emitted to the atmosphere by incineration.

Figure 5 Municipal waste treatment pathways in EU25+2



Source: Eurostat (2007).

3.4.6 US – dental waste

Considering that about 70% of US fillings are replacements, that not all fillings are amalgams, etc., some 31 tons/yr. of mercury are calculated to go to emissions and waste in the US (Cain *et al.* 2007).

Referring to the methodology of Cain *et al.* (2007), the quantity of dental mercury entering the municipal wastewater system, including 1-1.5 tons from human wastes, is estimated at over 9 tons, of which just over 90% may be retained in wastewater treatment sewage sludge under normal operating conditions, estimated at about 8.5 tons.

According to Cain *et al.* (2007), about 20% of US sewage sludge is incinerated, some 60% is spread on agricultural and other land, about 15% is landfilled, and the rest is disposed of in other ways.

3.4.7 China

An estimate for China indicated that 10.4 metric tons of mercury emissions were released in 2003 from "burning of household waste" (Tsinghua 2006; Wu *et al.* 2006). However, this estimate likely represents only formal incineration, which is not commonly used to treat municipal waste in China.

3.4.8 India

According to Visvanathan *et al.* (2004): "In most Asian countries today, solid waste disposal still means dumping…. These unplanned heaps of uncovered wastes, often burning and surrounded by pools of stagnated polluted water, rat and fly infestations with domestic animals roaming freely and families of scavengers picking through the wastes is not only an eyesore but a great environmental hazard. Most of the Asian countries are facing similar problems, e.g. in Thailand or India 70% to 90% of landfills are just open dump sites."

The following case study summary has been prepared based on input provided in the survey (Appendix 2).

Case study on mercury-added products in waste - India

The population of India exceeds 1.1 billion persons, of whom nearly 30% are urban dwellers and about 70% rural.

India generates some 80 million tonnes of **municipal waste** per year only in urban areas. Half of that, or about 115 thousand tonnes per day, is collected for disposal. There are four major urban incinerators with a treatment capacity of about 2,000 tonnes per day, but two of these incinerators are currently out of commission. Therefore, over 98% of the collected urban municipal waste goes to recognised landfill sites, where open burning and waste pickers are common. The uncollected fraction of urban municipal waste goes to open dumps or trash piles, throughout the urban areas, that are commonly burned. It is estimated that at least the same quantity of waste is generated in rural areas, where virtually all of it goes to open dumps, and where burning is also common.

India has a total of 538 **medical waste** incinerators, of which 229 have no flue gas control device, and 102 are single-chamber incinerators. None of the incinerators have any mercury emission controls. The total biomedical (including infectious) waste generated in India is on the order of 100 thousand tonnes per year – more specifically 319 tonnes per day, of which 144 tonnes per day are subject to some kind of waste treatment. The rest of the biomedical waste is untreated and mostly incinerated or burned less formally.

There is very little special collection or recycling of used **batteries**, which typically go to the municipal waste stream. Among other types of batteries, it was reported that 1.65 million mercury-zinc batteries were marketed in 2000. Assuming all button cells, they represented about one tonne of mercury

India consumes over one million mercury **thermometers** per year, mostly used in the health care industry. Very few thermometers are collected separately, and the vast majority end up in the municipal waste stream.

Around 40% of **dental** fillings, placed mostly in urban areas, are mercury amalgams. Some larger hospitals or specialised clinics have devices to remove some of the mercury from the waste stream, but most ends up in municipal waste and wastewater.

250-300 million mercury-containing **lamps** are used in India every year. Nearly all of these go to the municipal waste.

Greenpeace recently estimated that about 50,000 tonnes of **e-waste** were imported to India annually. The residues of this waste are typically going to land disposal and frequent burning.

In various parts of the country mercury is used in traditional medicine, cultural artefacts and as a **fungicide or insecticide** for seed grains and human hair. Afghanistan has reported a similar use of mercury to treat hair, wool and carpets, so there may be other uses in India, such as wool and carpets, that have not yet been reported. In any case, some of this mercury will end up in land disposal.

Perhaps using a different definition of medical waste from that above, Visvanathan (2006) estimated medical waste generation in India at 330,000 tonnes/yr., assuming 1-2kg waste per bed per day, which may be too high (see Table 11). Based on 20g Hg emission per tonne of medical waste (USEPA 1997), the total mercury emission to the atmosphere from this source could be as high as 6.6 tonnes per year.

3.4.9 Philippines

In a recent report of the Asian Development Bank, some 3,670 healthcare facilities were identified in "Metro" Manila (the city's greater metropolitan area), generating more than 47 tonnes of healthcare waste daily, of which 55-60% was identified as infectious waste.

Table 10 Estimates of healthcare waste generated in Metro Manila (ADB 2004)

Type of facility	Infectious waste (kg/day)	Non-infectious waste (kg/day)	Total (kg/day)
Accredited hospitals			
Government	5971	6850	12,821
Private	3996	4584	8580
Health centres	802	1203	2005
Medical clinics	2580	3870	6450
Dental clinics	5880	1960	7840
Veterinary clinics	372	93	465
Pharmaceutical laboratories	5772	1443	7215
Blood banks	204	51	255
Funeral parlours	1176	196	1372
Medical schools	132	33	165
Research institutions	48	12	60
Total	**26,933**	**20,294**	**47,228**

Source: ADB (2004).

According to interested parties such as government offices and private hospitals (representing 35-40% of all infectious waste generated in the Metro Manila area), most of them segregate the waste and use a microwave treatment system to treat the infectious fraction. However, due to generally limited funds, most of the treated wastes reportedly go then to municipal dumpsites (ADB 2004).

3.4.10 Asian overview

Table 11 provides an overview of estimates of medical waste generated in a number of Asian countries.

Table 11 Estimates of medical waste generated in various Asian countries

Country	Waste generation (kg bed $^{-1}$ day^{-1})	Total wastes (Mg yr^{-1})
Bangladesh	0.8 – 1.67	93,075 (only in Dhaka)
Bhutan	0.27	73
China	-	730,000
India	**1 – 2**	**330,000**
Malaysia	1.9	-
Nepal	0.5	365
Pakistan	1.06	250,000
Sri Lanka	0.36	6,600 (Only in Colombo)
Thailand	0.68	-
Metro Manila (Philippines)	-	17,155
Vietnam	2.27 (Hanoi)	60,000

Source: Visvanathan (2006)

3.4.11 Brazil

The following case study summary has been prepared based on input provided in the country survey (Appendix 2).

Case study on mercury-added products in waste – Brazil

The population of Brazil is around 190 million persons, of whom about 80% live in urban areas and about 20% rural.

There are 30 thousand hospitals, clinics and other health care units in Brazil. 185 tonnes of **medical waste** are incinerated daily. Meanwhile, 74% of the municipalities in Brazil dump hospital waste in the open. It is estimated that there are about 14 tonnes of mercury in Brazil's medical waste every year, and only one tonne of mercury in dental waste. Chairside traps for collecting **dental** amalgam wastes are apparently not widely used.

There are 13 industry-owned **hazardous waste** incinerators dealing with nearly 50 thousand tonnes of industrial hazardous waste annually.

80 million tonnes of **municipal waste** are generated each year, of which 30% goes to open dumps, nearly 50% to sanitary landfills and just over 20% to regulated landfills. The amount of landfill waste burned in open dumps and sanitary landfills has not been estimated. There are no municipal waste incinerators in operation.

Brazil consumes some 800 thousand button cell **batteries** every year, and there are regulations limiting the mercury content. However, it has been reported that about 400 thousand button cells are smuggled into Brazil each year, and these have been found to contain excessive mercury, amounting to some 32 tonnes of mercury per year. Separate collection of batteries has begun, but only on a very small scale, so the vast majority of these batteries – and the mercury in them – go to the municipal waste stream.

About 150 million energy-efficient **lamps** are disposed of each year, of which over 90% appear to go to municipal waste.

The use of mercury **fungicides** for agricultural applications is banned in Brazil but some recent uses have been identified.

Finally, **cultural practices or rituals** using mercury are impossible to estimate as they are not openly discussed.

3.4.12 Waste allocation for this analysis

AMAP/UNEP (2008) has derived some estimates of the split between different types of waste disposal, which we have respected except in a few instances of newer information sources, such as European Commission (2008). Kindbom *et al.* (2007) is another useful source for details of the EU situation, while Cain *et al.* (2007) is a well researched source describing the US situation.

As noted below, in this analysis product manufacturing, recycling and cremation are not considered to generate traditional waste streams in which "mercury-added products" would be routinely incinerated or otherwise burned. Nevertheless, there is some discussion of these emission sources at the end of the analysis.

Combining all of the product groups above, for ease of presentation, Table 12 shows the allocation of the economic output (as presented in Table 7) of mercury from mercury-added products among recycling and the main waste disposal pathways.

Table 12 For each geographical region, allocation of the economic output of mercury from mercury-added products among the main waste disposal pathways and recycling

	Deep underground or secure disposal	Medical waste incineration	Municipal & hazardous waste incineration	Municipal wastewater sludge disposal	Landfill & uncontrolled waste disposal	Recycling
East and Southeast Asia	0%	2%	5%	3%	86%	4%
South Asia	0%	1%	4%	2%	90%	3%
European Union	1%	4%	15%	7%	57%	16%
CIS & Other European countries	0%	1%	12%	3%	72%	12%
Middle Eastern States	0%	0%	3%	4%	89%	3%
North Africa	0%	1%	4%	2%	89%	4%
Sub-Saharan Africa	0%	1%	12%	1%	83%	4%
North America	2%	3%	15%	3%	62%	16%
Central America & Caribbean	0%	1%	4%	6%	86%	3%
South America	0%	1%	4%	6%	86%	2%
Australia N. Zealand & Oceania	0%	1%	6%	4%	72%	17%

In concluding this section, Table 13 shows the quantities of mercury (corresponding to the allocations presented in Table 7 and Table 12) contained in mercury-added products that are estimated to transit to the main waste disposal pathways. It should be noted that the "deep underground or secure disposal" and "recycling" columns have been deleted since the mercury allocated to these pathways is considered to be not subject to burning, and therefore not directly relevant to our objective of estimating emissions from burning.

Table 13 For each geographical region, allocation of the mercury (in tonnes) in mercury-added products among the main waste disposal pathways (2005)

	Medical waste incineration	Municipal & hazardous waste incineration	Municipal wastewater sludge disposal	Landfill & uncontrolled waste disposal
East and Southeast Asia	9	24	15	398
South Asia	1	4	2	96
European Union	8	32	17	124
CIS & Other European countries	1	6	2	40
Middle Eastern States	0	1	3	43
North Africa	0	1	0	14
Sub-Saharan Africa	0	3	0	24
North America	7	37	9	157
Central America & Caribbean	1	2	3	37
South America	1	3	6	75
Australia N. Zealand & Oceania	0	1	1	12

It should be remembered that for this analysis, atmospheric releases from incineration or other burning will not include releases during product manufacturing, releases during recycling, releases during cremation or releases from breakage during product use or waste handling, which may be significant.

3.5 Sub-pathways for disposal of mercury-added products in waste

This section will analyse the next level of mercury flows from products in the waste stream after the mercury has been partitioned among the four major waste disposal pathways identified above.

First, it is necessary to determine in further detail what happens to waste that is landfilled or dumped in an uncontrolled manner. In this case, most of the references cited previously were not very informative. For example, as mentioned in Section 3.3.4, AMAP/UNEP (2008) has made some rough estimates of the split between “managed” and “unmanaged” landfill, but does not fully take into account the extent of burning that occurs in landfills and uncontrolled waste dumping. Information from UNEP workshops (e.g. UNEP (2004), the Beirut workshop), the surveys carried out for this investigation (Appendix 2), etc., suggest that this split needs to be further explored. Therefore, such sources as those described in Section 4 were used to develop estimates of the more detailed waste pathways.

Second, the urban vs. rural allocation of uncontrolled waste disposal has not been closely investigated by other researchers. This allocation is important not only because of the different per capita quantity of waste generated in urban and rural areas, as indicated in some of the surveys (Appendix 2), but also because the composition of the waste differs to some extent. The mercury content of waste disposed of in an uncontrolled manner is therefore seen to be correlated with the general wealth of an urban or rural population as reflected in the per capita GDP, the urban vs. rural population split, and the quantities of waste generated by the typical urban or rural resident.

These factors were all taken into account in deriving the allocation of waste among different types of landfill and uncontrolled dumping, as shown in Table 14.

Table 14 Allocation of waste among different types of landfill and uncontrolled dumping

	Hazardous waste landfill	Managed landfill	Uncontrolled waste disposal (urban)	Uncontrolled waste disposal (rural)	Total landfill and uncontrolled waste disposal
East and Southeast Asia	0%	10%	54%	36%	100%
South Asia	0%	10%	40%	50%	100%
European Union	10%	60%	24%	6%	100%
CIS & Other European countries	0%	30%	54%	16%	100%
Middle Eastern States	0%	30%	56%	14%	100%
North Africa	0%	10%	63%	27%	100%
Sub-Saharan Africa	0%	10%	47%	43%	100%
North America	10%	60%	27%	3%	100%
Central America & Caribbean	0%	10%	73%	17%	100%
South America	0%	40%	54%	6%	100%
Australia N. Zealand & Oceania	10%	60%	27%	3%	100%

4 Pathways for burning of mercury-added products in waste

4.1 General discussion

This section will assess how much mercury from mercury-added products gets burnt in each of the major waste disposal pathways. It is predicated on a reasonable understanding of each of the relevant waste pathways and disposal practices.

Medical, municipal and hazardous waste incineration have already been discussed. AMAP/UNEP (2008) has made some rough estimates of the split between different types of incinerators, which we have largely respected here. Kindbom *et al.* (2007) is a useful source for the EU situation. Cain *et al.* (2007) is a very good source for the US situation. There is less information on sludge waste incineration, which is a lesser contributor to air emissions of mercury, although it has generally been assumed that percentages of sludge waste incinerated are similar to those for municipal and hazardous waste incineration.

Again, the most difficult area for which to find data concerns the burning of waste disposed of in an uncontrolled manner.

In the literature, open burning and landfill fires are referred to by many different names, some with different shades of meaning, but they all imply uncontrolled emissions:

- backyard trash burning
- residential landfill burning
- landfill burning (often intentional and legal)
- landfill fires (often intentional, but also unintentional, e.g. from spontaneous combustion)
- burn barrels
- rural waste burning
- open garbage burning

The following sources of information, among others, on incineration, landfill fires and open burning in various countries have been consulted for this analysis.

4.2 Incineration

4.2.1 Small-scale incinerators in Africa and India

According to WHO (2004), low-cost, small-scale incinerators promise effective sterilization of healthcare waste, and these units have been constructed in many settings. However, as evident in Figure 6, there remain a variety of common problems, including operator training, management and supervisor support, operation and maintenance, and siting:

- “Kenya: Some 44 De Montfort type incinerators were constructed in 2002, of which 55% are in intermittent or regular use. Tests and interviews were conducted at 14 sites (Adama 2003, as cited by WHO 2004). Only 1 of 14 sites had an operator with ‘near to adequate’ skills, fewer than 40% of health facility managers demonstrated any level of commitment, many technical defects were observed in the equipment, and most incinerators were operated improperly (Taylor 2003, as cited by WHO 2004).
- Tanzania: A total of 13 De Montfort incinerators were constructed in 2001 and 2003, and all were in use. Of these, <40% had trained operators, 70% had low smoke disturbance, and 60% have safe ash disposal (Adama 2003, as cited by WHO 2004).
- Burkina Faso: Where utilized, equipment was poorly operated and underutilized, i.e., the expected number of syringes incinerated fell short by about two-thirds (Adama 2003, as cited by WHO 2004).
- India: Eight 1 to 2 year-old De Montfort incinerators at hospitals in India were surveyed by Health Care Without Harm (HCWH 2002, as cited by WHO 2004). This survey indicated visible smoke from the stack; smoke emission from the chamber door and air inlets; mixed waste including sharps and non-infectious waste, despite some attempt at segregation at source; large quantities of unburned materials (sometimes plastics, syringes, glass, paper and gauze) in the ash; deficient ash disposal practices; siting in all cases near populated areas (e.g., playground, orphanage, hospital staff quarters, a primary school, town center), and a lack of operator training.”

Figure 6 Assessment of small-scale incinerators

Figure 1 Photos indicating operational/training problems with De Montfort type incinerators.
Left: Incinerator operator wearing motorcycle helmet instead of respiratory protective gear (Mac Robert Hospital, Gurdaspur, Punjab, October 2002, taken from HCWH, 2002). Center: General waste to be burned (Kulathummel Salvation Army Hospital, Thiruva Nanthapuram, Kerala, Sept. 2002, taken from HCWH, 2002). Right: Black smoke indicating high pollutant emissions (WHO presentation, Bradley Hersh, location and date unknown, taken from HCWH, 2002)

Figure 2 Photos indicating construction problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door frame damaged and also off-set inside making cleaning difficult. Right: Loading door frame rusted and hinge broken.

Figure 3 Photos indicating maintenance problems for De Montfort Incinerators in Kenya.
All from Taylor (2003). Left: Front door hinges damaged and frame dislodged from mortar. Right: Damaged masonry and loose fire-bricks

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Source: Page exerpted from WHO (2004).

4.2.2 Brazil

There are 30 thousand hospitals, clinics and other health care units in Brazil. An estimated 185 tonnes of medical waste are incinerated daily, although ¾ of the municipalities in Brazil dump hospital waste in the open.

Figure 7 A medical waste incinerator typical for many countries

Medical waste incineration is a major source of airborne mercury emissions, dioxins and furans around the world.

Photo: J Karliner, HCWH.

4.2.3 US medical waste incineration

US releases to the air from mercury-added products have been presented in Table 5 above. Taking account of a larger scope of mercury wastes, the US Environmental Protection Agency estimated atmospheric emissions of mercury only from hazardous waste incinerators for the year 1996 at 6.3 metric tons (US EPA 1998).

The mercury content in the medical waste stream originates primarily from mercury in discarded health care products and chemicals, including thermometers, dental amalgam, batteries, laboratory chemicals, pharmaceuticals, fluorescent lamps, high-intensity discharge lamps (mercury vapour, metal halide, and high-pressure sodium), etc. Due to the higher prevalence of these materials in the waste stream, there is typically much more mercury in medical waste than in general municipal waste. According to the US Environmental Protection Agency, before stricter controls were established, it was estimated that medical waste in the US contained up to 50 times more mercury than municipal waste, per unit of waste (US EPA 2004).

Similarly, in the absence of sophisticated flue gas controls, the amount of mercury emitted from a typical medical waste incinerator was estimated to average more than 60 times that emitted from the average infectious waste incinerator (UNEP 2002) – once again highlighting the role of mercury-added products in incinerator emissions.

4.2.4 Togo biomedical waste treatment

The Togo delegation at OEWG 2 in Nairobi stated, "Biomedical waste in Togo is not treated properly, but simply burnt" (Togo 2008).

4.2.5 Nepal waste incineration

The following details are provided by Ram Charitra Sah, who is leading a project by the name of Mercury Import, Use, Management and Awareness Raising (Nepal 2008).

Municipal waste incineration:

- No municipal waste incinerator exists in the country
- Solid waste collection < 60% in urban areas
- Uncollected and non segregated wastes are often open burned
- Many small urban centres use non segregated wastes (including biodegradable waste) for landfilling as a part of land development for construction

Healthcare waste incineration:

- No proper hazardous waste incinerator exists in the country
- A very rudimentary infectious waste burning site behind the hospital with couple of meter tall stack
- Guideline for health care waste handling and disposal has been developed recently
- Kathmandu Metropolis together with private health care centre developing a common waste disposal site

4.2.6 Cambodia waste incineration

According to the UNEP mercury inventory for Cambodia (Cambodia, 2008), no general household waste is formally incinerated. However, in total, solid waste amounting to 3,525.60 tonnes is calculated to be burned in industrial incinerators, of which five incinerators are for burning production wastes in garment factories for feeding the steam ovens (249.60 tonnes annually), and one incinerator burns other industrial wastes (3,276 tonnes annually).

According to the *Inventory Report of Unintentionally Produced POPs in Cambodia* (Cambodia 2004), the medical waste incinerators in Cambodia are classified into three types: (i) local medical waste incinerator (see Figure 8); (ii) SICIM incinerator; and (iii) modern incinerator. These incinerators are mostly operated with the burning of fuel oil, wood or other biomass. It is estimated that about 676 local medical waste incinerators, 25 SICIM incinerators, and 2 modern incinerators are operated within the public health sector. According to the report, about 800 tonnes of medical waste are burned every year.

Figure 8 Two methods of waste management in Cambodia

Uncontrolled dumping and open burning at Kampong Cham Province

Typical medical waste incineration facility operating in Cambodia

Source: Cambodia (2008)

4.2.7 Uganda medical waste incineration

According to a completed questionnaire as in Appendix 2, Uganda has a total of 107 hospitals (excluding private clinics) around the country. These include two National Referral Hospitals (NRHs), ten Regional Referral Hospitals (RRHs), thirty eight District Hospitals (DHs), forty five Non-Governmental Hospitals (NGHs), nine private hospitals, two military hospitals and one prison hospital. All of the health care facilities in the country dispose of their medical waste using a combination of open pit, open air burning, burying, incineration, discharge into waste water systems, and dumping into a landfill.

One of the major hospitals that keeps records of its waste generation is Mulago National Referral Hospital in Kampala. Every day it generates 2,000 kg of medical waste and another 7,000 kg of domestic waste while treating an average of 1,900 out-patients and 2,300 in-patients per day. Mulago has one of the few functioning medical incinerators in Uganda – single chamber, no filters, temperatures typically below 800ºC, and no flue gas control devices.

Figure 9 below shows a picture of the incinerator at Mulago that burns the 2,000 kg of medical waste generated each day. The ash from this incinerator is mixed with the remaining 7,000 kg of domestic waste generated at the hospital, and dumped in an urban landfill in Kitezi near Kampala.

Figure 9 The medical waste incinerator at Mulago National Referral Hospital in Kampala

4.3 Landfill fires

A brief look at some information on landfill fires, in addition to information found in other parts of the text, is included below.

4.3.1 United Kingdom

UK landfill operators surveyed by Bates (2004) estimated that, at any one time, deep-seated fires are occurring at about 80 percent of landfills. Such fires are generally more difficult to identify and extinguish than surface fires (Bates 2004).

4.3.2 United States

In the US, dump and landfill fires are reported at a rate of 8,400 fires per year. In fact, in the US landfill fires are an accepted method of reducing refuse volumes and operating costs, and of increasing a landfill's operating life (FEMA 2002), even though landfill fires have been identified as one of the largest dioxin sources in the US (USEPA 2005).

4.3.3 Kenya

The following summary has been prepared describing the situation at a dumpsite close to Nairobi.

Dandora Municipal Dumping Site in Nairobi, Kenya

Improper management of solid waste is one of the main causes of environmental pollution and degradation, especially in developing countries and countries with economies in transition. Many regions lack adequate solid waste regulations and proper disposal facilities, including for harmful waste. Such waste may be infectious, toxic or radioactive. Specific sites are often designated for municipal waste disposal. However, depending on local regulations and management, a great variety of waste may be dumped in an uncontrolled manner, segregated for recycling purposes, or simply burnt.

Dandora municipal waste dumping site in Nairobi, Kenya

Dandora, located to the East of Nairobi, is the main dumpsite for most of the solid waste from the Nairobi area. Surrounding the dump are informal settlements and residential estates. Over 2,000 tonnes of waste generated and collected from the 4.5 million area residents are deposited daily in the dumpsite. What initially was intended to refill an old quarry has given rise to a big mountain of garbage, perpetually smoldering and smoking. Dumping at the site is unrestricted, and industrial, agricultural, domestic and medical wastes (including used syringes) are seen strewn around the dumpsite. The Nairobi River also passes beside the dumpsite. Some of the waste from the dump ends up in the river, thus carrying environmental and health risks to people living in the vicinity as well as those living downstream who may use the water for domestic and agricultural purposes like irrigation.

According to a recent study, the mercury concentration in samples collected from the waste dump registered a mean value of 46.7 ppm, while those collected along the river bank registered a mean value of 18.6 ppm. Both of these values greatly exceed the WHO acceptable level of 2 ppm mercury in waste. It was determined that the dumpsite exposes the local residents to unacceptable levels of environmental pollutants with adverse health impacts. The local church dispensary treats more than 9,000 persons each year for respiratory ailments such as upper respiratory tract infections, chronic bronchitis and asthma. A high number of children and adolescents living around the dumpsite also have gastrointestinal and dermatological illnesses including fungal infections, allergies and unspecified dermatitis/pruritis – inflammation and itchiness of the skin.

Source: UNEP 2007.

4.4 Open burning

A reasonable overview demonstrating the prevalence of open burning around the world is provided below.

4.4.1 China

According to Tsinghua (2006): " no statistical data are available for the amount of waste disposed informally in China. But these sources cannot be negligible, because there were 768.51 million rural population in China in 2003, and the average waste produced in rural area is about 0.9~1.7 kg per person per day, and most rural waste were usually dumped and incinerated informally in recent years. Thus in 2003, the informal general waste in China was 364.66 million tons."

Considering that the mercury content of rural waste in China could average at least 0.5-1.0 ppm (Tsinghua (2006) suggested using the emission factor of 2.8g/t of "household waste," but this seems too high for rural populations), this would imply 180-360 tonnes mercury content of rural waste in China. If 25% of the waste generated in rural areas were burnt, and assuming a typical emission factor, mercury emissions could be 40-80 tonnes, although they would not all be linked specifically to mercury-added products.

Then one might compare China's rural waste (above) with urban municipal waste disposal. The urban population of China in 2003 was at least 500 million persons. Moreover, it is well known that urban residents generate more waste than the rural population. Therefore the urban municipal waste may be estimated at 300-350 million tonnes. However, the UN statistics on Municipal Waste Treatment from 2005 (http://unstats.un.org/unsd/environment/wastetreatment.htm) reported total (formal) municipal waste collected for all of China at less than 150 million tonnes. While the estimates of waste generated per person may be somewhat high, or they may well include large amounts of industrial wastes, nevertheless this small example demonstrates the enormous difference, in many countries, between volumes of waste generated, and volumes collected.

4.4.2 Argentina

For Argentina, 55% of municipal waste reportedly goes to unregulated landfill (open dumps), and 38% of that is burned, for a total of 21% of all municipal waste subject to open burning (Argentina 2005).

4.4.3 Malaysia

Informal waste burning is prohibited in Malaysia. Illegal waste burning may take place, but it is not common as the regulation is said to be strictly enforced due to the Government's particular sensitivity to haze problems (Malaysia 2006).

4.4.4 Madagascar

According to data presented in the excellent mercury inventory for Madagascar (Rambolatahiana 2008), 7807 tonnes/d of municipal waste are generated in Madagascar, of which 66 % are in rural areas and 34 % urban, although only 43 % of the urban wastes are actually collected. Of the total 7807 tonnes/d, more than 85% are subject to burning, comprising more than half of the urban waste and virtually all of the rural waste, as shown in Table 15.

Table 15 Madagascar waste disposal (tonnes/day)

Disposition	Rural	Urban	Total
Uncontrolled burning	5138	1558	6696
Landfill	0	1111	1111
Total waste	**5138**	**2669**	**7807**

Source: Inventaire des déchets, Tab 114 (Rambolatahiana 2008)

In the rural areas, the method of disposing of waste (5138 tonnes/d) is everywhere the same. Holes typically 0.5-1.0 meter deep are excavated in the ground, and once these holes have been filled with waste they are set alight – perhaps a traditional method for dealing with vermin at the same time. After burning, the holes are filled in and new ones are dug (Rambolatahiana 2008).

The inventory goes on to explain how this traditional open burning process does not fully combust all of the waste, and in fact only 30% of the waste may be considered to be converted completely to ash. It should be kept in mind, however, that whether or not a certain percentage of the waste has been completely combusted, it has nevertheless been exposed to a high enough temperature that most of the mercury content would have been released to the atmosphere.

Overall, some 30-35 tonnes of mercury are estimated to be disposed to waste each year (approximately 85-90% to household waste, 5% to industrial waste, <0.5% to medical waste, and 2-10% captured in wastewater sludges), mostly due to mercury-added products in the waste stream (Rambolatahiana 2008), of which more than 15 tonnes may become air emissions due to burning processes.

The largest product contributors to mercury emissions are incinerated mercuric-oxide batteries (imported) and zinc-air batteries (produced locally), which appear to contribute some 80% of total mercury emissions from products.

4.4.5 Cambodia

According to the Cambodia Mercury Inventory (Cambodia 2008), the Solid Waste and Hazardous Substances Management Office of the Ministry of Environment reported that the amount of solid waste collected and dumped throughout the country in 2006 is approximately 466,556 tonnes, reporting: "All collected general (municipal) wastes are goes to dumping site, where wastes have been burning frequently by natural and/or human activities (waste compacted activities, scavengers burned, etc.)." The informal waste disposal (which must be estimated at an additional 2.5-3.0 million tonnes) and pathways are not discussed in this report "due to no reliable information or data supports."

4.4.6 United States

In the US, Cain *et al.* (2007) estimated that about 3 percent of municipal waste is incinerated in "burn barrels"[6] and other informal burning, of which they estimated that 90 percent of the mercury content of the waste is emitted to the atmosphere. The burn barrel estimates are based on an inventory of dioxin sources compiled by the USEPA (2006). No estimate is made of landfill fires and related mercury emissions.

Table 16 Disposition of municipal solid waste in the US, 1999-2005

	1999	2000	2005
Landfill	77%	75%	79%
Incinerator	18%	21%	18%
Burn barrels	5%	3%	3%
Compost	0.2%	0.2%	0.2%

4.4.7 Other countries

In **New Zealand**, medical waste incineration is said to be responsible for 6% of dioxin emissions; landfill fires responsible for 39% of dioxin emissions; and domestic waste burning responsible for 11% (UNEP 2005b). These numbers give some idea of the relative importance of these waste disposal practices.

According to UNEP (2005b), on the "**typical Pacific island chain**," domestic rubbish-burning and fires at rubbish dumps were identified as two of the major contributors to dioxin releases. Domestic rubbish and garden wastes are burnt by at least 40% of all households. This is despite the fact that regular rubbish collection services are provided in most of the urban areas. Burning is also a problem at most of the rubbish dumps, which are scattered throughout the country. These fires are often started by scavengers.

According to UNEP (2005b), in the "**typical LDC**," traditional waste management has typically focused on the "town dump" or backyard burning. Dumps receive all manner of wastes and are periodically burned to reduce volume (or may spontaneously combust and perpetually smoulder). Medical wastes (including pathogenic wastes) are generally disposed of in incinerators adjacent to the island's hospitals and medical centres. These incinerators are typically small, single chamber, batch units that handle all of the trash collected at the centre and are operated by the custodial staff. Ashes are disposed of in local landfills. Some unincinerated medical wastes (including sharps) have been found in MSW landfills but the amount is small.

Syria's Damascus Cleanness Directorate estimated "informal waste incineration" at 10% of the total amount of general wastes (Syria, 2008).

UNEP (2005b) further noted: "Medical/hospital waste incineration is practiced at several sites in **Syria** with uncontrolled batch combustion. A recent visit … to the medical waste incineration plant in Najha (40 km south of Damascus) had shown that the plant is operated under poor combustion conditions with no control of emissions to air and land."

Lebanon reported open burning of a particularly precise volume of domestic waste (including landfill sites) of 130,821 tonnes/yr., which is more than 10% of the country's

[6] Cain *et al.* (2007) define burn barrels as "steel drums used for the burning of residential solid wastes by households. This category includes all forms of "backyard burning" and related informal combustion of municipal solid waste."

domestic waste. It also reported medical waste incineration of 2140 tonnes/yr., two-thirds of which was uncontrolled batch-type combustion (no air pollution controls), and one-third controlled batch combustion (virtually no air pollution controls) (UNEP 2005b).

Liberia reported that municipal waste incineration is done crudely by burning in open dumps, some of which are near residential areas (UNEP 2005b).

Mauritius reported that dioxin emissions due to open burning were roughly equivalent to those generated by waste incineration (without controls). This observation could be interpreted to suggest that the volume of waste incinerated may be somewhat greater than the volume of waste burned in the open (UNEP 2005b).

Sri Lanka estimated that about 5% of its total solid waste stream was subject to open burning and/or landfill fires, and suggested that landfill fires consume more waste than open burning (UNEP 2005b).

4.4.8 UNEP advice regarding open burning

According to UNEP (2005b), "In principle, open burning should simply be prohibited." Open burning is an environmentally unacceptable process that generates chemicals listed in Annex C of the Stockholm Convention, as well as numerous other toxic products resulting from incomplete combustion. Consistent with Annex C, Part V, Section A, Subparagraph (f) of the Stockholm Convention, the best guidance is to reduce the amount of material disposed of via this method with the goal of elimination altogether.

According to UNEP, other waste management techniques that should be implemented include:

- avoid including non-combustible materials, such as glass and bulk metals, wet waste and materials of low combustibility;
- avoid waste loads containing high chlorine content, whether inorganic chloride such as salt, or chlorinated organics such as PVC; and
- avoid materials containing catalytic metals such as copper, iron, chromium and aluminium, even in small amounts.

Materials to be burned should be dry, homogeneous or well blended, and of low density, such as non-compacted waste (UNEP 2005b).

4.4.9 Summary of burning in various waste pathways

Table 17 combines the observations in the many sources cited above to suggest the percentage of each waste stream that will most likely be burned in each major geographical region.

Table 17 Percentage of waste that will be burned in each sub-pathway

	Percent of medical waste incinerated with some emission controls	Percent of medical waste incinerated with no emission controls	Large-scale M&HW incineration with emission controls	Large-scale M&HW incineration without emission controls	Small-scale M&HW incineration without emission controls	Percent of municipal wastewater sludge burned	Percent of hazardous waste landfill burned	Percent of managed landfill burned	Percent of uncontrolled waste disposal (urban) burned	Percent of uncontrolled waste disposal (rural) burned
East and Southeast Asia	10%	90%	10%	45%	45%	4%	0%	3%	8%	24%
South Asia	10%	90%	10%	45%	45%	3%	0%	5%	12%	36%
European Union	60%	40%	60%	30%	10%	17%	0%	1%	4%	12%
CIS & other Euro-pean countries	40%	60%	40%	30%	30%	11%	0%	2%	8%	24%
Middle Eastern States	40%	60%	40%	30%	30%	3%	0%	2%	8%	24%
North Africa	10%	90%	10%	45%	45%	3%	0%	4%	12%	36%
Sub-Saharan Africa	0%	100%	0%	0%	100%	1%	0%	6%	15%	45%
North America	90%	10%	90%	5%	5%	17%	0%	1%	4%	12%
Central America & Caribbean	10%	90%	10%	45%	45%	3%	0%	2%	8%	24%
South America	40%	60%	40%	30%	30%	5%	0%	2%	8%	24%
Australia N. Zealand & Oceania	60%	40%	60%	30%	10%	8%	0%	1%	4%	12%

4.5 Mercury emission factors for waste burning

This section will assess how much mercury from the burning of mercury-added products is subsequently emitted to the atmosphere. The calculation relies on emission factors, which simply indicate what percentage of the total mercury in a given type of waste is released to the atmosphere when that waste is burned. Of course, in the ideal case an emission factor takes account of the particular combustion process and temperature, the composition of the waste, etc. For the purposes of this assessment, the emission factors shown in Table 18 are based largely on those estimated by the key reference documents listed in Section 2.5.

Table 18 Mercury emission factors for incineration and other waste combustion

	Medical waste incinerated with some emission controls	Medical waste incinerated with no emission controls	Large-scale M&HW incineration with emission controls	Large-scale M&HW incineration without emission controls	Small-scale M&HW incineration without emission controls	Burning of municipal wastewater sludge	Landfill fires and open burning of domestic waste
East and Southeast Asia	60%	80%	50%	80%	90%	70%	60%
South Asia	60%	80%	50%	80%	90%	70%	60%
European Union	40%	80%	50%	80%	90%	70%	60%
CIS & other European countries	40%	80%	50%	80%	90%	70%	60%
Middle Eastern States	40%	80%	50%	80%	90%	70%	60%
North Africa	60%	80%	50%	80%	90%	70%	60%
Sub-Saharan Africa	60%	80%	50%	80%	90%	70%	60%
North America	5%	80%	10%	80%	90%	70%	60%
Central America & Caribbean	50%	80%	50%	80%	90%	70%	60%
South America	50%	80%	50%	80%	90%	70%	60%
Australia N. Zealand & Oceania	50%	80%	50%	80%	90%	70%	60%

5 Findings

5.1 Observations

It needs to be kept in mind that most nations have a limited capability to minimize mercury emissions during the waste treatment and disposal process. In fact, the waste treatment and disposal infrastructure in most parts of the world does not even lend itself to the segregation, handling, recycling, or pollution control measures necessary to manage mercury wastes safely and effectively. This waste management challenge once again underscores the desirability and urgency of phasing out the use of mercury-added products as the only viable means of addressing this problem.[7]

It is also evident that as emissions tied to the incineration and other burning of mercury-added products are better quantified and understood, there will be increasing pressure on various stakeholders – not least the government authorities – to deal with these emissions, and increased pressure to implement a range of existing (but not widely implemented) policies to phase out mercury-added products and to encourage the many viable and competitively priced alternatives.

5.2 Global air emissions from burning mercury-added products

5.2.1 Mass flow diagram

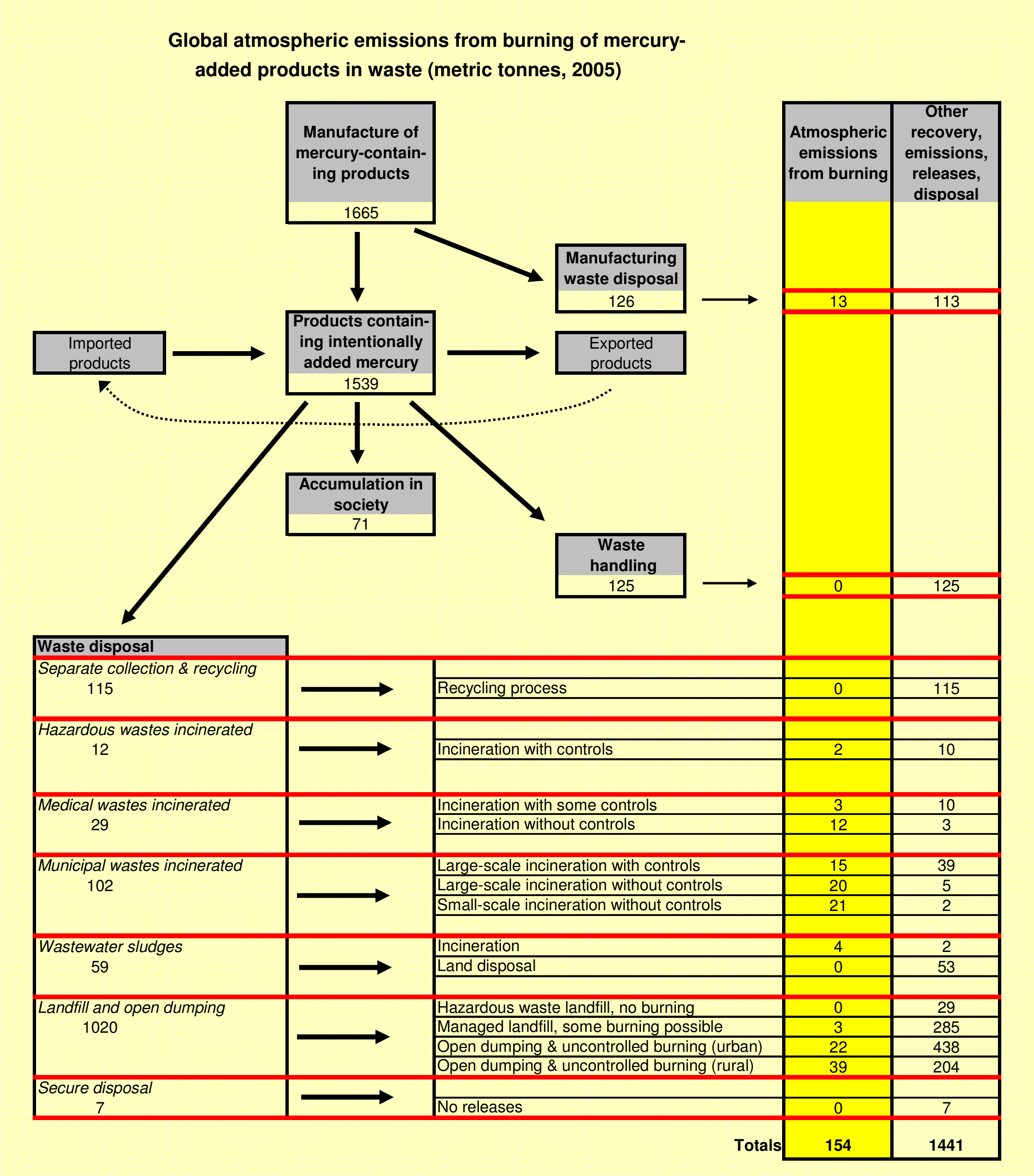
The general results of this assessment are summarised in Figure 10, which presents the best estimates of the quantity of mercury consumed in the global production of mercury-added products, the "flows" of mercury from products into wastes, the burning of some fractions of those wastes and the resulting atmospheric emissions.

Globally, the main sources of air emissions from the burning of mercury-added products (excluding emissions related to manufacturing waste disposal) are municipal waste incineration (about 41% of the total air emissions related to the burning of mercury-added products) and uncontrolled burning of domestic waste (about 45% of the total). Medical waste incineration accounts for about 11% of the total air emissions, and wastewater sludge incineration accounts for only about 3%.

It is evident in Figure 10 that, as a global average, open burning is estimated to release about 5% of the mercury in domestic waste disposed of in uncontrolled urban dumps, and up to 20% of the mercury in domestic waste disposed of in uncontrolled rural dumps. It should be kept in mind that despite our best efforts, the estimates of open burning remain uncertain. However, even if our estimates are moderately raised or lowered, such changes would make relatively little difference in the overall mercury emissions to air as calculated here.

[7] If any further proof were needed of the viability of the phase-out option, the Swedish Government decided on 15 January 2009 to introduce a blanket ban on mercury, meaning that no products containing mercury may be placed on the Swedish market. In practice this means that alternative techniques will have to be used in dental care, chemical analysis and the chloralkali industry, among others, in addition to the existing ban in Sweden – already from the early 1990s – on the manufacture and sale of other products containing mercury, including thermometers and other measuring devices and electronic components.

Figure 10 Mercury mass flow diagram:
Global atmospheric emissions from burning mercury-added products in waste (2005)



5.2.2 Uncertainty in global emissions

Therefore, while the different categories of combustion emissions are associated with different levels of uncertainty (e.g., less uncertainty related to municipal waste incineration, and more uncertainty related to uncontrolled burning of waste), this assessment has calculated a total of about 140 tonnes mercury emissions (not including burning of product manufacturing wastes), which is our “best estimate” within a wider range of some 100-200 tonnes. This is more than two times the estimate of the recent report of the UNEP Mercury Air Transport and Fate Research partnership (UNEP 2008b) – to the extent the latter's emissions due to actual burning processes may be identified.[8] It is also more than two times the estimates of the other two reports compared in Section 6.

For the four main categories of waste disposal analysed, not including product manufacturing waste disposal, the ranges of mercury emissions to the air from the burning of mercury-added products are estimated as in Table 19.

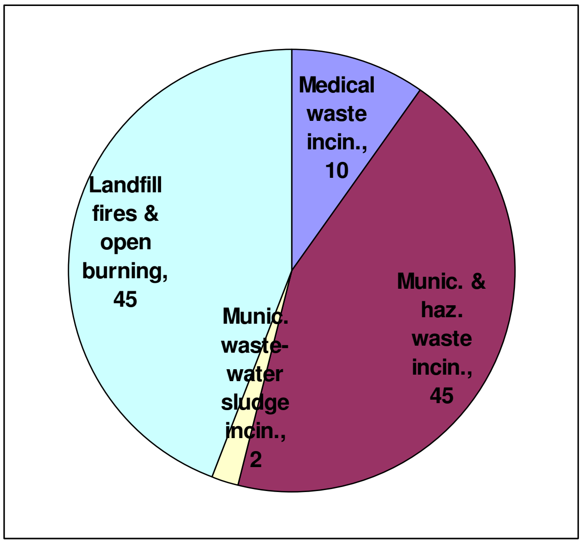
Table 19 Global mercury emissions (tonnes) from burning mercury-added products (2005)

Key waste stream burning processes	Atmospheric mercury emissions (tonnes)
Medical waste incineration	10-25
Incineration of mercury-added products in municipal and hazardous waste	45-70
Incineration of municipal wastewater sludge from products	2-8
Landfill fires and open burning of mercury-added products in domestic waste	45-100
Total	**~100-200**

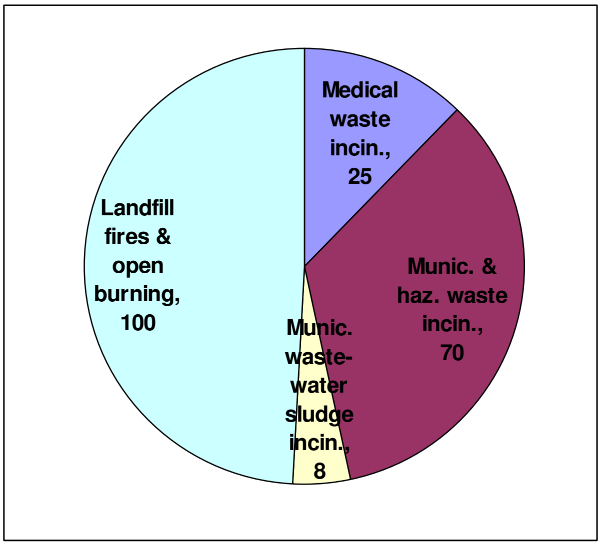
The distribution of global emissions among these burning processes is presented graphically in Figure 11.

Figure 11 Global mercury emissions (tonnes) from burning mercury-added products (2005)

Lower end of range



Upper end of range



[8] For example, the authors do not separately identify mercury emissions due to the burning of waste, as compared to non-combustion waste disposal emissions such as from product breakage and landfill degassing.

5.2.3 Mercury emissions by region and waste disposal pathway

Resulting from the preceding methodology, Table 20 shows the estimated mercury emissions from the burning of mercury-added products by geographic region and by disposal pathway.

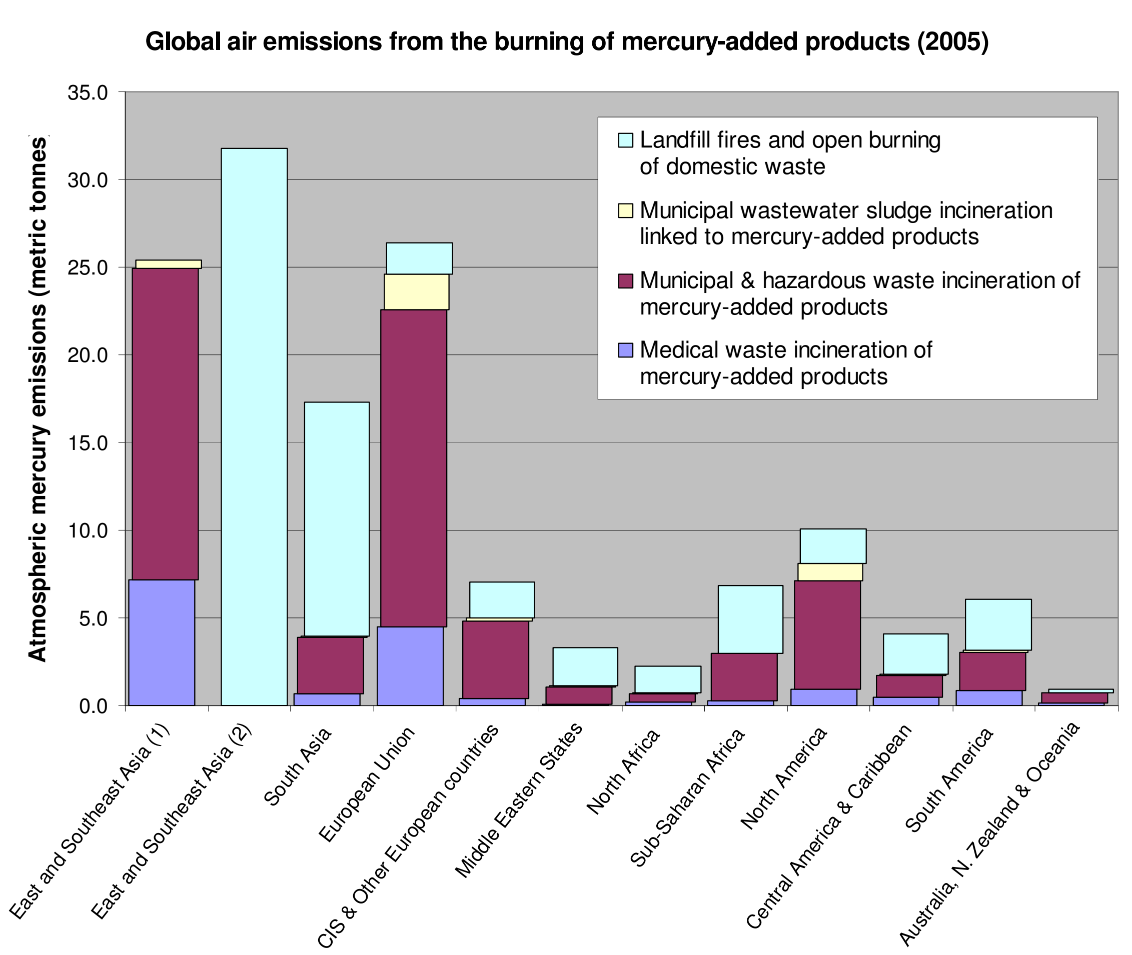
Table 20 Global air emissions (tonnes Hg) from the burning of mercury-added products, by geographic region and disposal pathway (2005)

	Medical waste incineration of mercury-added products	Municipal & hazardous waste incineration of mercury-added products	Municipal wastewater sludge incineration linked to mercury-added products	Landfill fires and open burning of domestic waste	Total
East and Southeast Asia	7	18	<1	32	**57**
South Asia	<1	3	~0	13	**17**
European Union	5	18	2	2	**26**
CIS & other European countries	<1	4	~0	2	**7**
Middle Eastern States	0	1	0	2	**3**
North Africa	~0	<1	0	2	**2**
Sub-Saharan Africa	~0	3	0	4	**7**
North America	1	6	1	2	**10**
Central America & Caribbean	<1	1	~0	2	**4**
South America	1	2	~0	3	**6**
Australia N. Zealand & Oceania	~0	<1	0	~0	**1**
Total	**16**	**58**	**4**	**64**	**141**

Note: Columns and rows may not add precisely due to rounding.

Figure 12 presents the same results graphically.

Figure 12 Global air emissions (tonnes Hg) from the burning of mercury-added products, by geographic region and disposal pathway (2005)



The magnitude of emissions in East and Southeast Asia (and South Asia to a lesser extent) due to landfill fires and open burning of domestic waste reflects a combination of significant open burning, especially in rural areas, a large amount of mercury consumed in products in this region (not to mention in substantial imports of waste electronic equipment), and very low recycling rates.

Likewise with regard to incineration, even though formal incineration of municipal waste is not common in most countries in Asia, the generation of large volumes of waste, the relatively high use and disposal of mercury-added products, and the fact that Japan, in particular, incinerates a very high percentage of its waste help to explain the magnitude of regional atmospheric mercury emissions from incineration.

With regard to other regions, the European Union incinerates a large fraction of its municipal waste but has limited controls on mercury emissions from incinerators, while the US also has a high rate of incineration but has recently mandated stricter incinerator controls. All other regions have low incineration rates, and also relatively lower total volumes of municipal waste.

5.2.4 Mercury emissions by region and product category

In order to provide a different perspective on the same data, Table 21 shows the estimated mercury emissions from the burning of mercury-added products by geographic region and by product category.

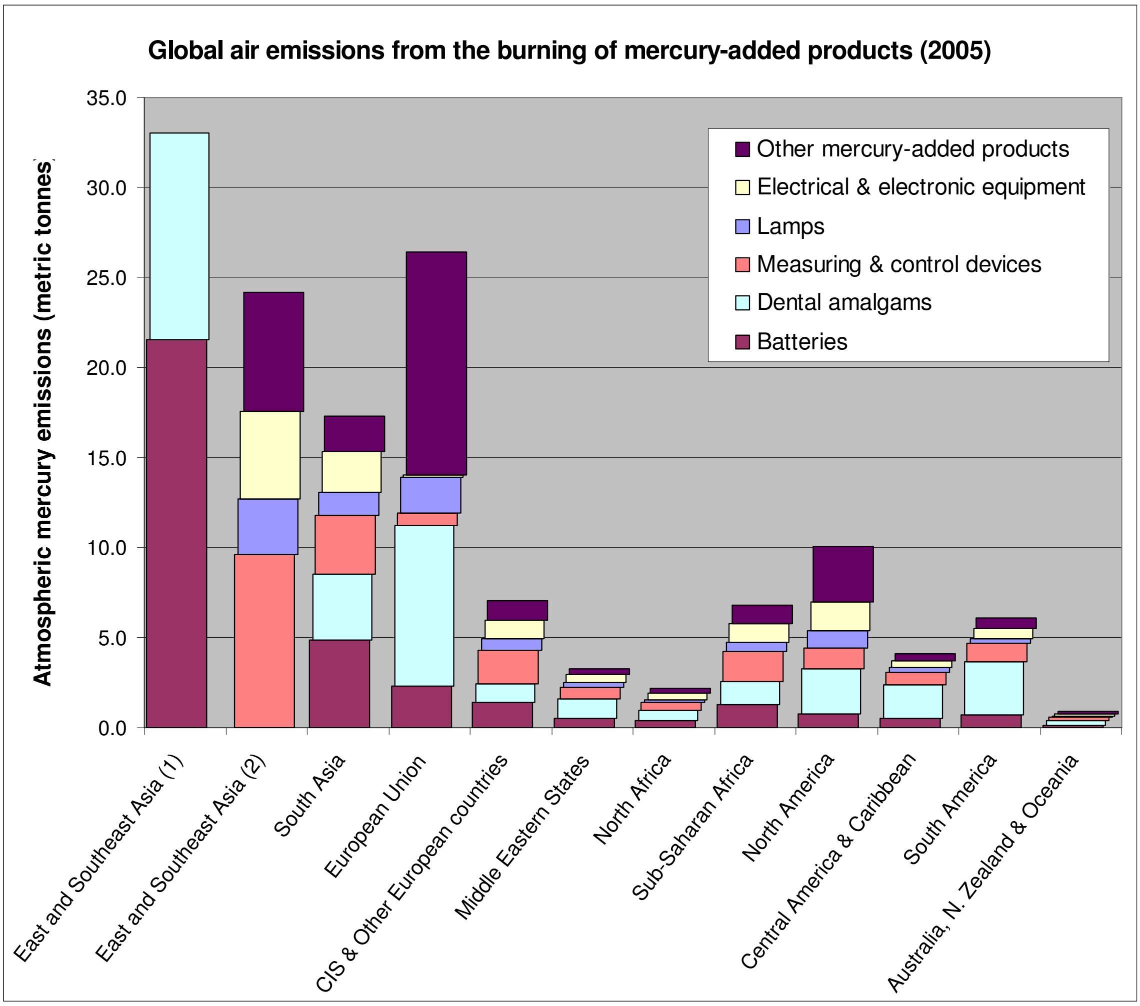
Table 21 Global air emissions (tonnes Hg) from the burning of mercury-added products, by geographic region and product category (2005)

	Batteries	Dental amalgams	Measuring & control devices	Lamps	Electrical & electronic equipment	Other mercury-added products	Total
East and Southeast Asia	22	11	10	3	5	7	**57**
South Asia	5	4	3	1	2	2	**17**
European Union	2	9	<1	2	~0	12	**26**
CIS & other European countries	1	1	2	<1	1	1	**7**
Middle Eastern States	<1	1	<1	~0	<1	<1	**3**
North Africa	<1	<1	<1	~0	<1	<1	**2**
Sub-Saharan Africa	1	1	2	<1	1	1	**7**
North America	1	3	1	1	2	3	**10**
Central America & Caribbean	<1	2	<1	~0	<1	<1	**4**
South America	<1	3	1	<1	<1	<1	**6**
Australia N. Zealand & Oceania	~0	~0	~0	~0	~0	~0	**1**
Total	**34**	**36**	**22**	**9**	**13**	**28**	**141**

Note: Columns and rows may not add precisely due to rounding.

Figure 13 presents the same results graphically.

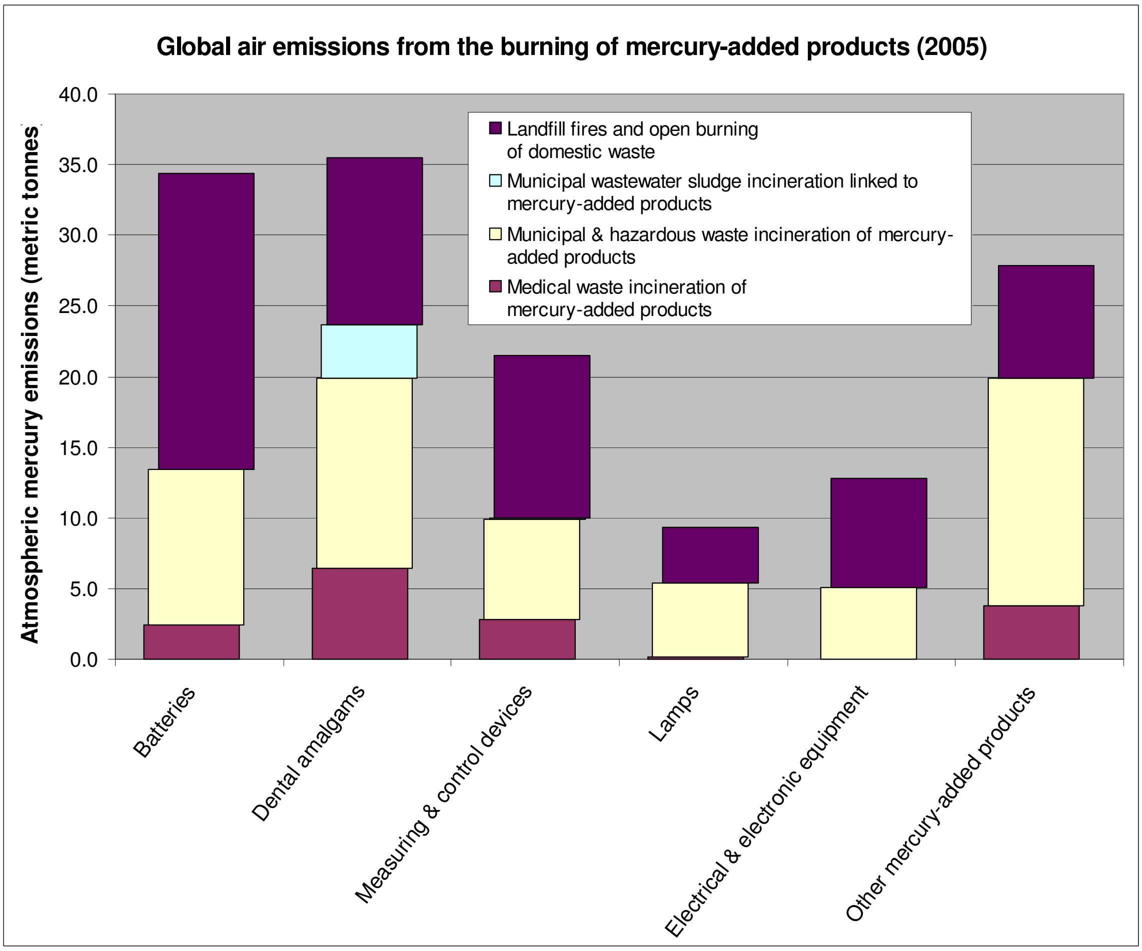
Figure 13 Global air emissions (tonnes Hg) from the burning of mercury-added products, by geographic region and product category (2005)



5.2.5 Mercury emissions by product category and waste disposal pathway

In order to provide a third and final perspective on the same data, Figure 14 shows the estimated mercury emissions from the burning of mercury-added products by product category and by waste disposal pathway.

Figure 14 Global air emissions (tonnes Hg) from the burning of mercury-added products, by product category and disposal pathway (2005)



5.3 Global mercury emissions linked to mercury-added products

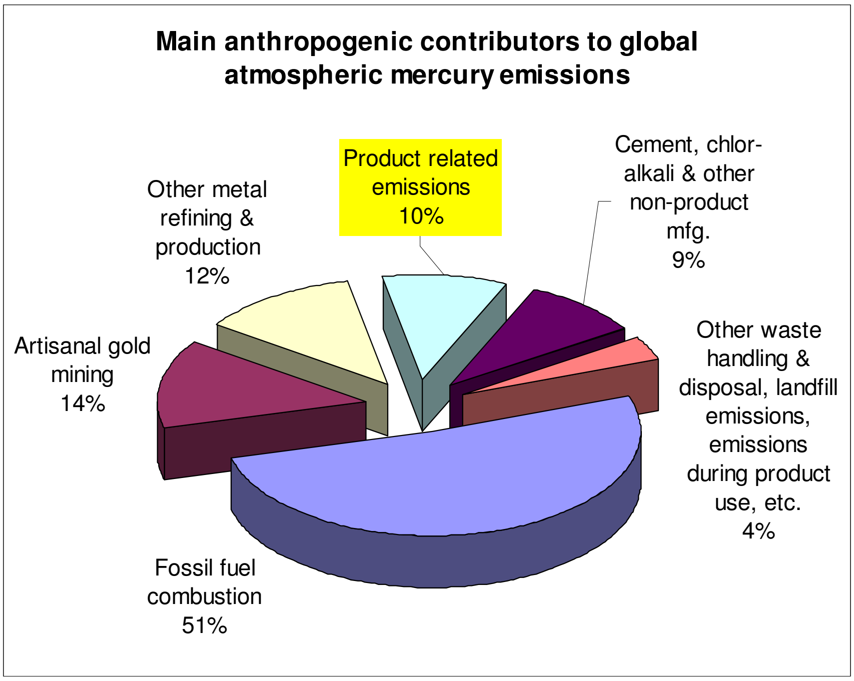
The previous discussion has focused specifically on emissions from burning mercury-added products in the major waste streams – municipal and hazardous waste, medical waste, wastewater sludge, and landfill and uncontrolled dumping.

However, it should be stressed that there are other less "direct" emissions associated with the burning of mercury-added products that have not been investigated in this analysis. Specifically, as indicated by both the AMAP/UNEP (2008) and UNEP (2008b) research teams, cremation may add 20-30 tonnes of global mercury emissions, not to mention industrial incineration of product manufacturing wastes and sludges (10-25 t Hg), non-combustion landfill emissions (10-45 t Hg), emissions during waste handling (3-8 t Hg), emissions from the wastewater treatment process (4-8 t Hg) and emissions from products that go through metal scrap processing (5-10 t Hg). Together these additional sources come to some 50-125 t mercury.

Finally, product-related sources not linked to waste disposal, such as product manufacturing emissions, product breakage during use, etc., have been estimated by other researchers at 15-40 t mercury. When added to all of the above sources, global product-related mercury emissions are in the range of 165-365 t, with a best estimate of around 250 t mercury, or some 10% or more of all anthropogenic mercury emissions.

The various estimates of global anthropogenic emissions of the three recent research reports compared in Section 6, while differing in some respects, are combined in the following figure – relative to total product-related emissions. It should be noted that product-related emissions are of the same general magnitude as major industrial process emissions and metal refining emissions, both of which are already subject to intense scrutiny.

Figure 15 Relative contribution of main anthropogenic sources of mercury emissions to air (~2005)



6 Comparison of results with other research

While other researchers have included in their calculations mercury emissions to air from the combustion of wastes containing mercury-added products, none have taken careful account of the substantial emissions contributed by landfill fires and open burning of domestic waste.

Focusing solely on the presence of mercury-added products in the waste stream, the top part of Table 22 compares our estimates with three other recent estimates of emissions to the atmosphere from waste burning processes.

In their 2007 peer-reviewed paper published in *Ambio,* for example, Swain *et al.* (2007) based their emission estimates on models using available data from 1995 and 2000. The authors estimated annual global mercury emissions to the atmosphere as a result of human activities at about 2400 tonnes, of which 110 tonnes were estimated to result from the disposal of mercury-added products, including no more than 50 tonnes emitted from incinerators. Moreover, the estimate of 50 tonnes was based on measurements carried out by the US EPA even before it had implemented tighter restrictions on US incinerator emissions of mercury.[9]

Even the highest estimate of 70 tonnes shown in the top part of Table 22, as published by the UNEP Mercury Fate and Transport Partnership (UNEP 2008b), includes other emissions in addition to those from burning mercury-added products.

The lower part of Table 22 helps to explain the other elements that make up the waste emission estimates of these other researchers, and indicates the broader range of emissions related to the disposal of both product and non-product waste.

To the credit of these other research teams, it should be noted that mercury emissions from mercury-added products in the waste stream, while important, comprised only a small part of their efforts, and therefore did not receive the same level of attention as they did in this analysis.

The higher mercury emission estimates revealed by this study are due in large part to the inclusion of the open burning of mercury-added products in landfills and uncontrolled dumps. They are also due to the fact that a significant amount of dental waste goes to the municipal waste stream and to sludge waste that may be incinerated, and that more mercury continues to be used (and disposed of) in "other" product categories than previous studies have reported, as demonstrated in the recent study carried out for the European Commission (2008).

[9] Mercury emission controls have been required on US incinerators of medical and infectious waste since 1997, and on municipal waste incinerators since 2002, although some incinerators had already begun to comply by 2000.

Table 22 Comparison of different estimates of mercury emissions from waste disposal

	Mercury Policy Project, "Mercury Rising" (this report)	***Ambio*, Socioeconomic Consequences (Swain *et al.* 2007)**	**Hg Air Transport & Fate Research Partnership (UNEP 2008b)**	**Global Atmospheric Mercury Assessment (AMAP/UNEP 2008)**
Reference year	***2005***	***2005***	***2007***	***2005***
Burning of mercury-added products in general waste				
Medical waste incineration	15	13	20*	incl. M&HWI
Municipal & hazardous waste incineration (M&HWI) of mercury-added products	58	37	50*	57
Incineration of municipal wastewater sludge from products	4	incl. M&HWI	incl. M&HWI	incl. M&HWI
Landfill fires and uncontrolled burning of mercury-added products in domestic waste	64	no estimate	no estimate	incl. M&HWI
Total	**141**	**50**	**70***	**57**
* A certain (undefined) percentage of these emissions should be attributed to the disposal of mercury process or other wastes not specifically linked to mercury-added products. Therefore, a somewhat lower number should be used for comparative purposes.				
Other waste disposal emissions related to mercury-added products				
Cremation	no estimate	no estimate	25	26
Industrial incineration of product wastes & sludges	13	10	22	incl. M&HWI
Landfill emissions from mercury-added products - non-combustion	no estimate	no estimate	10	45
Waste handling emissions	no estimate	no estimate	no estimate	5
Wastewater treatment process emissions	no estimate	no estimate	4	no estimate
Mercury-added products in metal scrap processing	no estimate	no estimate	no estimate	7
Other non-product waste disposal emissions				
Municipal & hazardous waste incineration	no estimate	no estimate	6	no estimate
Industrial incineration of non-product wastes & sludges	no estimate	15	44	no estimate
Non-product landfill emissions - non-combustion	no estimate	no estimate	3	no estimate
Wastewater treatment process emissions	no estimate	no estimate	3	no estimate
Total estimated mercury emissions from waste disposal	**no estimate**	**75**	**187**	**140**

7 Conclusions and recommendations

In conclusion, the purpose of this study was to provide better estimates to decision-makers and others as they grapple with atmospheric releases of mercury from all sources. Based upon our findings, we believe it is important to recognize that the burning of products containing mercury is much more significant than previously suspected, and in fact constitutes at least two times more mercury emissions to the global atmosphere than previously thought.

In order to reduce mercury emissions associated with the burning of mercury-added products, several options are available. The politically easiest – and lowest risk – solution is to accelerate the shift to mercury-free products. This shift is well underway in some countries, and the health sector, for example, is increasingly moving away from devices containing mercury. Other approaches for reducing mercury emissions include separating products from the waste stream, avoiding incineration (which reduces other emissions as well as mercury) through commitments to other waste strategies, enhanced restrictions on open burning, and various other measures.

To date, some countries have succeeded better than others at reducing emissions from mercury-added products, but most countries, particularly in the developing world, are not doing well because of the challenges they face regarding waste management.

Eliminating mercury at source is generally preferable because then the mercury is not available for release, and the impacts of mercury throughout the product lifecycle are avoided. Phasing out the marketing and use of most mercury-added products is feasible, achievable and cost-effective, given the experience of several countries where phase-outs are underway or already accomplished, given the demonstrated viability of non-mercury products already on the market, and given the limited number of countries where mercury products continue to be made.

The magnitude of mercury releases to air from sources involving the combustion, both controlled and uncontrolled, of mercury-added products attests to the need for globally coordinated actions to phase out the manufacture, sale and use of such products. Toward that end, and inspired by the decisions of Norway and Sweden to ban all uses of mercury, not to mention the examples of many other governments to phase out various uses, it is recommended that the United Nations Environment Program Governing Council take the following steps at its February 2009 meeting in Nairobi:

1) Establish an Intergovernmental Negotiating Committee (INC) for the purpose of negotiating a free-standing legally binding instrument on mercury that shall include, in part, provisions to phase out as soon as possible the use of mercury in the manufacture of products for which adequate non-mercury alternatives are available, such as measuring devices, batteries, and switches, recognizing that the time frames for such phase-outs may differ depending upon the product and the circumstances of the different countries.

2) Request that UNEP, in the interim period before such an instrument becomes effective, assume responsibility for the awareness-raising, analytical, technical and legal support activities necessary to encourage manufacturers of mercury-added products, and countries where such manufacturers are located, to identify and implement the actions needed to shift production toward mercury-free alternative products.

3) Recognize that combustion of mercury-added products in incinerators, landfill fires and open burning of domestic waste is a significant contributor of mercury and other toxics to both local and global ecosystems, and urge countries to take steps to stop these practices and to move expeditiously towards safe, just, sustainable and more environmentally-sound alternatives.
4) Request that UNEP take account of the additional emissions identified in this report in its revision of the draft AMAP/UNEP (2008) Technical Background Report to the Global Atmospheric Mercury Assessment.

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APPENDIX 1
Regional country groups as defined for this study

Region	Countries grouped in each region
East and Southeast Asia	Brunei Darussalam, Cambodia, China and Taiwan, China-Hong Kong, China-Macao, Democratic People's Republic of Korea, Indonesia, Japan, Lao People's Democratic Republic, Malaysia, Mongolia, Myanmar, Papua New Guinea, Philippines, Republic of Korea, Singapore, Thailand, Viet Nam
South Asia	Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan, Sri Lanka
European Union (EU-25)	Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, United Kingdom
Commonwealth of Independent States(CIS) and Other Europe[1]	Albania, Andorra, Armenia, Azerbaijan, Belarus, Bosnia Herzegovina, Bulgaria, Croatia, Georgia, Gibraltar, Iceland, Kazakhstan, Kyrgyzstan, Norway, Republic of Moldova, Romania, Russian Federation, Serbia and Montenegro, Switzerland, Tajikistan, The Former Yugoslav Republic of Macedonia, Turkmenistan, Ukraine, Uzbekistan
Middle East	Bahrain, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territories, Oman, Qatar, Saudi Arabia, Syria, Turkey, United Arab Emirates, Yemen
North Africa	Algeria, Egypt, Libya, Morocco, Tunisia
Sub-Saharan Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia, Zimbabwe
North America	Canada, Greenland, United States of America
Central America and the Caribbean	Anguilla, Antigua, Barbuda, Aruba, Bahamas, Barbados, Belize, British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Mexico, Montserrat, Netherlands Antilles, Aruba, Nicaragua, Panama, Saint Kitts, Nevis, Anguilla, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, Turks and Caicos Islands, US Virgin Islands
South America	Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, Venezuela
Australia, New Zealand and Oceania	Australia, Christmas Islands, Cocos Islands, Cook Islands, Fiji, French Polynesia, Federated States of Micronesia, Kiribati, Marshall Islands, North Mariana Islands, Nauru, New Caledonia, New Zealand, Niue, Norfolk Islands, Palau, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna Islands

Notes:

1- *In order to treat the European Union as a single region, the decision was made to include EEA countries such as Switzerland and Norway and other neighbouring countries in the "CIS and Other Europe" region.*

APPENDIX 2
Questionnaire – Request for additional information

Project memo

Project: Global Mercury Product Phase-Outs Tied to Waste Incineration

Project coordinator: Michael Bender – Mercury Policy Project/Tides Center

Subject: NGO input – data on waste incinerators, waste quantities, and if possible, mercury products in the waste stream

Background
Mercury uses and releases pose a considerable risk to people, fish and the environment. The UN Environment Program Governing Council has determined that mercury emissions – globally – need to be significantly reduced in order to reduce health and environmental impacts. A major source of mercury in the environment is due to mercury in products, which eventually enter the waste stream and are incinerated, releasing mercury to the atmosphere.

Project Significance
Anthropogenic emissions of mercury to the global atmosphere have been estimated at 2400 metric tons annually. The annual global consumption of mercury for use in products is roughly 1200-1600 metric tons. Typical sources of mercury in municipal solid waste include batteries, measuring devices, discarded electrical and electronic equipment (including fluorescent tubes and CFLs), dental waste, etc. Most of these products eventually enter the waste stream, and many of them are subsequently incinerated. Yet the most recent report by experts in 2007, using models based on limited data from 1995 and 2000, estimated that only 150 metric tons of global atmospheric emissions are due to the burning of mercury in municipal wastes. At the same time, however, the same experts admitted that even for Europe, their atmospheric mercury emissions estimates from waste incineration are uncertain by a factor of five!

Addressing this uncertainty is critical because in recent years various governments and non-governmental organizations have focused some of their efforts on reducing and eliminating mercury in products. However, because emission estimates are so uncertain, the contribution of mercury products to air emissions from waste burning has not been given the prominence it deserves.

The collection of better data is also critical because UNEP has just recently commissioned a global atmospheric emissions report that is to be an important input into the deliberations of the UNEP Governing Council in February 2009. Due to budget and data constraints, it appears unlikely that the authors of that report will generate new data, especially with regard to emissions from waste incineration.

So we propose a different tack. Based upon the activities of the UNEP and others, we know there are basic data now available about the consumption and disposal of mercury-added products in different countries and regions, and basic information available about the composition of waste streams. If we are able to collect better information about specific incinerators, and if we obtain information to better quantify other burning of wastes in various countries, we believe that mercury emissions estimates can be greatly improved.

Objectives

We are in an excellent position to collaborate with our worldwide NGO network to generate some new and valuable information that will influence the UNEP deliberations and decision.

If we can gather and present sufficiently reliable information so that waste related mercury emissions are better quantified and understood, UNEP and NGOs will be able to apply more pressure on national governments to establish and implement policies that aim to phase mercury out of products and to provide comparable alternatives at a reasonable price.

NGO role – data needs

We naturally assume that NGOs based in a country are considerably more familiar with these issues in their country and region than are external experts. Therefore, we hope that even when specific references may not be available to respond to certain data needs, it may be possible to obtain educated estimates from people who deal with these issues on a daily basis.

To ensure consistency of responses, we urge that the attached questionnaire/tables be completed to the extent feasible. **Please note that, although the questionnaire appears long, the most important data we seek is only in response to the first two tables.** The tables are presented in the order of their importance to the final analysis. After the first three, the other tables have been prepared in case NGOs in some countries or regions may have useful estimates of other aspects of mercury products in the waste stream. Any other relevant information that may be useful can of course be provided in comments or attached as an appendix.

Schedule

The consultants working for UNEP are expected to produce a draft report of global mercury emissions in April 2008. We hope to receive information from NGOs around the world before April, so we will have time to analyse the information, ask for any clarifications and then use that information to make comments to the UNEP draft. So as usual, the sooner you can respond, the better, and in case we hope to have all responses before April 2008.

APPENDIX 2 (continued)

Information tables – incineration of mercury in products and wastes

Contact organisation or person who coordinated this data gathering	Responses	Comments
Name		
Address		
Telephone		
Email		
Country or region covered by these tables		
Population (millions)		
Rural/urban population split (%)	% rural % urban	

Waste incinerators

(Note: highest priority questions are in italics)

In order to estimate overall mercury emissions from incineration of solid waste, it is important to understand the characteristics of the various waste incinerators. Municipal and medical waste incinerators may be well designed, but sometimes operated at lower than design temperature, or with frequent temperature fluctuations, or be poorly maintained, etc. Likewise, flue gas emission controls, if any, may not be appropriate for the actual operating parameters of the incinerator. With regard to mercury emissions, some mercury will be trapped in any device that removes dust and particulates from the flue gases, but the majority of mercury vaporised during the burning process will likely be emitted to the atmosphere.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Please provide a separate list of all medical waste incinerators, the tonnes of medical waste treated per day or per year, any flue gas control devices, any limits on mercury emissions, and a general assessment of whether each incinerator is operated according to the manufacturer's specifications.		
If individual medical waste incinerator details are unavailable, please estimate simply the tonnes of medical waste that go to medical waste incinerators.		
Please provide a separate list of all municipal waste incinerators, the tonnes of municipal waste treated per day or per year, any flue gas control devices, any limits on mercury emissions, and a general assessment of whether each incinerator is operated according to the manufacturer's specifications.		
If individual municipal waste incinerator details are unavailable, please estimate simply the tonnes of municipal waste that go to municipal waste incinerators.		

Quantities and destinations of mercury in the solid waste stream

(Note: highest priority questions are in italics)

Several of the following tables are used to calculate the quantities of mercury from products going to the municipal solid waste stream. This table aims to identify the overall magnitude of the municipal solid waste stream, and where the waste in the municipal solid waste stream is likely to end up.

Improper management of solid waste is one of the main causes of environmental pollution and degradation, especially in developing countries and countries with economies in transition. Many regions lack adequate solid waste regulations and proper disposal facilities, including for harmful waste. Such waste may be infectious, toxic or radioactive. Municipal waste dumping sites are designated places set aside for waste disposal. Depending on local regulations and management, such waste may be dumped in an uncontrolled manner, segregated for recycling purposes, or simply burnt.

In the case of a dumpsite located to the East of Nairobi, this is the main dumpsite for most of the solid waste from the Nairobi area. Surrounding the dump are informal settlements and residential estates. Over 2,000 tonnes of waste generated and collected from the local area are deposited daily in the dumpsite. What initially was intended to refill an old quarry has given rise to a big mountain of garbage, perpetually smouldering and smoking. Dumping at the site is unrestricted, and industrial, agricultural, domestic and medical wastes (including used syringes) are seen strewn around the dumpsite. The Nairobi River also passes beside the dumpsite. Some of the waste from the dump ends up in the river, thus carrying environmental and health risks to people living in the vicinity as well as those living downstream who may use the water for domestic and agricultural purposes like irrigation. According to a study, the mercury concentration in samples collected from the waste dump registered a mean value of 46.7 ppm, while those collected along the river bank registered a mean value of 18.6 ppm. Both of these values greatly exceed the WHO acceptable exposure level of 2 ppm. It was determined that the dumpsite exposes the local residents to unacceptable levels of environmental pollutants with adverse health impacts. A high number of children and adolescents living around the dumpsite had respiratory, gastrointestinal and dermatological illnesses such as upper respiratory tract infections, chronic bronchitis, asthma, fungal infections, allergies and unspecified dermatitis/pruritis – inflammation and itchiness of the skin.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
What is the overall magnitude of the municipal waste generated in your country or region? By municipal waste, we include all domestic waste, commercial waste from shops and restaurants, and even dental, medical, industrial and construction waste if it gets mixed together with other municipal waste. It may be useful to consider separately urban and rural areas. For purposes of comparison, the quantity of municipal waste generated in industrialised countries may reach 4-5 kg/person/day.		
To the extent it is separate from the		

municipal waste stream, what is the overall magnitude of medical waste generated in your country or region?		
With regard to the separation of mercury products from the municipal and medical waste streams, are any further efforts made other than the measures already described in the tables above?		
Approximately what percentage of the municipal waste stream goes to an authorised and regulated normal landfill (no burning)?		
Approximately what percentage of the municipal waste stream goes to an authorised and regulated hazardous waste landfill (no burning)?		
Approximately what percentage of the municipal waste stream goes to an authorised and regulated municipal waste incinerator?		
Approximately what percentage of the municipal waste stream goes to an authorised and regulated hazardous waste incinerator?		
Approximately what percentage of the municipal waste stream goes to relatively unregulated land disposal, and how much of that may eventually be burned?		
Approximately what percentage of the municipal waste stream is disposed in some other manner (e.g. surface water, old mine shafts) ,and how much of that may eventually be burned?		

Mercury in batteries
(Note: highest priority questions are in italics)

The use of mercury in various types of batteries is decreasing, but has been extensive. This has been among the largest product uses of mercury in recent decades. Mercury has mainly been used in primary (non-rechargeable) batteries, of which the main ones are described below.

Mercury is used in high concentrations (about 30-32% by weight) in mercury oxide batteries (sometimes called zinc-mercury batteries). In the past these have mostly been sold as button cells, but there have also been significant markets for larger cylindrical and other shapes. The sale of mercury oxide batteries is now severely restricted in many countries, but some specific uses (e.g. military and medical applications) may still be common, and trade statistics appear to indicate significant ongoing use in some countries.

Button cell shaped batteries of alkaline, silver oxide and zinc/air types still typically contain mercury (at concentrations of some 1-2% mercury by weight). China may have produced as many as 10 billion of these batteries in 2004. In addition to plain battery sales, batteries may be imported and exported in substantial amounts enclosed in other products like electronics, toys, greeting cards that make sounds, etc.

In other battery types the mercury content is generally lower. Previously, alkaline cylindrical cells on the European market had mercury concentrations of around 1%. Due to environmental restrictions, however, the mercury content of cylindrical alkaline batteries has been greatly reduced, and most global battery brands are now produced without intentionally added mercury content. However, some nationally or regionally traded brands of alkaline batteries with mercury added still exist, and may be significant. China, for example, in 2004 produced some 5 billion mercury-added cylindrical alkaline-manganese batteries, as well as over 9 billion mercury-added paste-type cylindrical zinc-manganese batteries.

Questions applicable to your country or region (for 2006)	Responses	Sources, references, comments (e.g. different practices urban vs. rural, etc.)
If you are aware of any use of mercury oxide batteries, what is the approximate number used? Are they cylindrical batteries or button cells?		
Please estimate the total consumption of button cell batteries.		
If possible, can you estimate how many of them are alkaline, silver oxide and zinc/air batteries?		
Please estimate the total consumption of cylindrical batteries.		
Can you be reasonably certain these are mostly alkaline batteries?		
If not, do you know what kind of batteries they are?		
With regard to discarded button cell batteries, approximately what percentage is collected separately for recycling?		
Approximately what percentage of the discarded button cell batteries is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of the discarded button cell batteries goes into the municipal waste stream, i.e. discarded with other household and commercial waste?		

Mercury thermometers (Note: highest priority questions are in italics)		
Mercury thermometers have traditionally been used for most medium-range temperature measurements. Today they are increasingly substituted by electronic and other thermometer types, but the degree of substitution varies considerably from one country to another. Major types of mercury thermometers that remain in widespread use include thermometers used primarily to measure body temperature, e.g. in hospitals, clinics or at home, ambient air temperature thermometers, thermometers used in chemical laboratories and educational establishments, and thermometers integrated in the controls of some machines (e.g. large diesel engines) and industrial equipment. Mercury thermometers may contain less than one gram of mercury, or up to several hundred grams of mercury per unit, depending on the size and application.		
Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Approx. how many thermometers of all kinds are purchased ("consumed") annually in your country or region?		
Roughly how many of these are mercury thermometers?		
Can you estimate how many mercury thermometers are used in medical establishments (hospitals and clinics), and how many are used elsewhere?		
With regard to discarded mercury thermometers, approximately what percentage is collected separately for recycling? (It may help to consider separately the cases of "medical" thermometers and non-medical thermometers.)		
Approximately what percentage of discarded mercury thermometers is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of discarded mercury thermometers goes into the municipal waste stream, i.e. discarded with other household and commercial waste?		

Dental mercury amalgams

(Note: highest priority questions are in italics)

Dental amalgam fillings consist of an alloy of mercury, silver, copper and tin (typically just under 50% mercury by weight). The alloy is usually supplied to dentists either 1) as pure mercury along with a powder mix of the other metals, which are weighed and mixed in the clinic; or 2) as small capsules where mercury and the metal powder are present in the right proportions and need only to be mixed (e.g. in the capsule before opening) in the clinic, prior to filling the cavity in the tooth.

The previous amalgam filling, if any had to be removed, becomes dental mercury waste. Likewise, the preparation and shaping of the new amalgam filling generates a certain amount of mercury waste as well. Depending on the solid and liquid waste disposal practices of each dentist or clinic, significant quantities of mercury amalgam wastes may end up in the municipal waste or in the wastewater stream.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Please try to estimate the average number of amalgam fillings in the average mouth of the population ages 10-60. For comparative purposes, the average in industrialised countries is in the range of 6-10 fillings.		
Considering all of the amalgam fillings placed in a year, approximately what percentage of fillings are placed in relatively sophisticated hospitals or clinics, and what percentage of fillings are placed in relatively unsophisticated surroundings? (This question is to help identify differences, if any, in typical waste disposal practices.)		
With regard to mercury in dental wastes, approximately what percentage of the mercury waste is collected separately for recycling? It may be useful to consider separately the more sophisticated and less sophisticated dental practices?		
Approximately what percentage of mercury in dental wastes is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of mercury in dental wastes likely goes into the municipal (solid) waste stream, i.e. discarded with other household and commercial waste?		
Approximately what percentage of mercury in dental wastes likely goes into the wastewater stream, and from there to a wastewater treatment plant (preferably) or to local water bodies?		

Manometers, barometers and other pressure measuring devices using mercury

(Note: highest priority questions are in italics)

Mercury is used in a variety of blood pressure gauges, industrial manometers, meteorological barometers, and pressure controls. While some of these devices may be fitted with a simple electrical contact, most of them are non-electrical in design.

Blood pressure gauges in medical use are still mostly mercury models, although mercury-free devices are becoming more common. To fill pressure valves in district heating and educational uses, metallic mercury is often supplied separately rather than together with the valve. In fact, for virtually all mercury pressure devices, it may be necessary to add mercury at different times during use. Likewise, when the device is discarded, the mercury may eventually be disposed of with the apparatus or separately. Non-mercury alternatives exist for all of these devices and are gradually substituting for them in increasing numbers.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Approx. how many mercury blood pressure gauges (also known as "sphygmomanometers") are purchased ("consumed") annually in your country or region? These are mostly used by hospitals and medical clinics.		
With regard to discarded mercury blood pressure gauges, approximately what percentage of the mercury in them is collected separately for recycling?		
Approximately what percentage of the mercury in discarded blood pressure gauges is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of the mercury in discarded blood pressure gauges goes into the municipal waste stream, i.e. discarded with other household and commercial waste?		
Approx. how many non-medical mercury-containing manometers, barometers and pressure controls are purchased ("consumed") annually in your country or region?		
With regard to discarded non-medical mercury-containing manometers, barometers and pressure controls, approximately what percentage of the mercury in them is collected separately for recycling?		
Approximately what percentage of the mercury in discarded non-medical mercury-containing manometers, barometers and pressure controls is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of the mercury in non-medical mercury-containing manometers, barometers and pressure controls likely goes into the municipal waste stream, i.e. discarded with other household and commercial waste?		

Mercury lamps

(Note: highest priority questions are in italics)

Mercury is used in small amounts in a number of different types of “discharge” lamps, with fluorescent tubes and compact fluorescent lamps (CFLs) as the most common types. Over 70% of the mercury-containing lamps sold in industrialised countries are linear fluorescent tubes. The remainder are compact fluorescent lamps for domestic use, or specialty mercury lamps (commonly known as metal halide, mercury vapour, high-pressure sodium, and neon lamps) that are typically for commercial or municipal use. Significant progress has been made by some producers to reduce the amount of mercury used per lamp, with reductions of a factor of 5-10 achieved in newer mercury lamps as compared to models of 10-15 years ago.

Older lamp designs with relatively higher mercury content are, however, still on the market, and may still be sold in large quantities as they tend to be cheaper than low-mercury lamps. Non-mercury alternatives for mercury lamps, with similar energy saving specifications, are not yet widely available on the market, although some (e.g. ultra-bright LEDs) are available for specific applications (e.g. traffic signals), and others are under development. Other light sources containing mercury include special lamps for photographic purposes, chemical analyses (atomic absorption spectrometry lamps), ultraviolet sterilisation, and back-lighting for flat-screen displays of computers and televisions.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Approx. how many straight tube fluorescent lamps are purchased (“consumed”) annually in your country or region?		
Approx. how many compact fluorescent lamps (CFLs) are purchased (“consumed”) annually in your country or region?		
Approx. how many high-intensity discharge (HID) mercury lamps are purchased (“consumed”) annually in your country or region? These are used primarily for energy-efficient lighting of streets and highways, parking lots, sports stadiums, industrial buildings, etc.		
Are neon lights frequently used for signs and decorations in your country? These tend to be more common in areas with more commerce and higher population.		
With regard to discarded mercury lamps, approximately what percentage of these lamps is collected separately for recycling? It may be useful to consider separately the cases of fluorescent tubes and CFLs on the one hand, and HID lamps on the other hand.		
Approximately what percentage of mercury lamps is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of mercury lamps likely goes into the municipal waste stream, i.e. discarded with other household and commercial waste?		

Electrical and electronic switches, contacts and relays with mercury

(Note: highest priority questions are in italics)

Electrical and electronic switches, contacts and relays with mercury are used in many applications, such as:

- level or "tilt" switches in thermostats, car boot or bonnet lids (lighting), car ride-control systems, freezer or washing machine lids, "fall alarms" for the elderly, railway signals, sewerage pumps, water pumps, car ABS sensors, light-activators in children's shoes, etc.,
- multiple-pole level switches in excavation machines,
- mercury-wetted contacts (in electronics),
- data transmission relays or "reed relays",
- thermo-switches, etc.

In some countries mercury in electrical components have been increasingly substituted for nearly two decades, and mercury-free substitutes are being used for most or all of these applications. However, while there is increasing awareness of mercury-free substitutes, the status and extent of substitution varies considerably from one country to another.

With regard to mercury use in products, it is very difficult for most countries to have an idea of the scale of mercury used in electrical and electronic applications. Therefore, the questions below are very limited. Furthermore, these questions should not be confused with the problem of mercury (and other toxics) in imported waste electrical and electronic equipment (known in the European Union as WEEE) that many countries are struggling to deal with. Any information on mercury in imported WEEE may be provided in the table following this one.

Questions applicable to your country or region (for 2006)	Responses	Sources, references, comments (e.g. different practices urban vs. rural, etc.)
Do you have any information on the quantities of mercury (excluding mercury in batteries – see previous table on batteries) present in electrical and electronic equipment that is purchased annually in your country or region?		
Approximately what percentage of discarded electrical and electronic equipment is collected separately for recycling or repair?		
Approximately what percentage of discarded electrical and electronic equipment is collected separately for special disposal, such as to a hazardous waste landfill or hazardous waste incinerator?		
Approximately what percentage of discarded electrical and electronic equipment likely goes into the municipal (solid) waste stream, i.e. discarded with other household and commercial waste?		

Imported waste electrical and electronic equipment (WEEE) containing mercury (Note: highest priority questions are in italics)		
As mentioned above, many countries are dealing with the problem of mercury (and other toxics) in imported waste electrical and electronic equipment (also known as WEEE). Sometimes this imported equipment is labelled as “used” equipment for repair and reuse, but often it becomes just another waste disposal pathway. After a shipment of WEEE arrives in a country, it is typically broken down by “recyclers” in search of any components of value, and then the residual waste is disposed of by burning, or by dumping on land or in surface water.		
Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Do you have any information on the number of tonnes of used EEE or WEEE imported into your country or region in 2006?		
If so, can you estimate what percentage of this used EEE or WEEE was actually repaired and reused, and what percentage went to “recycling?”		
With regard to the final destination of the residual waste after “recycling”, can you estimate approximately what percentage of the final waste was burned, what percentage was disposed on land, what percentage went to a more formal landfill, and what percentage eventually ended in runoff or disposal to surface water?		

Pesticides, biocides and fungicides using mercury compounds

(Note: highest priority questions are in italics)

Many mercury compounds are toxic to micro-organisms, and mercury compounds have been used as biocides (slimicides) in pulp and paper production, in paints, and on seed grain and other agricultural applications. One of the major uses of mercury compounds as biocides was as "seed dressing" to prevent seeds spoiling during storage. These uses have been discontinued or banned in many countries.

In the former Soviet Union the production of organomercurial pesticides was initiated in 1955 with a production that reached 200 metric tons/year by 1960. The main compound used was ethyl mercury chloride, but 14 different compounds are known to have been used as pesticides in the country. Production of organomercurial pesticides in the Russian Federation has ceased, but it is estimated that in recent years 20-40 metric tons has annually been used from old stocks.

In Australia, a liquid fungicide product containing methoxy-ethyl mercuric chloride has been used to control pineapple disease in sugarcane sett.

In India the use of organomercurial pesticides in 1999-2000 was 85 metric tons, according to the Directorate of Plant Protection, although production appears now to have ceased. Formerly a number of mercury-based pesticides were used in India, but today most are banned.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
If you have evidence of the use of mercury compounds as pesticides, biocides, fungicides, etc. in 2006, can you please describe the applications and estimate the quantities of mercury involved?		
Is there any evidence that current or previous uses of mercury compounds for these applications have resulted in mercury-containing solid waste in 2006?		
If so, is it possible to estimate the quantity of mercury in solid waste in 2006 that may have gone to an authorised final disposal site, on the one hand, and the quantity of mercury that may have entered the municipal solid waste stream, on the other hand?		

Cosmetics, creams, soaps and related products containing mercury

(Note: highest priority questions are in italics)

Mercury has been used for many years in skin lightening creams, soaps, and as preservatives in some eye cosmetics. The mercury used in skin lightening soaps and creams is inorganic mercury. It is combined with iodide or sometimes chloride and becomes a "salt." This type of mercury is absorbed through the skin. The production and use of mercury-added cosmetics has decreased significantly in the West over the past decades; however, several countries continue production and use. This use of mercury is disturbing not only for the health implications, but also because the product is completely diffused to the environment after use.

The use of skin lightening cosmetics is reported to be widespread in many African and Asian countries and other parts of the world. Approximately 25% of 210 women questioned in Bamako, Mali, in the early 1990s used skin bleaching agents. Among these, 11% used mercury-added products, and 16% used agents of undetermined composition.

In 2000 the Danish EPA found seven types of mercury-added soaps marketed in Denmark. These soaps contained 1-3% mercury iodide.

In Dakar, Senegal, 53% of 425 women questioned in 2002 were current users of a skin bleaching agent that contained 10% mercury iodide.

In Lagos, Nigeria, 77% of 440 traders (women and men) interviewed in 2002 used skin lightening cosmetics. Mercury based preparations were not the most prevalent, but they were widely used. There have been similar surveys and findings in Togo, Kenya, Tanzania, etc.

The Indonesian Food and Drug Control Agency (BPOM) issued a public warning in 2004, when it identified 51 beauty care products containing mercury and Rhodamin B colour additive that were being sold in markets across the country, mostly in Jakarta and Riau provinces. Many of the products were whitening lotions and creams imported from China and Thailand. Only three were registered with the agency.

New York newspapers reported in January 2005 a case of mercury poisoning by a product called Recetas de la Farmacia - Crema Blanqueadora, which was manufactured in the Dominican Republic. Likewise, a sample of Mekako soap purchased in the US in 2004 was found to contain nearly 1% mercury.

In April 2005 Hong Kong newspapers reported a 39-year-old woman who suffered from mercury poisoning after using Whitening Sunblock Cream bought in South China's Shenzhen city.

Questions applicable to your country or region (for 2006)	Responses	Sources, references, comments (e.g. different practices urban vs. rural, etc.)
Are skin-lightening creams and soaps commonly used in your country or region?		
If so, approximately what percentage of the total adult population might be using such products regularly?		
Are you aware of specific evidence of the use of mercury in such products purchased in your country or region between 2004 and 2006?		
Do you believe the general public is reasonably well informed about the danger of mercury in skin-lightening creams and soaps?		

Religious rituals, cultural practices and traditional medicine using mercury

(Note: highest priority questions are in italics)

In many urban areas, stores known as *botánicas* sell a variety of herbal remedies, cultural and religious items used in certain Latino and Afro-Caribbean traditions, including *Santería*, *Palo*, *Voodoo*, and *Espiritismo*. In these traditions, metallic mercury, often sold under the name *"azogue,"* is used to attract luck, love, good health or money; to protect against evil; or to speed the action of spells through a variety of recommended uses, including carrying mercury in a sealed pouch prepared by a spiritual leader, wearing it as an amulet, sprinkling it on the floor or in an automobile, mixing it with perfumes or adding it to devotional candles or oil lamps. For pharmaceutical purposes it is also sometimes taken internally to treat gastrointestinal disorders, or added to bath water, detergent or cosmetic products.

Surveys in several cities in the USA in 2004 found that some 20-40 percent of Hispanic respondents reported sometimes using mercury for magic or religious purposes. Researchers estimated that this could result in long-term contamination of homes or apartment buildings, where toxic vapours may linger for months or even years, leading to possible neurological and respiratory symptoms in apartment residents.

In India and Pakistan, and among some expatriate communities, Ayurvedic preparations are used. In 2004 a medical researcher purchased 70 traditional Ayurvedic preparations imported from India and Pakistan at South-Asian grocery stores in a US city. 14 of the preparations were found to contain potentially toxic levels of mercury, lead and/or arsenic. These preparations were marketed to treat illnesses ranging from colic in children to urinary tract infections.

Likewise, in Hindu practices mercury, or *parad*, is used in statues, objects and amulets for a range of health-related, ceremonial and religious purposes.

Mercury is also used in many homeopathic products and Asian (especially Chinese) medicines, e.g. as Cinnabaris – a complex of sulphides that contain mainly mercuric sulphide; Calomelas – mercurous chloride (calomel); or Hydrargyri oxydum rubrum – red mercuric oxide; etc.

Questions applicable to your country or region (for 2006)	**Responses**	**Sources, references, comments (e.g. different practices urban vs. rural, etc.)**
Do you have any evidence or information of mercury used in religious rituals, cultural practices and traditional medicine in your country or region?		
If so, describe what practices or medicines are being used, and please try to estimate the quantities of mercury that may be used in a typical year.		
Is it possible to speculate whether some of the mercury used is recovered? If so, how much is recovered, and can you describe the likely mercury waste disposal pathways of the remainder?		