Note to reader

This draft version of Chapter 2 in the Technical Background Report to the Global Mercury Assessment 2018 is made available for review by national representatives and experts. The draft version contains material that will be further refined and elaborated after the review process. Specific items where the content of this draft chapter will be further improved and modified are:

1. Key findings/messages
2. Figures will be updated/redrawn.
3. Redundant significant figures in tables and quoted values will be rounded.
4. Section on *Emission Factors and Technology Profiles (2.2.1.2).*
5. Uncertainty ranges to be double-checked and/or added
6. Comparisons between GMA 2018 inventory estimates for the nominal year 2015 and national estimates. Will be compiled in Annex 7
7. Comparing 2010 and 2015 global inventory estimates (Chapter 2.4)
8. Conclusions (chapter 2.5)

Contents

Chapter 2. Global Emissions of Mercury to the Atmosphere from anthropogenic sources

Key Findings/Messages:

Anthropogenic emissions of mercury to the atmosphere currently amount to more than 2000 tonnes per year, accounting for about 30% of mercury emitted annually to the atmosphere, the remainder coming from natural processes (60%) that result in re-emission of mercury previously deposited to soils and water (much of which is itself derived from earlier anthropogenic emissions and releases), and natural sources (ca. 10%).

A new global inventory of mercury emissions to air from anthropogenic sources in 2015 (primarily utilising activity data from 2014) quantifies emissions from 20 key sectors at ca. 2150 (1960 – 2745) tonnes. Additional emissions of the order of tens to hundreds of tonnes per year may arise from smaller anthropogenic sources not currently detailed in the global inventory work.

Inventory methodologies are constantly improved as new information and data becomes available. Changes in emissions estimates for different periods therefore reflect both real-world trends and artefacts of improvements in inventory methods and data availability. Simple comparisons between the new inventory and previous inventories can result in misinterpretation and should therefore be avoided.

Global emissions of mercury to the atmosphere in 2015 are approximately 12% higher than they were in 2010. Continuing action to reduce emissions has resulted in modest decreases in emissions in some regions (North America and EU) but emissions have increased in most other regions. Increased economic activity in these regions (including recovery following the economic down-turn that may have influenced global emissions in 2010) therefore appears to have more than offset any efforts to reduce mercury emissions.

Regional and sectoral attribution of the 2015 global emissions inventory indicates that emissions patterns in 2015 are very similar to those in 2010. The majority of the 2015 emissions occur in Asia (52%; primarily East and South-east Asia) followed by Sub-Saharan Africa (17%) and South America (13%). In the latter two regions, ASGM-associated emissions account for about 70-75% of the emissions. ASGM also account for a significant part of emissions in Central America and the Caribbean (40%) and East and South-east Asia (25%), and constitute almost 34% of the global total. In

other regions, emissions associated with energy production and industrial emissions predominate.

Stationary combustion of fossil fuels and biomass is responsible for about 25% of the estimated global emissions, primarily from coal burning (22%). Emissions from combustion of biomass for energy production are quantified for the first time in the 2015 inventory work and comprise about 2.5% of the global inventory. Main industrial sectors remain non-ferrous metal production (15% of the global inventory), cement production (11%) and ferrous metal production (3.5%). Emissions from wastes from mercury-containing products comprise ca. 7.5% of the global inventory estimate in 2015.

2.1 Sources of anthropogenic mercury emissions to the atmosphere: Introduction

Previous assessments (UNEP, 2013; AMAP/UNEP, 2013) have described how industrial activities to produce power and other commodities, together with a range of intentional uses of mercury in processes and products result in anthropogenic emissions of mercury to the atmosphere. Such emissions currently amount to more than 2000 tonnes per year, accounting for about 30% of mercury emitted annually to the atmosphere, the remainder coming from natural processes (60%) that result in re-emission of mercury previously deposited to soils and water (much of which is itself derived from earlier anthropogenic emissions and releases) and natural sources such as volcanoes (ca. 10%).

Mercury emissions to air are associated with a number of anthropogenic activities that can be characterized as 'by-product' or 'intentional-use' sectors (AMAP/UNEP, 2013). Stationary combustion of fossil fuels (coal in particular), and high temperature processes involved in industrial activities such as primary metal smelting and cement production give rise to 'unintentional' mercury emissions (i.e., the mercury emissions are a 'by-product' of their presence in trace quantities in fuels and raw materials). Intentional-use sectors include the use of mercury-containing products (e.g. lamps, batteries, instrumentation) or dentistry (dental amalgam), where much of the mercury emissions to air (and releases to water) are associated with waste disposal. A further intentional use of mercury is in artisanal and small-scale gold mining (ASGM) where mercury is used to extract gold from gold bearing sediments and rocks. Of these sources, stationary combustion of coal (for power, industry and domestic/residential heating) and artisanal gold mining were estimated to be responsible for over 60% of emissions to air in 2010.

Mercury emissions to air have changed over time. Historically gold and silver mining has been a major source of mercury emissions and releases. These emissions/releases have had local and regional impacts that can be traced today in sedimentary records. With the advent of the industrial revolution (ca. 1850s) and the subsequent rise of fossil fuel economies, mercury emissions increased, likely reaching a maximum in the latter decades of the 20th century, coincident with peak coal use. Emissions have declined since then but remain high, estimated at around 2000 tonnes per year during the first decades of the 21st century. These emissions give rise to global pollution; including long-range transport to remote regions (see Chapter 4), with associated concerns for impact on health of wildlife and human populations (see Chapters 7 and 8).

The GMA2013 (UNEP, 2013, AMAP/UNEP, 2013) included a first global inventory of anthropogenic mercury emissions to air for 2010 prepared according to a new core methodology, an extension of methods employed to produce earlier global inventories for the years 1995-2005 (Pacyna et al. ref). As part of the work to update the GMA2013, a new global inventory of anthropogenic mercury emissions to air has been produced, for the target year 2015. This inventory addresses emissions from the source sectors and activities identified in Table X1; these include 3 new sectors not previously quantified, namely biomass combustion (for energy production), secondary steel production and mercury emitted during production of vinyl chloride monomer (VCM), a raw material for plastics including polymer polyvinyl chloride (PVC). The table also identifies additional sectors not yet fully quantified in global emission inventory work.

2.2 Estimating 2015 global anthropogenic mercury emissions to air: Methodology and important considerations

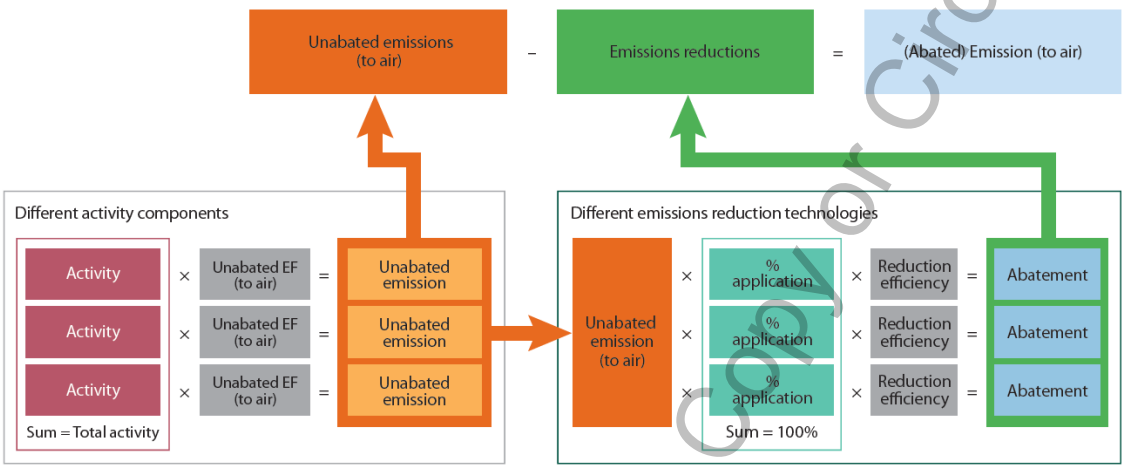
2.2.1 General methodology

The methodology employed to produce the 2015 global inventory of anthropogenic emissions to air is essentially the same as that applied in developing the 2010 inventory reported in the GMA 2013 (AMAP/UNEP, 2013). The methodology applies a mass-balance approach (see Figure M1) to derive emissions estimates that considers:

- the amounts of fuels and raw materials used, or commodities produced (activity data);
- the associated mercury content of fuels and raw materials and the types of process involved (reflected in 'unabated' emissions factors); and
- technology applied to reduce (abate) emissions to air (through technology profiles that reflect the degree of application and the degree of effectiveness of air pollution controls)

The ASGM and mercury-added product sectors employ variations on this approach.

Figure M1. General methodology



The general methodological approach and its development from earlier methods that were used to produce the original (1995, 2000 and 2005) global inventories of emissions to air is described in the GMA2013 report (AMAP/UNEP, 2013 - Section 2.2) and not repeated here. However, a key element in the delivery of the GMA is transparency. Consequently, the following documentation includes a discussion of some of the more significant changes that have been applied in the methodology and/or to key parameters that influence calculated emissions estimates for particular sectors. Generally this reflects improvements in available information. The current report therefore also includes a comprehensive set of annexes (Annexes 1-8) that present the (updated) factors and assumptions applied in calculating the 2015 emissions estimates, together with the activity data used and the resulting emission estimates on a country/sector basis.

In addition to improving the methods used to estimate global emissions by incorporating new information, the method used to geospatially distribute the global inventory has also been upgraded as part of the GMA2018 work. These new developments allow national estimates to be mapped (gridded) at a finer resolution for use in modelling work.

2.2.1.1 Activity data

Information on amounts of fuel or raw materials used in different applications or amounts of products or commodities produced is the basis for estimating emissions of mercury to air. This activity data is available from various sources, such as national statistics agencies, international organisations and industry associations.

2130 Sectors and sources of activity data used in preparing the 2015 global estimates are presented in
2131 Table X1. Activity data applied to national emission estimates are presented in Appendix 5.

2132 Whenever available, statistics for the target year 2015 have been used for this emission inventory. In
2133 many cases, information for 2015 was not available at the time of preparing the inventory; therefore,
2134 data from 2014 (and in some cases earlier) were used.

2135 *Table X1 – LIST OF SECTORS / CODES – SOURCES OF ACTIVITY DATA USED*

Sector Code	Sector description	Activity Code	Activity description	Sources of Activity data.	Year of activity data
ASGM	Artisanal and small-scale gold mining	ASGM	Artisanal and small-scale gold mining	AGC, 2017	2014 (and earlier)
BIO	Biomass burning (domestic, industrial and power plant)	PSB - DR	domestic residential burning	IEA 2016	2014
		PSB - IND	industry	IEA 2016	2014
		PSB - PP	power plants	IEA 2016	2014
CEM	Cement production (raw materials and fuel, excluding coal)	CEM	cement (fuels excl.)		
		PC- CEM	pet coke	IEA 2016	2014
		See also BC–IND-CEM and HC-IND-CEM			
CREM	Cremation emissions	CREM	Cremation emissions	National reports and International Cremation Statistics	2014
CSP	Chlor-alkali production (mercury process)	CSP-C	capacity based		
		CSP-P	production based		
NFMP	Non-ferrous metal production (primary Al, Cu, Pb, Zn)	AL-P	aluminium (primary production)	USGS 2016	2013/2014
		CU-P	copper (primary production)	USGS 2016	2013/2014
		CU-T	copper (total production)	USGS 2016	2013/2014
		PB-P	lead (primary production)	USGS 2016	2013/2014
		PB-T	lead (total production)	USGS 2016	2013/2014
		ZN-P	zinc (primary production)	USGS 2016	2013/2014
		ZN-T	zinc (total production)	USGS 2016	2013/2014
		See also BC–IND-NFM and HC-IND-NFM			
NFMP-AU	Large-scale gold production	GP-L	gold production	USGS 2016	2013/2014

NFMP-HG	Mercury production	HG-P	mercury production	USGS 2016	2013/2014
OR	Oil refining	CO-OR	oil refining		
PISP	Pig iron and steel production (primary)	PIP	iron and steel (primary production)	USGS 2016	2013/2014
		See also BC–IND-PIP and HC-IND-PIP			
SC-DR-coal	Stationary combustion of coal (domestic/residential, transportation)	BC-DR	brown coal	IEA 2016	2014
		HC-DR	hard coal	IEA 2016	2014
SC-DR-gas	Stationary combustion of gas (domestic/residential, transportation)	NG-DR	natural gas	IEA 2016	2014
SC-DR-oil	Stationary combustion of oil (domestic/residential, transportation)	CO-HF-IND	heavy fuel oil	IEA 2016	2014
		CO-IND	crude oil	IEA 2016	2014
		CO-LF-IND	light fuel oil	IEA 2016	2014
SC-IND-coal	Stationary combustion of coal (industrial)	BC-IND-CEM	brown coal (cement industry)	IEA 2016	2014
		BC-IND-NFM	brown coal (NFM industry)		2014
		BC-IND-OTH	brown coal (other industry)		2014
		BC-IND-PIP	brown coal (ferrous metal industry)		2014
		HC-IND-CEM	hard coal (cement industry)	IEA 2016	2014
		HC-IND-NFM	hard coal (NFM industry)		2014
		HC-IND-OTH	hard coal (other industry)		2014
		HC-IND-PIP	hard coal (ferrous metal industry)		2014
SC-IND-gas	Stationary combustion of gas (industrial)	NG-IND	natural gas	IEA 2016	2014
SC-IND-oil	Stationary combustion of oil (industrial)	CO-HF-IND	heavy fuel oil	IEA 2016	2014
		CO-IND	crude oil	IEA 2016	2014
		CO-LF-IND	light fuel oil	IEA 2016	2014
SC-PP-coal	Stationary combustion of coal (power plants)	BC-L-PP	brown coal (lignite)	IEA 2016	2014
		BC-S-PP	brown coal (sub-bituminous)	IEA 2016	2014
		HC-A-PP	hard coal (anthracite)	IEA 2016	2014
		HC-B-PP	hard coal (bituminous)	IEA 2016	2014

SC-PP-gas	Stationary combustion of gas (power plants)	NG-PP	natural gas	IEA 2016	2014
SC-PP-oil	Stationary combustion of oil (power plants)	CO-HF-PP	heavy fuel oil	IEA 2016	2014
		CO-LF-PP	light fuel oil	IEA 2016	2014
		CO-PP	crude oil	IEA 2016	2014
SSC	Secondary steel production	SP-S	secondary steel production	Steel statistical yearbook 2015, World Steel Association 2015	2014
VCM	Vinyl-chloride monomer (mercury catalyst)	VCM	Vinyl-chloride monomer	National and literature information combined with Hg consumption data for VCM production by world region from P. Maxson	2015
WASOTH	Waste (other waste)	WASOTH	other waste	Estimated consumption of Hg in mercury added products in 2015 by world region (P. Maxson)	2015
WI	Waste incineration (controlled burning)	WI	waste incineration	Estimated consumption of Hg in mercury added products in 2015 by world region (P. Maxson)	2015
Other (sectors not yet fully characterized in the global inventory)	Contaminated sites				2010 GMA
	Oil and gas extraction (upstream of refineries)			IPIECA estimate (R. Cox, pers. comm.)	
	Other (including pulp and paper, secondary non-ferrous metals, food industry)			Residual totals from national PRT inventories covering primarily North America, Europe and Australia	
	Incineration of industrial and sewage sludge and some hazardous wastes				

2136

2137 ***2.2.1.2 Emission Factors and Technology Profiles***

2138 Information on (unabated and abated) emissions factors and technological profiles (reflecting degree

2139 of application and effectiveness of air pollution control (APC) technologies to reduce emissions of

mercury; see AMAP/UNEP, 2013) are detailed in Annex 6. These factors are defined for individual countries where data are available; where national data are lacking, default factors are applied to groups of countries based on assumptions regarding their level of technological development. For ASGM associated emissions an alternative approach is employed (see Annex 2). The assignment of (emission and APC technology) factors for particular countries/sectors builds on work described in the GMA 2013, and utilises a considerable amount of new information that has become available since that time from published literature, in particular concerning China, as well as information acquired from national experts from more than 25 countries from all world regions during inventory workshops and meetings organized as part of the 2015 inventory compilation activity.

Revision to applied emission factors and assumptions regarding application and effectiveness of APC technologies can significantly affect derived (national-sector) emission estimates; some revisions reflect developments (e.g., in applied APC measures, or changes in sources of fuels or raw materials used nationally) since 2010; others reflect improved information on, e.g. mercury content of fuels and raw materials that would also apply in relation to revised 2010 emissions estimates. Revisions to factors applied in the 2015 inventory work are – for the most part – not yet reflected in the UNEP Toolkit that is been used as the basis for most national Minamata Initial Assessments (MIAs), etc.; see section 2.3.4. The following section discusses some of the more significant changes introduced for individual sectors.

[Additional text will be added. See Annex 6.]

2.2.2 Sector specific methodologies - significant changes and improvements

For the sectors: Stationary Combustion – oil burning; Stationary Combustion – gas burning; Primary production of non-ferrous metals – mercury from cinnabar ore, and; Chlor-alkali production, methods employed are essentially identical to those applied in the GMA2013 (AMAP/UNEP, 2013). Updated information on the basis for calculations applied in the 2015 inventory can be found in Annex 6.

The following sections describe substantive methodological changes that have been introduced in relations to some specific sectors. These changes can have implications for calculated estimates that need to be appreciated when comparing 2015 inventory estimates with previous estimates (including 2010 inventory estimates presented in GMA 2013). For a more detailed discussion of the results regarding emission estimates for selected emission source sectors see section 2.3.3.

1. Methodology update: Stationary Combustion – coal burning

The methods are essentially the same as those applied in the GMA 2013 (AMAP/UNEP, 2013).

For stationary combustion of coal in power plants (SC-coal-PP) and in industry (SC-coal-IND) technology profiles for several countries have been updated. The updates are based on new information concerning application of advanced APCDs in some countries, and better information regarding their effectiveness at reducing emissions of mercury to the atmosphere.

For hard coal and brown (HC and BC) coal combustion, activity data for coal used in industry are now separated between cement (-CEM) iron and steel (-PIP) non-ferrous metal (-NFM) and other industrial uses (-OTH). This allows attribution of industrial coal burning emissions to specific industrial sectors. Unabated Emission Factors (UEFs) applied are equivalent to those defined for the coal-IND activities in the GMA 2013.

For more details see Annex 6.

2. Methodology: Stationary Combustion – biomass burning

Mercury is a trace contaminant present in varying concentrations in biomass fuel and mercury emissions to air arise when biomass is combusted in power plants, in industry and in domestic/residential use. This source was not addressed in the 2010 global emission inventory.

Emission estimates for 2015 have been developed following the general inventory methodology and using activity data from IEA on amounts of biomass combusted as fuel in power plants, industry, and domestic/residential use. IEA data only cover solid biomass used as fuel for energy production, therefore the 2015 emission estimates presented do not include wildfires (a natural source) or agricultural burning, an anthropogenic (or at least anthropogenically enhanced) source that can be a significant activity in some countries. Emission factors were derived using the heat value for air dried wood of 16 MJ/kg (IEA Energy Statistics manual, OECD/IEA, 2005) and literature discussing mercury content in biomass. Detailed information on the factors used in estimating emissions from biomass burning is presented in Annex 6.

3. Methodology update: Cement production

Mercury emissions associated with cement production originate from use of mercury-containing fuels (including conventional, mainly fossil fuels and co-incinerated wastes) and raw materials (limestone, iron oxides, fly ash, clay, silica, etc.). The majority of the emissions occur during clinker production (calcination) in high temperature kilns. Emissions can also occur during drying and preheating processes, but these are assumed to be much lower than those from calcination. Very small amounts of mercury are bound in the clinker itself, therefore subsequent stages of

2202 cement production (blending clinker with other materials, such as gypsum to form cement) are
2203 assumed to be a negligible source of mercury emissions (UNEP, 2015).

2204 The main conventional fuels used in the cement industry are coal and petroleum coke. Allocation
2205 of mercury emissions from these fuels in emission inventories and studies can vary – they are
2206 often aggregated with other fossil fuel combustion or included in the emission factors for cement
2207 production. For example, coal combustion in the cement industry was included under the
2208 category 'stationary combustion of fuel in industry' in the 2010 inventory.

2209 A new development in the methodology applied to prepare the 2015 inventory estimates
2210 concerns the way in which emissions associated with fuels and raw materials used in the cement
2211 industry are derived. In the 2015 global inventory (i.e. the work reported here), emissions
2212 associated with (conventional) fuel combustion in the cement sector are now allocated to new
2213 (sub-)activities under the sectors concerned with stationary combustion of coal, and in the case
2214 of petroleum coke a sub-activity under cement itself. The annexes to this report therefore
2215 separately present information on emission factors, activity data and mercury emissions for coal
2216 and petroleum coke combusted in the cement industry. This modification to the methodology
2217 also allows separate assignment of technology profiles for this sector facilitating better
2218 comparison of emission estimates and emission factors with other data sources.

2219 These changes have been implemented to allow better attribution of emissions between
2220 contributions from fuel and cement raw materials. This is done for all fuels, except for co-
2221 incinerated waste. The contribution from alternative fuels (mainly consisting of waste) varies
2222 considerably between the countries and this is considered in the emission factors applied in the
2223 current inventory (see Annex 6).

Key modifications to cement sector emission factors and technology profiles
The methodology used to estimate cement sector emissions is similar to that applied in the GMA 2013, but with the following changes: • Unabated emission factors (UEFs) are first calculated per tonne clinker and then adjusted with respect to country- or region-specific clinker/cement ratios. • Mercury emissions from combustion of petroleum coke, previously included in UEF for cement, are allocated to a separate sector – fossil fuel combustion in cement sector. • Region-specific default UEF values are developed for all countries based on data on clinker/cement ratios, energy demand and co-incineration of waste as alternative fuel obtained from the GNR database (GNR, 2014). This means that a global-average default UEF is no longer applied for cement emission calculations, only country-specific or region-specific UEFs. • Values of Hg content in raw materials and co-incinerated waste are adjusted in accordance with data presented in recent articles and reports and provided by national experts. The default Hg

content of total raw mix is estimated assuming variable additions of Hg-rich materials such as fly ash and iron oxides and is thus higher than Hg content of limestone alone.

- A distribution factor to air of 0.95 is used (as opposed to a value of 0.8 based on the default UNEP 2011 value that was applied in the 2010 global inventory calculations). This revision is based on the information in BAT/BEP and Wang 2014 indicating that only about 1-5 % of the total mercury input is bound in clinker.
- All technology profiles associated with the cement sector (cement production and related fuel combustion) have been harmonized since process-related emissions (originating in raw materials) and energy-related emissions (originating in fuels) are usually treated in the same abatement system at cement facilities.

For further details see Annex 6.

4. Methodology update: Primary iron and steel production

Primary pig iron and steel is typically produced at integrated facilities where raw materials (iron ore, limestone, lime, dolomite, and metal scrap) undergo several processes. Mercury emissions originate from mercury in these raw materials and fuels used (mainly coal/coke). Virtually all mercury emissions occur during thermal processes – sintering/pelletizing, pig iron production in blast furnaces, and steel-making in basic oxygen furnaces (UNEP, 2015).

Key modifications to pig iron and steel sector emission factors and technology profiles

The methodology used to estimate pig iron and steel sector emissions is similar to that applied in the GMA 2013, but with the following changes:

- The steel-making stage in basic oxygen furnaces is included.
- Hg input from dolomite is included.
- Values of Hg content in raw materials are adjusted with respect to data presented in recent articles and reports and provided by national experts.
- Combustion of coal in production of pig iron and steel is now identified as a separate (sub-) activity under 'industrial stationary combustion emissions'

For further details see Annex 6.

5. Methodology: Secondary steel production

Most secondary steel production is based on an Electric Arc Furnace (EAF) process using steel scrap as the input material. Mercury may be present as a contaminant in the scrap steel, in amounts that are highly variable depending on the type of scrap. In some countries, mercury-containing scrap may be sorted and removed before the scrap enters the EAF. Mercury contained in scrap that is not removed in this way is released during the EAF smelting process. This source was not addressed in the 2010 global emission inventory.

Emission estimates for 2015 have been developed following the general inventory methodology using activity data on annual steel production by EAF from the World Steel Association. Default UEFs were derived from Wang 2016b, Roseborough et al 2008, Burger Chakrabortry 2013, Ocio et al 2012, Kim et al 2010, and BREF_IS (table 8.1) and a default technology profile was developed based mainly on national information in Kim et al 2010 and Roseborough et al 2008. For further details see Annex 6.

6. Methodology update: Primary production of non-ferrous metals (copper, lead and zinc)

Primary production of the non-ferrous metals copper, lead and zinc are a significant source of mercury emissions and releases from both raw materials (metal ores) and fuels used in the process. Metal ores are mined and concentrated; concentrates are further pre-treated, roasted, smelted and refined. Most of the mercury present in metal concentrates evaporate during high-temperature roasting (or sintering) and smelting stages (UNEP, 2017). Releases from ore mining operations are not included in the scope of this inventory.

Most large smelters include acid plants that remove a substantial part of the mercury emitted from the off-gas during the smelting stage. This mercury is either treated as waste (if removed prior to acid production) or contained in the acid (BAT/BEP, 2017). Acid plants are considered a form of (air) pollution control device in the applied methodology.

Key modifications to primary non-ferrous (copper, lead, zinc) sector emission factors and technology profiles
The methodology used to estimate non-ferrous copper, lead and zinc sector emissions is similar to that applied in the GMA 2013, but with the following changes: • Concentrate/metal ratios and values of Hg content in concentrates have been adjusted to reflect new information and data presented in recent articles and reports and provided by national experts. Assumptions on metal content in concentrates are also revised based on concentrate/metal ratios provided in recent literature. • A distribution factor to air of 1 was applied in the 2010 global inventory based on the default UNEP Toolkit value (UNEP 2011). This value has now been adjusted to take account of information in Hui 2016 indicating that about 3-10% of the total mercury input is bound in smelting slag. The proportion of mercury bound in smelting slag is assumed to be 0.9 for Zn (a weighted average over two main production processes, assuming that hydrometallurgical process is used more widely than pyrometallurgical), 0.96 for Cu and 0.97 for Pb. • Default technology profiles of country groups 1 and 2 are revised and imply higher abatement levels in the current inventory than in 2010. • Combustion of coal in production of non-ferrous metals is now identified as a separate (sub-) activity under 'industrial stationary combustion emissions' For further details see Annex 6.

7. Methodology update: Primary production of non-ferrous metals – aluminium

The methodology used to estimate NFM-aluminium production sector emissions is similar to that applied in the GMA 2013, but with a small adjustment to the applied bauxite/alumina ratio based on BREF data. For a group of countries producing alumina for export only, a new emission factor has been developed, see details in Annex 6.

8. Methodology update: Primary production of non-ferrous metals – large-scale gold production

The methodology used to estimate NFM-large-scale gold production sector emissions is similar to that applied in the GMA 2013; however, the default technology profile for group 1 countries has been revised and implies higher abatement levels in the current inventory than in the 2010 inventory. See Annex 6.

Activity data on large-scale gold production from the USGS includes a number of footnotes concerning difficulties distinguishing ASGM and large-scale gold production in some countries. Where possible these notes have been considered in the light of other published information and or discussions with national experts to correctly characterize gold production; however, the possibility of that (some) ASGM produced gold is included in activity data for large-scale gold production remains for some countries.

9. Methodology update: Oil refining

The methodology used to estimate emissions from oil refineries is similar to that applied in the GMA 2013; with some minor adjustments to the assumptions (weighting) applied when calculating mercury content of oils refined in different countries. These adjustments result in a small decrease in total emissions from this sector if 2010 calculations are repeated, but may significantly influence estimates for individual countries. Although industry sources have delivered new information on mercury content of oil from different regions (IPIECA, 2012), for reasons of commercial confidentiality they are unable to specify the exact sources of these oils (i.e., the countries/fields of origin). This means that lack of reliable information on mercury-content of refined oils remains an important limitation in estimating national emissions and releases from oil refineries. Other knowledge gaps include information to resolve different assumptions regarding fate of mercury emitted/released during refinery operations (see section 2.3.3(8), below). See also Annex 6.

10. Methodology: Vinyl Chloride Monomer (VCM) production with mercury-dichloride ($HgCl_2$) as catalyst

Two processes are used in the manufacture vinyl chloride monomer: the acetylene process that uses mercuric chloride on carbon pellets as a catalyst, and a process based on the oxychlorination of ethylene that does not use mercury. Production of VCM with mercury-containing catalyst occurs only in a few countries (China, India and the Russian Federation). Mercury can be emitted during the production of VCM but a large part of the mercury remains in the used catalyst. Recycling of used catalyst is, however, an additional substantial source of mercury emissions. The 2015 estimates of mercury emissions to air from VCM production and from recycling of mercury-containing catalyst are based on national information, in combination with literature information; for further information see Annex 6.

This source was not addressed in the 2010 global emission inventory.

11. Methodology update: Waste and waste incineration

Mercury emissions from waste originating from mercury-added products (lamps, batteries, measuring devices, etc.) have been estimates based on assumptions regarding their entry into different waste streams. The majority of wastes associated with mercury-added products end up in landfill or (controlled/uncontrolled) incinerated waste. Mercury 'consumption' in these mercury-added products is defined in terms of final regional consumption of mercury products to take account of the fact that, for example, although most measuring and control devices are produced in China, many of them are exported, 'consumed' and disposed of in other countries.

It is important to recognize that estimates for mercury emitted from the waste sector do not currently include emissions due to incineration of industrial waste and sewage sludge, or (in most cases) hazardous waste. This is because it is not currently possible to obtain reliable information on the amounts of such wastes incinerated, and more importantly the mercury content of such wastes, which can be highly variable. This subject is further discussed below in relation to national comparisons, chapter 2.3.4.

Key modifications to (mercury-added product) waste and waste incineration sector emission factors and technology profiles
The basic methodology applied to estimate mercury emissions from waste originating from mercury-added products is the same as that applied for the 2010 inventory. • In the 2010 global inventory (GMA 2013) about 30% of the Hg was assumed to remain in products in society and not be emitted until later. In the 2015 global inventory this component is set to zero, to (to some extent) take account of the continuous release of materials in societal use. Consequently, all Hg consumed in one year (2015) is now distributed on pathways of safe storage, breakage or flow into the waste stream.

- Mercury consumed in mercury-added products is distributed on different pathways using distribution factors with emission factors applied to estimate emissions; some distribution factors have been revised based on information from national experts.
- A new technology group was added, covering the least developed level of technology for waste handling. Most countries in Sub-Saharan Africa were assigned to this technology level based on information from experts responsible for coordinating regional MIAs; some additional reclassifications of countries between technology groups, relative to assignments used in the 2010 global inventory, were also applied.

For further details see Annex 3.

12. Methodology update: Crematoria emissions

Methods employed were essentially identical to those applied in the GMA2013. Updated information on regional mercury consumption in dental uses in 2015 was obtained from Maxson (2017) and, where available, cremation statistics updated based on national information and data from the Cremation Society of Great Britain (CSGB, 2017). The methodology is considered sub-optimal in that it does not take account of, e.g. the relationship between time of application of amalgam fillings and life-expectancy, and other factors that will determine cremation emissions following use of mercury in dental amalgam. However it provides a first-level estimate of emissions from this use of mercury that can be compared with other such estimates (e.g., those derived in national inventories or MIAs, see section 2.5). See also Annex 4.

13. Methodology update: Artisanal and small-scale gold production (to be completed)

The information base that underpins the assumptions applied regarding use of mercury in artisanal and small-scale gold mining has been significantly updated and improved for a number of countries. Improved knowledge also resulted in an adjustment to the factors applied in assigning ASGM emissions associated with use of whole ore amalgamation and concentrate amalgamation. This results in a small decrease in the estimate of emissions to air per unit of mercury consumed in ASGM that is reflected in both retrospectively updated (national) estimates for 2010, as well as for 2015. See Annex 2.

2.2.3 Uncertainties

In the GMA2013 a simplistic approach was applied to calculate uncertainties associated with the 2010 inventory estimates. Essentially, this involved calculating high- and low-range estimates for individual country-sector emissions based on assumptions regarding reliability of activity data and (unabated) emission factors. Uncertainties associated with assumptions about applied technologies were ignored. It was noted that this approach would result in over-estimation of uncertainties associated with aggregated emissions estimates such as regional, sectoral or global totals. However,

2338 the method did provide a reminder that inventory estimates – whatever their source or basis – have
2339 large associated uncertainties and need to be regarded in this light.

2340 In the 2015 inventory work, a more detailed evaluation of uncertainties has been applied considering
2341 three different approaches: (i) calculating uncertainties using the approach applied in the GMA,
2342 2013; (ii) applying a modification of this whereby uncertainties associated with technology
2343 assumptions were also introduced, and (iii) employing the propagation of errors method (Frey, et al.,
2344 2006) to evaluate uncertainties associated with aggregated estimates. The latter method was
2345 adapted to apply a cut-off in extreme situations, e.g. so that removal efficiency could not exceed
2346 100%. Further assumption were applied in relation to other factors; for example, unabated emissions
2347 factors used in range estimates were based on assumptions regarding skewed (log-normal)
2348 distribution of mercury-content of fuels and raw materials.

2349 Further details of these three approaches are described in Appendix A. Results of the modified
2350 approach to individual country-sector estimates are reflected in the values tabulated in Annex 8.
2351 Uncertainty estimates associated with aggregated emission estimates using the propagation of errors
2352 approach are included in the values presented in section 2.3, below.

2353 At the global level, uncertainties calculated using approach (i) are -54% / +150%, using method (ii) -
2354 63% / +206%, and using method (iii) -8.4% / +30%.

2355 2.3 Estimating 2015 global anthropogenic mercury emissions to 2356 air: Results

2357 In this section, results for the 2015 global inventory estimates are reviewed from the perspective of
2358 region- and sector-based summaries followed by commentaries on comparisons with national
2359 inventories and air emissions on a sector by sector basis, and an evaluation of apparent trends in
2360 emissions between 2010 and 2015.

2361 The global inventory of mercury emissions to the atmosphere from anthropogenic sources in 2015 is
2362 2150 tonnes (range ca. 1965 – 2743 tonnes).

2363 This global inventory total for 2015 does not include sectors that are not yet addressed discretely in
2364 the inventory work; for example it does not include the ca. 80 tonnes that, in the GMA2013 work was
2365 attributed to emissions to air from 'contaminated sites'. In the case of contaminated sites, emissions
2366 from 'contaminated sites' can be assumed to be similar in 2010 and 2015.

2367 Some key observations are as follows:

- The 2015 inventory total of 2150 tonnes aligns with the GMA2013 statement that global emissions to air in the first part of the 21 century from principle anthropogenic sectors are of the order of 2000 tonnes per year.
- Uncertainties associated with the current global inventory total of 2150 tonnes are of the order of -10% and +30% (i.e., an approximate range of 1930-2800 tonnes).
- Estimated global mercury emissions to air from anthropogenic sources in 2015 are approximately 12% higher than the inventory for 2010, when 2010 estimates are retrospectively updated for comparable methodology and sectors not addressed in the original 2010 inventory. This increase appears to be mainly associated with increased economic activity in certain regions. Possible reasons for the increase are discussed in more detail in sections 2.3.3 and 2.4.
- Sectors not yet addressed in the national-sector estimated inventory may contribute additional emissions to air of the order of some tens-to-hundreds of tonnes per year. These include, for example, ca. 70-95 tonnes of emissions from contaminated sites and XXX from other sectors noted in this report (see section xxx). For example, the global inventory total rises to 2230 tonnes if estimated emissions from contaminated sites are included.

2.3.1 Summary of results by region

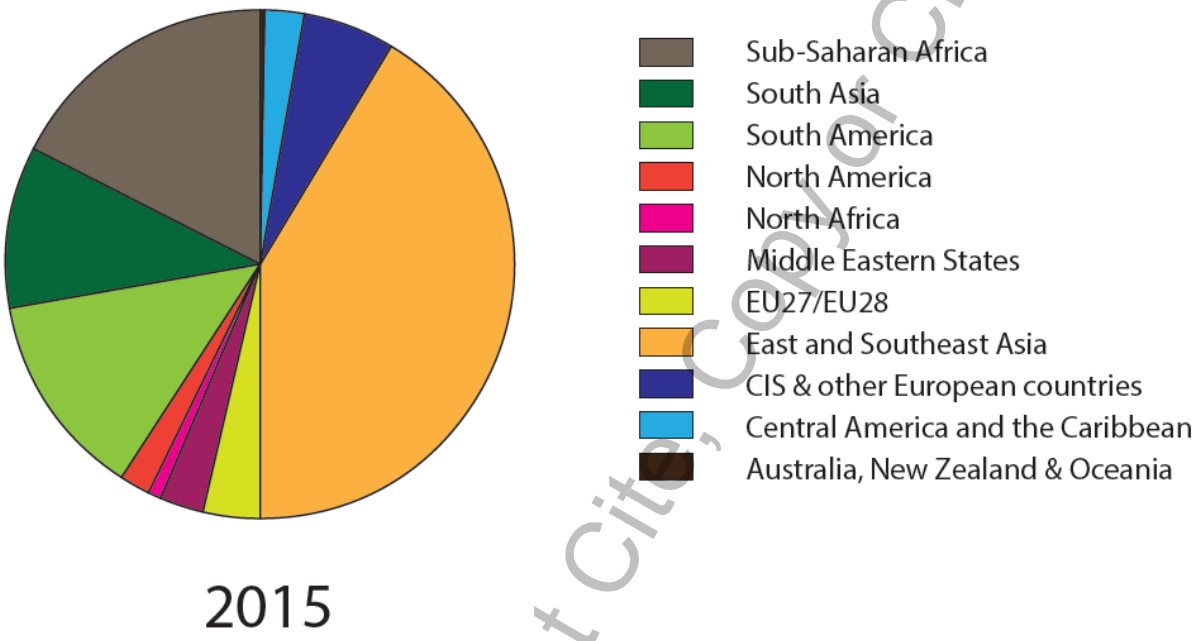
The regional (sub-continental) contributions to the global inventory in 2015 are illustrated in Figure R1. The emissions pattern is very similar to that in 2010, with the majority of the emissions occurring in Asia (52%, of which 42% in East and South-east Asia) followed by Sub-Saharan Africa (17%) and South America (13%) (see also Table R1). The consistency in the regional distribution of emissions illustrated in Figure T1 (above) between the 2010 (GMA 2013), 2010 updated and 2015 datasets discussed in this report indicates that these patterns are robust and not influenced to any undue extent by artefacts resulting from changes in methodology and additional sectors introduced since the GMA2013 work.

ASGM-associated emissions account for about 70-75% of the emissions that occur in South America and Sub-Saharan Africa.

If ASGM-associated emissions are discounted, the East and South-east Asian region remains the region responsible for the majority of emissions (48% on the non-ASGM total), with South Asia responsible for a further 15%. The non-ferrous metals industry is the main source of emissions in Sub-Saharan Africa and the 'CIS and other European countries' region; thus these two regions, between them, contribute a further 15% of the total non-ASGM emissions. In the remaining regions, coal combustion still accounts for the major part of the emissions in North America (over 60%), the EU (over 50%) and Australia, New Zealand and Oceania (36%). In the Middle Eastern States and North Africa, the cement industry is the principle source of emissions (43% and 52% of the regional totals, respectively). Sources associated with wastes from mercury-containing products account for

2404 approximately 10-20% of emissions in most regions, somewhat higher in North Africa (27%) and
2405 lower in the EU and East and South-east Asian regions.

2406 All percentage contributions need to be considered in relation to the total (absolute) amounts of
2407 mercury emitted in each sub-region. The sector-based emission discussion (section 2.3.3) provides
2408 additional insights into the relative amounts of emissions from different source sectors.



2409

2410 *Figure R1: Regional breakdown of global emissions of mercury to air from anthropogenic sources in*
2411 *2015.*

2412

2413 *Table R1: Regional breakdown of global emissions of mercury to air from anthropogenic sources in*
2414 *2015 (and 2010). (Greyed out numbers should not be used for comparative purposes Regional total*
2415 *rounded to 3 significant figures).*

2416 (Preliminary) Estimates and Comparsions (Version 13 June 2017)

Subregion		***2015*****	***2010*** (AMAP/UNEP, 2013)
Australia, New Zealand & Oceania	2010 by-product sectors	7.53	21.46
	Mercury in products (waste) (CREM / WASOTH / WI)	1.15	0.81*

	ASGM	-	-
	Regional total	**8.68** **(6.77 - 13.5)**	**22.3**
Central America and the Caribbean	2010 by-product sectors	26.83	20.50
	Mercury in products (waste) (CREM / WASOTH / WI)	6.06	3.60*
	ASGM	23.74	23.63
	Regional total	**56.6** **(xxx - xxx)**	**47.7**
CIS & other European countries	2010 by-product sectors	95.54	95.60
	Mercury in products (waste) (CREM / WASOTH / WI)	15.18	7.15*
	ASGM	12.69	12.48
	Regional total	**123** **(105– 167)**	**115**
East and Southeast Asia	2010 by-product sectors	628.27	467.15
	Mercury in products (waste) (CREM / WASOTH / WI)	50.92	38.20*
	ASGM	210.80	271.87
	Regional total	**890** **(725 – 1470)**	**777**
EU27/EU28	2010 by-product sectors	72.02	81.20
	Mercury in products (waste) (CREM / WASOTH / WI)	7.13	7.42*
	ASGM		
	Regional total	**79.2** **(68 – 108)**	**88.6**
Middle Eastern States	2010 by-product sectors	43.65	32.46
	Mercury in products (waste) (CREM / WASOTH / WI)	9.98	4.55*
	ASGM	0.26	-

	Regional total	**53.9 (41.5 – 95.5)**	**37.0**
North Africa	2010 by-product sectors	15.28	10.99
	Mercury in products (waste) (CREM / WASOTH / WI)	5.55	2.38*
	ASGM		
	Regional total	**20.8 (13.4 – 45.7)**	**13.4**
North America	2010 by-product sectors	38.07	53.99
	Mercury in products (waste) (CREM / WASOTH / WI)	5.59	6.76*
	ASGM	-	-
	Regional total	**43.7 (36.0 – 62.7)**	**60.8**
South America	2010 by-product sectors	55.70	52.21
	Mercury in products (waste) (CREM / WASOTH / WI)	11.28	7.82*
	ASGM	211.41	184.73
	Regional total	**278 (220 – 328)**	**245**
South Asia	2010 by-product sectors	182.15	135.29
	Mercury in products (waste) (CREM / WASOTH / WI)	36.35	17.30*
	ASGM	4.50	1.13
	Regional total	**223 (187 – 293)**	**154**
Sub-Saharan Africa	2010 by-product sectors	91.82	78.60
	Mercury in products (waste) (CREM / WASOTH / WI)	17.02	4.28*
	ASGM	262.39	232.99
	Regional total	**371 (330 – 417)**	**316**

Global inventory	2010 by-product sectors	1141.26	1049.46
	New by-product sectors (BIO / VCM / SSC)	115.60	n/a
	Mercury in products (WI / WASOTH / CREM) (waste/cremation)	166.21 (162.44/3.77)	100.28* (95.51/4.78)
	ASGM	725.74	726.77
	Global inventory total (sum of national sector-based estimates)	**2149** **(1964 – 2743)**	**1876**

*In 2010 ca. 30% of mercury consumed in products was allocated as 'remaining in society'; in the 2015 and updated 2015 values this amount is incorporated in the waste-stream estimates. For valid comparison the 2010 value would be multiplied by 1.3 (i.e. WASTE category total would be ca. 124.16 rather than ca 95.51
** The indicated uncertainties are based on the propagation of errors approach; for by-product sectors, individual country-sector estimates were assigned uncertainties based on the modified GMA2013 approach (including uncertainties associated with APC technology); for ASGM and sectors concerning waste from mercury-containing products, the basic GMA2013 approach was used for country-estimates.

2.3.2 Summary of results by sector

As with the regional breakdown, the relative breakdown of anthropogenic mercury emissions in 2015 between sectors is, in most respects, very similar to that in 2010. The predominant source sector is ASGM (ca. 33.8%) followed by stationary combustion of coal (ca. 22.4%; of which 13.9%, 6% and 2.6% in, respectively, power plants, industrial uses and domestic/residential burning). These are followed by emissions from non-ferrous metal production (ca. 15.1%, of which 3.8% in large-scale gold production and 1% from production of mercury), and cement production (ca. 10.8%). Emissions associated with disposal of mercury-containing product waste (7.6%), ferrous-metal production (3.4%, of which 0.5% from secondary steel production), stationary combustion of other fuels (3%, from combustion of oil, gas and biomass – the latter a newly included component contributing 2.6%) and other (2.9%, with another newly included sector – VCM – responsible for 2.3% of this) make up the rest. See Figure S1 and Table S1.

More detailed discussions are presented in 2.3.3 and other sections – for changes from 2010-2015 see section (2.4).

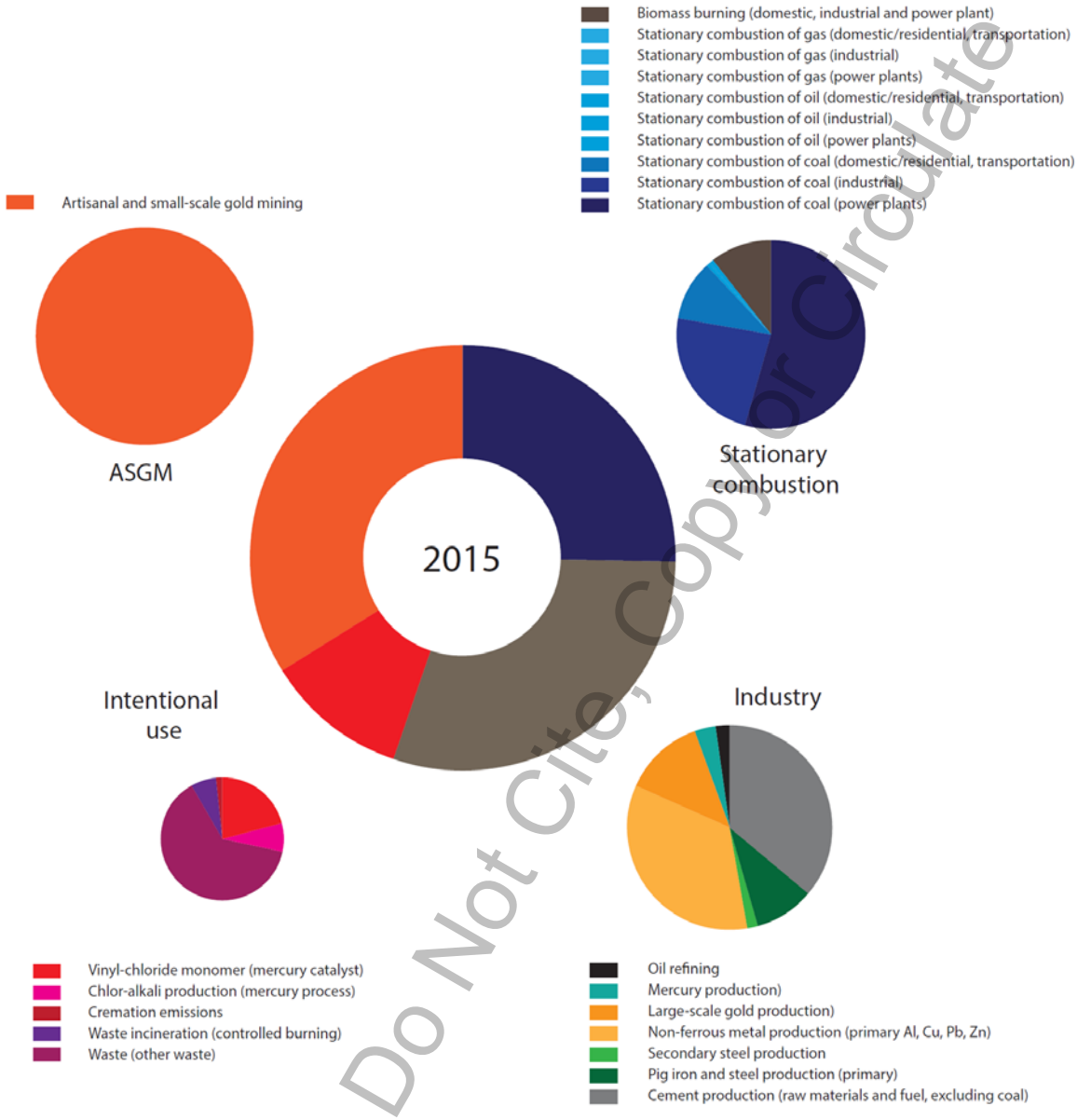


Figure S1: Proportions of global emissions of mercury to air from different anthropogenic source sectors in 2015.

2448 *Table S1: Global emissions of mercury to air from different anthropogenic source sectors in 2015 (and*

2449 *2010) [uncertainty ranges to be added when available for complete dataset]*

2450 (Preliminary) Estimates and Comparsions (Version 13 June 2017)

Sector Code	Description	Activity Code	Description	***2015*****	***2010 GMA***
ASGM	Artisanal and small-scale gold mining	ASGM	Artisanal and small-scale gold mining	725.75	726.77
BIO	Biomass burning (domestic, industrial and power plant)	PSB - DR	domestic residential burning	43.57	n.e.
		PSB - IND	industry	7.98	n.e.
		PSB - PP	power plants	5.37	n.e.
CEM	Cement production (raw materials and fuel, excluding coal)	CEM	cement (fuels excl.)	232.03	173.05
		PC- CEM	pet coke	0.99	n.e.
		See also BC–IND-CEM and HC-IND-CEM			
CREM	Cremation emissions	CREM	Cremation emissions	3.77	4.78
CSP	Chlor-alkali production (mercury process)	CSP-C	capacity based	15.78	26.46
		CSP-P	production based	1.61	1.89
NFMP	Non-ferrous metal production (primary Al, Cu, Pb, Zn)	AL-P	aluminium (primary production)	7.28	4.91
		CU-P	copper (primary production)	42.87	83.99
		CU-T	copper (total production)	4.03	9.90
		PB-P	lead (primary production)	32.70	4.40
		PB-T	lead (total production)	2.89	0.37
		ZN-P	zinc (primary production)	17.11	19.44
		ZN-T	zinc (total production)	115.69	70.32
		See also BC–IND-NFM and HC-IND-NFM			
NFMP-AU	Large-scale gold production)	GP-L	gold production	81.16	97.33
NFMP-HG	Mercury production)	HG-P	mercury production	21.60	11.75
OR	Oil refining	CO-OR	oil refining	14.02	15.99
PISP	Pig iron and steel production (primary)	PIP	iron and steel (primary production)	61.92	45.47
		See also BC–IND-PIP and HC-IND-PIP			

SC-DR-coal	Stationary combustion of coal (domestic/residential, transportation)	BC-DR	brown coal	1.99	2.71
		HC-DR	hard coal	54.00	53.25
SC-DR-gas	Stationary combustion of gas (domestic/residential, transportation)	NG-DR	natural gas	0.17	0.16
SC-DR-oil	Stationary combustion of oil (domestic/residential, transportation)	CO-DR	crude oil	0.00	0.00
		CO-HF-DR	heavy fuel oil	0.57	0.71
		CO-LF-DR	light fuel oil	2.16	1.85
SC-IND-coal	Stationary combustion of coal (industrial)	BC-IND-CEM	brown coal (cement industry)	2.59	8.10
		BC-IND-NFM	brown coal (NFM industry)	0.11	
		BC-IND-OTH	brown coal (other industry)	4.73	
		BC-IND-PIP	brown coal (ferrous metal industry)	0.14	
		HC-IND-CEM	hard coal (cement industry)	43.20	94.14
		HC-IND-NFM	hard coal (NFM industry)	3.35	
		HC-IND-OTH	hard coal (other industry)	43.11	
		HC-IND-PIP	hard coal (ferrous metal industry)	31.00	
SC-IND-gas	Stationary combustion of gas (industrial)	NG-IND	natural gas	0.13	0.10
SC-IND-oil	Stationary combustion of oil (industrial)	CO-HF-IND	heavy fuel oil	1.15	2.71
		CO-IND	crude oil	0.06	0.08
		CO-LF-IND	light fuel oil	0.21	0.24
SC-PP-coal	Stationary combustion of coal (power plants)	BC-L-PP	brown coal (lignite)	59.81	61.39
		BC-S-PP	brown coal (sub-bituminous)	41.22	27.39
		HC-A-PP	hard coal (anthracite)	2.58	2.00
		HC-B-PP	hard coal (bituminous)	194.42	225.36
SC-PP-gas	Stationary combustion of gas (power plants)	NG-PP	natural gas	0.34	0.29
SC-PP-oil	Stationary combustion of oil (power plants)	CO-HF-PP	heavy fuel oil	2.06	3.22

		CO-LF-PP	light fuel oil	0.17	0.14
		CO-PP	crude oil	0.31	0.36
SSC	Secondary steel production	SP-S	secondary steel production	10.14	n.e.
VCM	Vinyl-chloride monomer (mercury catalyst)	VCM-P	Vinyl-chloride monomer production	2.58	n.e.
		VCM-R	Vinyl-chloride monomer recycling	45.95	n.e.
WASOTH	Waste (other waste)	WASOTH	other waste	147.50	89.36*
WI	Waste incineration (controlled burning)	WI	waste incineration	14.94	6.15*
Total				**2149**	**1876**

2451

Other potential emissions (sectors quantified only as global totals)			
	contaminated sites	82 (70 – 95)	82 (70 – 95)
	misc. industrial, manufacturing activities (pulp and paper, food industry, chemical industry, lime production, etc.)	To be inserted	To be inserted
	oil and gas extraction	To be inserted	To be inserted
	industrial/sewage sludge	To be inserted	To be inserted
	Potential Global Inventory including possible additional sectors	**2230**	**1960**

2452

2453 * In 2010 ca. 30% of mercury consumed in products was allocated as 'remaining in society'; in the 2015 values
2454 this amount is incorporated in the waste-stream estimates. For valid comparison the 2010 value would be
2455 multiplied by 1.3 (i.e. WASOTH category total would be ca. 115.46 rather than ca 89.36, and the WI category
2456 total would be 15.40 rather than 6.15.

2457 ** The indicated uncertainties are based on the propagation of errors approach; for by-product sectors,
2458 individual country-sector estimates were assigned uncertainties based on the modified GMA2013 approach
2459 (including uncertainties associated with APC technology); for ASGM and sectors concerning waste from
2460 mercury-containing products, the basic GMA2013 approach was used for country-estimates.

2461 n.e. - not estimated in the 2010 GMA inventory

2462

2463 2.3.3 Sector-based observations

2464 Observations made below include comparisons between 2015 inventory estimates and updated 2010

2465 inventory estimates (see section 2.4).

1. Stationary Combustion – coal, oil and gas burning

Mercury emissions from stationary combustion of fossil fuels are estimated to account for ca. 490 tonnes of mercury emissions to air in 2015, with coal-burning responsible for by far the largest amount (482 tonnes) followed by oil (7 tonnes) and gas (1 tonne). Of these emissions, about 300 tonnes are associated with burning of fossil fuels in power plants, 130 tonnes in industrial uses and the remaining 60 in other, primarily domestic and residential uses. Coal burning is therefore the second largest contributor to global mercury emissions after ASGM.

The 2015 inventory estimate (based largely on IEA 2014 activity data) is 298 (260-355) tonnes from coal burning in power plants (an increase of 13% on a revised estimate for 2010) and 128 (107-150) tonnes in in industry (close to the estimate for 2010). Mercury emissions from coal burning in other (mainly domestic and residential uses) are also relatively stable between 2010 and 2015 at around 55 (37-70) tonnes.

Considering the increase in emissions from coal burning in power plants in more detail, these are almost entirely due to increased emissions in the East and South-east Asian and South Asia regions. Increased mercury emissions of ca. 19 tonnes in each of these regions, constitute a rise of ca. 21% in East and South-east Asia and 42% in South Asia. Decreasing mercury emissions from coal burning in power plants were observed in Australia, New Zealand & Oceania (-15%), CIS & other European countries (-4%), the EU region (-2%) and North America (-13%).

A new feature of the 2015 inventory is the differentiation of emissions from coal burning in industry between some major component activities. Of the total emissions from coal burning in industry of 128 tonnes, ca. 46 tonnes of this was associated with the cement industry, 31 tonnes with ferrous metal production, 3.5 tonnes with non-ferrous metal production, and 48 tonnes with other industrial uses. These emissions are accounted in the 2015 inventory under coal combustion but may also be taken into account as additional emissions when considering the cement, ferrous and non-ferrous metal sectors (see below).

2. Stationary Combustion – biomass burning

Biomass burning constitutes a new sector introduced in the 2015 inventory. Estimated emissions are based on IEA activity data and concern only biomass burning of primary solid biofuels for energy production (in power, industrial, and domestic/residential situation). Thus, they do not include biomass burning from, for example, agricultural burning or land clearance practises that take place in many countries.

2497 The estimated mercury emissions from primary solid biofuel burning in 2015 are 57 tonnes (47-
2498 70 tonnes; ca. 2.5% of the global inventory). A comparable value of ca. 51 tonnes was calculated
2499 retrospectively for 2010.

2500 The main emissions from biomass burning are associated with East and South-east Asia, South
2501 Asia and Sub-Saharan Africa (ca. 29%, 22% and 25% of the biomass emissions total, respectively).

2502 **3. Cement production**

2503 Estimated total global mercury emissions to air from the cement sector are 233 (116-781) tonnes
2504 in 2015. However, the updated methodology allows an improved differentiation of the
2505 contribution to mercury emissions associated with fuels burned in cement-clinker production
2506 and the non-fuel raw materials. In the 2015 inventory, therefore, a part of the emissions
2507 accounted under 'industrial coal combustion' are identified with use of coal as fuel in the cement
2508 industry. If this additional 46 tonnes of emissions is accounted under cement production, the
2509 contribution of the cement sector in the global inventory rises from ca. 10.8% to ca. 13% making
2510 the cement sector the third largest contributor after ASGM and coal burning.

2511 The total mercury emissions in 2015 directly associated with the cement sector (233 tonnes) is
2512 considerably higher than the ca. 172 tonnes associated with this sector in 2010, an increase of
2513 35%. Only in the EU region do the estimated emissions from the cement sector decrease
2514 between 2010 and 2015 (by ca. 25%); in all other regions increases are observed, of between ca.
2515 6% in the Australia, New Zealand, Oceania region, up to 108% in Sub-Saharan Africa. These
2516 emission trends closely mirror the trends in cement production in the different regions, i.e. the
2517 primary activity data used in calculating emissions for the cement sector (see Figure S3).

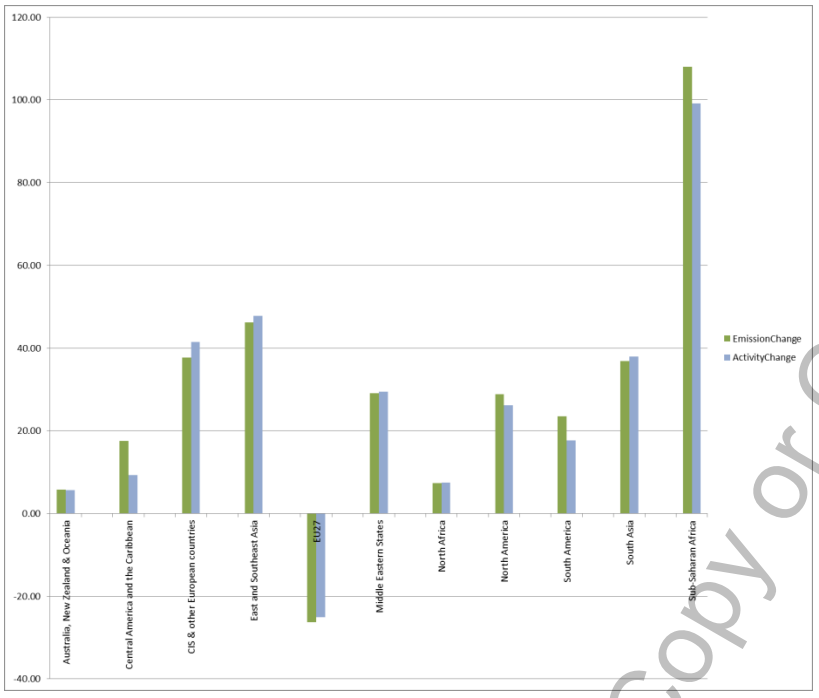


Figure S3: Relative (%) changes from 2010 to 2015 in activity data (cement production) and mercury emissions associated with cement production in different regions.

4. Ferrous metal production (pig iron and steel and secondary steel)

Mercury emissions from primary ferrous metal (pig iron and steel) production are estimated at about 62 tonnes in 2015, with a relatively large uncertainty range (20-226 tonnes) which is somewhat higher than the 45 tonnes in the 2010 inventory presented in the GMA2013 or updated 2010 estimate of 53 tonnes).

Of the increase in mercury emissions between 2010 (updated) and 2015, 7.4 tonnes of this amount is from increased emission in East and South-East Asia, 1.2 tonnes in South Asia and 0.3 tonnes in the CIS and other European region. These three regions are responsible for, respectively 71%, 6.5% and 11% of emissions from primary non-ferrous metal production. Emissions from this sector in South America (responsible for about 3% of the sector emissions) decreased by 0.4 tonnes.

In the previous work (GMA2013) secondary steel production was not included but this sector has been added in the present work.

The resulting estimated emissions from secondary steel production in 2015 are 10 (7.5-18) tonnes of mercury (ca. 0.5% of the global inventory), with a (retrospectively calculated estimate of 9.7 tonnes in 2010). These totals are higher than might be expected and the reason for this

level of emission is unclear at present; assumptions applied in the calculation of the estimated emissions are presented in Section 2.2.2(5) and Annex 6.

5. (Primary) non-ferrous metal production (Al, Cu, Pb, Zn)

Primary production of copper, lead and zinc, and aluminium, were together estimated to be responsible for some 226 tonnes of mercury emissions in 2015 i.e. an increased in comparison to the ca. 200 tonnes estimated for 2010. It should be noted that the estimates for emissions from this sector have relatively large associated uncertainties (range 153-326 tonnes in 2015).

For aluminium, increased emissions in percentage terms are highest in the EU region, but in absolute terms the Asian regions and Central America are responsible for 2.7 tonnes of increased emissions, partly offset by decreased emissions in other regions, resulting in an overall increase in global emissions from this sector of 2.6 tonnes (from to 4.6 to 7.3 tonnes).

Primary production of copper, lead and zinc make a significantly greater contribution to global mercury emissions, 215 tonnes in 2015 (from 194 tonnes in 2010). Here again, increased emissions in the East and South-east Asian and South Asia regions (29 and 2 tonnes, respectively) offset decreases in emissions in most other regions.

Secondary production of non-ferrous metals is not yet addressed as a separate activity in the global emissions inventory activity (see section xxxx).

6. (Primary) non-ferrous metal production (Hg)

Estimated mercury emissions to air associated with production of mercury increased considerably between 2010 (11.7 tonnes) and 2015 (21.6 tonnes). With small decreases in estimated emissions from mercury production in the CIS and other European countries region and North Africa, the increased emissions are mainly from a doubling of the estimates for emissions in East and South-east Asia (from 9.5 to 18.9 tonnes from mercury production in China) and new emissions in the Central American region (2 tonnes of emissions resulting from 300 tonnes of mercury production in Mexico), with a small contribution from South America (0.2 tonnes emissions in Argentina)

7. (Primary) non-ferrous metal production (large scale-gold production)

Mercury emissions from large-scale gold production in 2015 are estimated at ca. 81 (69-94) tonnes which is lower than the 2010 estimates of 97 tonnes. Some of this reduction can be explained by revisions in both activity data and emission factors to better reflect the current situation in e.g. East and South-east Asia and Sub-Saharan Africa. In other regions, in particular

Australia, New Zealand and Oceania (where Australian emissions predominate) and North America, slightly decreased emissions (10.7 and 0.9 tonnes, respectively) are also partly caused by revisions to technology profiles that imply higher abatement levels associated with technology improvements introduced in the period between 2010 and 2015.

Again, the large uncertainties associated with these emission estimates need to be borne-in-mind.

8. Oil refining

Mercury is a trace contaminant present in varying concentrations in produced oil and gas. Mercury emissions associated with oil and gas production arise during different phases of operations. Emissions associated with the production (well-head) activities (including emissions from flaring) are currently not quantified in the global emission inventory due to lack of relevant information. Mercury is removed from oil and gas prior to its transport, in particular by pipelines, to avoid corrosion and damage to distribution systems. A significant part of the removal is done in connection with oil refining operations. Following the 2010 inventory, IPIECA released a commentary on the GMA results [IPIECA Fact Sheet to INC5], concluding that the GMA estimates for emissions to air were significantly over-estimated; they reported estimates of emissions to air of ca. 1.35 tonne as opposed to the ca. 13 tonnes. Total inputs (i.e. amounts of oil refined multiplied by mercury content of the oil) associated with the refinery sector do not differ greatly between the approaches employed in the GMA and the IPECA calculations. The main differences between the GMA and IPIECA estimates for emissions to air (and releases to water) appear to be associated with the assumptions regarding the fate of mercury at refineries. In the IPIECA approach, for example, 5% emissions to air are assumed, based on studies at US refineries [WSPA, 2009 REF in IPIECA note] (with the major part of the mercury – 87% - associated with solid waste). The GMA (and UNEP Toolkit) methodology assumes higher emissions to air (ca. 25%) based on other industry reported studies [e.g. IKIMP, 2012 and references cited therein], with less of the mercury input being distributed to other media. No new information was identified that allowed this discrepancy regarding fate of mercury from oil refineries to be resolved.

9. Chlor-alkali production

Emissions from intentional use of mercury in the chlor-alkali industry have been decreasing for some time in most parts of the world. In part this is due to increased attention to best practices to reduce emissions, but primarily it is due to the shift from production based on the mercury-process to membrane production technology.

Emission estimates for this sector decreased from ca. 25 tonnes in 2010 to around 17.4 tonnes in 2015.

It should be noted that for many parts of the world, updated activity data relevant to the 2015 inventory period are lacking; consequently emission trends can only be described reliably in relation to the EU, North America and South Asia regions, where emissions decreased by ca. 2.8 tonnes (40%), 0.9 tonnes (83%) and 1.9 tonnes (74%) between 2010 and 2015, respectively. In the case of South Asia, the reductions are largely associated with reported phase-out of mercury-process chlor-alkali production in India.

Although a relatively small component in the total global inventory, the continuing decrease in global mercury emissions from the chlor-alkali sector between 2010 and 2015 is a positive development that is not considered to be related to changes in inventory methodology.

10. Waste and waste incineration

Mercury emissions to air from disposal of waste from mercury-containing products are estimated at 162 tonnes in 2015; 147 (120-225 tonnes) from uncontrolled burning and landfill, and 15 (9-32) tonnes from controlled incineration.

The 2015 estimated emissions from these sectors are considerably higher in comparison to the 2010 estimate of 96 tonnes. This is to a large extent due to a change in methodology where previously ca. 30% of mercury in mercury-containing products was assumed to be 'retained in society'. In the 2015 updated methodology, this amount is now accounted as part of the waste-stream. If the 2010 GMA estimates are updated with this new methodology only, the emissions for 2010 would be 131 tonnes.

Based on updated 2010 estimates, emissions from waste sectors declined in the EU and North America regions (by 33% and 45%, respectively; equivalent to 3-4 tonnes of mercury emitted in these regions). In all other regions, waste-associated mercury emissions increased by more than 10 tonnes in South Asia and Sub-Saharan Africa, and around 3-5 tonnes in the Middle East, CIS and other European countries and East and South-east Asia. Increases in Australia, New Zealand and Oceania and South America regions were minor.

Emissions from the waste sector have large associated uncertainties; quoted ranges only reflect uncertainties attributed to activity data (i.e. estimates of regional consumption of mercury in mercury-containing products).

In general, the estimates addressed in the global inventory do not include industrial wastes and only partially include waste that may be classified as hazardous or medical waste, some of which may also be incorporated in fuels used in, e.g. the cement industry.

Emissions associated with waste from mercury-containing products is also an area where large discrepancies have been identified between estimates made in the GMA inventory and those included in some national inventories as part of (preliminary) Minamata Initial Assessments (see section 2.3.4).

11. Crematoria emissions

Human cremation represents a relatively small but important source of emissions associated with intentional use of mercury – specifically mercury use in dental amalgam fillings. Estimated global mercury emissions to air from cremations are highly uncertain, but evaluated to be less than 5 tonnes per year (in 2015 and 2010) (ca. 0.25% of the global inventory). The proportion of regional emissions associated with cremation is slightly greater (around 1%) in the Australia, New Zealand and Oceania region and the EU and North America, likely reflecting comprehensive access to dental care that – in past decades at least – included widespread use of mercury amalgam fillings. Cultural and religious practises associated with burial and cremation also play a role in determining whether cremation emissions are a significant part of the national air emission profile.

Cremation emissions are only part of the emissions associated with use of mercury in dental applications. The 2015 global inventory does not yet quantify emissions that can occur during preparation and routine disposal of mercury fillings. Other work has estimated emissions to air from these activities at XXX [REF]; they are also expected to contribute to mercury releases in waste waters.

12. Artisanal and small-scale gold production

Intentional use of mercury in ASGM is the predominant source of mercury emissions to air at the global level in the 2015 inventory, as was also the case in 2010. There remain, however, large uncertainties associated with emission from ASGM.

ASGM activities take place in 7 of the 11 sub-regions considered in the current work. Of the estimated total global emissions from ASGM, of ca. 725 tonnes in 2015, ca. 36% of this amount (262 tonnes) is from Sub-Saharan Africa, and 29% (ca. 210 tonnes) from each of South America and East and South-east Asia. Mercury emissions from ASGM activities in Central America and

the Caribbean, the CIS region and South Asia are considerably lower (4.5 – 24 tonnes in 2015) with a very minor contribution also from Middle Eastern States.

ASGM-associated emissions are thus the predominant source of mercury emissions in some regions, accounting for about 70-75% of the emissions that occur in South America and Sub-Saharan Africa, about 40% of emissions in Central America and the Caribbean and about 25% of the emissions occurring in East and South-east Asia.

The estimated emissions from ASGM in 2015 (725 tonnes) are very close to the value reported for 2010 in the GMA2013. However, this masks some important differences. Firstly, a recalculation of the 2010 emissions using the improved information base on ASGM-related activities, and revised emission factor assumptions results in a reduction in the emissions estimate for 2010 to ca. 680 tonnes. This implies that, rather than remaining constant, ASGM emissions increased by ca. 7% between 2010 and 2015. Furthermore, there are differing trends in emissions between 2010 and 2015 in different regions. The most significant increases are for South America (mercury emissions increasing from ca. 165 in 2010 to 210 tonnes in 2015) and Sub-Saharan Africa (from ca. 230 to 260 tonnes); conversely, ASGM emissions from East and South-east Asia declined from an estimated 245 tonnes in 2010 to 210 tonnes in 2015. In the latter region, estimates of ASGM emissions in China sharply declined (attributable to banning of mercury use in ASGM) but this was largely offset by increasing emissions in other countries, Indonesia in particular.

2.3.4 Comparing GMA global inventory estimates with national inventories

The target for the GMA 2018 air emissions inventory activity remains the production of a robust global inventory for the target year of 2015, for a defined set of sectors for which reliable global estimates can be produced. Although it presents emission estimates broken down by sector for each of some 200 countries, the applied methodology is directed at global/regional rather than national level application.

All methods and approaches associated with generation of emissions estimates (whether produced by measurements or theoretical calculations) have (often large) associated uncertainties. It should therefore not be expected that estimates produced using different approaches (global vs national, etc.) will necessarily be identical. Estimates may differ for several reasons including:

- use of activity data corresponding to different years or different sources
- differences in reporting/sector attribution
- differences in applied EFs
- assumptions applied in deriving annual emissions estimates from measurements

Differences between national/sector estimates that comprise the global inventory estimates presented in this report and national emission estimates from other sources provide an important part of estimate verification. Differences can often be explained, and even where this is not the case can reveal limitations in methodology or data that guide further attention and future work.

A major new development since the GMA2013 work is that a large number of countries are engaged in preparing new national inventories or national emission/release estimates, many of these associated with the Minamata Initial Assessments (MIAs) or Minamata National Action Plans (NAPs). This allows increased possibilities for comparing the global and nationally derived emissions estimates.

In relation to estimates compiled as part of the MIA process, most of the MIAs use an approach based on the UNEP Toolkit. The Toolkit was updated in 2013 to reflect new information compiled in developing the 2010 global inventory. In general, new refinements introduced in the work to produce the 2015 global inventory will not yet be reflected in the UNEP Toolkit.

Comparisons between GMA 2018 inventory estimates for the nominal year 2015 and national estimates will be compiled in Annex 7 [not yet available].

Information compiled as part of the GMA 2018 work, including information exchanged at international meetings (organized under the project inventory component) has identified the over 70 national inventories that may be suitable for comparison with the 2015 inventory estimates. These include:

i. Inventories prepared under the auspices of the UN ECE Convention on Long-range Transboundary Air Pollution (CLRTAP) reporting for 2015: 38 countries covering primarily the EU and CIS and Other European countries regions, but also Canada. An initial evaluation, based on total national mercury emission estimates for these countries indicated that GMA inventory estimates are generally somewhat higher than LRTAP reported emissions. For 5 countries (Bulgaria, Kazakhstan, Kyrgyzstan, Macedonia and Serbia) differences between GMA estimates and CLRTAP reported emissions are substantial and need further investigation. Excluding these countries, total estimated emissions to air are 66 tonnes in CLRTAP reporting compared with 81 tonnes in the GMA inventory.

   For most (ca. 2/3) of national CLRTAP inventories, the reported total emissions are lower than the GMA estimates, with GMA inventory estimates for individual countries on average ca. 60% greater than emissions reported to CLRTAP. It is not unlikely that there are gaps in CLRTAP national mercury inventories as in recent years efforts to improve CLRTAP reporting have largely been directed at greenhouse gas emissions, while mercury and some other air

pollutants (e.g. other heavy metals and Persistent organic pollutants, POPs) have received low priority.

ii. Inventories currently being compiled as part of MIAS for about 30 countries from the Sub-Saharan Africa, East and South-east Asia, South Asia, South America and Central America and the Caribbean regions. At the time of preparation of this draft, the majority of MIA inventories are preliminary, and not all were made available for preliminary consideration under the GMA activity. Therefore direct comparisons have not been completed but some provisional conclusions can be drawn based on results from some countries, and discussions with MIA national and regional coordinators.

Comparisons between GMA inventory results and results presented in (preliminary) MIA inventories gave rise to the following general observations:

- With few exceptions, MIAs are being prepared using the UNEP Toolkit which is available in two versions: Level 1 and Level 2. The Toolkit Level 1 approach is designed to be employed for producing first rough estimates of mercury emissions and releases. The Toolkit's Level 2 is designed to represent national circumstances at a more detailed level, supported by available national data. There can be very substantial differences between emissions/release estimates for individual countries produced using the UNEP Toolkit Level 1 and Toolkit Level 2. For this reason, comparisons made between GMA inventory and MIA results focus on MIAs produced using Toolkit Level 2.
- In general, estimates of national emission totals agree fairly well, but there can be significant differences on the sector level. These differences may be due to methodological differences in the approach for MIAs and GMA respectively, or use of different years of (activity) data, but can also be due to errors in national data collection for the MIAs, or regarding the GMA estimates, application of default emission factors and technology profiles not representative for that specific country.
- The GMA inventory is based on activity data for a particular year – nominally 2015 (but typically 2014). Most MIAs appear to be based on 'most recent available data' and often the exact year of activity data concerned is not defined. Activity data is a major factor determining estimated emissions using the GMA and Toolkit approaches, and consequently lack of consistency in this respect is a possible explanation for substantial differences between GMA and MIA inventory estimates.
- Other reasons identified on the basis of preliminary comparisons that may explain differences between the GMA estimates and the MIAs are:

  - MIA estimates associated with oil and gas extraction – a component currently not included in the GMA inventory.
  - MIA estimates associated with waste categories such as industrial waste and waste waters, currently not included in the GMA inventory
  - Estimates of emissions from large scale gold mining, where the default factor in the Toolkit is 3 times higher than that applied in the GMA inventory methodology; data necessary to improve quantification of emissions from this sector are largely lacking.

- For Cu production, the GMA approach may over-estimate the degree of application and effectiveness of abatement, at least for some African countries.
- For cement production there are differences in assumptions applied in calculating emission estimates.
- Some differences in ASGM/large-scale gold sector emissions estimates exist. The Toolkit default factors and methodology were revised in 2017; however many MIAs are still using earlier Toolkit versions.
- Caution should be applied to avoid double counting in totals for inputs to waste and releases to some pathways from products in MIA results, as prescribed in the Toolkit
- A major source of differences between GMA inventory estimates and preliminary MIA estimates can be traced to differences in estimates associated with use and disposal of waste (in particular waste burning) from mercury-added products. The methodology applied in the GMA work and the Toolkit approaches are very different. GMA emissions from waste are based on estimates of the amount of mercury in mercury-added products that are consumed in the country, while MIAs (using the UNEP Toolkit approach) calculate emissions using generic numbers for mercury-content of burned waste.
- Discrepancies exist between estimates of amounts of mercury reported in MIAs for mercury-containing products and regional consumption estimates presented in the UNEP Trade and Supply report (used as the basis for GMA estimates). In some MIAs, problems have been identified with data collection, especially for mercury-added products, including differentiation of, for example, consumption of mercury-containing lamps and batteries and mercury-free lamps and batteries. Generally, countries have substantial data gaps for products. These problems may be exacerbated by insufficiently detailed customs statistics and lack of resources to contact producers and importers for supplementary information. Consequently, there are indications that the default factors for Hg content in general waste burnt (applied in many of the MIAs) may be too high.

iii. National inventories provided by [Australia], Canada, Japan, Republic of Korea, Russia and United States.

Detailed comparisons between GMA estimates and national inventories provided by these countries are presented in Annex 7 [not yet complete]. Tables AC1-5; Table C1 below presents some example (preliminary) comparisons with GMA estimates for main sectors.

From this table it is apparent that estimates match to differing degrees for different sectors, and that this also varies between countries. However, in these example comparisons, the degree of consistency between national inventory estimates and the GMA estimates for this group of countries is generally good, and (with some exceptions) well within the bounds of associated uncertainties. Part of the difference can be explained by differences in the way emissions are assigned between sectors. This is particularly the case for some of the stationary combustion sectors and differentiation of power, industrial and

domestic/residential burning sources, and whether or not fuels are included under stationary combustion or individual industrial sectors. One identified potential inconsistency is that activity data from IEA (used in GMA 2018) do not always match with nationally reported activity data, e.g. for fuel consumption reported by Canada, where differences have been attributed to data set timing (monthly and annual, provisional and revised) and possible use of different factors for conversions from physical fuel units to energy units.

Some national inventories include additional emissions that are not yet quantified in the GMA inventory. Such 'other' sources include emissions from activities such as other chemical manufacturing processes; other mineral products (e.g., lime manufacturing), secondary non-ferrous metal production, oil and gas extraction, pulp and paper industry, and food industry, etc.). These emission sources are currently difficult to quantify at the global scale – largely due to lack of comprehensive activity data as well as lack of emission factors for highly variable process technologies. However, for the few (generally developed) countries reporting emissions from 'other' sources the contribution is approximately 5-20% of the national inventory totals, which extrapolated globally (on non-ASGM emissions totals) could represent additional emissions of the order of 100-200 tonnes.

2824 Table C1. [Example] Comparison between national inventory results and GMA 2015 (provisional) estimates

Sector	Australia		Canada*		Japan		Republic of Korea		Russia		USA			
	national	GMA 2015	national	GMA 2015	national	GMA 2015	national	GMA 2015	national	GMA 2015	national	GMA 2015	national	GMA 2015
Stationary combustion in power plants														
- coal			846	1748	1300	1264		1471			20750	22013		
- oil			0	11	13	155		30			39	40		
- gas			0	10	2	19		5			822	61		
Stationary combustion in industry														
- coal			251	129	240	341		214			986	2507		
- oil			60	19	2	71		25			4525	43		
- gas			0	4	1	3		2			1375	28		
Stationary combustion (domestic/ residential/other)														
- coal			0	5	0	0		0			1	205		
- oil			0	72	0	103		44			1772	363		
- gas			0	7	0	4		3			52	51		
Biomass burning			0	539	0	358		92			528	2441		
Cement			273	128	5500	3475		1258			2875	3131		
Ferrous metal production														
- primary pig iron and steel			617	200	2000	2219		687			1537	513		
- secondary steel			0	117	540	599		340			4140	1288		
Non-ferrous metal production														
- primary copper/lead/zinc			0	42	260	1623		295			573	108		
- primary aluminium			20	35	0	0		0			0	126		
- large-scale gold			0	339	0	16		0			521	485		
- mercury production			354	0	0	0		0			0	0		
Chlor-alkali industry			9	0	0	0		0			82	183		
VCM			0	0	0	0		0			0	0		
Oil refining			0	69	120	1135		968			240	1012		
ASGM			0	0	0	0					0	0		
Waste														
- controlled incineration			670	118	1500	1132		580			1812	1252		

- other (landfill, etc.)			304	309	3850	2246		683			2995	3296		
Cremation			247	89	69	101		41			1128	523		
Other			924	0	1351	0					3271			
Total			4574	3990	16747	14864		6739			50024	39668		

*Canada also reports emissions (totalling 4387 kg) under the CLRTAP reporting system.

2.4 Comparing 2010 and 2015 global inventory estimates

2.4.1 Cautionary Notes

Inventory methodologies are constantly improved as new information and data becomes available. With each new round of inventory development, methods are improved, both with respect to understanding of important factors/parameters and availability, and quality of essential data. This has implications for consistency over time. Changes in emissions estimates for different periods reflect both real-world trends and artefacts of improvements in inventory methods and data availability. Over-simplistic comparisons between the new inventory and previous inventories can result in misinterpretation and should therefore be avoided.

The increased focus on mercury emissions resulting from the adoption of the Minamata Convention, has also led to new research activities, national efforts and industrial focus related to mercury emissions. These efforts all contribute to providing more accurate and complete information on mercury emissions but unavoidably also introduce changes to both current and previous emission inventories.

It is inevitable that comparisons will be made between results presented in the GMA2013 (AMAP/UNEP, 2013) and the results in this update GMA – including comparing individual country-sector based estimates in the 2010 and 2015 inventories. If the implications of methodological refinements, addition of new sectors, improved quality of base information, etc. are not properly appreciated, such comparisons can result in inappropriate and misleading conclusions. It is strongly recommended that any such comparisons therefore refer to the information presented in this report only.

2.4.2 Observations on Changes from 2010 to 2015

As a first step in trying to address some of these issues and gain a reliable insight into whether apparent changes in emissions patterns between 2010 and 2015 represent real changes in emissions or are just artefacts of improved information and methodologies, an updated 2010 inventory was prepared in addition to the 2015 inventory. This updated 2010 inventory incorporated various 'improvements' including new (relevant) information on emission factors and application of APC technology, as well as updated activity data[1]. It also included a retrospective calculation of 2010 emissions for some sectors newly introduced in the 2015 inventory.

[1] In the 2010 inventory presented in the GMA 2013 much of the activity data used were preliminary, corresponding to the period for which latest-data were available (typically 2008 or 2009). The updated 2010 inventory values

Figure T1 compares the pattern of regional emissions in 2010 (GMA2013) with the updated-2010 inventory and the 2015 inventory. The updated estimate of total emissions to air for 2010 is very similar (at the global level) to the original global estimate for 2010 published in the GMA 2013 (AMAP/UNEP, 2013). This consistency is also apparent when considering aggregated emissions for (most) regions and sector groupings. The fact that changes in methods introduced for estimating emissions from specific sectors or country groups, the use of more representative 2010 activity data, and other 'artefacts' (including the introduction of at least one sector in 2015 not represented in the updated 2010 inventory) do not appear to have unduly influenced global or regional inventory results is considered a validation of the general approach employed for deriving global inventory estimates. At the same time, however, it should be noted that values for individual country-sector estimates have in some cases changed significantly.

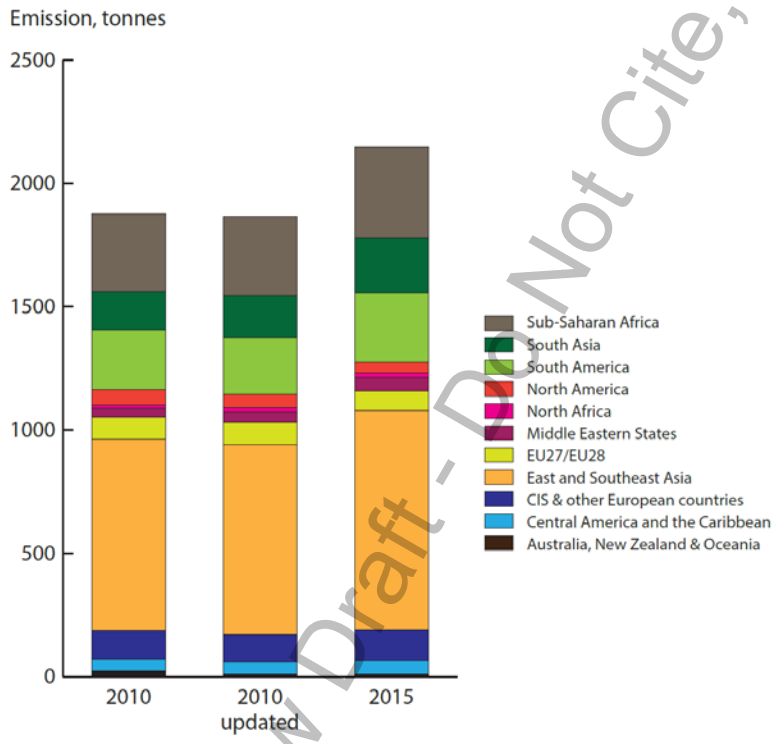


Figure T1: Regional breakdown of global emissions of mercury to air from anthropogenic sources in 2015 in relation to 2010.

presented in this report include a number that have been revised for 'final' 2010 activity data. The 2015 inventory presented in this report is largely based on latest available activity data (in most cases 2014).

Where relevant, the discussions in section 2.3.3 attempt to address the issue of whether apparent trends (between 2010 and 2015 estimates) reflect genuine changes in emissions over time or are artefacts related to improved information, etc. On the basis of this evaluation of apparent changes, the following observations are made:

Global emissions of mercury to the atmosphere in 2015 are approximately 12% higher than they were in 2010. Continuing action to reduce emissions has resulted in modest decreases in emissions in some regions (North America and EU) but increasing emissions in most other regions. Increased economic activity, as reflected in 'activity data' on consumption of fuels and raw materials and production of products is a major factor in driving up emissions associated with energy and industrial sectors in a number of regions. In this respect, differences between 2010 and 2015 may also reflect recovery following the economic down-turn that may have influenced global emissions in 2010. These factors appear to have more than offset any (technological) efforts to reduce mercury emissions.

Mercury emissions to air have decreased between 2010 and 2015 in three of the eleven world regions, namely in North America, in EU and in Australia, New Zealand & Oceania. In the case of North America in particular, shifts in fuel use (from coal to oil/gas) in the energy sector, combined with introduction of highly efficient APCD at major point sources appears to be a major factor in the changes observed. In both Canada and Australia closure or major changes in applied technology (including APC technology) at a few significant point sources associated with non-ferrous metal and large-scale gold production have resulted in decreasing national emissions.

In all other regions,, however, the estimated emissions to air increased.

Higher emissions in 2015 than in 2010 were estimated for a number of the large source sectors: cement production, coal combustion in power plants, non-ferrous metal production (primary Al, Cu, Pb, Zn), for mercury production, primary iron- and steel production, and for emissions from waste (mercury added products). For chlor-alkali production and for large scale gold production the estimated emissions decreased between 2010 and 2015. Other source sectors were comparatively smaller and/or estimated emissions were rather similar to 2010 (see table S1).

Table T1, below, presents an overview of the scale of changes in emissions in different areas for the main sectors addressed in the 2015 global emissions inventory. [Table to be developed]

2.5 Conclusions (emissions to air)

To be prepared following peer review – see also box with Key Findings/Messages at start of this chapter)

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(Other references are as in GMA 2013 Technical report)

Appendix A. Details of methods for calculating Uncertainty Ranges

(i) Calculating uncertainties using the approach applied in the GMA, 2013

A relatively crude (and intentionally conservative) approach was adopted to provide some quantification of the scale of uncertainties in the estimates presented in the GMA 2013 (see Table U1).

Of the three major components contributing to the uncertainties associated with the emission estimates: uncertainties associated with activity data; uncertainties associated with (unabated) emission factors; and uncertainties associated with assumptions made regarding applied (Hg emissions control) technologies, only the first two were considered.

In general, the uncertainties associated with emission factors (including plant operating conditions and technologies used to reduce Hg emissions) are assumed to be considerably more important in determining uncertainties in the overall emissions estimates than those associated with activity data. For example, the EMEP/EEA (2009) air pollutant emission inventory guidebook assigns uncertainties associated with activity data (not specific to Hg) of the order of ± 5–10%. Evaluation of uncertainties associated with (emission factor-based) estimates depends on the procedures involved. For estimates based on a small number of measurements at representative facilities (or engineering judgment based on relevant facts) or engineering calculations based on assumptions alone – which between them cover the case for most Hg emissions estimates – the uncertainties are considered to be of the order of ± 50% to ± an order of magnitude.

For emissions based on Hg consumption in intentional use sectors, and associated waste handling, upper and lower range estimates were produced using the respective upper and lower ranges of the Hg consumption data. These however do not reflect the considerable uncertainties associated with the assumptions made regarding Hg flow in waste streams and associated emission factors. Consequently uncertainties in estimates associated with these sectors were assigned at ± a factor of 3. Uncertainties associated with the assumptions regarding assignment of countries to particular 'country groupings' for applied technology or waste handling procedures were not taken into account.

Table U1. Procedures adopted for calculating low/high range emissions estimates.

		Lower range estimate	Upper range estimate	Ref.
Activity data derived from IEA/official national sources	OECD countries	Activity minus 5%	Activity plus 5%	Modified after EMEP/EEA, 2009
Activity data derived from IEA/official national sources	Non-OECD countries	Activity minus 10%	Activity plus 10%	Modified after EMEP/EEA, 2009
Activity data derived from other sources		Activity minus 30%	Activity plus 30%	Based on AMAP/UNEP 2008
Unabated EFs	All countries	0.7*UEF# for coal sectors; 0.5*UEF# or 0.25*UEF for all other sectors	1.3*UEF# for coal sectors; 1.5*UEF# or 1.75* UEF for all other sectors	Assumptions applied in GMA 2013
Emissions estimates for intentional-use waste stream emissions and emissions from cremations		0.3 * mid-range estimate	3 * mid-range estimate	
Emissions estimates for ASGM		Mid-range estimate minus 15-100% depending on country	Mid-range estimate plus 15- 100% depending on country	

(ii) Introducing uncertainty associated with APC technology assumptions

In a modified version of the GMA2013 approach, uncertainties for technology profiles were introduced by considering 'average reduction efficiency', defined as the sum of the (weighted) abatement. The calculation of the average reduction efficiency for iron and steel production in country group 1 (48.7%) is illustrated in Table U2 below. The average reduction efficiency may also be derived by dividing the emission estimate with the activity data set and the unabated emission factor.

Table U2 Default technology profile applied for pig iron and steel production for country group 1

Technology	Emission reduction efficiency, %	Degree of application, %	Weighted reduction efficiency, %
Standard APC: ESP/CYC/FGD (sinter plant)	20	30	6
Efficient APC: ESP+FGD/ACT/ESP+ACT (sinter	55	60	33

plant)			
Very efficient APC: ESP+ACT/RAC (sinter plant)	97	10	9.7
		Average reduction efficency:	48.7

Uncertainty associated with the removal efficiency was then categorized into 4 different profiles, based on the average removal efficiency for that particular activity, see Table U3. It should be noted that this approach was only applied for 'by-product' sectors; no uncertainty on the removal efficiency was applied in the case of estimated emissions from artisanal gold mining or intentional-use waste streams.

Table U3. Procedures adopted for calculating low/high range technology profiles

Abatement profile	**Average reduction efficiency**	**Low bound**	**High bound**	**Ref.**
Low	0-30%	0% reduction	Average reduction efficiency plus 40%	Assumptions applied in this work
Medium	30-50%	Average reduction efficiency minus 20%	Average reduction efficiency plus 20%	Assumptions applied in this work
High	50-85%	Average reduction efficiency minus 10%	Average reduction efficiency plus 10%	Assumptions applied in this work
Very high	85-100%	Average reduction efficiency minus 5%	Average reduction efficiency plus 5%. However, a maximum bound of 99.99% is adopted.	Assumptions applied in this work

(iii) Employing the propagation of errors method to evaluate uncertainties associated with aggregated estimates

The error propagation method is a method for combining uncertainties. In the current assessment, an approach based on the procedure recommended in the IPCC guidelines for calculating the uncertainty for greenhouse gas emissions (Frey, et al., 2006) was used to evaluate the uncertainties associated with aggregated emissions estimates (regional and sectoral totals and the global inventory total).

The combined uncertainty for one activity (i.e. a national-sector/activity emission estimate) is calculated according the following equation:

$$U_{combined} = \sqrt{U_{AD}^2 + U_{TF}^2 + U_{UEF}^2}$$

where:

U_{AD}: Uncertainty associated with the activity data, see Table 2.1.

U_{UEF}: Uncertainty associated with the unabated emissions factor, see Table 2.1.

U_{TF}: Uncertainty associated with the average reduction efficiency, see Table 2.3.

The maximum uncertainty derived using the assumptions quantified in Table X2 and Table X3 were employed. The uncertainty for the activity data and the technology profile are assumed to be normally distributed around the mean. However, cut-offs were applied on the uncertainty for technology profiles to eliminate cases where the average removal efficiency would be greater than 100% or lower than 0%. The high / low uncertainty for the technology profiles can therefore differ in some cases.

Since the unabated emission factor is largely dependent on the mercury content of the fuel/raw material, the unabated emission factor is assumed to be log-normally distributed. This reflects common properties of such materials; see for example Wu et al (2010) for mercury content in coal, Hylander & Herbert (2008) for mercury content in nonferrous metal ores, and (REF) for mercury content in crude oils. The uncertainty around the unabated emission factor is thus assigned to a high and a low range uncertainty, based on the geometric mean and geometric standard deviation. The geometric mean is calculated with the following equation:

$$\mu_g = e^{\ln(\mu) - \frac{\ln\left(1+\left(\frac{U_{UEF}}{200}\right)^2\right)}{2}}$$

μ_g: Geometric mean

μ: Arithmetic mean, the unabated emission factor used in this study

U_{UEF}: The maximal uncertainty for the unabated emission factor

The geometric standard deviation is calculated with the following equation:

$$\sigma_g = e^{\sqrt{\ln\left(1+\left(\frac{U_{UEF}}{200}\right)^2\right)}}$$

3104 σ_g Geometric standard deviation

3105 The high and low uncertainty for the unabated emission factor is derived with help of two logarithmic
3106 transformations:

$$U_{UEF,low} = \frac{e^{\ln(\mu_g) - 1.96 \cdot \ln(\sigma_g)} - \mu}{\mu} \cdot 100$$

$$U_{UEF,high} = \frac{e^{\ln(\mu_g) + 1.96 \cdot \ln(\sigma_g)} - \mu}{\mu} \cdot 100$$

3107 The following equation is used for combining the uncertainty:

$$U_{total} = \sqrt{\left(\frac{ee_1 \cdot U_{combined,1}}{EE}\right)^2 + \left(\frac{ee_2 \cdot U_{combined,2}}{EE}\right)^2 + \cdots + \left(\frac{ee_n \cdot U_{combined,n}}{EE}\right)^2}$$

3108 where:

3109 ee: Emission estimate for one activity in one country

3110 EE: Emission estimate for the combined inventory. In this study the combined inventory
3111 is calculated at a global, sector and subcontinental level.

3112 The IPCC guidelines are primary developed for calculating uncertainties associated with greenhouse gas
3113 emission estimates. Uncertainties associated with e.g. anthropogenic CO_2 emission factors are relatively
3114 small compared with those for mercury. The results of applying the error propagation method to
3115 mercury emissions may therefore be weak in some cases. Underestimation or overestimation of the
3116 uncertainties may also be a consequence where:

3117 1. Distributions are non-Gaussian
3118 2. Correlations exists between the activity data, the technology profiles and the unabated emission
3119 factor.

3120 Notwithstanding these limitations, the uncertainty estimates obtained using the propagation of errors
3121 approach are considered to better represent the scale of the uncertainties for aggregated inventory
3122 estimates than those achieved by simply summing uncertainties for individual (country-sector) emission
3123 estimates.

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Annex 1 Description of method used to estimate 2015 mercury emissions to air from main 'by-product' emission sectors and the chlor-alkali industry, including an example calculation

Annex 2 Description of method used to estimate 2015 mercury emissions to air from artisanal and small-scale gold mining, including an example calculation

Annex 3 Description of method used to estimate 2015 mercury emissions to air from wastes associated with mercury added products, including an example calculation

Annex 4 Description of method used to estimate 2015 mercury emissions to air from use in dental amalgam and human cremation

Annex 5 Activity data used in the calculation of emission estimates

Annex 6 Emission factors and technology profiles used in the calculation of emission estimates

Annex 7 Comparisons with National Inventories (to be completed)

Annex 8 Global Inventory Estimates 2015