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 [Example calculation to be updated]

The 2015 inventory estimates for most sectors are based on a three step approach:

Step 1 involves compiling **activity data** – statistical data concerning consumption of fuels and raw materials and production of products that are relevant to calculation of Hg emissions from energy/industrial sectors; and data on Hg consumption in intentional use sectors and in mercury added products that allows estimates to be made of Hg emissions from waste streams, etc.

Step 2 involves the compilation of 'emission factors' that can be applied to the activity data to derive estimates of **unabated/uncontrolled emissions to air** – a typical example might be the fraction of Hg in coal that is released to the atmosphere when the coal is burned (prior to any technological measures to reduce emissions of air pollutants). Important to note here is that these are **unabated emission factors (UEF)** and therefore differ from the **(abated) emission factors (AEF)** that are commonly reported/used to produce end-of-pipe emissions estimates. These UEFs can be considered as being similar to the **input factors** applied in the UNEP Toolkit approach, but differ in that – in most cases – they relate to the emissions/inputs only to air as opposed to the total release of Hg to all media that are obtained from the UNEP Toolkit input factors. To take this comparison a stage further, the UEFs employed in this work are approximately comparable to the UNEP Toolkit input factors multiplied by their respective **distribution factor (DF)** for the proportion of the input released to air; however, it should be noted that UNEP Toolkit factors were not always adopted, and information developed during the current work is being used in updating of the UNEP Toolkit factors. The UEFs, when applied to the activity data from step 1 yield estimates of unabated (uncontrolled) emissions to air from the activity concerned.

Step 3 involves an attempt to represent the 'technology' that is applied in the respective sectors in different countries to control (reduce) Hg emissions to the air – typically through the application of **air pollution control devices (APCDs)**. These technologies are characterized by their effectiveness (Hg emissions reduction efficiency) and their degree of application. In Step 3 it is necessary to recognize that available information – based on a relatively few (but increasing number of) measurements made at individual plants in certain (mainly developed) countries – demonstrates that effectiveness of APCDs is very variable and depends on plant operating conditions, specific characteristics of fuel and raw materials, etc. In addition, the general scarcity of relevant information on both the effectiveness of APCDs and their degree of application in various sectors/countries means that assumptions need to be made. First, on the basis of available information, technologies have been grouped according to their general degree of effectiveness at reducing Hg emissions; and according to their degree of use (e.g., commonly applied APCD configurations). Second, countries have been assigned – on the basis of an assumed general level of technological implementation of APCDs – into five groupings (see Chapter 2.X). Information on the effectiveness and degree of implementation of APCDs in those countries for which information is available (derived from published literature, grey literature and application of the UNEP Toolkit, etc.) has then been used to characterize the **technological profile** for the country-group to which the country belongs. The resulting technology profile – or a specific national profile for countries where such detailed data are available – has been applied to the unabated/uncontrolled emissions estimates resulting from Step 2 to produce abated (controlled) emission estimates for all countries/sectors for which activity data are available from Step 1. These estimates constitute the global inventory of Hg emissions to air from the represented anthropogenic sectors.

As described, the applied methodology relies on statistical data and assumptions concerning emission factors and technological profiles, etc., that are based on often very limited available information. However, this methodology is designed to derive global emissions inventories and to compile relevant statistics and other information in a manner that allows it to be transparent, readily updatable as new information becomes available, and potentially useful for other purposes (such as emission scenario development).

A full description of the emission factors and technology profiles applied in this work, is given in Annex 6, which also contains extensive notes explaining their basis, and comparisons with emission factors used in other studies (including the UNEP Toolkit, GMA2013 and the 2005 inventory) .

The documentation procedures described above and transparency regarding assumptions made, etc., is intended to allows for future updates of the inventory for individual countries and sectors as more detailed information becomes available.

Example calculation [To be updated]

The following example shows the calculations applied to estimate Hg emissions from cement production in China. Under the regionalization approach described in Section 2.2.3.1, China is in the Group 3 countries with respect to characterization of applied technology.

According to the US Geological Survey, China produced 1629000 kt of cement in 2009 (see Annex 5).

The (country-specific) UEF applied to cement production in China is 0.087 g/t cement (see Annex 6). About 80% of cement production in China is based on coal; emissions from the fuels are not included in this UEF (these are accounted under the SC-IND – stationary fossil fuel combustion in industrial uses – sector). This UEF is the same as that employed as the generic UEF for cement production resulting from Hg in raw materials (limestone) in the absence of co-incineration of waste. The resulting unabated emission estimate for this sector in China is therefore 141.723 tonnes [= 1629000000 × 0.087 grams].

In Group 3 countries the technology profile applied for cement production (see Annex 6) would infer that ~20% of the emissions from cement production in China are not subject to any emission control, and 80% are subject to (basic particulate matter) emission controls that reduce Hg emissions by about 25%. On the basis of these assumptions, the associated (abated) Hg emissions would be reduced from around 142 to around 113 tonnes, with some 28.3 [= 141.723 × 0.8 × 0.25] tonnes of Hg being captured by the APCDs.

However, national information provided by China indicated that a more accurate representation of the abatement technology applied in the Chinese cement sector is that all Chinese cement plants are fitted with dust removal systems (about 80% equipped with fabric filters and about 20–40% with electrostatic precipitators) with an effective Hg capture of 40%. Applying this new profile, about 56.7 (141.723 × 1 × 0.4) tonnes of Hg are removed by the APCDs, resulting in an estimated emission to air form the cement sector in China of some 85 tonnes.

To estimate an uncertainty range for this estimate, these calculations were repeated using low and high values of 1140300 and 2117700 kt, respectively for the activity data (see Section 2.2.7, Table 2.3; ± 30% applied to activity data from sources other than International Energy Agency (IEA) or official national data). In addition, for the low range estimate the UEF was reduced from 0.087 to 0.046 g/t [= 0.087 minus half the difference between this value and the tabulated low UEF of 0.005 g/t]; and for the high range estimate a UEF of 0.238 g/t was applied [= 0.087 plus half the difference between this value and the tabulated high UEF of 0.389 g/t] (see Annex 6 and Section 2.2.7, Table 2.3). No adjustments were made to account for uncertainties in the applied technology profile (i.e., the reduction in emissions due to abatement technology). The resulting range of (abated) estimates is therefore 31.4 [= 1140300000 × 0.046 × 0.000001 × 0.6] to 302 [= 2117700 × 0.389 × 0.000001 × 0.6] tonnes, where the first term is the activity in tonnes, the second term is the UEF in g/t, the third term is the factor to convert the emission estimate from grams to tonnes, and the fourth term is 1 minus the 40% reduction due to abatement).

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

[To be updated, current description from GMA2013]

The 2010 inventory estimate of Hg emissions from artisanal and small-scale gold mining (ASGM) is based on an understanding of ASGM, direct field evidence, a wide variety of secondary information sources, analysis of official trade data, and extrapolation of these various data. There is now reasonably good information about where ASGM is occurring. Main information sources used include: decades of archives from the Northern Miner – a mining trade magazine that regularly reports the 'presence of artisanals'; reports and conference materials from the World Bank; reports and follow-up from the UNDP/GEF/UNIDO Global Mercury Project (GMP); reports from currently operating GEF-UNIDO projects, reports from other intervention programs such as the Swiss Agency for Development and Cooperation (SDC), the Canadian International Development Agency (CIDA), the World Wildlife Fund (WWF), etc.; reports and abstracts from the International Conferences on Mercury as a Global Pollutant (ICMGP) up to 2011 (10 congresses); reports from the MMSD (2002); articles published in the peer reviewed literature; and new field reports from field programs and intervention programs that are directly involved with government and people employed in the ASGM economy – miners and gold and Hg merchants.

Based on information on practices used in different countries, it is estimated that, on average 45% of Hg used in ASGM is emitted to the atmosphere with the remainder released to land and water. In regions where concentrate amalgamation is practiced, although the absolute amount of Hg used is typically lower than in other practices such as whole ore amalgamation, 75% of the Hg used is emitted to the atmosphere, whereas localities that practice whole ore amalgamation use much more Hg per unit gold produced, but release a much larger portion of the Hg to aquatic and terrestrial systems, some of which is re-emitted to the atmosphere at later times. Estimates from Australia and Canada (Winch et al., 2008; Parsons et al., 2011) suggest that a large proportion of the Hg used in historical gold mining operations in the 1800s has been remobilized.

The total amount of Hg used in ASGM applications (see Table A2.1) can be estimated using four main approaches: (1) direct measurements – using a balance to directly weigh amounts of Hg used; (2) applying a mercury/gold (Hg:Au) ratio to estimates of gold production based on the type of process used (whole ore amalgamation or concentrate amalgamation or the use of emission controls like retorts, etc.); the estimates of gold production can come from the number of miners actively mining and their average yearly gold production, or from other sources such as government reports on gold production or mining populations; (3) interviewing miners and gold merchants who buy or sell Hg; (4) using official trade data. The first three approaches involve directly working with miners and gold merchants. This information can then be used to constrain, through triangulation a more robust estimate of the amount of Hg used and released to the environment and the amount emitted to the atmosphere.

The most reliable results are rooted in field work and relationships with stakeholders. In order to do this, personnel making the estimation must be capable of understanding mining practices and gold trade. Mercury use practices and gold production are key pieces of information. Determining these requires combining information from field data, miners, mining communities, buyers, traders, geological surveys, ministries responsible for mining, mining commissions, the private sector, exploration company press releases, industry magazines, environmental ministries, and others. This information must be analyzed to understand what is reasonable based on expert knowledge of geology, mining, ASGM practices, mining communities, and socio-economics. The results of the analysis should be discussed with stakeholders such as miners, concession holders, local governments, and national governments to obtain their input and help constrain the analysis.

The fundamental questions that need to be answered in order to make an annual estimate of Hg use and emissions are:

1. Is mercury used?
2. What are the practices in use? (consider: Whole ore amalgamation? Concentrate amalgamation? Mercury activation?)
3. How much mercury is used per unit gold? – grams of mercury lost per grams of gold produced? (consider: Do miners discard used mercury? Do the miners use retorts or recycle mercury?)
4. How much gold do miners produce per year?
5. What is the total number of miners?

The format of the questions needs to be adapted to local conditions. For example, it is often necessary to convert the amount of gold produced per day into an annual number by taking into account further information about work habits throughout the year – for example, how work varies seasonally.

The quality of estimates varies across countries and can be grouped into four main classes: class 1 = presence/absence, no quantitative information, error can be greater than ±100% (25 countries); class 2 = some indication of quantity of Hg used, estimated average error ±75% (20 countries); class 3 = quantitative data but not significantly updated within past five years, error ±50% (17 countries); class 4 = recent quantitative data; error ±30%.

Example calculation

The following example describes the method used to make a class 4 estimate of Hg releases from ASGM in Burkina Faso over a two-year time frame (2011/2012).

The Director of the Ministry of Mines, Geology, and Quarries estimates 600 000 adults living on 221 ASGM sites that are registered as ASGM exploitation permits, and plotted on a cadastral map. At least the same number inhabits and operates on unregistered land. Meetings were held before and again after field visits with: miners in the field, government agencies, miners associations (formal + informal), gold traders and Hg traders. The results are as follows: All ASGM activities use Hg. This began around year 2000. Whole ore amalgamation is never done. Concentrate amalgamation is done. Mercury activation is not practiced. Miners do not throw away dirty Hg. Miners never use retorts or recycle Hg in other ways – amalgam is burned using an open flame. The amount of Hg used per unit gold produced is on average 1.3 parts mercury to 1 part gold (i.e., a mercury to gold ratio of 1.3:1). This accounts for the Hg that ends up in the amalgam (1 part) and the Hg that is lost during processing to the tailings (0.3 parts). All Hg used is released to the environment, with 75% (that in the amalgam 1/1.33) directly emitted to the atmosphere during amalgam burning and the residual (0.3 parts) lost to the tailings. In Burkina Faso, it is likely that the amount lost to the tailings is re-emitted to the atmosphere on a relatively short time scale of one to several years as the tailings are accumulated in above ground piles and later reprocessed.

200 000 of the 600 000 official ASGM population (1 in 3) are estimated to be active miners. They produce 20 to 30 tonnes of gold per year (~25). This is reasonable considering the known geology (abundance of gold-bearing formations of sufficient grade throughout the country), a processing lens (gold production per miner using the observed processing techniques), and through a socio-economic lens based on the cost of living at ASGM localities. This estimate was discussed with the gold buyers and site owners and the Ministry of Mines and was found to be reasonable by these groups. The amount of Hg used and emitted to the atmosphere is thereby determined as follows: 25 tonnes of gold are produced annually; all of it is amalgamated using 32.5 tonnes of Hg per annum. All amalgam is burned openly thereby emitting 25 tonnes of Hg directly to the atmosphere with the remaining 7.5 tonnes being released to the land and water in the waste stream (tailings). The Hg contained in tailings is likely to also be emitted to the atmosphere within a decade.

It may be helpful to briefly describe some of the other supporting information that is typically used in determining the annual gold production and Hg use. In Burkina Faso, ASGM miners typically operate in 5–10 person partnerships consisting of diggers, haulers, crushers, millers, and amalgamators. Women also work in groups, but typically only haul, crush and process tailings. Relatively small amounts of Hg are used (1.3 units Hg for 1 unit gold) and awareness of the dangers of Hg is low and therefore retorts are not currently used for economic or health reasons, indicating that no Hg is recycled. Ore grades are high (often 10–50 g/t) but traditional mining is inefficient (15–50% recovery). On average, miners yield half a gram per day for about 270 days per year, equating to about 135g/miner/year. They receive 70–80% of the international price when selling to the local buyer who has a relationship to the land holder of the site. Using 80% of a gold price of USD 1500/oz (USD 48.24/g), each miner makes about USD 5209/year or 434/month. However, costs for miners are high and estimated to be USD 200–500/month and consist of costs for processing (milling and Hg), food, shelter, transport, and family including off-site family.

The estimate for Burkina Faso serves also to make some useful points for emissions estimations in general. The previous (2005 inventory) emission estimate for Burkina Faso was about 3 t Hg/y based on MMSD (Mining, Minerals and Sustainable Development) work in 2001 and presence/absence data from mining trade magazines and newspaper reports in 2008. The current estimate of 32.5 t Hg/y represents a ten-fold increase. This increase is not a result of increased use but rather of better reporting. This serves to illustrate the potential magnitude and the expected direction of uncertainties in countries that are currently estimated to be using a conservative minimum amount of Hg (0.3 t Hg/y) based on a simple presence/absence criteria or countries for which estimates are becoming dated. In other words, it is likely that the estimated quantity of Hg being used annually in ASGM globally will rise as better data become available through better inventory work.

In conclusion, robust estimations of Hg emissions from ASGM remain sparse and the global estimate needs further development. The current estimate of roughly 1600 tonnes total Hg use per year ±50% is a conservative minimum assigning small numbers and large errors to countries where little information exists. The estimate has risen since the last estimate published in 2008 primarily due to improved reporting rather than increased use, albeit the latter has likely also occurred due to the increase in the price of gold. The estimation of Hg use in ASGM requires trained experts that can reliably assess the informal gold economy and its Hg use, as well as reliably upscale field observations to national levels. Aside from technical geo-scientific expertise, this frequently requires establishing adequate relationships with the numerous stakeholders. Relevant and updated information about Hg use in ASGM is being compiled regularly in the online mercury-watch database (www.mercurywatch.org). Significant knowledge gaps remain but these can (and are) being addressed with increasing reliability.

Table A2.1. Mercury consumption in artisanal and small-scale gold mining and calculation of associated emissions.

Country	Quality of data [a]	ASGM Hg use, t			Percent of total Hg applied to concentrate amalgamation	Percent of total Hg applied to whole ore amalgamation	Emission Factor [b]	Year of most recent data	Mean air emission, t
		min	mean	max					
Total		910.0	1607.8	2305.6					726.771
Angola	1	0.1	0.3	0.5	100%	0%	0.75	2009	0.225
Benin	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Bolivia	4	84.0	120.0	156.0	25%	75%	0.38	2012	45.000
Botswana	2	0.2	0.8	1.4	50%	50%	0.50	2010	0.400
Brazil	4	31.5	45.0	58.5	50%	50%	0.50	2007	22.500
Burkina Faso	4	24.6	35.1	45.6	100%	0%	0.75	2011	26.325
Burundi	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Cambodia	3	3.8	7.5	11.3	50%	50%	0.50	2006	3.750
Cameroon	2	0.4	1.5	2.6	100%	0%	0.75	2011	1.125
Central African Republic	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Chad	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Chile	2	1.0	4.0	7.0	50%	50%	0.50	2009	2.000
China	3	222.3	444.5	666.8	25%	75%	0.38	2004	166.688
Colombia	3	90.0	180.0	270.0	17%	83%	0.33	2012	60.000
Congo	2	0.4	1.5	2.6	100%	0%	0.75	2010	1.125
Costa Rica	1	0.1	0.3	0.5	50%	50%	0.50	1998	0.150
Dominican Republic	1	0.1	0.3	0.5	100%	0%	0.75	1997	0.225
Democratic Republic of Congo	2	3.8	15.0	26.3	100%	0%	0.75	2010	11.250
Ecuador	3	25.0	50.0	75.0	20%	80%	0.35	2007	17.500
El Salvador	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Equatorial Guinea	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Ethiopia	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
French Guiana	3	3.8	7.5	11.3	100%	0%	0.75	2008	5.625
Gabon	1	0.1	0.3	0.5	100%	0%	0.75	2010	0.225
Gambia	1	0.1	0.3	0.5	100%	0%	0.75	1996	0.225
Ghana	4	49.0	70.0	91.0	100%	0%	0.75	2010	52.500
Guatemala	2	0.4	1.5	2.6	50%	50%	0.50	2005	0.750
Guinea	3	0.2	0.3	0.5	100%	0%	0.75	2002	0.225
Guinea-Bissau	1	0.1	0.3	0.5	100%	0%	0.75	2002	0.225

Guyana	3	7.5	15.0	22.5	100%	0%	0.75	2008	11.250
Honduras	1	0.1	0.3	0.5	50%	50%	0.50	1999	0.150
India	3	0.8	1.5	2.3	100%	0%	0.75	2010	1.125
Indonesia	4	122.5	175.0	227.5	17%	83%	0.33	2008	58.333
Ivory Coast	1	0.1	0.3	0.5	100%	0%	0.75	2012	0.225
Kenya	2	1.9	7.5	13.1	100%	0%	0.75	2002	5.625
Kyrgyzstan	2	1.9	7.5	13.1	50%	50%	0.50	2004	3.750
Lao Peoples Democratic Republic	3	0.7	1.3	2.0	100%	0%	0.75	2007	0.975
Lesotho	1	0.1	0.3	0.5	100%	0%	0.75	2002	0.225
Liberia	1	0.1	0.3	0.5	100%	0%	0.75	2003	0.225
Madagascar	2	0.4	1.5	2.6	100%	0%	0.75	2003	1.125
Malawi	1	0.1	0.3	0.5	100%	0%	0.75	2001	0.225
Malaysia	2	0.9	3.5	6.1	50%	50%	0.50	1992	1.750
Mali	4	14.0	20.0	26.0	100%	0%	0.75	2011	15.000
Mauritania	1	0.1	0.3	0.5	100%	0%	0.75	2004	0.225
Mexico	2	1.9	7.5	13.1	50%	50%	0.50	2003	3.750
Mongolia	4	8.1	11.5	15.0	50%	50%	0.50	2007	5.750
Mozambique	3	2.0	4.0	6.0	100%	0%	0.75	2009	3.000
Nicaragua	3	0.8	1.5	2.3	50%	50%	0.50	1999	0.750
Niger	1	0.1	0.3	0.5	100%	0%	0.75	2000	0.225
Nigeria	3	10.0	20.0	30.0	100%	0%	0.75	2011	15.000
Panama	2	0.4	1.5	2.6	50%	50%	0.50	1999	0.750
Papua New Guinea	2	1.8	7.0	12.3	50%	50%	0.50	2010	3.500
Paraguay	1	0.1	0.3	0.5	100%	0%	0.75	2012	0.225
Peru	4	49.0	70.0	91.0	25%	75%	0.38	2010	26.250
Philippines	4	49.0	70.0	91.0	25%	75%	0.38	2010	26.250
Russia	2	2.8	11.0	19.3	50%	50%	0.50	2001	5.500
Rwanda	1	0.1	0.3	0.5	100%	0%	0.75	1992	0.225
Senegal	2	0.4	1.5	2.6	100%	0%	0.75	2010	1.125
Sierra Leone	1	0.1	0.3	0.5	100%	0%	0.75	2004	0.225
South Africa	2	1.9	7.5	13.1	50%	50%	0.50	2005	3.750
Sudan	3	30.0	60.0	90.0	100%	0%	0.75	2011	45.000
Suriname	3	3.8	7.5	11.3	100%	0%	0.75	2008	5.625
Tajikistan	2	1.0	4.0	7.0	100%	0%	0.75	1996	3.000
Tanzania	4	31.5	45.0	58.5	100%	0%	0.75	2009	33.750
Thailand	2	0.4	1.5	2.6	100%	0%	0.75	2007	1.125
Togo	2	1.0	4.0	7.0	100%	0%	0.75	2002	3.000

Uganda	3	0.4	0.8	1.2	100%	0%	0.75	2008	0.600
Uzbekistan	1	0.1	0.3	0.5	100%	0%	0.75	2001	0.225
Venezuela	3	7.5	15.0	22.5	25%	75%	0.38	2005	5.625
Viet Nam	2	1.9	7.5	13.1	50%	50%	0.50	2001	3.750
Zambia	1	0.1	0.3	0.5	100%	0%	0.75	2008	0.225
Zimbabwe	3	12.5	25.0	37.5	20%	80%	0.35	2009	8.750

[a] Class1=presence/absence, no quantitative info (±100%); class 2=some indicator of quantity(±75%), class 3=quantitative data but not within last 5 years (±50%), calss 4=recent quantitative data (±30%)

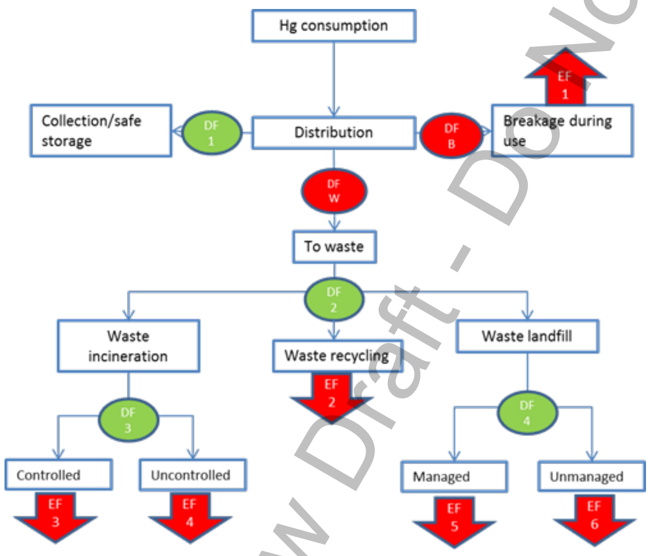
[b] mission factor for concentrate amalgamation = 0.75 (1/1.3); Emission factor for whole ore amalgamation = 0.25 (1/4).

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

Mercury emissions to air from mercury added products (see section on sectors/activities below) are produced using a slightly different but comparable methodology to that applied to calculate emissions from unintentional emission sectors (see Annex 1). Use is made of available data on regional patterns of consumption of Hg and Hg-containing products, since national consumption data are unavailable in most cases. Mercury releases at various points in the life-cycle of these products are calculated using assumptions regarding rates of breakage, waste handling, and factors for emissions to air, etc.

The method applied is the same as in the 2010 inventory (GMA 2013) and a variation of the method used in the 2005 inventory (AMAP/UNEP, 2008) where product-related Hg emissions from eleven regions of the world were estimated. The methodology allows for a consistent and transparent treatment and calculation of product-related Hg emissions for each individual country, also taking country-specific information into account, where available. The method is schematically described in Figure A3.1.

Figure A3.1. Schematic representation of the model used to estimate mercury emissions from waste streams associated with mercury added products.



The input data consist of estimated Hg consumption in one year (2015) covering the product groups: batteries, measuring and control devices, lamps, electrical and electronic devices, and other uses (Table A3.1).

Table A3.1. Mercury consumption by world region and application, 2015 (Maxson, 2017).

	Average, t						
	Batteries	Measuring devices	Lamps	Electrical devices	Other use [a]	Dental applications [b]	Total
East and Southeast Asia	95	208	69	52	62	45	531
South Asia	33	39	12	12	59	35	190
European Union (27 countries)	8	3	13	1	84	56	165
CIS and other European countries	13	12	7	7	37	15	91
Middle Eastern States	13	18	7	9	9	12	68
North Africa	8	6	4	2	5	4	29
Sub-Saharan Africa	24	11	5	19	15	6	80
North America	9	2	8	19	61	32	131
Central America and the Caribbean	9	9	4	6	8	5	41
South America	18	20	9	8	13	10	78
Australia New Zealand and Oceania	1	1	3	13	1	3	22
Total	231	329	141	148	354	**223**	1426
	Minimum, t						
	Batteries	Measuring devices	Lamps	Electrical devices	Other	Dental applic-ations	Sum
East and Southeast Asia	72	177	55	42	44	41	431
South Asia	23	32	10	10	30	29	134
European Union (27 countries)	6	2	11	0	59	44	122
CIS and other European countries	9	9	5	5	19	11	58
Middle Eastern States	9	13	5	6	4	9	46
North Africa	5	4	3	2	3	3	20
Sub-Saharan Africa	7	8	4	9	4	4	36
North America	7	2	7	16	42	27	101
Central America and the Caribbean	6	8	4	4	4	4	30
South America	13	14	6	5	7	7	52
Australia New Zealand and Oceania	1	1	2	9	0	3	16
Total	158	270	112	108	216	**182**	1046
	Maximum, t						
	Batteries	Measuring devices	Lamps	Electrical devices	Other	Dental applic-ations	Sum
East and Southeast Asia	119	239	83	62	81	50	634
South Asia	43	47	14	14	89	40	247
European Union (27 countries)	9	3	15	1	110	67	205

CIS and other European countries	17	16	10	10	56	20	129
Middle Eastern States	17	24	9	11	13	14	88
North Africa	10	8	5	3	8	5	39
Sub-Saharan Africa	40	14	7	28	25	8	122
North America	10	2	9	21	79	37	158
Central America and the Caribbean	12	11	5	8	12	6	54
South America	23	25	12	10	20	14	104
Australia New Zealand and Oceania	1	1	4	17	1	4	28
Total	301	390	173	185	494	**263**	1808

[a] The ‘other use’ category includes, for example, pesticides, fungicides, laboratory chemicals, chemical intermediates, pharmaceuticals, preservative in paints, traditional medicines, cultural and ritual uses, cosmetics – especially skin-lightening creams, etc.

[b] Consumption in dental applications is not included in the calculations described in this Annex; the methodology employed to calculate emissions from dental amalgam use associated with human cremation are described in Annex 4.

The consumption is estimated for each product group for eleven regions of the world; East and Southeast Asia, South Asia, European Union, CIS and other European countries, Middle Eastern States, North Africa, Sub-Saharan Africa, North America, Central America and the Caribbean, South America, Australia New Zealand and Oceania. Consumption in this context refers to the region where the product is used and thus subsequently ends up in the waste stream, and not the region where it was produced.

In order to estimate the consumption in each country of the world, the consumption figures (for batteries, measuring devices, lighting, electrical devices and other uses – see Table A3.1) as compiled by Maxson (2017) for each region were distributed between the countries in that region based on Gross Domestic Product (GDP) at Purchasing Power Parity (PPP). GDP-PPP data for individual countries were obtained from the data catalog at the World Bank (World Bank, 2016) and where countries were not available in the list from the World Bank, from the World Factbook by the CIA (CIA, 2016). In the model the estimated amount of Hg in products consumed in a country is distributed to three different initial pathways (Figure A3.1) using distribution factors. The main initial paths of the products containing Hg are collection for safe storage (no emissions assumed), breaking and releases of Hg during use, paths to the waste stream (with further differentiation of waste pathways). In the inventory for 2010 there was an additional pathway for products remaining ‘in use’ in society. This pathway, amounting to 30 % of the mercury consumed, did not contribute any emissions in those calculations since emissions were considered to be delayed. That way of thinking is more in line with reality, but only takes 70% of the Hg contained in products into account. In order to simulate emissions to air from one year´s consumption of mercury, this pathway was removed in the 2015 inventory. It should be pointed out that only one years´ consumption is taken into account, while any emissions from stocks remaining in society from previous years consumption in mercury added products are not included in the estimates. This remaining Hg will of course in current or future years be distributed to one of the endpoints as the product reaches its end of life.

The share of Hg in products entering the waste stream is distributed between waste recycling, waste incineration and waste landfill. The amounts of Hg going to waste incineration and waste landfill are further distributed between two levels of waste management, controlled incineration and uncontrolled waste burning and managed and unmanaged waste landfill. Controlled in this context represents waste incineration with efficient air pollution abatement installed and controlled, well managed landfill with relatively low expected emissions of Hg. The uncontrolled burning implies no or poor abatement of air emissions, and unmanaged landfills (or waste dumping) includes a higher degree of, for example, fires where higher Hg emissions would be expected.

In order to take into account varying waste management practices, five different ‘profiles’ of distribution factors and emissions factors were assumed. Each country has been assigned one of these five generic profiles based on assumptions (and available information) regarding national/regional waste handling practices, including discussions with regional representatives (see Chapter 2.X). In the in inventory for 2010 there were only four different "profiles", while a fifth, representing least developed waste handling technologies was added in the 2015 inventory.

In the model, several assumptions regarding distribution factors and emission factors have been made. Discussions have been held with representatives from all of the world's regions and assumptions have been adjusted accordingly. More or less rough generalizations are however inevitable in order to perform harmonized and transparent calculations for all individual countries, since country-specific information in most cases is scarce or non-existent.

The initial distribution factors determine the amount distributed to the waste stream. Table A3.2 presents the general distribution factors used for the five different profiles. The distribution for break and release during use is the same for all profiles, while the share collected for safe storage varies.

Table A3.2. Initial distribution factors for mercury-containing products.

Profile	Collection/safe storage	Break during use	To the waste stream	Total
1	15%	3.5%	81.5%	100%
2	5%	3.5%	91.5%	100%
3	1%	3.5%	95.5%	100%
4	1%	3.5%	95.5%	100%
5	1%	3.5%	95.5%	100%

The waste stream distribution pathways, given as distribution factors, are presented in Table A3.3. There are different assumptions regarding the share of Hg contained in products which is recycled, as well as on the shares going to waste incineration and landfill. For profiles 3 and 4 the distributions between recycling, incineration and landfill are the same. A differentiation is introduced in the specific distribution factors for the share of the incinerated and landfilled waste that is treated under controlled or uncontrolled conditions.

Table A3.3. Waste distribution factors and specific distribution factors for controlled and uncontrolled waste incineration and waste landfill.

Waste distribution pathways					
Profile	Waste recycling	Waste incineration		Waste landfill	
1	17%	18%		65%	
2	4%	12%		84%	
3	2%	5%		93%	
4	2%	5%		93%	
5	2%	5%		93%	
Specific distribution factors for incineration and landfill		Incineration		Landfill	
Profile		Controlled	Uncontrolled burning	Managed	Unmanaged
1		100%	0%	60%	40%
2		40%	60%	30%	70%
3		20%	80%	30%	70%
4		15%	85%	10%	90%
5		1%	99%	1%	99%

At this stage in the model calculations, the initial amount of Hg in products in a specific country has been distributed to all endpoints in the model (Figure A3.1) where emissions to air can occur. Emissions are calculated by applying emission factors (EF) according to Table A3.4 to the distributed individual amounts of Hg. For all endpoints, except for unmanaged landfill, the EFs are the same for all assigned generic profiles of waste management. The expected releases of Hg from unmanaged landfills are highly dependent on the frequency and duration of landfill fires. The more landfills under fire, the more Hg will be released. Rough assumptions and simplifications, largely based on Maxson (2009) and Wiedinmyer et al (2014), have been applied for developing profile EFs for unmanaged landfills, taking landfill fires into account.

Table A3.4. Emission factors (fraction emitted) applied to distributed amounts of mercury in products.

Profile	Break/release during use	Waste recycling	Waste incineration, controlled	Waste incineration, uncontrolled	Landfill, controlled	Landfill, unmanaged
1	0.1	0.03	0.1	0.9	0.05	0.07
2	0.1	0.03	0.1	0.9	0.05	0.14
3	0.1	0.03	0.1	0.9	0.05	0.14
4	0.1	0.03	0.1	0.9	0.05	0.23
5	0.1	0.03	0.1	0.9	0.05	0.23

It should be noted that where relevant national information was available, factors applied to specific countries were adjusted accordingly, such was the case for example for the distribution factors applied in the case of Japan, Republic of Korea, China, Egypt, Tunisia and for countries in South America.

In the 2015 inventory, emissions using the above methodology are quantified under two main categories: emissions associated with controlled incineration (WI) and all other (waste) components (WASOTH). The WI component is assumed to be associated with incineration at (large incineration) facilities with applied APC technology. The amount of Hg calculated as emitted from waste incineration in this work of course only includes the mercury added product groups concerned in this section. Additional emissions of Hg could arise from incineration of other types of Hg-containing waste, such as sewage sludge, industrial wastes, etc.

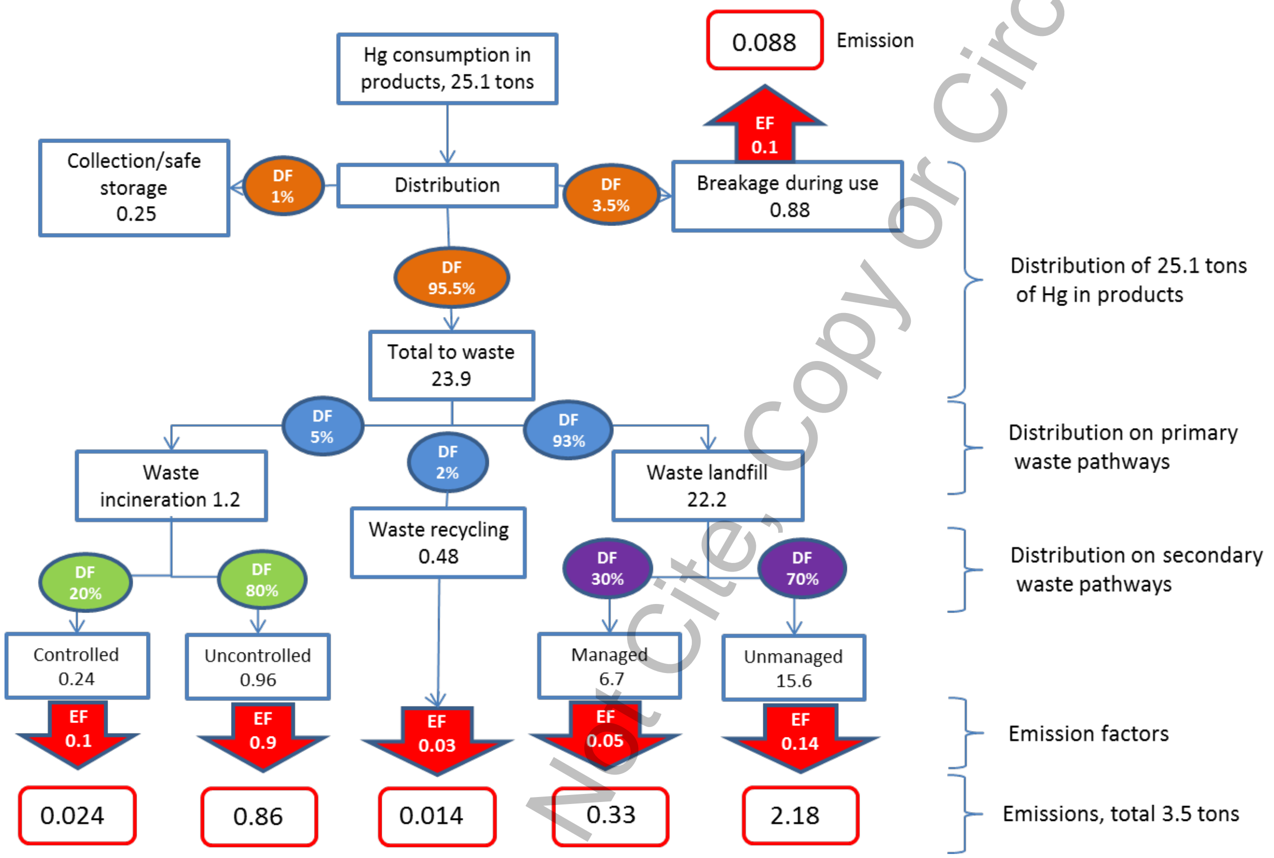
Example calculation

The following example shows the calculation scheme applied to estimate product waste emissions for Mexico. Mexico belongs to the Central America and the Caribbean region, which has an estimated consumption of Hg in intentional use products (batteries, measuring control devices/lighting, electronic devices and other – with dental uses excluded) of 36 tonnes (see Table A3.1). Based on GDP-PPP, 25.1 tonnes of this Hg consumption is attributed to Mexico.

Under the regionalization approach described in Chapter 2.X, Mexico's general waste stream characterization and waste management practices are best described by Profile 3 (see Tables A3.2 to A3.4).

The flow chart Figure A3.2 illustrates how, on this basis, emission estimates to air totaling about 3.5 tonnes are calculated; of which about 0.024 tonnes are estimated to be emitted from controlled waste incineration.

Figure A3.2. Example calculation of mercury emissions from waste streams associated with mercury added products.



Annex 4: Description of method used to estimate 2015 mercury emissions to air from use in dental amalgam and human cremation [To be updated, current description from GMA2013]

Emissions from use of Hg in dental amalgam fillings can occur during the preparation of the amalgams and their subsequent removal and disposal in wastes. They can also occur when human remains with amalgam fillings are cremated. Emissions associated with the latter, that is, cremation sources, were estimated using a similar approach to that employed for estimating emissions associated with other intentional-use sectors. That is to say, Hg consumption in dentistry (see Annex 3, Table A3.1) was combined with assumptions regarding its use and fate. Emissions were calculated based on an emission factor of 0.04 g per g Hg consumption – derived using the UNEP Toolkit default factor of 2.5 g per cremation and an average per capita (dental) consumption based on the European average, which may result in an overestimation of emissions for countries where the average number of amalgams per person will be lower than the European average.

Mercury amounts associated with fillings in cremated human remains were allocated to countries based on regional consumption statistics and population distributions, also taking into account factors such as religious practices and regulations in some countries concerning human cremation.

Owing to information regarding increasing use of air pollution control devices (including activated carbon systems) at crematoria in some countries, emissions from cremation sources in countries in the EU27 region and some countries in Asia (Japan, Republic of Korea, Taiwan) were reduced assuming an abatement of 75% of the emission.

Annex 5: Activity data used in the calculation of emission estimates

Data available in external spreadsheet (Annex5-ActivityData)

A large part of national activity data has been collected from two international sources, the International Energy Agency (IEA) for fuels used, and from United States Geological Survey (USGS) for metals and relevant non-fuel minerals.

Most of the national activity data regarding energy related fuels is collected from the International Energy Agency (IEA) database for the year 2014. For some countries national information is not available in the IEA database, but aggregated in one of three regions; Other Africa, Other Non-OECD Americas or Other Asia. In those cases, the total use of a specific fuel per sector was distributed between the countries in that group by using GDP-PPP as a weighing factor. Solid biomass in the domestic/residential sector was distributed using population data.

Other Africa includes Burkina Faso; Burundi; Cabo Verde; Central African Republic; Chad; Comoros; Djibouti; Equatorial Guinea; Gambia; Guinea; Guinea-Bissau; Lesotho; Liberia; Madagascar; Malawi; Mali; Mauritania; Réunion; Rwanda; Sao Tome and Principe; Seychelles; Sierra Leone; Somalia; Swaziland and Uganda

Other Non-OECD Americas includes Antigua and Barbuda; Aruba; Bahamas; Barbados; Belize; Bermuda; British Virgin Islands; Cayman Islands; Dominica; Falkland Islands (Malvinas); French Guiana; Grenada; Guadeloupe; Guyana; Martinique; Montserrat; St. Kitts and Nevis; Saint Lucia; Saint Pierre et Miquelon; St. Vincent and the Grenadines and Turks and Caicos Islands.

Other Asia includes Afghanistan; Bhutan; Cook Islands; Fiji; French Polynesia; Kiribati; Lao People's Democratic Republic; Maldives; New Caledonia; Palau; Papua New Guinea; Samoa; Solomon Islands; Timor-Leste; Tonga and Vanuatu.

From USGS (https://minerals.usgs.gov/minerals/pubs/commodity/) data on production of metals and minerals is available per country. The latest available information was used, which mostly refers to information for 2013 or 2014.

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

General comments

During compilation of country-specific UEFs, an effort was made to use as much national data as possible.

In many of the literature sources, only abated country-specific EFs were reported, often with no specification on the abatement technologies and their implementation rates. Considering the methodology used in the current inventory, these AEFs were not directly applicable in the calculations. They were, however, used as benchmarks when calculating country-specific UEFs and generic UEFs. Where possible, information relating to abatement technologies was extracted and used in developing technology profiles.

The default technology profiles reflect assumptions based on available national information for countries in the respective groups regarding Hg reduction efficiencies associated with typically employed APCD configurations and their degree of application (including the application of integrated acid plants in the case of copper, lead and zinc smelters). In particular, use was made of available information from European countries, Republic of Korea, Japan and USA (Group 1); Australia and China (for coal burning in power plants) (Group 2); South Africa and China (Group 3); Russia (Group 4); India (Group 5). These profiles represent a starting point for further refinement as additional (national) information becomes available.
This annex provides detailed information for the following sectors:

A6.1 Coal combustion, hard coal (anthracite and bituminous coal)
A6.2 Coal combustion, brown coal (sub-bituminous coal and lignite)
A6.3 Oil combustion
A6.4 Natural gas combustion
A6.5 Biomass combustion
A6.6 Pig iron and steel production
A6.7 Secondary steel production (Electric arc furnace, EAF)
A6.8 Non-ferrous metal production: copper (Cu)
A6.9 Non-ferrous metal production: lead (Pb)
A6.10 Non-ferrous metal production: zinc (Zn)
A6.11 Non-ferrous metal production: mercury (Hg) dedicated production from cinnabar ore
A6.12 Non-ferrous metal production: aluminium (Al) production from bauxite ore
A6.13 Large-scale gold production
A6.14 Cement production
A6.15 Oil refining
A6.16 Chlor-alkali industry
A6.17 Vinyl chloride monomer (VCM) production with Hg catalyst

A 6.1 Coal combustion, hard coal (anthracite and bituminous coal)

Basis for 2015 emission estimates: UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning combustion of hard coal (anthracite and bituminous coals).

Applied UEFs: These are shown in Table A6.1.

Comparative EFs: These are shown in Table A6.2.

Discussion of EFs: The generic default UEFs derived in this work are the result of expert evaluation and are intended to represent a reasonable general default factor, based on consideration of a wide range of literature, including the UNEP Toolkit (UNEP, 2011b and UNEP 2017), Paragraph-29 (UNEP, 2010a) study data, recent UNEP reports on coal combustion in power plants in China, Russia and India, peer-reviewed journal articles and other literature, including country-specific data and national reports.

Basic assumptions during calculations of UEF: For hard coal combustion, the UEFs represent the Hg content of coal; these are generally reported on a dry weight basis.

Applied technology profile: This is shown in Table A6.3.

Discussion of technology profile: In addition to discussions with representatives from different countries, the following references were important sources of information when deriving the technology profiles used in this work: UNEP (2010b: table 1 + table 4; 2011c,d, 2014), Pavlish et al. (2010), Pudasainee et al. (2009b, 2010), BREF (2006), Srivastava et al. (2006), Kim et al. (2010a,b), Nelson et al. (2009), UNEP/CIMFR-CSIR (2012), Wu et al (2016b), Garnham & Langerman (2016), US EPA (NEEDS v.5.15 Database).

Comparison with UNEP Toolkit factors: In UNEP toolkit (UNEP toolkit spreadsheet January 2017) the default UEF has been updated to correspond to the default factor of 0.15 g/t applied in this work.

Comparison with 2005 inventory factors: The default factor applied when calculating emissions in 2005 (0.2 g Hg/t coal) is a global average abated factor. The default factors used in the current inventory are unabated and differentiated by coal type.

Gaps/needs to improve factors and profiles: Information base for assumptions regarding technology profiles.

Table A6.1. Applied unabated emission factors for coal combustion, hard coal (anthracite and bituminous coal).

	Unabated Emission Factor (UEF)				Source	Notes/adjustments to reported data
	Low	Inter-mediate	High	Units		
Generic default factors						
anthracite - PP		0.15		g/t		Expert evaluation of reasonable general default factor based on UNEP Toolkit (UNEP, 2011b), other literature, country-specific data.
bituminous - PP		0.15				
hard coal - IND		0.15				
hard coal - DR		0.15				
Australia						
PP anthracite		0.068		g/t		P. Nelson (pers. comm.)
PP bituminous		0.068		g/t		P. Nelson (pers. comm.)
IND hard coal		0.042		g/t		
DR hard coal		0.068		g/t		
Canada						
PP bituminous		0.070		g/t	Mazzi et al, 2006: figure 1	Average of data in figure 1
China						
PP bituminous		0.17		g/t	Zhang et al 2015, Wang et al 2012	
IND hard coal		0.17		g/t		
DR hard coal		0.19		g/t	UNEP, 2011c; Sloss, 2008	
India						
PP bituminous		0.14		g/t	UNEP/CIMFR-CSIR, 2012, UNEP 2014	Average of coals burned in PPs in India
IND hard coal		0.292		g/t	Mukherjee et al., 2008	
DR hard coal		0.292		g/t		
Japan						
PP bituminous		0.0454		g/t		National information
IND hard coal		0.0454		g/t		National information
DR hard coal		0.0454		g/t		
Republic of Korea						
PP anthracite		0.082		g/t	Kim et al., 2010a: table 3	Table 3
PP bituminous		0.046		g/t	Kim et al., 2010a,b	Mixed coals
IND hard coal		0.069		g/t	Kim et al., 2010a	Average of 0.082 and 0.046
DR hard coal		0.046		g/t	Kim et al., 2010b	Mixed coals
Russian Federation						
PP bituminous		0.063		g/t	UNEP, 2011d	Weighted average Hg content of coals consumed in Russia
IND hard coal		0.1		g/t		
DR hard coal		0.1		g/t		
South Africa						

PP bituminous		0.28		g/t	Garnham and Langerman, 2016	Weighted average
IND hard coal		0.28		g/t		
DR hard coal		0.28		g/t		
USA						
PP bituminous		0.1		g/t	Sloss, 2008	Srivastava et al., 2006

Table A6.2. Comparative emission factors for coal combustion, hard coal (anthracite and bituminous coal).

	Unabated Emission Factor (UEF)				**Source**	**Notes/adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
All coals	0.050	0.15	0.500	g/t	UNEP 2017	UNEP Toolkit default input factor same as this work

	Abated Emission Factor (AEF)				**Source**	**Notes/adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
2005 inventory All coals – power plants		0.2			AMAP/UNEP, 2008	
2005 inventory All coals – residential and commercial boilers		0.3			AMAP/UNEP, 2008	

Table A6.3. Applied technology profile for coal combustion, hard coal (anthracite and bituminous coal).

	Technologies	**Reduction efficiency, %**			**Degree of application (%)**					**Source**
					Country group					
		Low	**Inter-mediate**	**High**	**1**	**2**	**3**	**4**	**5**	
Default: **PP anthracite**	Level 0: None		0							See discussion in Section A6.2
	Level 1: Particulate matter simple APC: ESP/PS/CYC		25		30	65	70	100	100	
	Level 2: Particulate matter (FF)		50		5	30	30			
	Level 3: Efficient APC: PM+SDA/wFGD		65		20					
	Level 4: Very efficient APC: PM+FGD+SCR		70		40	5				
	Level 5: Mercury specific		97		5					
Default: PP bituminous	Level 0: None		0							See discussion in Section A6.2
	Level 1: Particulate matter simple APC: ESP/PS/CYC	15	25	60	30	65	70	100	100	
	Level 2: Particulate matter (FF)	40	50	93	5	30	30			
	Level 3: Efficient APC: PM+SDA/wFGD	35	65	99	20					
	Level 4: Very efficient APC: PM+FGD+SCR	90	90	99	40	5				

	Level 5: Mercury specific	95	97	99	5					
Default: **IND hard coal**	Level 0: None		0				25	50	75	See discussion in Section A6.2
	Level 1: Particulate matter simple APC: ESP/PS/CYC		25		25	25	50	50	25	
	Level 2: Particulate matter (FF)		50		25	50	25			
	Level 3: Efficient APC: PM+SDA/wFGD		50		25	25				
	Level 4: Very efficient APC: PM+FGD+SCR		90		25					
	Level 5: Mercury specific		97							
Default: **DR hard coal**	Level 0: None		0		50	50	100	100	100	See discussion in Section A6.2
	Level 1: Particulate matter simple APC: ESP/PS/CYC		25		50	50				
Country-specific										
Republic of Korea	**PP bituminous**									
	SCR+cESP+wFGD		75		100					National information
	PP anthracite									
	ESP		78		28					National information
	cESP+wFGD		83		38					
	SCR+cESP+wFGD		77		34					
Australia	**PP bituminous**									
	ESP		46.5			75				Nelson et al., 2009, Table 44
	FF		83.1			19				
	ESP/FF		90.0			6				
South Africa	**PP coal not defined**									
	ESP		25.0				67			Garnham and Langerman, 2016 (reduction efficiency generic)
	FF		50.0				24			
	ESP+FF		50.0				9			
Brazil	**PP coal not defined**									
	ESP+PS						100			This work
Mexico	**PP coal not defined**									
	lowNOx						35.6			This work
	modNOx						7.8			
	ESP						5.2			
	SCR						1.7			
India	**PP bituminous**									
	Mostly ESP (some PPs other APC and coal washing)		42						100	Average value presented in UNEP (2014)
Europe (EU28+Norway)	**PP bituminous**									
	FF		40.0		40					BREF, 2006
	ESP/FF+FGD		75.0		30					
	ESP/FF+FGD+high dust		90.0		30					

	SCR									
Sweden	**PP bituminous**									National comments
	Particulate matter (FF)		50		20					
	ESP/FF+FGD+high dust SCR		90		80					
Russian Federation	**PP bituminous**									
	Level 1: Particulate matter simple APC: ESP/PS/CYC		25					43		National information
	Level 2: Particulate matter (FF)		50					53		
	Level 3: Efficient APC: PM+SDA/wFGD		65					4		
	IND bituminous									
	Level 1: Particulate matter simple APC: ESP/PS/CYC		25					100		
China and Hong Kong[a]	**PP all coals**									
	ESP+wFGD		60			13.9				Wu et al 2016b
	FF+wFGD		86			0.2				
	ESP-FF+wFGD		95			1.4				
	SCR+ESP+wFGD		70			63.5				
	SCR+FF+wFGD		88			4				
	SCR+ESP+wFGD+wESP		94			2.5				
	SCR+ESP-FF+wFGD		97			14.6				
	IND all coals									
	WET		23			47				
	IDRD		38			41				
	FF+WFGD		86			11				
	ESP-FF+WFGD		95			1				
USA	**PP bituminous**									
	no control		0		0.1					Derived from NEEDS v.5.15 Database (XLSX) Accessed 2017-03-02
	ESPH		10		1.0					
	ESPC		36		23.0					
	ESPH+WS		42		1.4					
	ESPC+WS+ SNCR (not all)		66		4.0					
	ESPC+B+WS+SNCR		70		2.0					
	ESPC+B		80		1.6					
	B		89		2.3					
	ACI+APC combination		90		58.5					
	APC combinations 1		93		0.8					
	APC combinations 2		95		4.6					
	APC combinations 3		97		0.6					
Japan	**PP bituminous & IND bituminous**									
	APCD		72.9		100					Generic APCD for power plants and industry

[a] China – assigned to Group 2 for coal burning in power stations (in Group 3 for other sectors).

A 6.2 Coal combustion, brown coal (sub-bituminous coal and lignite

Basis for 2015 emission estimates: UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning combustion of brown coal (sub-bituminous coal and lignite).

Applied UEFs: These are shown in Table A6.4.

Comparative EFs: These are shown in Table A6.5.

Discussion of EFs: The generic default UEFs are derived in this work as expert evaluation of a reasonable level of a general default factor, based on a literature survey including UNEP Toolkit (UNEP, 2011b, UNEP 2017) and other literature, including country-specific data.

During compilation of country-specific UEFs, an effort was made to use as much national data as possible. One issue that arose during this work was that some lignite and sub-bituminous coals have very high moisture content (up to 50% in some coals burned in power plants in Australia; P. Nelson pers. comm.). If high moisture content coals are burned (without drying), then there is potential for over-estimating EFs if these are derived from coal Hg content values on a dry weight basis without adjusting for the moisture content.

Basic assumptions during calculations of UEF: For brown coal combustion, the UEFs represent the Hg content of coal as burned.

Applied technology profile: This is shown in Table A6.6.

Discussion of technology profile: In addition to discussions with representatives from different countries, the following references were important sources of information when deriving the technology profiles used in this work: UNEP (2010b: table 1 + table 4, 2011c,d), Pavlish et al. (2010); Pudasainee et al. (2009b, 2010), BREF (2006), Srivastava et al. (2006), Kim et al. (2010a,b), Nelson et al. (2009), UNEP/CIMFR-CSIR (2012), US EPA (NEEDS v.5.15 Database).

Comparison with UNEP Toolkit factors: In UNEP toolkit (UNEP toolkit spreadsheet January 2017) the default UEF has been updated to correspond to the default factors of 0.1 and 0.15 g/t applied in this work.

Comparison with 2005 inventory factors: The default factor applied when calculating emissions in 2005 (0.2 g Hg/t coal) is a global average abated factor. The default factors used in the current inventory are unabated and differentiated by coal type.

Gaps/needs to improve factors and profiles: (1) Information base for assumptions regarding technology profiles. (2) Moisture content of lignite and sub-bituminous coals burned in different countries and the implications of high moisture content for emission factors that are normally derived from coal Hg content expressed on a dry weight basis.

Table A6.4. Applied unabated emission factors for coal combustion, brown coal (sub-bituminous coal and lignite).

	Unabated Emission Factor (UEF)				Source reference	Notes/Adjustments to reported data
	low	Inter-mediate	high	units		
Generic default factor						
sub-bituminous - PP		0.15		g/t		Expert evaluation of reasonable general default factor based on UNEP Toolkit (UNEP, 2011b), other literature, country-specific data. .
lignite - PP		0.10				
brown coal - IND		0.15				
brown coal - DR		0.15				
Australia						
PP lignite		0.032		g/t	P. Nelson (pers. comm.)	UEF takes into account high moisture content of coal
PP sub-bituminous		0.032		g/t	P. Nelson (pers. comm.)	UEF takes into account high moisture content of coal
IND brown coal		0.068		g/t		
DR brown coal		0.032		g/t		
Canada						
PP sub-bituminous/lignite		0.07		g/t	Mazzi et al, 2006: figure 1	Average of data in figure 1
Germany						
PP lignite		0.063		g/t		UEF takes into account high moisture content of coal
Russia						
PP lignite		0.063		g/t	UNEP, 2011d	Weighted average Hg content of coals consumed in Russia
IND brown coal		0.1		g/t	UNEP, 2011d	
DR brown coal		0.1		g/t	UNEP, 2011d	
India						
PP lignite		0.140		g/t	UNEP.CIMFR-CSIR, 2012	Average of Indian coals burned in PPs
IND brown coal		0.292		g/t	Mukherjee et al., 2008	
Mexico						
PP sub-bituminous		0.293		g/t	This work	Non-washed coal, P. Maíz, 2008.
IND brown coal		0.293		g/t		
USA						
PP sub-bituminous		0.055		g/t	UNEP, 2010a; This work (A. Kolker, pers. comm.)	UEF takes into account high moisture content of coal

Table A6.5. Comparative emission factors for coal combustion, brown coal (sub-bituminous coal and lignite).

	Unabated Emission Factor (UEF)				**Source reference**	**Notes/Adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
Sub-bituminous/lignite	0.050	0.15/0.1	0.500	g/t	UNEP, 2017	UNEP Toolkit default input factor same as this work

	Abated Emission Factor (AEF)				**Source reference**	**Notes/Adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
2005 inventory All coals – power plants		0.2			AMAP/UNEP, 2008	
2005 inventory All coals – residential and commercial boilers		0.3			AMAP/UNEP, 2008	

Table A6.6. Applied technology profile for coal combustion, brown coal (sub-bituminous coal and lignite).

	Technologies	**Reduction efficiency (%)**			**Degree of application (%)**					**Ref.**
					Country group					
		low	**Inter-mediate**	**high**	**1**	**2**	**3**	**4**	**5**	
Default: PP sub-bituminous	Level 0: None		0.0							See discussion in Section A6.3
	Level 1: Particulate matter simple APC: ESP/PS/CYC	0.0	10.0	25.0	30	65	70	100	100	
	Level 2: Particulate matter (FF)	20.0	50.0	85.0	5	30	30			
	Level 3: Efficient APC: PM+SDA/wFGD	0.0	40.0	75.0	20					
	Level 4: Very efficient APC: PM+FGD+SCR	0.0	25.0	47.0	40	5				
	Level 5: Mercury specific	50.0	75.0	95.0	5					
Default: PP lignite	Level 0: None		0.0							See discussion in Section A6.3
	Level 1: Particulate matter simple APC: ESP/PS/CYC	0.0	2.0	10.0	30	65	70	100	100	
	Level 2: Particulate matter (FF)	0.0	5.0	10.0	5	30	30			
	Level 3: Efficient APC: PM+SDA/wFGD	0.0	20.0	55.0	20					
	Level 4: Very efficient APC: PM+FGD+SCR	0.0	20.0	96.0	40	5				
	Level 5: Mercury specific	50.0	75.0	95.0	5					
Default: IND brown coal	Level 0: None		0.0				25	50	75	See discussion in Section A6.3
	Level 1: Particulate matter simple APC: ESP/PS/CYC		5.0		25	25	50	50	25	
	Level 2: Particulate		50.0		25	50	25			

	matter (FF)									
	Level 3: Efficient APC: PM+SDA/wFGD		30.0		25	25				
	Level 4: Very efficient APC: PM+FGD+SCR		20.0		25					
	Level 5: Mercury specific		75.0							
Default: DR brown coal	Level 0: None		0.0		50	50	100	100	100	See discussion in Section A6.3
	Level 1: Particulate matter simple APC: ESP/PS/CYC		5.0		50	50				
Country-specific										
Australia	**PP sub-bituminous**									
	ESP		46.5			100				Nelson et al., 2009: table 43
Russian Federation	**PP sub-bituminous**									
	Level 1: Particulate matter simple APC: ESP/PS/CYC		10					43		National information
	Level 2: Particulate matter (FF)		50					53		
	Level 3: Efficient APC: PM+SDA/wFGD		40					4		
	IND sub-bituminous									
	Level 1: Particulate matter simple APC: ESP/PS/CYC		5					100		
USA	**PP sub-bituminous**									
	no control		0		0.04					Derived from NEEDS v.5.15 Database (XLSX) Accessed 2017-03-02
	ESPC		3		21					
	ESPH		6		0.1					
	ESPC+WS+SCR		16		19					
	ESPH+WS		20		2					
	ESPC+B		25		6.5					
	ESPC+		35		0.1					
	B+SNCR		57		0.1					
	ESPC+B+WS		70		0.6					
	B		73		16					
	ACI+APC		90		34					
	PP lignite									
	no control		0		15					
	ESPC+C		38		0.4					
	ESPC WS		44		41					
	B		57		2.5					
	ACI+APC comb		90		41					

A 6.3 Oil combustion

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning combustion of crude oil, heavy fuel oil and light fuel oil.

Applied UEFs. These are shown in Table A6.7.

Comparative EFs. These are shown in Table A6.8.

Discussion of EFs.

Basic assumptions during calculations of UEF. Default UEFs used in this work were based on the lower range default input factors employed in the UNEP Toolkit (UNEP, 2011b), using twice these values. This choice was based on comparison of the UNEP Toolkit defaults and available information on Hg content of crude and refined oil.

Applied technology profile. This is shown in Table A6.9.

Discussion of technology profile. It was assumed that only major point sources in Group 1–3 countries will employ APCDs that reduce Hg emissions from oil combustion, and the reported effectiveness of such devices for reducing Hg emissions from oil combustion is generally low. For sources other than power plants and industrial facilities it was assumed that no emission abatement is applied.

Comparison with UNEP Toolkit factors. The UNEP Toolkit default input factors of 0.055 g/t for crude and heavy fuel oil and 0.006 g/t for light fuel oil are somewhat higher than the values selected for use in this work, which were based on the lower range UNEP default factors.

Comparison with 2005 inventory factors. An abated EF of 0.001 g/t was applied in the 2005 inventory calculations, comparable to that for light fuel oil burning in the 2010 inventory, but relatively low compared with the UEFs applied to crude oil and heavy fuel oil combustion in 2010.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.7. Unabated emission factors (EFs) applied for oil combustion.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factors						
crude oil - PP		0.01		g/t	UNEP, 2011b	Twice the UNEP Toolkit default minimum value, see discussion.
heavy fuel oil - PP		0.02				
light fuel oil - PP		0.002				
crude oil - IND		0.01				
heavy fuel oil - IND		0.02				
light fuel oil - IND		0.002				
crude oil - DR		0.01				
heavy fuel oil -DR		0.02				
light fuel oil - DR		0.002				
Republic of Korea						
PP crude oil		0.027		g/t	Kim et al., 2010a	

Table A6.8. Comparative emission factors (EFs) for oil combustion.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
Crude oil	0.005	0.055	0.300	g/t	UNEP, 2011b	
Heavy fuel oil	0.010	0.055	0.100		UNEP, 2011b	
Light fuel oil	0.001	0.006	0.010		UNEP, 2011b	
Abated EF						
2005 inventory		0.001			AMAP/UNEP, 2008	

Table A6.9. Technology profile applied for oil combustion.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
PP crude oil									
Level 0: None		0.0				50	100	100	
Level 1: PM+FGD (cESP, scrubbers+FGD)		50.0		100	100	50			
PP heavy fuel oil									
Level 0: None		0.0				50	100	100	
Level 1: PM+FGD (cESP, scrubbers+FGD)		50.0		100	100	50			
PP light fuel oil									
Level 0: None		0.0		50	50	50	100	100	
Level 1: PM+FGD (cESP, scrubbers+FGD)		50.0		50	50	50			
IND crude oil									
Level 0: None		0.0		50	50	50	100	100	
Level 1: PM (cESP, scrubbers)		10.0		50	50	50			
IND heavy fuel oil									
Level 0: None		0.0		50	50	50	100	100	
Level 1: PM (cESP, scrubbers)		10.0		50	50	50			
IND light fuel oil									
Level 0: None		0.0		50	50	50	100	100	
Level 1: PM (cESP, scrubbers)		10.0		50	50	50			
DR crude oil									
Level 0: None		0.0		100	100	100	100	100	
DR heavy fuel oil									
Level 0: None		0.0		100	100	100	100	100	
DR light fuel oil									
Level 0: None		0.0		100	100	100	100	100	

A 6.4 Natural gas combustion

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning combustion of natural gas (activity data in TJ, gross calorific value).

Applied UEFs. These are shown in Table A6.10.

Comparative EFs. These are shown in Table A6.11.

Discussion of EFs.

Basic assumptions during calculations of UEF. Calorific values of natural gas vary (e.g., North Sea natural gas 39 MJ per m^3 (NPL, 2012); generic value 43 MJ per m^3 (Engineering Toolbox, 2012)); a value of 40 MJ per m^3 has been assumed for purposes of developing a UEF in this work. The UNEP Toolkit emission factors (0.2 and 100 µg/m^3, for pipeline and raw/untreated gas respectively) used as a basis for suggested generic UEF values are derived based on analysis of Hg concentrations in natural gas. Emissions estimates assume combustion of pipeline/consumer gas (with low Hg content); if raw/untreated gas is burned at installations the emissions would be considerably higher (by a factor of 500).

Applied technology profile. This is shown in Table A6.12.

Discussion of technology profile. It was assumed that APCDs are either absent at sites where natural gas is burned, or are inefficient at reducing Hg emissions to air from this source.

Comparison with UNEP Toolkit factors. The UNEP Toolkit (UNEP, 2011b) input factors are used as the basis for the UEFs. The Toolkit document indicates use of a conversion factor of 26 Nm^3/TJ for converting between natural gas volume and calorific value; the correct factor based on the current work would be 25 000 Nm^3/TJ.

Comparison with 2005 inventory factors. Emissions from natural gas combustion were not included in the 2005 inventory.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles and type of gas burned.

Table A6.10. Unabated emission factors (UEFs) applied for natural gas combustion.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor		0.005		g/TJ	UNEP, 2011b	Pipeline/consumer quality gas; UEF g/TJ based on UNEP (2011b) value of 0.2 µg/m^3
Generic default factor		2.5				Raw/pre-cleaned gas; UEF g/TJ based on UNEP (2011b) value of 100 µg/m^3

Table A6.11. Comparative emission factors (EFs) for natural gas combustion.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
Natural gas		0.2		µg/m^3	UNEP, 2011b	Pipeline/consumer quality gas; DF = 1
		100				Raw/pre-cleaned gas; DF = 1

Table A6.12. Technology profile applied for natural gas combustion.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									

None		0.0		100	100	100	100	100	

A 6.5 Biomass combustion

Basis for 2015 emission estimates: UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning combustion of primary solid biomass (IEA, 2016).

Applied UEFs: These are shown in Table A6.13.

Comparative EFs: These are shown in Table A6.14.

Discussion of EFs: The generic default UEFs are derived in this work as expert evaluation of a reasonable level of a general default factor, based on a literature survey including UNEP Toolkit (UNEP 2017) and other general or country specific literature, e.g. Huang et al 2011, Zhang et al 2013, Obrist et al 2011, Kindbom and Munthe 1998, Pirrone et al 2010, Friedli et al 2009, and literature cited in those papers.

Basic assumptions during calculations of UEF: For biomass combustion, the UEFs represent the Hg content of biomass as burned. A conversion of data on Hg content in biomass in mg/t to mg/GJ was made using a heating the value of 16 MJ/kg for air dried wood, moisture content 10-20% (IEA Energy Statistics manual, OECD/IEA, 2005).

Applied technology profile: This is shown in Table A6.15.

Discussion of technology profile: The removal efficiencies of abatement technologies were adopted from combustion of brown coal. The application rates of air pollutant abatement technologies for the technology groups were developed based on very limited national information and complemented with assumptions.

Comparison with UNEP Toolkit factors: In UNEP toolkit (UNEP toolkit spreadsheet January 2017) the default UEF is 0.03 (0.007-0.07) g Hg/t (dry weight), which corresponds to 1.67 mg/GJ (using a heating value of 18 MJ/kg for oven dried wood (IEA Energy Statistics manual, OECD/IEA, 2005). All of the mercury in biomass is assumed to be emitted to air (output distribution factor = 1).

Gaps/needs to improve factors and profiles: Technology profiles and removal efficiencies. National data on Hg content in biomass.

Table A6.13. Applied unabated emission factors for biomass combustion.

	Unabated Emission Factor (UEF)				Source reference	Notes/Adjustments to reported data
	low	Inter-mediate	high	units		
Generic default factor						
Biomass*		1.25		mg/GJ		Expert evaluation of reasonable general default factor based on UNEP Toolkit (UNEP, 2017) and other literature. .
Biomass	5	20	50	mg/t	For comparison of units	

*conversion using heating value of 16 MJ/kg (air dried wood, moisture content 10-20%) (IEA Energy Statistics manual, OECD/IEA, 2005)

Table A6.14. Comparative emission factors for biomass combustion.

	Unabated Emission Factor (UEF)				**Source reference**	**Notes/Adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
Biomass	7	30	70	mg/t (dry weight)	UNEP, 2017	UNEP Toolkit default input factor

Table A6.15. Applied technology profile for biomass combustion.

	Technologies	Reduction efficiency (%)			Degree of application (%) Country group					Ref.
		low	Inter-mediate	high	1	2	3	4	5	
Default: PP biomass	Level 0: None		0		15	30	60	100	100	Table A6.6 sub-bituminous coal removal efficiencies assumed
	Level 1: Particulate matter simple APC: ESP/PS/CYC	0	10	25	60	50	30			
	Level 2: Particulate matter (FF)	20	50	85	20	20	10			
	Level 3: Efficient APC: PM+SDA/wFGD	0	40	75	5					
Default: IND biomass	Level 0: None		0				25	50	75	Table A6.6 sub-bituminous coal removal efficiencies assumed
	Level 1: Particulate matter simple APC: ESP/PS/CYC		5		25	25	50	50	25	
	Level 2: Particulate matter (FF)		50		25	50	25			
	Level 3: Efficient APC: PM+SDA/wFGD		30		25	25				
	Level 4: Very efficient APC: PM+FGD+SCR		20		25					
Default: DR biomass	Level 0: None		0		50	50	100	100	100	Table A6.6, sub-bituminous coal removal efficiencies assumed
	Level 1: Particulate matter simple APC: ESP/PS/CYC		5		50	50				

A 6.6 Pig iron and steel production

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary production of pig iron. Note: Emission estimates associated with secondary steel production are accounted for separately.

Applied UEFs. These are shown in Table A6.16.

Comparative EFs. These are shown in Table A6.17.

Discussion of EFs. During compilation of country-specific UEFs, an effort was made to use as much national data as possible. Most countries do not have complete mass balances but national data on material consumption and/or Hg content was used instead of generic values wherever possible.

The following literature sources were studied: UNEP (2017), BREF IS (2013), National information (provided by China, Republic of Korea, Japan and USA); Fukuda et al. (2011), Chakraborty 2013, Won 2012, Wang 2014, Zhang 2015, Wang 2016, Hui 2016, Mlakar 2010, Kim et al. (2010a), COWI, SSAB 2015, LKAB 2015.

Basic assumptions during calculations of UEF.

- Production processes included are coke oven, pellet plant, sinter plant, blast furnace and basic oxygen steelmaking.
- Materials included in the UEF are iron ore, lime/limestone and dolomite. Fuels – both combusted and injected in the process as reduction agents – are excluded.
- Import/export of sinter, pellets and fuels is not considered.
- Hg content of products (pig iron, steel) is zero, almost all Hg is volatised during thermal processes, especially sintering and pelletizing.
- Recycling of filter materials on-site is not considered for UEF since recycling is only possible if abatement is present.
- Energy re-use (further combustion of off-gases) is not considered.

Fuel and raw material consumption per 1 t of pig iron, according to the BREF-based mass balance:

- Iron ore: 0.09–2.97 t, intermediate value – 1.42 t (BREF IS, 2013; SSAB 2015)
- Limestone/lime: 0.04–0.40 t, intermediate value – 0.23 t (BREF IS, 2013; SSAB 2015)
- Dolomite: 0–0.05 t, intermediate value – 0.02 t (BREF IS, 2013; SSAB 2015)

Range of *Hg content of materials*:

- Iron ore: 0.001–0.097 g/t, intermediate value – 0.04 g/t (UNEP, 2017; Fukuda et al., 2011, Chakraborty 2013, Wang 2016, Hui 2016, and national information provided by Republic of Korea)
- Limestone/lime: 0.001–0.39 g/t, intermediate value – 0.04 g/t (UNEP, 2017; Fukuda et al., 2011, Mlakar 2010, Won 2012, Chakraborty 2013, Wang 2014, Zhang 2015, Wang 2016, and national information provided by Republic of Korea, Japan and China)
- Dolomite: 0.04–0.07 g/t, intermediate value – 0.06 g/t (Wang 2016)

The ratio hot metal / liquid steel is 0.74–0.98 t/t, intermediate value – 0.94 t/t (BREF IS, 2013; Fukuda et al., 2011; SSAB 2015).

For all UEFs, *distribution factor* = 1. Other pathways (sector-specific treatment/disposal) are assumed to refer to treatment of residues from abatement equipment (UNEP, 2017).

Applied technology profile. This is shown in Table A6.18.

Discussion of technology profile. Steel-making facilities are usually complex systems including several processes at different sites, all of which are usually equipped with separate APCDs. In the technology profiles in Table A6.18 APCDs installed at sinter plants are mainly considered because, according to the available information (UNEP, 2017, country inventories, reports, etc.), their input into Hg emissions is the most significant.

The following literature sources were studied: UNEP (2015), UNEP (2017), BREF IS (2013), Fukuda et al. (2011), Nelson et al. (2009), and national information provided by Brazil, China, Republic of Korea and Mexico.

Comparison with UNEP Toolkit factors. The default UEF used in this inventory (0.063 g Hg/t pig iron production) is ~26% higher than the UNEP Toolkit default factor (0.05 g Hg/t pig iron production).

Potential for double counting. Generic EFs for primary pig iron production compiled by the Swedish Environmental Institute (IVL) based on BREF mass-balance exclu de use of fuels: oil, gas, coke (produced from coal) and coal (added as pulverised coal and used for coke production). Emissions from these fuels are accounted in the sector Stationary combustion of coal and oil in industry of this inventory, so there should be no double counting.

Country-specific emission factors are derived using the same principle.

Comparison with 2010 inventory factors. The default emission factor used in the current inventory (0.063 g Hg/t pig iron production) is 26% higher than the default emission factor applied when calculating emissions in 2010 (0.05 g Hg/t steel production – same as in the UNEP Toolkit). Hg contents of iron ore and limestone have been revised based on the latest available data in the literature; the intermediate values are now higher than those used in 2010. In addition, the current emission factor takes into account basic oxygen steelmaking, which was not considered in the 2010 inventory. It also includes the use of dolomite in the production process excluded in 2010.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.16. Unabated emission factors (UEFs) applied for pig iron and steel production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	0.0001	0.063	0.450	g/t (primary) pig-iron production		Expert evaluation based on UNEP (2017), BREF IS (2013) and country-specific data.
Australia	0.003	0.054	0.253		BREF IS (2013); UNEP (2017), Fukuda et al., 2011	National data: 0.031 g Hg/t iron ore
Belarus	0.0002	0.074	0.360		BREF IS (2013); UNEP (2017)	National data: 0.088 g Hg/t limestone
Brazil	0.003	0.054	0.253		BREF IS (2013); UNEP (2017), Fukuda et al., 2011	National data: 0.031 g Hg/t iron ore
Canada	0.0001	0.058	0.450		BREF IS (2013); UNEP (2017)	National data: 0.017 g Hg/t limestone/lime
China	0.002	0.074	0.586		BREF IS (2013); Wang 2016 ; Zhang 2015	National data: 0.045 g Hg/t iron ore, 0.042 g Hg/t limestone, 0.056 g Hg/t dolomite
Chile	0.050	0.525	1.000		COWI	National data: total Hg input 0.05–1 g Hg/t pig iron
Denmark	0.0004	0.056	0.296		BREF IS (2013); UNEP (2017)	National data: 0.01 g Hg/t limestone/lime
Germany	0.0002	0.061	0.344		BREF IS (2013); UNEP (2017)	National data: 0.03 g Hg/t limestone/lime
India	0.004	0.073	0.187		BREF IS (2013); UNEP (2017), Chakraborty 2013	National data: 0.065 g Hg/t limestone/lime, 0.04 g Hg/t iron ore
Japan	0.052	0.055	0.113		Fukuda et al. (2011)	National data: 0.02 g Hg/t limestone/lime, 0.031 g Hg/t iron ore; 0.29 t limestone/t pig iron; 1.59 t iron ore /t pig iron

Republic of Korea	0.028	0.029	0.030		Kim et al., 2010a	UEFs reported in Kim et al, 2010a
Russia	0.008	0.098	0.202		BREF IS (2013); UNEP (2017)	National data: 0.06 g Hg/t iron ore; 0.05 g Hg/t limestone.
Slovenia	0.0003	0.055	0.295		BREF IS (2013); UNEP (2017), Mlakar 2010	National data: 0.008 g Hg/t limestone/lime
Sweden	0.001	0.048	0.146		UNEP (2017), SSAB 2015, LKAB 2015	National data: 0.03 t limestone/t pig iron; 1.23 t iron ore /t pig iron; 0.02 t dolomite /t pig iron
Switzerland	0.001	0.059	0.304		BREF IS (2013); UNEP (2017)	National data: 0.025 g Hg/t limestone/lime
USA	0.0001	0.034	0.257		BREF IS (2013); UNEP (2017), national information	National data: 0.016 g Hg/t iron ore, 0.045 g Hg/t limestone/lime

Table A6.17. Comparative emission factors (EFs) for pig iron and steel production.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air		0.05		g/t (primary) pig-iron production	UNEP, 2015	Default input factor 0.05 g/t; DF =1 if no abatement assumed. Fuels are excluded.
2010 inventory		0.05		g/t (primary) pig-iron production	UNEP, 2013	Default input factor 0.05 g/t; DF =1. Fuels are excluded.
EMEP/EEA	0.02	0.1	0.5	g/t (primary) steel production	EMEP/EEA, 2016	Numbers in g/t steel adjusted with the ratio 0.74–0.98 t pig iron/ t steel
	0.020	0.106	0.676	g/t (primary) pig-iron production		
	0.016	0.049	0.15	g/ t sinter		Numbers in g/t sinter adjusted with the ratio 0.116–1.621 t sinter/t pig iron (BREF)
	0.002	0.053	0.24	g/t (primary) pig-iron production		
Abated EF						
UNEP Toolkit abated input to air		0.048		g/t (primary) pig-iron production	UNEP, 2015	Default input factor 0.05 g/t; DF =0.95 assuming abatement (wet scrubber or similar)
EEA/EMEP	0.012	0.018	0.036	g/ t sinter	EMEP/EEA, 2016	Wet gas desulphurisation
	0.006	0.009	0.018			Dry ESP
	0.004	0.006	0.012			ACI + FF
	0.001	0.020	0.058	g/t (primary) pig-iron production		Numbers in g/t sinter adjusted with the ratio 0.116–1.621 t sinter/t pig iron (BREF). Same abatement implied.
	0.0007	0.010	0.029			
	0.0005	0.007	0.019			

Table A6.18. Technology profile applied for pig iron and steel production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
Level 0: None		0					20	100	BREF IS, 2013; UNEP, 2015; Fukuda et al., 2011
Level 1: Basic APC: WS(+FF) (sinter plant)		5			20	50	80		
Level 2: Standard APC: ESP/CYC/FGD (sinter plant)		20		30	80	50			
Level 3: Efficient APC:	40	55	75	60					

ESP+FGD/ACT/ESP+ACT (sinter plant)									
Level 4: Very efficient APC: ESP+ACT/RAC (sinter plant)	95	97	99	10					
COUNTRY-SPECIFIC PROFILES									
Australia									
Sinter plant: Regenerative activated carbon process + Pelletising plant: AIRFINE = ESP/CYC + quench. scrubber + fine WS	95	97	99		100				BREF IS, 2013; Nelson et al., 2009
Brazil									
Level 1		5				33			National information
Level 2		20				67			
China									
WS		5				5			National information
ESP + FF		20				85			
ESP + FGD		55				10			
Republic of Korea									
ESP+SCR+FGD		50		100					National information
Japan									
Sinter plant ESP + Blast furnace FF/ESP		26		30					Fukuda et al., 2011
Sinter plant ESP+FGD + Blast furnace FF/ESP		47		30					
Sinter plant ESP+ACT + Blast furnace FF/ESP		75		40					
Mexico									
Direct Flame Afterburner with Heat Exchanger / ESP / Wet cyclonic separator/ Gravity collector; venturi scrubbers; cyclones; mat or panel filter		20				51			National information
FF		5				30			
None		0				19			

A 6.7 Secondary steel production

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning secondary steel production with Electric Arc Furnace (World Steel Association, 2015).

Applied UEFs. These are shown in Table A6.19.

Comparative EFs. These are shown in Table A6.20.

Discussion of EFs. During compilation of country-specific UEFs, an effort was made to use as much national information as possible. National information was used instead of generic values wherever possible.

The following literature sources were studied: Wang 2016b, Roseborough et al 2008, Burger Chakrabortry 2013, Ocio et al 2012, Kim et al 2010, BREF_IS, table 8.1.

Basic assumptions during calculations of UEF. The national literature emission factors are given as abated emission factors. These were transformed into UEFs assuming reduction efficiencies according to the technology profile.

Applied technology profile. This is shown in Table A6.21.

Discussion of technology profile. A technology profile was developed based on UNEP 2017 and national information in Kim et al 2010 and Roseborough et al 2008.

The following literature sources were studied: Kim et al 2010, Roseborough et al 2008

Comparison with UNEP Toolkit factors. The default UEF used in this inventory (0.032 g Hg/t EAF steel produced) is not directly comparable to the UNEP Toolkit default factor, which is based on the number of recycled vehicles (0.2-2 g Hg/vehicle).

Potential for double counting. No potential for double counting.

Comparison with 2010 inventory factors. Secondary steel production was not included in the 2010 inventory

Gaps/needs to improve factors and profiles. Information base for assumptions regarding emission factors and technology profiles.

Table A6.19. Unabated emission factors (UEFs) applied for secondary steel production in Electric Arc Furnace (EAF).

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	0.002	0.032	0.200	g/t secondary steel produced (EAF)		Expert evaluation based on BREF_IS, table 8.1 and country-specific data.
China		0.026			Wang et al 2016b	Abated EF from source is 0.021
Republic of Korea		0.019			Kim et al 2010	Abated EF from source is 0.009
Turkey		0.017			Ocio et al 2012	Abated EF from source is 0.014

Table A6.20. Comparative emission factors (EFs) for secondary steel production.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
UNEP Toolkit-based unabated	0.2		2	g/vehicle	UNEP,	Unit for EF not comparable.

input to air					2015	

Table A6.21. Technology profile applied for secondary steel production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILES									
Level 0: None		0					25	50	Kim et al 2010, Roseborough et al 2008
Level 1: Particulate matter (ESP/PS/CYC)		10		20	20	50	75	50	
Level 2: Particulate matter (FF)		30		80	80	50			
Level 3: Particulate matter plus other abatement		50							
Level 4: Advanced abatement		80							

A 6.8 Non-ferrous metal production: copper (Cu)

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary copper production (and in some cases total copper production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.22.

Comparative EFs. These are shown in Table A6.23.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2017), BREF NF (2009), BREF NF (2014), EMEP/EEA (2016), Hylander and Herbert (2008), OUTOTEC, Boliden 2015, Kribek 2010, Kumari 2011, Wu 2012, Wu 2016, Zhang 2012, Hui 2016, AUST Cu, Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF.

- Initial oxidation stage (roasting or sintering of concentrate) is considered to be major source of Hg emissions.
- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes.
- Fuels can be a source of minor Hg inputs (UNEP, 2017) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in the UNEP Toolkit (UNEP, 2017) is therefore the same as Hg content of Cu concentrate.
- An integrated acid plant is considered as a part of applied technology profile, see discussion of technology profile.

Metal contents, recovery rates, concentrate/metal ratios:

- Copper content of concentrates: 15–51%, intermediate value 28% (UNEP, 2017; BREF NF 2014; EMEP/EEA, 2016, Boliden 2015, Kribek 2010, OUTOTEC);
- Mercury content of concentrates: 1–100 g/t, intermediate value 26 g/t (Hylander and Herbert 2008, UNEP 2017, Boliden 2015, Kribek 2010, Kumari 2011, Wu 2012, Wu 2016, Zhang 2012);
- Rate of copper recovery from concentrates: 85-97 %, intermediate value 93% (UNEP, 2017, Boliden 2015);
- Concentrate/copper ratios: 2.0-7.8, intermediate value 3.8 (BREF NF 2009, OUTOTEC, Zhang 2012, Boliden 2015).

For all UEFs, **distribution factor** = 0.96. 4% of the total Hg input is assumed to be bound in smelting slag (Hui 2016). Other pathways are assumed to refer to treatment of residues from abatement equipment (UNEP 2017; Maag, pers. comm.).

Applied technology profile. This is shown in Table A6.24.

Discussion of technology profile. Particular attention should be given to the comments in table note ‘b’. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 98% plus 90% of the remaining 2% = effective 99.8% reduction.

The following literature sources were studied: UNEP (2015), UNEP (2017), BREF NF (2009), Hylander and Herbert (2008), Kim et al. (2010a), Li et al. (2010), Wu 2016, national information provided by South Africa, Botswana, Namibia, Zambia, Australia, and Republic of Korea; Maag, pers. comm.; Wang, pers. comm., Euripidou, pers. comm., BAT/BEP 2017 NFM, Boliden 2015

Comparison with UNEP Toolkit factors. The default factor used (96.0 g/t Cu produced) is 11% lower than the default factor in the UNEP Toolkit (107.5 g/t Cu produced).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in ores, metal concentrates and reject materials. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2010 inventory factors. The default unabated EF applied in calculations for 2010 (107 g Hg/t Cu produced) is higher than the default unabated EF used in the current inventory (96 g/t Cu produced). This is due to the updates in mercury content of the concentrates and distribution factor (both are lower in this inventory than in calculations for 2010), based on the latest available national data as well as information in the literature.

Acid plants decrease Hg emissions significantly, and they are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 96 g/t would correspond to an abated EF of around 1–10 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.22. Unabated emission factors (UEFs) applied for non-ferrous metal production: copper.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	1.9	96.1	748	g/t Cu produced (primary production)	UNEP, 2017; OUTOTEC; BREF, 2009; Hylander and Herbert (2008), country-specific data	Expert evaluation; intermediate based on 26 g/t in concentrate (low/high based on 1 and 100 g/t in concentrate, respectively)
Australia	2.0	71.6	449		BREF, 2009; Hylander and Herbert (2008), AUST Cu	National data: 38% copper in concentrate
Canada	4.5	8.5	17.2		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 2.3 Hg/ t concentrate
China	6.4	16.1	245		Zhang 2012, Wu 2012, Wu 2016	National data: 3.7 Hg/ t concentrate, concentrate/copper ratio of 4.6
India	4.5	8.5	17.2		BREF, 2009; Kumari 2011, OUTOTEC	National data: 2.3 Hg/ t concentrate
Sweden	4.5	116.8	449		Boliden 2015, UNEP, 2017,	National data: 24% copper in concentrate, 91% recovery rate, concentrate/copper ratio of 4.7
Zambia	4.5	5.2	6.2		BREF, 2009; Kribek 2010	National data: 1.13 g Hg/ t concentrate, 23% copper in concentrate

Table A6.23. Comparative emission factors (EFs) for non-ferrous metal production: copper.

	Emission Factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air	1	30	300	g/t concentrate used	UNEP, 2017	Default input factor (Hg content of concentrate) 1–100 g/t; DF=1.
	2.1	107.5	716.8	g/t Cu produced	UNEP, 2017	Default input factor (Hg content of concentrate) 1–100 g/t; DF=1
2010 inventory	2	107	717	g/t Cu produced	AMAP/UNEP, 2013	Default input factor (Hg content of concentrate) 1-100 g/t; concentrate/Cu ratio 2.8-3.3; DF=1.
Abated EF						
EMEP/EEA	0.021	0.031	0.052	g/t Cu produced	EMEP/EEA, 2016	Abatement not specified
UNEP Toolkit abated input to air	1.9	96.8	645.1	g/t Cu produced	UNEP, 2017	Default input factor 2.1-716.8 g/t. No filters or only coarse, dry PM retention. DF = 0.9
	1.0	52.7	351.2	g/t Cu produced	UNEP, 2017	Default input factor 2.1-716.8 g/t. Wet gas cleaning. DF = 0.49
	0.2	10.8	71.7	g/t Cu produced	UNEP, 2017	Default input factor 2.1-716.8 g/t. Wet gas cleaning and acid plant. DF = 0.1
	0.04	2.2	14.3	g/t Cu produced	UNEP, 2017	Default input factor 2.1-716.8 g/t. Wet gas cleaning, acid plant and Hg specific filter. DF = 0.02

Table A6.24. Technology profile applied for non-ferrous metal production: copper.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	UNEP, 2015; BREF NF 2009; Hylander and Herbert , 2008; Kim et al., 2010a; Li et al., 2010
DEFAULT PROFILES									
Level 0: None or simple particle filters		0				2.5	5	10	
Level 1: Simple APC: particle control only		10							
Level 2: Basic APC: particle control + WGC [a]		50				2.5	5		
Level 3: Efficient APC: particle control + WGC + AP [b]		95			20	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX [c] + AP		99.8		100	80				
COUNTRY-SPECIFIC PROFILES									
Australia									
Level 4		99.8			100				National information
China									
None		0				0.3			Wu 2016, Wang, pers. comm.
DC		12				0.4			
DC+FGS		41				0.3			

DC+FGS+ESD+SCSA		87				1.6			
DC+FGS+ESD+DCDA		97				48.3			
DC+FGS+ESD+DCDA+DFGD		98.5				49.1			
Republic of Korea									
ESP-Venturi Scrubber-ESP-Boliden Norzink-DCDA		99.9		100					Kim et al., 2010a and national information
Sweden									
ESP + scrubber + Boliden/Norzink + DCDA		99.7		100					BAT/BEP 2017 NFM, Boliden 2015
Botswana									
Simple APC – particle control only		10					100		Euripidou, pers. comm
Namibia, South Africa									
Level 1: Simple APC: particle control only		10				15			Euripidou, pers. comm
Level 2: Basic APC: particle control + WGC [a]		50				25			
Level 3: Efficient APC: particle control + WGC + AP [b]		95				60			
Zambia									
Level 1: Simple APC: particle control only		10					15		Euripidou, pers. comm
Level 2: Basic APC: particle control + WGC [a]		50					25		
Level 3: Efficient APC: particle control + WGC + AP [b]		95					60		

[a] Particle control = cyclones and ESP, WGC = Wet gas cleaning; [b] integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; [c] Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 98%.

A 6.9 Non-ferrous metal production: lead (Pb)

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary lead production (and in some cases total lead production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.25.

Comparative EFs. These are shown in Table A6.26.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2017), BREF NF (2009), BREF NF (2014), EMEP/EEA (2016), Hylander and Herbert (2008), Kumari (2011), COWI, OUTOTEC, national information provided by Brazil; Kumari 2011, Wu 2012, Wu 2016, Zhang 2012, Hui 2016, Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF:

- Initial oxidation stage (roasting or sintering of concentrate) is considered to be major source of Hg emissions.
- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes.
- Fuels can be a source of minor Hg inputs (UNEP, 2017) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in UNEP Toolkit (UNEP, 2017) is therefore the same as Hg content of Pb concentrate.
- An integrated acid plant is considered as a part of applied technology profile, see discussion of technology profile.

Metal contents, recovery rates, concentrate/metal ratios:

- Lead content of concentrates: 35–90%, intermediate value 50% (BREF NF 2009)
- Mercury content of concentrates: 2–62.2 g/t, intermediate value 30 g/t (Hylander and Herbert 2008, UNEP 2017, Kumari 2011, Wu 2012, Wu 2016, Zhang 2012);
- Rate of lead recovery from concentrates: 80% (Paragraph 29 study [UNEP, 2010a] response from Brazil);
- Concentrate/lead ratios: 1.4-3.6, intermediate value 2.5 (COWI, OUTOTEC, Zhang 2012).

For all UEFs, <u>distribution factor</u> = 0.97. 3% of the total Hg input is assumed to be bound in smelting slag (Hui 2016). Other pathways are assumed to refer to treatment of residues from abatement equipment (UNEP, 2017; Maag, pers. comm.).

Applied technology profile. This is shown in Table A6.27.

Discussion of technology profile. Particular attention should be given to the comments in table note ‘b’. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 98% plus 90% of the remaining 2% = effective 99.8% reduction.

The following literature sources were studied: UNEP (2015), UNEP (2017), BREF NF (2009), Hylander and Herbert (2008), Kim et al. (2010a); Li et al., 2010, Wu 2016, national information provided by Republic of Korea; Maag, pers. comm.; Wang, pers. comm., Seo, pers. comm., BAT/BEP 2017 NFM, Boliden 2015

Comparison with UNEP Toolkit factors. The default factor used (73.1 g/t Pb produced) is slightly lower than the default factor in the UNEP Toolkit (75 g/t Pb produced).

Potential for double counting. UNEP TK EFs are derived based on analysis of Hg concentrations in ores, metal concentrates and reject materials. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2010 inventory factors. The default unabated EF applied in calculations for 2010 (75 g Hg/t Pb produced) is slightly lower than the default unabated EF used in the current inventory (73.1 g/t Pb produced). This is due to the update of distribution factor (lower in this inventory than in calculations for 2010).

Acid plants decrease Hg emissions significantly, and they are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 73.1 g/t would correspond to an abated EF of around 1–7 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.25. Unabated emission factors (UEFs) applied for non-ferrous metal production: lead.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Generic default factor	2.7	73.1	216	g/t Pb produced (primary production)	UNEP, 2017; OUTOTEC; BREF, 2009; Hylander and Herbert (2008), country-specific data	Expert evaluation; intermediate based on 30 g/t in concentrate (low/high based on 2 and 62 g/t in concentrate, respectively)
Bulgaria, Dem. Rep. Korea, Romania, Morocco, Myanmar, Russia, Serbia and Montenegro	10.1	18.3	26.1			Based on 7.5 g/t in concentrate
Argentina, Bolivia, Iran, Mexico, Peru	8.4	15.1	21.6			Based on 6.2 g/t in concentrate
Belgium, Italy, France, Germany, Japan, Republic of Korea, Poland, Sweden, United Kingdom, United States	6.8	12.2	17.4			Based on 5 g/t in concentrate
Australia	4.3	7.7	11.0		BREF, 2009; Wu 2012, OUTOTEC	National data: 3.2 Hg/ t concentrate
Canada	3.7	6.6	9.4		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 2.7 Hg/ t concentrate
China	8.3	44.3	102		Zhang 2012, Wu 2012, Wu 2016	National data: 27.1 Hg/ t concentrate, concentrate/lead ratio of 1.7

India	2.7	10.8	21.6		BREF, 2009; Kumari 2011, OUTOTEC	National data: 4.5 Hg/ t concentrate
Kazakhstan	4.3	7.7	11.0		BREF, 2009; Wu 2012, OUTOTEC	National data: 3.2 Hg/ t concentrate

Table A6.26. Comparative emission factors (EFs) for non-ferrous metal production: lead.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	Intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air	2	30	60	g/t concentrate used	UNEP, 2017	Default input factor (Hg content of concentrate) 2–60 g/t; DF=1.
	2.8	75	214.3	g/t Pb produced	UNEP, 2017	Default input factor (Hg content of concentrate) 2-60 g/t; DF=1.
2010 inventory	3	75	214	g/t Pb produced	AMAP/UNEP, 2013	Default input factor (Hg content of concentrate) 2-60 g/t; concentrate/Pb ratio 2.5-3.3; DF=1.
EMEP/EEA	0.8	1	1.2	g/t Pb produced	EMEP/EEA, 2016	
Abated EF						
EMEP/EEA	0.2	0.3	0.4	g/t Pb produced	EMEP/EEA, 2016	2015 technology level
UNEP Toolkit abated input to air	2.52	67.5	192.9	g/t Pb produced	UNEP, 2017	Default input factor 2.8-214.3 g/t. No filters or only coarse, dry PM retention. DF = 0.9
	1.37	36.8	105	g/t Pb produced	UNEP, 2017	Default input factor 2.8-214.3 g/t. Wet gas cleaning. DF = 0.49
	0.28	7.5	21.4	g/t Pb produced	UNEP, 2017	Default input factor 2.8-214.3 g/t. Wet gas cleaning and acid plant. DF = 0.1
	0.06	1.5	4.3	g/t Pb produced	UNEP, 2017	Default input factor 2.8-214.3 g/t. Wet gas cleaning, acid plant and Hg specific filter. DF = 0.02

Table A6.27. Technology profile applied for non-ferrous metal production: lead.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	Intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									UNEP, 2015; BREF NF 2009; Hylander and Herbert , 2008; Kim et al., 2010a; Li et al., 2010
Level 0: None or simple particle filters		0				2.5	5	10	
Level 1: Simple APC: particle control only		10							
Level 2: Basic APC: particle control + WGC [a]		50				2.5	5		
Level 3: Efficient APC: particle control + WGC + AP [b]		95			20	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX [c] + AP		99.8		100	80				
COUNTRY-SPECIFIC PROFILE									
China									
None		0			5.7				Wu 2016, Wang,
DC		12			6.2				

DC+FGS		41			12.6				pers. comm.
DC+FGS+ESD+SCSA		87			16.1				
DC+FGS+ESD+DCDA		97			59.4				
Republic of Korea									
ESP-Venturi Scrubber-ESP-Boliden Norzink-DCDA		99.9		100					Seo, pers. comm.
Sweden									
ESP + DOWA filter + DCDA		99.7		100					BAT/BEP 2017 NFM, Boliden 2015

[a] Particle control = cyclones and ESP, WGC = Wet gas cleaning; [b] integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; [c] Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 98%.

A 6.10 Non-ferrous metal production: zinc (Zn)

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary zinc production (and in some cases total production where primary production is not separately distinguished).

Applied UEFs. These are shown in Table A6.28.

Comparative EFs. These are shown in Table A6.29.

Discussion of EFs. Information on mass balances for non-ferrous metal production and Hg content of ores and concentrates produced and used in different countries is sparse. National data on consumption or raw materials and/or Hg content was used instead of generic values where available.

The following literature sources were studied: UNEP (2017), BREF NF (2009), BREF NF (2014), EMEP/EEA (2016), Hylander and Herbert (2008), Kim et al. (2010a), Kumari (2011), OUTOTEC, Paragraph 29 study [UNEP, 2010a] answer from Brazil, Wang 2010, Wu 2012, Wu 2016, Zhang 2012, Li 2010, Hui 2016, Hylander, pers. comm.; Maag, pers. comm.

Basic assumptions during calculations of UEF:
- Initial oxidation stage (roasting or sintering of concentrate) is considered to be major source of Hg emissions.
- Mining and concentrating processes are not considered due to lack of data. Inputs from these processes are considered as insignificant as they do not involve thermal processes.
- Fuels can be a source of minor Hg inputs (UNEP, 2017) but these inputs are considered insignificant compared to inputs from metal ores. Default input factor in in UNEP Toolkit (UNEP, 2017) is therefore the same as Hg content of Zn concentrate.
- An integrated acid plant is considered as a part of applied technology profile, see discussion of technology profile.

Metal contents, recovery rates, concentrate/metal ratios:
- Zinc content of concentrates: 33–60%, intermediate value 46% (Paragraph 29 study [UNEP, 2010a] answer from Brazil; BREF, 2009; Li et al., 2010)
- Mercury content of concentrates: 1-147 g/t, intermediate value 64 g/t (Hylander and Herbert 2008, UNEP 2017, Kumari 2011, Wu 2012, Wu 2016, Zhang 2012).
- Rate of Zn recovery from concentrates: 95–97% (Li et al., 2010)
- Concentrate/zinc ratios: 1.7-3.2, intermediate value 2.3. (Wang et al., 2010, OUTOTEC, Zhang 2012).

For all UEFs, **distribution factor** = 0.9. 1-17% of the total Hg input is assumed to be bound in smelting slag (Hui 2016) – we use 10% as a weighted average over the two main processes – hydrometallurgical (more widely used, with estimated share of Hg input bound in slag of 17%) and pyrometallurgical (share of Hg input bound in slag of 0.5-2.3%). Other pathways are assumed to refer to treatment of residues from abatement equipment (UNEP 2017; Maag, pers. comm.).

Applied technology profile. This is shown in Table A6.30.

Discussion of technology profile. Particular attention should be given to the comments in table note ‘b’. When considering Hg reduction efficiencies for combinations of acid plant removal (assumed 90%) and APCDs, the AP reduction efficiency applies to the remaining Hg that is not removed by the APCDs. Therefore the removal efficiency of an efficient basic particle matter + wet gas control configuration in combination with an acid plant is 50% plus 90% of the remaining 50% = effective 95% reduction; similarly the removal efficiency of an efficient particle matter + wet gas control + Hg-specific control configuration in combination with an acid plant is 98% plus 90% of the remaining 5% = effective 99.8% reduction.

The following literature sources were studied: UNEP (2015), UNEP (2017), BREF NF (2009), Hylander and Herbert (2008), Kim et al. (2010a), Li 2010, Wu 2016, Maag, pers. comm.; Wang, pers. comm.; Euripidou, pers. comm.

Comparison with UNEP Toolkit factors. The default factor used (130.8 g/t Zn produced) is 6% higher than the default factor in the UNEP Toolkit (123.3 g/t Zn produced).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in ores, metal concentrates and reject materials. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no double counting.

Emissions estimates are calculated separately for each (non-ferrous) metal. In cases where large parts of the production are associated with co-production of several metals from the same concentrate/ore, there may be an over-estimation of the summed emissions for the non-ferrous metal sector.

Comparison with 2010 inventory factors. The default unabated EF applied in calculations for 2010 (123 g / t Zn produced) is lower than the default unabated EF used in the current inventory (130.8 g/t Zn produced. This is due to the updates in metal content of the concentrates which is lower in this inventory than in calculations for 2010 (46% and 55%, respectively).

Acid plants decrease Hg emissions significantly, and are often combined with Hg-specific abatement measures that decrease Hg emissions even more. Applying abatement technology (in particular acid plants) to the UEF of 130.8 g/t would correspond to an abated EF or around 1–13 g/t; however under the current work this assumption is not applied to all production in all countries as some countries still have artisanal production where abatement factors are considerably lower.

Gaps/needs to improve factors and profiles. (1) Information on the Hg and metal content of concentrates processed in different countries, including details of co-production of non-ferrous metals. (2) Information base for assumptions regarding technology profiles, in particular detailed information on the amount of production in different countries that is associated with facilities with integrated acid plants as opposed to artisanal production or production at larger facilities with no integrated acid plant.

Table A6.28. Unabated emission factors (UEFs) for non-ferrous metal production: zinc.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factors	1.6	130.8	422	g/t Zn produced (primary production)	UNEP, 2017; OUTOTEC; BREF, 2009; Hylander and Herbert (2008), country-specific data	Expert evaluation; intermediate based on 64 g/t in concentrate (low/high based on 1 and 147 g/t in concentrate, respectively)
Australia	74.5	127.3	256		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 62.3 Hg/ t concentrate
Brazil	2.3	146.6	340		BREF, 2009; UNEP, 2017, Paragraph 29 study [UNEP, 2010a] answer from Brazil	National data: 41% zinc in concentrate
Canada	17.1	27.6	353		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 13.5 Hg/ t concentrate
China	1.8	159.7	737		Wang 2010, Zhang 2012, Wu 2012, Wu 2016, Hui 2016	National data: 77.5 Hg/ t concentrate, concentrate/zinc ratio of 2.4, DF = 0.86
Germany	9.3	299.1	422		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 146.4 Hg/ t concentrate
India	17.1	51.2	422		BREF, 2009; Kumari 2011, OUTOTEC	National data: 25 Hg/ t concentrate
Namibia	1.7	110.2	253		NAM Zn, BREF, 2009, UNEP, 2017	National data: 55% zinc in concentrate; 95% recovery rate
Norway	1.6	122.6	422		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 60 Hg/ t concentrate
Peru	1.6	74.8	422		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 37 Hg/ t concentrate

Russia	1.6	155.3	353		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 76 Hg/ t concentrate
Spain	66.7	162.4	422		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 79.5 Hg/ t concentrate
USA	1.6	33.9	60.3		BREF, 2009; UNEP, 2017, OUTOTEC	National data: 17 Hg/ t concentrate

Table A6.29. Comparative emission factors (EFs) for non-ferrous metal production: zinc.

	Emission Factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air	5	65	130	g/t concentrate used	UNEP, 2017	Default input factor (Hg content of concentrate) 5–130 g/t; DF=1.
	8.6	123.3	342.1	g/t Zn produced	UNEP, 2017	Default input factor (Hg content of concentrate) 5-130 g/t; DF=1.
2010 inventory	9	123	342	g/t Zn produced	AMAP/UNEP, 2013	Default input factor (Hg content of concentrate) 5-130 g/t; concentrate/Zn ratio 2.0-2.2; DF=1.
EMEP/EEA	2	5	8	g/t Zn produced	EMEP/EEA, 2016	
Abated EF						
EMEP/EEA	20.1	50.6	81.5	g/t Zn produced	EMEP/EEA, 2016	Abatement not specified2015 technology level
UNEP Toolkit abated input to air	7.7	111.0	307.9	g/t Zn produced	UNEP, 2017	Default input factor 8.6-342.1 g/t. No filters or only coarse, dry PM retention. DF = 0.9
	4.2	60.4	167.6	g/t Zn produced	UNEP, 2017	Default input factor 8.6-342.1 g/t. Wet gas cleaning. DF = 0.49
	0.9	12.3	34.2	g/t Zn produced	UNEP, 2017	Default input factor 8.6-342.1 g/t. Wet gas cleaning and acid plant. DF = 0.1
	0.2	2.5	6.8	g/t Zn produced	UNEP, 2017	Default input 8.6-342.1 g/t. Wet gas cleaning, acid plant and Hg specific filter. DF = 0.02

Table A6.30. Technology profile applied for non-ferrous metal production: zinc.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	UNEP, 2015; BREF NF 2009; Hylander and Herbert , 2008; Kim et al., 2010a; Li et al., 2010
DEFAULT PROFILE									
Level 0: None or simple particle filters		0				2.5	5	10	
Level 1: Simple APC: particle control only		10							
Level 2: Basic APC: particle control + WGC[a]		50				2.5	5		
Level 3: Efficient APC: particle control + WGC + AP[b]		95		20	100 20	95	90	90	
Level 4: Very efficient APC: particle control + WGC + HgX[c] + AP		99.8		80100	80				
COUNTRY-SPECIFIC PROFILE									
China									
None		0			4.5	2.3			Wu 2016, Wang, pers.

DC		12			3	9.9			comm.
DC+FGS		41			0.7	77.4			
DC+FGS+ESD+SCSA		87			1.3	10.4			
DC+FGS+ESD+DCDA		97			79.6				
Republic of Korea		99.2			10.9				
ESP-Venturi Scrubber-ESP-Boliden/Norzink-DCDA		99.9		100					Kim et al., 2010a, National information
Namibia									
Level 1: Simple APC: particle control only		10				15			Euripidou, pers. comm.
Level 2: Basic APC: particle control + WGC [a]		50				25			
Level 3: Efficient APC: particle control + WGC + AP [b]		95				60			
Algeria									
Level 1: Simple APC: particle control only		10						15	Euripidou, pers. comm.
Level 2: Basic APC: particle control + WGC [a]		50						25	
Level 3: Efficient APC: particle control + WGC + AP [b]		95						60	

[a] Particle control = cyclones and ESP, WGC = Wet gas cleaning; [b] integrated acid plant (AP) downstream of APCDs is assumed to remove 90% of the remaining Hg from gas flow; [c] Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, Outokumpu process, Bolchem, Sodium thiocyanate process, activated carbon filter/Lurgi process, Tinfos/Miltec process, Selenium scrubber or filter, lead sulphide process, Hg reclaiming tower. Average removal efficiency of Hg-specific abatement technologies is assumed to be 98%.

A 6.11 Non-ferrous metal production: Hg (dedicated production from cinnabar ore)

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary Hg production from cinnabar ore; restricted to countries with primary mine production.

Applied UEFs. These are shown in Table A6.31.

Comparative EFs. These are shown in Table A6.32.

Discussion of EFs. In the absence of any additional/new national information, the UNEP Toolkit factors were adopted in this work.

The following literature sources were studied: UNEP (2017), BREF (2009), BREF (2014), national information provided by Mexico.

Basic assumptions during calculations of UEF:

- Mining and concentrating processes are not considered due to lack of data.

For all EFs, distribution factor = 0.25 (as in the UNEP Toolkit, applied to total Hg release during the process).

Applied technology profile. This is shown in Table A6.33.

Discussion of technology profile. Minimal abatement in the form of basic particle matter control was assumed; production occurs in Group 3, 4 and 5 countries only.

Comparison with UNEP Toolkit factors. The default factor used (7500 g/t Hg produced) is the same as the factor in UNEP Toolkit.

Potential for double counting. The UNEP Toolkit EF, used as a generic value also in this work, is derived based on analysis of Hg concentrations in ore, concentrates and reject materials. The same principle was applied to country-specific EFs. Fuels are not included so there is no risk of double counting.

Comparison with 2010 inventory factors. The same unabated emission factor is used as in the calculations for 2010.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.31. Unabated emission factors (UEFs) applied for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		7500		g/t Hg produced	UNEP, 2017	The UNEP Toolkit factor has been adopted.

Table A6.32. Comparative emission factors (EFs) for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
<u>Unabated</u> EF						
UNEP Toolkit unabated input to air	5000	7500	10000	g/t Hg produced	UNEP, 2017	DF = 0.25, total Hg released = 20–40 kg/t Hg produced. DF applies here to Hg releases, not total Hg input (1020–1040 kg/t Hg produced). Since no information on control systems is found, the UNEP Toolkit EF is considered as unabated.
2010 inventory		7500		g/t Hg produced	AMAP/UNEP 2013	The UNEP Toolkit factor has been adopted.

Table A6.33. Technology profile applied for non-ferrous metal production: mercury (dedicated production from cinnabar ore).

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
Default profile									
Level 1: None or simple particle filters	10	10				100	100	100	Expert estimate
Mexico									
Particle control only		40				100			National information

A 6.12 Non-ferrous metal production: Aluminium (Al) and alumina production from bauxite ore

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning primary Al and alumina production from bauxite.

Applied EFs. These are shown in Table A6.34.

Comparative EFs. These are shown in Table A6.35.

Discussion of EFs. National data on material consumption and/or Hg contents was used instead of generic values wherever possible.

The following literature sources were studied: UNEP (2017), Nelson et al. (2009), BREF (2009), BREF (2014), national comments from China.

Basic assumptions during calculations of UEF:

- Emissions from Al production assume:
  -production of alumina from bauxite,
  -production of aluminium from locally produced alumina, and
  -production of aluminium from imported alumina;
- Digestion of bauxite is considered to be major source of Hg emissions
- Fuels can be a source of significant Hg inputs but these inputs are not included in the EFs.

Metal contents and ratios:
Bauxite/alumina ratio – 2.0-2.5, intermediate value 2.3 (Nelson et al. (2009), BREF (2009))
Alumina/aluminium ratio – 1.6-2.5, intermediate value 1.9 (BREF (2009))
Mercury content of bauxite – 0.07-1.00 g/t, intermediate value 0.49 g/t (UNEP 2017).

distribution factor = 0.15 (as in the UNEP Toolkit, applied to total Hg release during the process).

Since Al is produced from alumina, which is traded internationally, three different emission factors have been developed:

- The emission factor for production of Al from bauxite - applied to major bauxite-producing countries that also produce aluminium;
- The emission factor for production of Al from alumina - applied to major aluminium-producing countries that are not bauxite-producers (production from imported alumina);
- The emission factor for production of alumina for export - applied to major bauxite-producing countries that also produce alumina but not aluminium.

Applied technology profile. This is shown in Table A6.36.

Discussion of technology profile. The following literature sources were studied: UNEP 2011b, UNEP 2015, UNEP (2015), Nelson et al. (2009), BREF (2009), national information provided by China.

Comparison with UNEP Toolkit factors. The default factor used (0.31 g/t Al produced) is (rounded) equivalent to the default factors from the UNEP Toolkit (with adjustment for the application to Al production activity data rather than bauxite ore used).

Potential for double counting. UNEP Toolkit EFs are derived based on analysis of Hg concentrations in bauxite ore. Country-specific EFs are derived based on the same principle. Fuels are not included so there should be no potential for double counting.

Comparison with 2010 inventory factors. The default unabated EF applied in calculations for 2010 (0.32 g Hg/t Al produced) is slightly higher than the default unabated EF used in the current inventory (0.31 g/t Cu produced). This is due to the update in bauxite/alumina ratio, based on the latest available information in the literature.

Gaps/needs to improve factors and profiles. (1) Information on the basis for national production of Al (alumina vs. bauxite). (2) Information base for assumptions regarding technology profiles.

Table A6.34. Unabated emission factors (UEFs) applied for non-ferrous metal production: aluminium and alumina production from bauxite ore.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor						
Applied to major bauxite-producing countries	0.03	0.31	0.9	g/t Al produced		Expert evaluation based on UNEP, 2015; BREF, 2009; Nelson et al., 2009 and country-specific data
Applied to Al-producing countries without major bauxite production		0.05				
Applied to major bauxite-producing countries without Al-production (alumina for export)		0.26		g/t Al produced		
		0.16		g/t alumina produced		
Australia	0.04	0.05	0.06		Nelson 2009, UNEP 2017, BREF 2009	National data: 0.07 g Hg/t bauxite, 2.5 t bauxite/ t alumina
China	0.03	0.28	0.8		UNEP 2017, national information	National data: 2.0 t bauxite/ t alumina
Sub-Saharan African countries	0.10	0.13	0.2		UNEP 2017, BREF 2009	National data: 0.2 g Hg/t bauxite

Table A6.35. Comparative emission factors (EFs) for non-ferrous metal production: aluminium and alumina production from bauxite ore.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
	0.01	0.08	0.15	g/t bauxite used	UNEP, 2017	Default input factor (Hg content of bauxite) 0.07–1 g/t; DF to air = 0.15.
	0.04	0.32	0.70	g/t Al produced	UNEP, 2017; BREF, 2009; Nelson et al., 2009 and country-specific data	UNEP TK numbers are adjusted using bauxite/aluminium ratio ≈3.8–4.7 (2–2.46 t bauxite/t alumina) × 1.9 t alumina/t Al

Table A6.36. Technology profile applied for non-ferrous metal production: aluminium and alumina production from bauxite ore.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	Low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None		0					100	100	UNEP, 2011b; Nelson et al., 2009
Level 1: Particle control (cyclones+ ESP/FF) + WS		50			100	100			
Level 2: particle control (cyclones+ ESP/FF) + WS + Hg collection/reduction		75		100					
COUNTRY-SPECIFIC PROFILE									
China									
Cyclone + ESP/FF		60				100			National information

A 6.13 Large-scale gold production

Basis for 2015 emission estimates. UEFs applied to activity data concerning mine production of gold in tonnes. Activity is the production of gold from large-scale mine production (and is not including ASGM production).

Applied EFs. These are shown in Table A6.37.

Comparative EFs. These are shown in Table A6.38..

Discussion of EFs.

The following literature sources were studied: UNEP, 2010a, UNEP (2017), BAT BEP, Nelson, pers. comm., Yang 2016, Hui 2016

Basic assumptions during calculations of UEF:

The UEF depends on:

- Amount of Au in ore (which determines the ratio of tonnes of ore needed to produce a tonne of gold)
- Mercury content of ores
- Distribution factor to air (proportion of Hg that is released to air).

The first two at least are likely to vary considerably from mine to mine; however as it was not possible in this work to consider emissions estimates on a mine-by-mine basis, a generic average UEF was applied with the following assumptions:

Amount of gold in ore = a (generic) value of 4 g Au/t ore was assumed, yielding a ratio of 250 000 tonnes ore for one tonne of gold. Figure A6.1 illustrates the development of exploited Au-ore grade over past years, which in itself can be expected to have resulted in considerable changes in factors applicable to Hg releases from large-scale gold production. Generally, Hg releases would be expected to increase if the Au-content decreases and the Hg-content of the ore remains the same – which is not necessarily the case – due to the increased amount of ore mined for a given production of gold.

Figure A6.1. [To be included]

Mercury content of ore: 5.5 g Hg /t Au ore was used in the current global inventory calculations. For comparison, the UNEP Toolkit quotes a range of 10–100 g/t ore; UNEP Paragraph-29 (UNEP, 2010a) reported values of 0.1–100 g/t ore, and US Paragraph-29 sources (UNEP, 2010a) reported values of 0.1–30 g/t ore.

Distribution factor to air = 0.04 was used, adopted from the UNEP Toolkit (UNEP, 2017). Major part of the total mercury input (over 90%) is often released to land on-site, presumably without entering the roasting stage. On this basis, the (unabated) EF is = 5.5 × 250 000 × 0.04 = 55 000 g Hg emitted/tonne gold produced.

Applied technology profile. This is shown in Table A6.39.

Discussion of technology profile. According to the BAT BEP and information obtained from Australia (Nelson, pers. comm.) and China (Yang 2016, Hui 2016), it is not unusual with highly efficient APCDs used in large-scale gold production. BAT BEP reports that removal efficiency of APCDs on roasters – including acid plants and upstream abatement such as sulphur-impregnated activate carbon filter (the most common and proven technology in this sector) – can be higher than 99%. The Jerritt process used at some facilities in North America has a removal efficiency of 99.97% (BAT BEP). According to Hui 2016, all large-scale gold production in China is covered by APCDs that remove 97% to 99 % of Hg from the flue gas. In Australia, the new production technology launched in 2015 is claimed to reduce Hg emissions from large-scale gold production by 90% (Nelson, pers. comm.)). In the current inventory, we assume that the most efficient APCDs, applied mainly in technology group 1 countries, remove 99% of mercury. These can include sulphur-impregnated activate carbon filter, Boliden/Norzink process or Jerritt process with an acid plant downstream. Australia and China are assigned own technology profiles.

Comparison with UNEP Toolkit factors. UEF used in this work is about three times lower than the UNEP Toolkit default factor – 150 kg Hg/ t gold (assuming 3750 kg/gold produced and DF = 0.04). In the current inventory, Hg content of ore is assumed to be 5.5 g/t while in the UNEP Toolkit the value of 15 g Hg/t ore is used.

Potential for double counting. UEFs are derived from Hg and gold content of ores. Fuels consumed at gold production plants are not included so there is no risk of double counting.

Comparison with 2010 inventory factors. The default factor used in the current inventory is the same as used in calculations for 2010.

Gaps/needs to improve factors and profiles. Relevant information on Hg and Au content of ores and concentrates processed in different countries, including the distribution of these factors for individual mines/processing facilities. Information on APCDs employed at large-scale gold production facilities.

Table A6.37. Emission factors applied for large-scale gold production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		55000		g/t (mine) Au produced	UNEP, 2017	4 g Au/t ore; 5.5 g Hg/tonne Au ore; DF = 0.04 (applied to Hg in ores).
China		26000		g/t (mine) Au produced	Yang 2016	National data : 0.73g Hg/ t Au concentrate, 0.004% Au in Au concentrate, 70% recovery rate, DF = 0.89 (applied to Hg in concentrated Au, including roasting and cyanidation stages).
Australia		12000		g/t (mine) Au produced	Nelson, pers. comm.	Expert estimate based on national data: 1.24 g Hg/ t Au ore.

Table A6.38. Comparative emission factors (EFs) for large-scale gold production.

	Emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
<u>Unabated</u> EF						
UNEP Toolkit input to air	10	150	300	g/t ore used (extracted)	UNEP, 2017	Default input factor 15 (1-30) g/t ore used, or 3750 (250-7500) kg/t gold produced; DF to air = 0.04.
2010 inventory		55000		g/t (mine) Au produced	UNEP, 2013	

Table A6.39. Technology profile applied for large-scale gold production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None or simple particle filters None		0		100	100	100	100	100	Expert estimate based on BAT BEP, Nelson, pers. comm., Yang 2016, Hui 2016
Level 1: Simple APC: particle control only		10					100		
Level 2: Basic APC: simple particle control + WGC[a]		25				80			
Level 3: Medium-efficiency APC: more efficient particle control + WGC[a]		40			80	20			
Level 4: Efficient APC: particle control + WGC + less efficient HgX + AP[b]		95		80	20				
Level 5: Very efficient APC: particle control + WGC + more efficient HgX + AP		99		20					
Australia									
No control		0			50				Nelson, pers. comm.
Ultra-fine grinding (UFG) mill		90			50				
China									
Single-phase roasting +APCD		97				30			Hui 2016, Yang 2016
Dual-phase roasting +APCD		98				13			
Production with cyanidation+ APCD		99				57			

[a] Particle control = cyclones and ESP, WGC = Wet gas cleaning; [b] Hg-specific abatement technologies (HgX) can be the following processes and equipment types: Boliden/Norzink process, sulphur-impregnated active carbon filter, Jerritt process. Average removal efficiency of Hg-specific abatement technologies combined with an integrated acid plant (AP) downstream of APCDs is assumed to be 95% for less efficient technologies and 99% for more efficient technologies.

A 6.14 Cement production

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning production of cement.

Applied UEFs. These are shown in Table A6.41.

Comparative EFs. These are shown in Table A6.42.

Discussion of EFs. During compilation of unabated country-specific EFs, an effort was made to use as much national data as possible. Most of the countries do not have complete mass balances but national data on material consumption and/or Hg contents was used instead of generic values wherever possible.

The following literature sources were studied: UNEP 2017, BREF (2013), national comments and personal communication (Maioli, Seo, Solórzano, Suzuki); BAT BEP, GNR 2014, UNEP (2010a; report and answers to the questionnaire by Barbados, Brazil, Cyprus, Iceland, USA), CSI (2005), CEMBUREAU (2010), Mlakar 2010, Won 2012, Chakraborty 2013, Wang 2014, Zhang 2015, Wang 2016, Fukuda et al. 2011, Cementa 2015, VDZ 2014.

Basic assumptions during calculations of UEF:

- Only clinker formation stage is considered; subsequent mixing stage is assumed to make insignificant input into Hg emissions compared to the thermal processes according to UNEP (2017), with the exception of fly ash addition during mixing which is not accounted for.
- Recycling of filter materials on-site is not considered for UEF since recycling is only possible if abatement is present.

Raw materials – input to the raw mill – are assumed to be a mixture of limestone with other, often more Hg-rich materials (clay, shale, fly ash, iron oxide, etc.). Significant amount of raw materials other than limestone can result in different input and emission factors. For countries that provided data on country-specific raw material consumption, this data was used in calculations.

Range of **Hg content** of raw materials:

- Total raw mix: 001–0.46 g/t, intermediate value – 0.09 g/t (UNEP, 2017, Mlakar 2010, Seo, pers. comm., Suzuki, pers. comm., Won 2012, Chakraborty 2013, UNEP (2010a), Wang 2014, Zhang 2015, Wang 2016, Fukuda et al. 2011, Cementa 2015, CSI 2005, BREF 2013)
- Limestone: 0.001–0.46 g/t, intermediate value – 0.04 g/t (UNEP, 2017, Mlakar 2010, Seo, pers. comm., Suzuki, pers. comm., Won 2012, Chakraborty 2013, UNEP (2010a), Wang 2014, Zhang 2015, Wang 2016, Fukuda et al. 2011, CSI 2005, BREF 2013)
- Clay: 0.001–0.45 g/t, intermediate value 0.08 g/t (UNEP, 2017, Suzuki, pers. comm., CEMBUREAU (2010), BREF 2013, Won 2012, Wang 2014)
- Shale: 0.002–0.44 g/t, intermediate value 0.05 g/t (Wang 2014, UNEP, 2017, CEMBUREAU (2010)).
- Iron oxide: 0–0.68 g/t, intermediate value 0.24 g/t (CEMBUREAU (2010), Wang 2014).
- Fly ash: 0.03–0.39 g/t, intermediate value 0.14 g/t (Won 2012).

Fuel combustion in the cement industry is accounted for in the section “Fossil fuel combustion in cement production” (section A6.14a below), except for co-incinerated waste. Fossil fuels are therefore excluded from UEF. Characteristics of co-incinerated waste (also called alternative fuels when referring to co-incineration in cement kilns):

- Calorific value – 22.9 MJ/kg, which is calculated as a weighted average over most wide-spread alternative fuels in Europe (according to BREF 2013).
- Mercury content: 0.006–0.57 g/t, intermediate value – 0.24 g/t (CEMBUREAU, 2010; Cementa 2015, Mlakar 2010, Won 2012, BREF 2013)

Instead of using one world-wide UEF default, we apply either country-specific UEF or regional UEF defaults based on specific values of parameters summarized in Table A6.40 below:

Table A6.40. Parameters for calculation of regional UEF for cement production (Source – GNR 2014).

Region	Thermal energy demand, MJ/kg clinker	Fuel substitution by waste, % of thermal energy	Clinker/cement ratio, t/t
North America	3.81	15 %	0.77
Central America	3.67	11 %	0.74
South America	3.65	6 %	0.65
Oceania	3.36	5 %	0.78
Middle East	3.43	3 %	0.81
CIS	4.59	1 %	0.81
Asia	3.36	5 %	0.78
Africa	3.78	3 %	0.75
EU-27	3.75	27 %	0.73

For all EFs, **distribution factor** = 0.95 (BAT BEP); 5% of the Hg input is assumed to be bound in clinker.

Applied technology profile. This is shown in Table A6.43.

Discussion of technology profile. For countries with data on dust recycling back to the cement kiln, removal efficiencies are assumed to be 50% lower than generic or country-specific numbers for the same types of technologies based on APC outlet/inlet ratios of Hg concentrations or flows. This is because dust recycling results in an increased part of the Hg ultimately emitted to the air (UNEP, 2017, BAT BEP) even though in this case removal efficiency cannot be defined as outlet to inlet ratio. Number 50% is based on distribution factors presented in the UNEP Toolkit for cases with and without dust recycling (particle control only applied).

The following literature sources were studied: UNEP (2011b), UNEP 2010a, UNEP 2017, BREF (2010), BREF (2013), CEMBUREAU (2010), national comments and pers. comm. (Hagström, Maioli, Solórzano, Suzuki, Seo, Hoenig, Euripidou); Nelson et al. (2009), Pudasainee et al. (2009a), UNEP (2010a; report and answers to the questionnaire), Theloke et al. 2008; NESHAP, 2010; Senior, 2010; US EPA, 2008.

Comparison with UNEP Toolkit factors: The range of (central) regional default factors used in this inventory is 0.092-0.113 g Hg/t cement. This is higher than the Toolkit default unabated factor for cement production without waste co-incineration (0.088 g Hg/t cement) and lower than the Toolkit default unabated factor for production facilities with waste co-incineration (0.120 g Hg/t cement).

Potential for double counting: Generic EFs for cement production includes waste co-incineration but not coal, petroleum coke or oil, which are accounted in a separate sector, so that there should be no double counting. Country-specific EFs are derived using the same principle. However, in cases when the reported numbers are used, these numbers can include use of coal and oil so there is a possibility of double counting for these countries.

Comparison with 2010 inventory factors. The default unabated factors applied when calculating emissions in 2010 are 0.087 g Hg/t cement without waste co-incineration and 0.118 g/t cement with waste co-incineration (assuming 12% thermal substitution by waste). In the current inventory, no single world-average emission factor was derived but several regional emission factors instead, varying from 0.092 g Hg/t cement to 0.113 g Hg/t cement. All of these emission factors include waste co-incineration – from 1% in CIS countries to 27% in the EU-27. The default values are lower than those used in for 2010 mainly due to the revised mercury contents of raw materials and especially waste (0.32 g Hg/t waste is used for 2010, which is 33% higher than 0.24 g/t waste used now), calorific value of waste, and clinker/cement ratios.

Gaps/needs to improve factors and profiles. Information base for assumptions regarding technology profiles.

Table A6.41. Unabated emission factors (UEFs) applied for cement production.

	Unabated emission factor	Source	Notes/adjustments

	low	intermediate	high	units		to reported data
Generic default factors						
North America	0.001	0.111	0.855	g/t cement		Based on BREF 2013, GNR 2014, UNEP, 2017 and country-specific data. Waste co-incineration is included.
Central America	0.001	0.106	0.789			
South America	0.001	0.092	0.659			
Oceania	0.001	0.109	0.775			
Middle East	0.001	0.113	0.788			
CIS	0.001	0.112	0.762			
Asia	0.001	0.109	0.775			
Africa	0.001	0.105	0.733			
EU-27	0.001	0.110	0.921			
Algeria	0.001	0.099	0.688	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.52 MJ/kg clinker, 3% waste, CC ratio = 0.70
Australia	0.001	0.110	0.783	g/t cement	CSI, 2005; GNR 2014, BREF 2013, UNEP, 2017	National data: 6% waste
Austria	0.001	0.114	1.178	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.72 MJ/kg clinker, 63% waste, CC ratio = 0.70
Barbados	0.002	0.071	0.813	g/t cement	UNEP 2010a; GNR 2014, BREF 2013, UNEP, 2017	1.81 t limestone + 0.43 t shale /t clinker.
Belarus	0.006	0.109	0.285	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 0.088 g Hg/t raw mix.
Belgium	0.001	0.112	0.989	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 35% waste
Brazil	0.027	0.029	0.105	g/t cement	UNEP 2010a, Maioli, pers. comm.; GNR 2014, BREF 2013, UNEP, 2017	2.09 t raw mix (0.02 g Hg/t) /t clinker
Canada	0.001	0.023	0.700	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.81 MJ/kg clinker, 10% waste, CC ratio = 0.77, 0.02 g Hg/ t raw mix
China	0.013	0.071	0.885	g/t cement	GNR 2014, BREF 2013, UNEP, 2017, Zhang 2015, Wang 2014	1.5 t limestone + 1.2 t iron oxide/t clinker
Cyprus	0.001	0.071	0.602	g/t cement	UNEP 2010a, GNR 2014, BREF 2013, UNEP, 2017	1.4 t limestone + 0.44 t clay + 0.01 t iron oxide + 0.02 t waste/t clinker.
Czech Republic	0.001	0.117	1.061	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.72 MJ/kg clinker, 39% waste, CC ratio = 0.76
Denmark	0.011	0.024	0.419	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 47% waste, 0.01 g Hg/t raw mix

Egypt	0.001	0.122	0.848	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 4.00 MJ/kg clinker, 3% waste, CC ratio = 0.87
Estonia	0.001	0.111	0.955	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 31% waste
Finland	0.001	0.115	1.093	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 47% waste
France	0.001	0.109	0.890	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.95 MJ/kg clinker, 24% waste, CC ratio = 0.73
Germany	0.006	0.052	0.222	g/t cement	GNR 2014, BREF 2013, UNEP, 2017, VDZ 2014	3.78 MJ/kg clinker, 45% waste, CC ratio = 0.70; 1.59 t limestone (0.03 g Hg/t) + 0.05 t clay (0.08 g Hg/t) + 0.05 t fly ash (0.08 g Hg/t) + 0.01 t iron ore (0.04 g Hg/t) /t clinker.
Greece	0.001	0.103	0.714	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3% waste
Greenland	0.001	0.111	0.855	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.81 MJ/kg clinker, 15% waste, CC ratio = 0.77
Hungary	0.001	0.111	0.955	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 31% waste
Japan	0.088	0.088	0.088	g/t cement	GNR 2014, Suzuki, pers. comm.	Country-specific mix and Hg content. Fossil fuels excluded. CC ratio = 0.76
Iceland	0.001	0.114	0.778	g/t cement	UNEP (2010a), GNR 2014, BREF 2013, UNEP, 2017	National data: 3.75 MJ/kg clinker, 27% waste, CC ratio = 0.73, 1.7 t raw mix/ t clinker
India	0.048	0.124	0.200	g/t cement	GNR 2014, Chakraborty 2013, UNEP, 2017	National data: total input 0.187 g Hg/t clinker, CC ratio = 0.70
Ireland	0.001	0.115	1.093	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 47% waste
Italy	0.001	0.108	0.817	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.58 MJ/kg clinker, 12% waste, CC ratio = 0.75

Republic of Korea	0.006	0.071	0.108	g/t cement	GNR 2014, Won 2012; Seo, pers. comm.	1.43 t limestone (0.06 g Hg/t) + 0.08 t clay (0.01 g Hg/t) + 0.04 t fly ash (0.14 g Hg/t) + 0.04 t silica stone (0.01 g Hg/t) /t clinker; CC ratio = 0.76
Latvia	0.001	0.111	0.955	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.75 MJ/kg clinker, 31% waste, CC ratio = 0.73
Luxemburg	0.001	0.112	0.989	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 35% waste
Mexico	0.001	0.040	0.440	g/t cement	Solórzano, pers. comm.; GNR 2014, BREF 2013, UNEP, 2017	1.29 t limestone + 0.002 t waste/t clinker.
Morocco	0.001	0.099	0.688	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.52 MJ/kg clinker, 3% waste, CC ratio = 0.70
Netherlands	0.001	0.112	0.989	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 35% waste
Norway	0.001	0.115	1.093	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 47% waste
Philippines	0.001	0.112	0.834	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.53 MJ/kg clinker, 10% waste, CC ratio = 0.79
Poland	0.001	0.114	1.003	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.82 MJ/kg clinker, 35% waste, CC ratio = 0.74
Portugal	0.001	0.103	0.714	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3% waste
Romania	0.001	0.103	0.714	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3% waste
Russia	0.038	0.039	0.057	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 4.59 MJ/kg clinker, 1% waste, CC ratio = 0.81, 0.03 g Hg/t raw mix
Slovenia	0.018	0.022	0.043	g/t cement	GNR 2014, BREF 2013, UNEP, 2017, Mlakar 2010	National data: 0.02 g Hg/t raw mix, 0.13 g Hg/t waste, 3% waste
Spain	0.001	0.110	0.852	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.70 MJ/kg clinker, 15% waste, CC ratio = 0.76

Sweden	0.002	0.052	0.096	g/t cement	GNR 2014, BREF 2013, UNEP, 2017, Cementa 2015	National data: 3.75 MJ/kg clinker, CC ratio = 0.92; 1.64 t raw mix (0.03 g Hg/t) + 0.09 t waste (0.12 g Hg/t) /t clinker
Switzerland	0.023	0.041	0.456	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 48% waste, 0.03 g Hg/ t raw mix
Thailand	0.001	0.115	0.810	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.30 MJ/kg clinker, 5% waste, CC ratio = 0.81
Tunisia	0.001	0.099	0.688	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.52 MJ/kg clinker, 3% waste, CC ratio = 0.70
Turkey	0.001	0.119	0.829	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.43 MJ/kg clinker, 3% waste, CC ratio = 0.85
UK	0.001	0.105	0.878	g/t cement	GNR 2014, BREF 2013, UNEP, 2017	National data: 3.83 MJ/kg clinker, 26% waste, CC ratio = 0.70
USA	0.001	0.055	0.564	g/t cement	UNEP (2010a), GNR 2014, BREF 2013, UNEP, 2017	3.87 MJ/kg clinker, 12% waste, CC ratio = 0.84, 1.42 t limestone (0.04 g Hg/t) /t clinker

Table A6.42. Comparative emission factors (EFs) for cement production.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit unabated input to air, no waste co-incineration	0.003	0.088	0.4	g/t cement	UNEP, 2017	Default input factor 0.004–0.5 g/t; DF to air = 0.8.
UNEP Toolkit unabated input to air, waste co-incineration	0.048	0.12	0.8		UNEP, 2017	Default input factor 0.06–1 g/t; DF to air = 0.8. Percentage of co-incinerated waste not specified.
2010 inventory, no waste co-incineration	0.003	0.087	0.4		UNEP, 2013	BREF-based mass-balance and expert evaluations with consideration to national data; DF to air = 0.8.
2010 inventory, waste co-incineration	0.05	0.118	0.8		UNEP, 2013	BREF-based mass-balance and expert evaluations with consideration to national data; DF to air = 0.8. Percentage of co-incinerated waste – 12%.
Abated EF						
UNEP Toolkit abated input to air, with waste co-incineration and no filter dust recycling	0.029	0.072	0.48		UNEP, 2017	Default input factor 0.08–0.8 g/t. Simple particle control (ESP/PS/FF). DF = 0.6
	0.019	0.048	0.32			Default input factor 0.08–0.8 g/t. Optimized particle control (FF-SNCR /FF+WS /ESP+GFD /optimized FF). DF

						= 0.4
	0.010	0.024	0.16			Default input factor 0.08–0.8 g/t. Efficient Hg pollution control (FF+DS / ESP+DS / ESP+WS / ESP+SNCR). DF = 0.2
	0.002	0.005	0.03			Default input factor 0.08–0.8 g/t. Very efficient Hg pollution control (wet FGD +ACI / FF +scrubber +SNCR). DF = 0.04
UNEP Toolkit abated input to air, with waste co-incineration and filter dust recycling	0.034	0.084	0.56		UNEP, 2017	Default input factor 0.08–0.8 g/t. Simple particle control (ESP/PS/FF). DF = 0.7
	0.029	0.072	0.48			Default input factor 0.08–0.8 g/t. Optimized particle control (FF-SNCR /FF+WS /ESP+GFD /optimized FF). DF = 0.6
	0.024	0.060	0.40			Default input factor 0.08–0.8 g/t. Efficient Hg pollution control (FF+DS / ESP+DS / ESP+WS / ESP+SNCR). DF = 0.5
	0.002	0.005	0.03			Default input factor 0.08–0.8 g/t. Very efficient Hg pollution control (wet FGD +ACI / FF +scrubber +SNCR). DF = 0.04
CEMBUREAU		0.035			CEMBUREAU, 2010	

Table A6.43. Technology profile applied for cement production.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None		0				20	50	100	BREF, 2010; UNEP, 2010a, 2011b; CEMBUREAU, 2010; Pudasainee et al., 2009a; Theloke et al. 2008, NESHAP, 2010; Senior 2010, US EPA, 2008
Level 1: Particulate matter simple APC: FF/ESP/PS		25		80	80	80	50		
Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF		55		15	20				
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR		75		4					
Level 4: Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR		95		1					
COUNTRY-SPECIFIC PROFILE									
Australia									
ESP		5			50				Nelson et al., 2009
FF		78			50				
Brazil									
PM: ESP or PS		25				50			Maioli, pers. comm.
PM: FF or other efficient PI FF		25				50			
Canada									
Level 1: Particulate matter simple APC: FF/ESP/PS		25		10					UNEP, 2010a

Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF		55		70					
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR		75		20					
China, Hong Kong									
Dust removal – FF/ESP		40				100			UNEP, 2010a
Germany									
Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF		55		75					Hoenig, pers. comm.
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR		75		25					
EU28 (if not separately listed) +Norway, Iceland and Switzerland									
Level 1: Particulate matter simple APC: FF/ESP/PS		25		39					Group 1 default adjusted to reflect increased controls due to regulation associated with increased use of co-incineration of waste
Level 2: Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF		55		30					
Level 3: Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR		75		30					
Level 4: Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR		95		1					
Japan									
Particulate matter simple APC: FF/ESP/PS		25		80					Suzuki, pers. comm.
Particulate matter optimised/ combination APC: FF+SNCR/FF+WS/ESP+FGD/optimised FF		55		15					
Efficient APC: FF+DS/ESP+DS/ESP+WS/ESP+SNCR		75		4					
Very efficient APC: wFGD + /ACI / FF + scrubber+ SNCR		95		1					
India									
Uncontrolled		0						1	UNEP, 2010a
ESP		25						99	
Republic of Korea									
Spray tower +PM(FF)		60.5		100					Seo, pers comm.
Mexico									
PM control: FF, ESP, cyclones		25				100			Solórzano, pers. comm.
Sweden									
FF+SNCR		55		28					Hagström, pers. comm.
FF + scrubber+ SNCR		75		72					
South Africa									
FF + ESP		30				100			Euripidou, pers. comm.
UK									
Particulate matter		25		26					UNEP 2010a
FF+SNCR		50		27					

ESP+WS		55		8					
ESP+DS		73		39					

A6.14a Fossil fuel combustion in cement production

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning amount of hard coal, brown coal and petroleum coke combustion in the cement sector.

Applied EFs. EFs for petroleum coke are shown in Table A6.44. EFs for hard coal are shown in Table A6.1 and for brown coal in Table A6.4.

Comparative EFs. For hard coal and brown coal, the same emission factors are used as in the more general coal combustion sector (see sections A6.1 and A6.2). For petroleum coke combustion, comparative EFs are shown in Table A6.45. DF to air for is assumed to be 1 for unabated emissions.

Discussion of EFs. During compilation of unabated country-specific EFs, an effort was made to use as much national data as possible.

The following literature sources were studied: UNEP (2017), BREF (2013), Fukuda et. al. 2011, Cementa 2015, Mlakar 2010, CEMBUREAU, 2010

Basic assumptions during calculations of UEF are same as for UEF in the more general coal combustion sector (see sections A6.1 and A6.2).

Applied technology profile. Default and country-specific technology profiles are harmonized with the technology profiles in the cement production sector, see above.

Discussion of technology profile. 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.

Comparison with UNEP Toolkit factors. The default input factor for unspecified pet.coke combustion in the UNEP Toolkit (0.02 g Hg/t oil product) is about twice as low the emission factors used in this inventory.

Potential for double counting. UEFs are derived from analysis of Hg concentration of coal and petroleum coke combusted at cement producing facilities. Combustion in cement production is intentionally separated from other fuel combustion and is not accounted in other sectors so there is no risk of double counting.

Comparison with 2010 inventory factors. Emissions from coal combustion in cement production were allocated to the coal combustion sector in the 2010 inventory. Emissions from petroleum coke combustion were included in the emission factors for cement production in the 2010 inventory.

Gaps/needs to improve factors and profiles. Additional information on Hg content of hard coal, brown coal and petroleum coke in different countries.

Table A6.44. Unabated emission factors (UEFs) applied for petroleum coke combustion in cement production.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor	0.010	0.040	0.370	g/t pet.coke	UNEP (2017), BREF (2013), CEMBUREAU, 2010, Cementa 2015, Fukuda et. al. 2011	Expert estimate based on available data. Default input factor 0.01–0.37 g/t. DF = 1
Slovenia	0.058	0.214	0.370		UNEP (2017), BREF (2013), CEMBUREAU, 2010, Mlakar 2010	National data: 0.214 g Hg/ t pet.coke
USA	0.010	0.050	0.250		UNEP (2017), BREF (2013), CEMBUREAU, 2010	National data: 0.05 g Hg/ t pet.coke

Table A6.45. Comparative emission factors (EFs) for petroleum coke combustion

	Emission Factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit-based unabated input to air	0.01	0.02	0.1	g/t pet.coke	UNEP, 2017	Default input factor (Hg content of pet.coke) 0.01-0.1 g/t; DF=1.
Abated EF						
EMEP/EEA	0.01	0.049	0.24	g/t clinker	EMEP/EEA, 2016	Industrial combustion. Abatement not specified.

A 6.15 Oil refining [Text to be updated]

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning amount of crude oil refined.

Applied EFs. These are shown in Table A6.46.

Comparative EFs. These are shown in Table A6.47.

Discussion of EFs. Regional and global UEFs are based on weighted averages derived from national UEFs. The values used for regional/global Hg content of crude oils are generally similar to those suggested by IPIECA (2012). The use of 25% as the factor for emissions to air is higher than that suggested by IPIECA (8%, based on studies at five San Francisco Bay refineries, McGuire et al., 2009) but consistent with values given in UNEP (2011b; provided by Petroleum Association of Japan for Japanese refineries, and reported by US-EPA [Wilhelm et al., 2001] cited in IKIMP [2012]).

The following literature sources were studied: UNEP (2011b), BREF (2012b), EMEP/EEA (2009), IKIMP (2012), IPIECA (2012), Petroleum Association of Japan, pers. comm., Wilhelm et al. (2007).

Basic assumptions during calculations of UEF:

- UEFs are based on information concerning Hg content of crude oils produced in different countries (mainly from Wilhelm et al., 2007 and Petroleum Association of Japan, pers. comm.; and assume that 25% of the Hg in refined oil is emitted to air (UNEP, 20011b; IKIMP, 2012) [**Update!!**]
- Where a country's production exceeds its consumption, it is assumed that the refined oil is from national sources. Where national consumption exceeds production (or there is no national production) assumptions are made regarding the proportions of the refined oil that are obtained from different (national, regional and global) sources, and use is made of national, regional and global UEFs accordingly [**Is this still relvant? UPDATE**]
- The oil extraction stage and transport prior to refining is not included although these activities can potentially give rise to significant releases of Hg (UNEP, 2011b)
- Combustion of fuels in oil refineries is account separately as stationary combustion.

Applied technology profile. This is shown in Table A6.48.

Discussion of technology profile. It was assumed that APCDs are either absent at oil refineries, or are inefficient at reducing Hg emissions to air from this source.

Comparison with UNEP Toolkit factors. The default factor used (0.0034 g/t crude oil refined) is significantly lower than the UNEP Toolkit default factor of 0.038 g/t crude oil refined.

Potential for double counting. UEFs are derived from analysis of Hg concentration of (refined) crude oil. Fuels consumed at oil refineries are not included so there is no risk of double counting.

Comparison with 2005 inventory factors. Emissions from oil refining were not included in the 2005 inventory.

Gaps/needs to improve factors and profiles. Additional information on Hg content of oil from different sources (countries and fields), and on the volumes, sources and Hg content of the oil refined in different countries/refineries.

Table A6.46. Unabated emission factors (UEFs) applied for oil refining.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		Not used		g/t crude oil refined		Weighted average of national estimates and their proportional contribution to global supply.
India		0.014716			Wilhelm et al., 2007; Petroleum Association of Japan, pers. comm., UNEP, 2011b; IKIMP, 2012 [To be updated]	
China		0.005066				
Czech Republic		0.001806				
Hungary		0.001806				
Kuwait		0.00025				
Myanmar		0.012973				
Morocco		0.001928				
Turkmenistan		0.001131				
Libya		0.001928				
Chile		0.000966				
Slovakia		0.001806				
Bulgaria		0.001806				
Peru		0.000966				
Turkey		0.000368				
Ecuador		0.000966				
Switzerland		0.001131				
Ireland		0.001806				
Bahrain		0.000368				
Trinidad and Tobago		0.000835				
Iraq		0.000175				
Israel		0.000368				
Cuba		0.000835				
United Arab Emirates		0.000425				
Oman		0.000375				
Sri Lanka		0.001806				
Tunisia		0.001928				
Uzbekistan		0.001131				
Denmark		0.000437				
Croatia		0.001131				
New Zealand		0.000521				
Ukraine		0.001131				
Nigeria		0.00075				
Yemen		0.000368				
Angola		0.0004				
Nicaragua		0.000835				
Kenya		0.000843				
Ivory Coast		0.000075				
Gabon		0.00025				
Ghana		0.000843				
Kyrgystan		0.001131				
Tajikistan		0.001131				
Japan		0.00739				
United States		0.001294				
Korea- Rep. of		0.00739				
Thailand		0.012973				
Taiwan		0.012973				
Indonesia		0.012973				
Singapore		0.012973				
Malaysia		0.009425				

Russia		0.000775				
Germany		0.001806				
Vietnam		0.016625				
Argentina		0.004025				
Italy		0.001806				
Spain		0.001806				
Philippines		0.012973				
United Kingdom		0.001806				
France		0.001806				
Brazil		0.000966				
Netherlands		0.001806				
Algeria		0.003325				
Canada		0.001081				
Norway		0.004875				
Mexico		0.0009				
Belgium		0.001806				
Venezuela		0.00105				
Iran		0.000525				
Poland		0.001806				
Egypt		0.001928				
Saudi Arabia		0.000375				
Greece		0.001806				
Sudan		0.0085				
Sweden		0.001806				
Australia		0.001191				
Belarus		0.001131				
Pakistan		0.001806				
Finland		0.001806				
Portugal		0.001806				
Romania		0.001806				
Kazakhstan		0.001131				
Austria		0.001806				
Columbia		0.00085				
South Korea		0.012973				
Bangladesh		0.001806				
Syrian Arab Rep.		0.000368				
Uruguay		0.000966				
Qatar		0.0005				
Azerbaijan		0.00025				
Dominican Republic		0.000835				
Jordan		0.000368				
Jamaica		0.000835				
Senegal		0.000843				
Congo		0.000843				
Brunei Darussalam		0.00065				
East and Southeast Asia		0.0130				
South Asia		0.0276				Weighted average based on national estimates and their proportional contribution to global supply for countries within region.
Europe		0.00113				
South America		0.000966				
Central America and the Caribbean		0.000845				
Sub-Saharan Africa		0.000843				

Table A6.47. Comparative emission factors (EFs) for oil refining.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
UNEP Toolkit input to air	0.001	0.038	0.075	g/t crude oil refined	UNEP, 2011b	Default input factor (Hg content of crude oil) 5–300 mg/t (mean value 55 mg/t); DF to air =0.25.
UEF based on BREF Hg concentrations	0.008	0.016	0.025	g/t crude oil refined	BREF, 2012b; UNEP, 2011b	Input factor (Hg content of crude oil) 30–100 mg/t (BREF, range); DF to air =0.25 (UNEP, 2011b).
Abated EF						
EMEP/EEA	0.002	0.0051	0.015	g/t crude oil refined	EMEP/EEA, 2009	Abatement not specified

Table A6.48. Technology profile applied for oil refining.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
None		0		100	100	100	100	100	

A 6.16 Chlor-alkali industry

Basis for 2015 emission estimates. UEFs and technology employed to reduce emissions from this sector, applied to activity data concerning chlorine (Cl_2) production capacity (or production where available) using Hg-cell technology are the same as in last AMAP/UNEP inventory. Only the activity data has been updated since the last global mercury assessment. Some countries have however closed all their chlor-alkali facilities.

Applied UEFs. These are shown in Table A6.49.

Comparative EFs. These are shown in Table A6.50.

Discussion of EFs. The following sources were studied: UNEP (2011b), OSPAR (2011), national information received from: Argentina, Brazil, India (Corporate Responsibility for Environmental Protection [CREP] Charter); Romania, and LRTAP sources.

OSPAR (2011) reported ranges of Hg emissions in 2009 of 0.14–1.64 g/t Cl_2 with >90% to air. This is comparable to 2007 (0.17–2.68 g/t) with only five out of 30 plants still reporting emissions >1 g/t (compared to nine plants in 2007 and 17 plants in 2005) and most plants emitting between 0.5 and 1 g/t. Conversion to membrane technology and shutdown of plants is a more common option than the reduction of emissions below the 0.5 g/t emission value. The emission average for all European plants (including the plants outside the OSPAR Convention area) is below 1 g/t. The one remaining Swedish plant was identified as the best performing Hg-based chlor-alkali plant in the OSPAR region.

Applied technology profile. This is shown in Table A6.51.

Discussion of technology profile. The EC Reference Document on Best Available Techniques in the Chlor-alkali Industry identifies the Hg-free membrane process as BAT. In as far as chlor-alkali production based on Hg-cell technology is concerned; much of the abatement potential lies in application of best practices and good management of operations. As such, technological abatement is represented as BAP in the technology profile, with reduction effectiveness based on reported national data largely for the OSPAR region. For India, information was used describing application within the chlor-alkali industry in India of the CREP Charter which incorporates: complete recycling of Hg-bearing effluent; treatment of cell-room ventilation gas; reduction of Hg in hydrogen gas; installation of salt washery unit; installation of Hg distillation units; brine sludge treatment and disposal in secured landfill.

Comparison with UNEP Toolkit factors. In this work, the applied UEFs were based on the low-intermediate ranges of the UNEP Toolkit (UNEP, 2011b) default factors reflecting trends in reductions in Hg consumption in the chlor-alkali industry in recent years; this also converged estimates towards recently reported national emissions estimates for some countries. Recent research, however, indicates that commonly applied emission estimation approaches do not always include (potentially significant) fugitive emissions.

Potential for double counting. There is no identified potential double counting associated with estimates for the chlor-alkali sector.

Gaps/needs to improve factors and profiles. Information on potential Hg releases associated with non-standard operating conditions (accidental releases) in developed countries, and improvements in applied technology and BAP in other countries.

Please note. The following 22 countries has no new activity data compared to last inventory (AMAP/UNEP,2013): Algeria, Angola, Azerbaijan, China, Columbia, Cuba, Indonesia, Iran, Iraq, Israel, Korea- Dem. Rep., Libya, Morocco, Myanmar, Pakistan, Peru, Philippines, Serbia, Montenegro, Slovakia, Syria, Turkmenistan and United Arab Emirates. This implies that the emission estimates for these countries are the same as in the last report.

Table A6.49. Unabated emission factors (UEFs) for the chlor-alkali industry.

	Unabated emission factor				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Generic default factor		20		g/t Cl_2 capacity	UNEP, 2011b	UNEP Toolkit low–intermediate (unaccounted consumption considered released)
Argentina	3.75	10	21.6	g/t Cl_2 production		National comments (5.8 g/t): Intermediate: 57.88 g/t Cl_2 produced (df 0.1); 15% of production High: 215.97 g/t Cl_2 produced (df 0.1); 3.3 % of production; Low: 15.34 g/t Cl_2 produced (df 0.245); 82% of production
Brazil		10				
Italy		20		g/t Cl_2 capacity	OSPAR, 2011	Based on OSPAR (2011)
Sweden		0.5			OSPAR, 2011	Based on OSPAR (2011)
OSPAR countries (Belgium, Finland, France, Germany, Spain, Switzerland) excluding the UK		2.5			OSPAR, 2011	Based on OSPAR (2011) and UNEP Toolkit (with assumed on-/off-site storage/recycling/ dumping)
Other Group 1 and 2 countries		5			UNEP, 2011b	UNEP Toolkit low (with assumed on-/off-site storage/recycling/ dumping)
Group 3 countries		10			UNEP, 2011b	UNEP Toolkit low–intermediate (with assumed on-/off-site storage/recycling/ dumping)

Table A6.50. Comparative emission factors for the chlor-alkali industry.

	Emission factor (EF)				Source	Notes/adjustments to reported data
	low	intermediate	high	units		
Unabated EF						
	5	42	80	g/t Cl_2 produced	UNEP, 2011b	For production using Hg-cell technology; 0.2 of total release is to air (unaccounted consumption considered released)
	2.5	21	40	g/t Cl_2 produced	UNEP, 2011b	For production using Hg-cell technology; 0.1 of total release is to air (with assumed on-/off-site storage/recycling/ dumping)
	2.2	18.6	35.5	g/t NaOH produced	UNEP, 2011b	For production using Hg-cell technology; (with assumed on-/off-site storage/recycling/ dumping). For conversion between a Cl_2-basis and an NaOH basis, the following factor can be used: g/t NaOH = g/t Cl_2/1.128 (based on European Commission, 2001b cited in UNEP, 2011b)

Table A6.51. Technology profile applied for the chlor-alkali industry.

Technology	Reduction efficiency, %			Degree of application, %					Source
				Country group					
	low	intermediate	high	1	2	3	4	5	
DEFAULT PROFILE									
Level 0: None		0					100	100	
Level 1: advanced BAP		50		100	100	100			
COUNTRY-SPECIFIC PROFILE									
India		50						100	

A 6.17 Vinyl Chloride Monomer (VCM) production and recycling of catalyst

Basis for 2015 emission estimates: National information and information from literature, in combination with Hg consumption data for VCM production by world region from P. Maxson.

Applied UEFs: These are shown in Table A6.52.

Comparative EFs: These are shown in Table A6.53.

Discussion of EFs: The EFs used are country specific.

Applied output distribution factors: These are shown in Table A6.54.

Discussion of output distribution factors: The distribution factors to air from VCM production as well as the fractions of catalyst Hg that goes to recycling are based on country specific information. The distribution factor of Hg to air from recycling of spent catalyst is based on information in Lin et al 2016, and applied to all countries.

Comparison with UNEP Toolkit factors: In UNEP toolkit (level 2 spreadsheeet, January 2017) the default factor is 120 (100-140) g Hg/t VCM produced. The default output distribution factor to air is 0.02 from VCM production and 0.6 to “sector specific treatment”.

Gaps/needs to improve factors and profiles: Up to date national information in general, but especially regarding recycling practices. According to current estimates recycling of catalyst Hg contributes more to air emissions than the actual VCM production.

Table A6.52. Applied unabated emission factors for VCM production

	Unabated Emission Factor (UEF)				Source reference	Notes/Adjustments to reported data
	low	average	high	unit		
VCM production						
Country specific						
China	49	86.9	97	g Hg/t VCM produced	UNIDO 2016, Lin et al 2016	Average from UNIDO 2016, low and high values from Lin et al 2016
India*		n.a.				
Russian Federation		96.07			National information	

*emission estimate for India based on estimated consumption of Hg in catalyst in South Asia region from P. Maxson (2017).

Table A6.53. Comparative emission factors for VCM production.

	Unabated Emission Factor (UEF)				**Source reference**	**Notes/Adjustments to reported data**
	low	**Inter-mediate**	**high**	**units**		
VCM production	100	120	140	g Hg/t VCM produced	UNEP, 2017	UNEP (2017) Toolkit default input factor

Table A6.54 Applied output distribution factors.

	Hg output distribution factors		Source reference	Notes/Adjustments to reported data
		units		
Factor to air from VCM production				
China	0.002	Fraction of catalyst Hg	Based on Lin et al 2016	China: assumption in this work: 90% removal of Hg in HCl acid plant
India	0.005		Burger Chakraborty et al 2013	
Russian Federation	0.02		National information	
To recycling of catalyst				
China	0.75	Fraction of catalyst Hg to recycling	Lin et al 2016	Russia: assumption that amount to sector specific treatment = recycling
India	0.5		Burger Chakraborty et al 2013	
Russian Federation	0.6		National information	
Factor to air from recycling				
Default	0.05		Lin et al 2016	