COST EFFECTIVENESS OF OPTIONS FOR A GLOBAL LEGALLY BINDING INSTRUMENT ON MERCURY

- IN THE PERSPECTIVE OF THE EUROPEAN UNION

FINAL REPORT
MAY 2012
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THE INTERNATIONAL NEGOTIATIONS ON A GLOBAL LEGALLY BINDING INSTRUMENT
ON MERCURY

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FINAL REPORT

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Extended executive summary

This study analyses the costs and effectiveness of options for a global legally binding instrument on mercury. It takes its outset in the current draft text of such an instrument (agreement, convention) negotiated in the International Negotiating Committee (INC) constituted by representatives of governments and intergovernmental organisations with UNEP as secretariat. The options selected for mercury release reductions, here termed "measures", are based on the March 2012 draft convention text (UNEP, 2012). While this study seeks to describe the global situation, this is done with the perspective of the European Union, and the costs and effectiveness assessment is primarily focused on developing regions and countries in economic transition, as well as, for some reduction options, the geographical territory of EU27. This summary focuses on implementation costs and effectiveness in the World excluding the EU and North America.

This study was performed under a contract including about 10 fee-weeks of work, involving also non-assessment activities. It has therefore been necessary to limit the assessment to easily available data and adapting a "best quick estimates" approach. As shown, many of the estimations made are associated with significant uncertainties, which could perhaps have been decreased had more time been available. All results of this study should be considered in this light. All background data used and assumptions made in the assessment are presented in the report text, to which we refer for details.

The measures currently covered in the draft negotiation text are the following (not original numbering):
1  Mercury supply
2  International trade in mercury
3  Products and processes
4  Artisanal and small scale gold mining (ASGM)
5  Emissions and releases
6  Storage, wastes and contaminated sites
7  Awareness-raising, research and monitoring, and communication of information
8  Other elements: Institutional arrangements, settlement of disputes, further development of the convention and final provisions.
The measures here numbered 1 through 6 are dealt with individually in this study, and the remaining measures are dealt with on an overview level.

**Mercury releases, demand and supply**

The analysis in this assessment is based on available estimates of global mercury releases, mercury demand and mercury supply. These are associated with uncertainties and alternative data sets available may deviate somewhat from the used data depending on the time of their estimation and the methodologies applied. But such deviations will likely not influence the results significantly. We have worked with the newest full data sets suiting the needs of the assessment. Apart from updated estimates for Artisanal Small-scale Gold Mining (ASGM), no major changes to individual mercury release sources have been introduced here. Estimates for release ranges for geographical regions have been calculated here as needed. The sources of the individual data are given in the report text.

Below, a summary of the data on anthropogenic mercury releases to the atmosphere, mercury demand by application and mercury supply by source are presented. The total quantified anthropogenic mercury releases to the atmosphere has been estimated to around 2300 tonnes/year, while the total quantified mercury demand has been estimated to around 4500 tonnes/year (both including updated 2011 estimates for ASGM). For details, see the report text.
Figure 0-1 Distribution of atmospheric mercury releases by source type, 2005 data except 2010 data for ASGM. Total quantified releases are estimated at around 2300 t/y (data sources, see report).

Figure 0-2 Distribution of mercury demand by application, 2005 data except 2010 data for ASGM. Total quantified demand is estimated at around 4500 t/y; "other" includes porosimetry and other minor uses (data sources, see report).
### Table 0-1   Mercury supply by main sources, 2007*1.

<table>
<thead>
<tr>
<th>Mercury supply, by main sources, 2007*1</th>
<th>Supply, t Hg/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated mercury mining</td>
<td>1.300-1.600</td>
</tr>
<tr>
<td>By-product mercury from non-ferrous</td>
<td>400-600</td>
</tr>
<tr>
<td>metal sector</td>
<td></td>
</tr>
<tr>
<td>Recycling/re-use from chlor-alkali</td>
<td>700-900</td>
</tr>
<tr>
<td>facilities</td>
<td></td>
</tr>
<tr>
<td>Recycling of mercury from catalysts,</td>
<td>600-800</td>
</tr>
<tr>
<td>production wastes and products</td>
<td></td>
</tr>
<tr>
<td>Commercially available mercury stocks</td>
<td>As needed (+)</td>
</tr>
<tr>
<td>Total</td>
<td>3.000-3.900+</td>
</tr>
</tbody>
</table>

Note: *1: As estimated by Maxson (2009). Recent update for mercury demand for ASGM indicate that the total mercury supply may be higher.

Total costs of quantified reduction options for the World excl. EU and North America
Table 0-2 presents a preliminary summary of annual costs for implementation of the listed mercury reduction options in the World except the EU and North America. The table presents both cost estimates based on an EU cost level and cost adjusted to reflect lower local prices in some regions of the World (Comparative price level (CPL) adjusted) for options where this was relevant. This includes options, where local labour and technical solutions play a part. Some options were quantified based on developing world prices only and are therefore not CPL adjusted; see details in the report. An OECD based CPL (comparative price level) index 100 was used for the EU and North America and a CPL index for Turkey of 59 was used for the rest of the World as no better factor was found. This factor influences the total costs of the quantified reduction options considerably and must be seen as a major source of uncertainty in the assessment.

As shown, the estimated costs for each reduction option vary considerably, yet the costs for substitution of batteries and dental amalgam and air emission reductions for coal fired power plants are significantly higher than for other reduction options, and these three options represent a major part of the total quantified costs. The costs for substitution of dental amalgam may become lower, if the so-called a-traumatic restoration technique (ART)\(^1\), reported to have lower costs yet lower durability than other alternatives, would become the preferred alternative in developing countries.

As indicated, the cost estimates are associated with substantial uncertainties, as more accurate data is not available. Most of these costs have never been aggregated to a global level and published before. For dental amalgam, a sensitivity analysis showed that alternative price assumptions would yield medium results 40-50% below the medium of the total costs shown for dental amalgam in Table 0-2. For batteries, a sensitivity analysis showed that alternative price and mercury demand assumptions would yield medium results 50-65% below the medium of the total costs shown for batteries in Table 0-2. In combination, these two alternative estimates would reduce the total CPL adjusted costs of the quantified reduction options from about 2-24 billion EUR/year to about 1-16 billion EUR/year. See report text for details.

Note that the costs are here quantified individually, though in reality several of the options are inter-dependent. An integrated analysis of two implementation reduction scenarios is summarised below. Costs of lifecycle management of mercury were included in the cost estimates for the mercury-added products batteries, dental amalgam and measuring and control devices\(^2\), but not for the mercury using processes chlor-alkali production and VCM production.

\(^1\) ART, a technique to insert a special type of dental fillings without drilling and with hand-tools only; its use is being promoted for developing regions by some stakeholders.

\(^2\) Such as mercury-containing thermometers and blood pressure gauges
Table 0-2  Summary of annual costs for implementation of the mercury reduction options listed, in the World except the EU and North America (Na), as well as reduction potential for each of these options.

<table>
<thead>
<tr>
<th>Measure and reduction options</th>
<th>World (excl EU+Na)</th>
<th>World (excl EU+Na), CPL adjusted</th>
<th>Reduction potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million EUR/y</td>
<td>Million EUR/y</td>
<td>t Hg eliminated from circulation/y</td>
</tr>
<tr>
<td>Supply:</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Supply, value of Hg not supplied for allowed uses*1 (distributional effect only)</td>
<td>22</td>
<td>140</td>
<td>22</td>
</tr>
<tr>
<td>Non-ferrous metals production, env. sound Hg waste disposal*1</td>
<td>1</td>
<td>16</td>
<td>0,59</td>
</tr>
<tr>
<td>Permanent env. sound disposal of Hg from other sources*2</td>
<td>1</td>
<td>3</td>
<td>1,2</td>
</tr>
<tr>
<td>International trade:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>International trade measure (adm. and support)*7</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Products and processes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Batteries, substitution *3</td>
<td>1.700</td>
<td>15.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Dental amalgam, substitution</td>
<td>-270</td>
<td>8.000</td>
<td>-160</td>
</tr>
<tr>
<td>Measuring and control devices, substitution</td>
<td>2</td>
<td>230</td>
<td>1,2</td>
</tr>
<tr>
<td>VCM production, Hg substitution</td>
<td>60</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution, costs assumed distributed over 10 years</td>
<td>60</td>
<td>120</td>
<td>60</td>
</tr>
<tr>
<td>ASGM:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed distributed over 10 years*7</td>
<td>80</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Emissions and releases:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal fired power plants, activated carbon injection (ACI)*4</td>
<td>1.200</td>
<td>14.000</td>
<td>710</td>
</tr>
<tr>
<td>Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning + disposal of captured Hg*1</td>
<td>110</td>
<td>210</td>
<td>110</td>
</tr>
<tr>
<td>Cement production, optimised fabric filters*5</td>
<td>530</td>
<td>2.300</td>
<td>310</td>
</tr>
<tr>
<td>Other measures and elements:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other measures (secretariat, adm., training, legislation, etc.)*6</td>
<td>40</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Total for quantified options (rounded)</td>
<td>3.500</td>
<td>40.000</td>
<td>2.200</td>
</tr>
</tbody>
</table>

Notes: *1: Whole World; for non-ferrous metal, most of the reduction potential is outside the EU and NA. 2*: Whole World. *3: Calculated as button cells, though appr. 33% are other types; see report text. *4: The filter technology may initially be North America/EU dominated, but is expected to be available from other regions too. Reduction number is reduced air emissions only. *5: 98% reduction potential only if filter dust is not re-introduced in cement kiln. *6: Also includes some administrative elements of technical reduction options. *7: No attempt has been made to quantify the uncertainty to these numbers. NA = Not available.
Cost- effectiveness of quantified options

While
Table 0-2 provides an overview of estimated costs, it cannot be used alone in a prioritisation of reduction options to be pursued, as the associated effects of the reductions options are not reflected.

Table 0-3 ranks the quantified reduction options by the estimated cost effectiveness in terms of money spent per kilogram (kg) of mercury eliminated from circulation in the biosphere\(^3\). The same information is presented graphically in Figure 0-3 in the form of a cost curve for the quantified reduction options. The curve describes how much mercury reductions can be attained at the lowest prices (length of the bar), and successively for all relevant reduction options quantified in this study. This ranking again emphasises that there are substantial differences in the cost effectiveness of the reductions options.

Similar data for by-product sources where the reduction options target air emission reductions only are presented separately in Table 0-4 and Figure 0-4 further below.

Note that the presented cost-effectiveness estimates are adjusted to reflect lower local prices in some regions of the World (CPL adjusted) for options where this was relevant. For comparison, non-adjusted cost-effectiveness estimates are presented in Appendix 1 to the report.

The above mentioned sensitivity analyses indicate that the cost-effectiveness estimates could be lower for batteries (50-70% lower) and dental amalgam (40-50% lower) with some alternative choices of base data sets; see report text for details. They would however remain among the relatively more costly reduction options seen in a cost-effectiveness perspective.

\(^3\) Meaning that the mercury would not be extracted from earth for intentional mercury uses, and would therefore not need any management to avoid adverse effects of mercury.
### Table 0-3

**Summary of cost effectiveness of quantified reduction options in terms of money spent per kg of mercury eliminated from circulation in the biosphere, as well as the total reduction potential for each of these options.**

<table>
<thead>
<tr>
<th>Reduction option</th>
<th>World (excl EU+Na); CPL adjusted</th>
<th>Reduc potentially</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EUR/kg Hg eliminated from circulation</td>
<td>t Hg eliminated from circulation/y</td>
</tr>
<tr>
<td>Batteries, substitution</td>
<td>Medium 11.000, Low 4.100, High 22.000</td>
<td>Medium RP 323</td>
</tr>
<tr>
<td>Dental amalgam, substitution*2</td>
<td>Medium 6.600, Low -830, High 18.000</td>
<td>Medium RP 227</td>
</tr>
<tr>
<td>Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning + disposal of captured Hg</td>
<td>Medium 460, Low 390, High 530</td>
<td>Medium RP 340</td>
</tr>
<tr>
<td>VCM production, Hg substitution*1</td>
<td>Medium 160, Low 80, High 230</td>
<td>Medium RP 770</td>
</tr>
<tr>
<td>Measuring and control devices, substitution</td>
<td>Medium 150, Low 5, High 540</td>
<td>Medium RP 264</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution*1</td>
<td>Medium 140, Low 90, High 190</td>
<td>Medium RP 257</td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed divided on 10 years</td>
<td>Medium 32, Low 32, High 32</td>
<td>Medium RP 1.310</td>
</tr>
<tr>
<td>Supply, value of Hg not supplied for allowed uses*1 (distributional effect only)</td>
<td>Medium 25, Low 10, High 40</td>
<td>Medium RP NR*5</td>
</tr>
<tr>
<td>Non-ferrous metals production, env. sound Hg waste storage</td>
<td>Medium 13, Low 1,0, High 24</td>
<td>Medium RP 500</td>
</tr>
<tr>
<td>Permanent env. sound storage of Hg from other supply sources</td>
<td>Medium 1,5, Low 0,9, High 2,0</td>
<td>Medium RP 1.500</td>
</tr>
<tr>
<td>Cement production, optimised fabric filters*4</td>
<td>Medium NR, Low NR, High NR</td>
<td>Medium RP NR</td>
</tr>
<tr>
<td>Coal fired power plants, activated carbon injection (ACI)</td>
<td>Medium NR, Low NR, High NR</td>
<td>Medium RP NR</td>
</tr>
</tbody>
</table>

**Notes:**
- *1: Cost for lifecycle management of Hg wastes not subtracted.
- *2: Air emissions in calculation only include crematoria emissions; real emissions are higher and thus the price per kg Hg will actually be lower.
- *3: If Hg deposited; thereby eliminated from air emissions and circulation in society with by-product acid.
- *4: 98% reduction potential only if filter dust is not re-introduced in cement kiln.
- *5: Attributed to reduced air emissions from non-ferrous metal smelters + permanent storage of other Hg supply. NR = Not relevant.
Table 0-4 summarises the estimated cost effectiveness of included options for mercury reductions in terms of money spent per kg of atmospheric emission reduction it will attain. The same information is presented in the cost curve in Figure 0-4.

The costs are of course higher when calculated per kg of atmospheric mercury emissions abated. This is because only some of the involved mercury amounts are currently released to the atmosphere, while other parts are released to aquatic and terrestrial environments or deposited in landfills/waste deposits.

Depending on the quality of the waste disposal, which is generally poor in the developing regions of the World, substantial parts of the mercury deposited may eventually be released to the broader environment over longer time.
Table 0-4: Summary of cost effectiveness of quantified reduction options in terms of money spent per kg of reduced mercury emissions to the atmosphere, as well as the total reduction potential for each of these options.

<table>
<thead>
<tr>
<th>Reduction option</th>
<th>World (excl EU+Na), CPL adjusted EUR/kg Hg reduced air emissions</th>
<th>Reduction potential t Hg reduced air emissions/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries, substitution</td>
<td>160.000  65.000  340.000</td>
<td>Medium Low High Medium RP</td>
</tr>
<tr>
<td>Dental amalgam, substitution*2</td>
<td>70.000  -7.700  220.000</td>
<td>22</td>
</tr>
<tr>
<td>Coal fired power plants, activated carbon injection (ACI)</td>
<td>25.000  1.800  48.000</td>
<td>280</td>
</tr>
<tr>
<td>VCM production, Hg substitution*1</td>
<td>8.000  3.900  11.690</td>
<td>15</td>
</tr>
<tr>
<td>Cement production, optimised fabric filters*4</td>
<td>6.000  5.400  6.500</td>
<td>134</td>
</tr>
<tr>
<td>Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning + disposal of captured Hg</td>
<td>2.400 € 1.100  3.700</td>
<td>107</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution*1</td>
<td>1.050  1.000  1.100</td>
<td>34</td>
</tr>
<tr>
<td>Measuring and control devices, substitution</td>
<td>940  53  2.500</td>
<td>42</td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed divided on 10 years</td>
<td>71  71  71</td>
<td>590</td>
</tr>
<tr>
<td>Supply, value of Hg not supplied for allowed uses*1 (distributional effect only)</td>
<td>NA  NA  NA</td>
<td>NA</td>
</tr>
<tr>
<td>Non-ferrous metals production, env. sound Hg waste storage</td>
<td>NA  NA  NA</td>
<td>NA</td>
</tr>
<tr>
<td>Permanent env. sound storage of Hg from other supply sources</td>
<td>NA  NA  NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes: *1: Cost for lifecycle management of Hg wastes not subtracted. *2: Air emissions in calculation only include crematoria emissions; real emissions are higher and thus the price per kg Hg will actually be lower. *3: If Hg deposited; thereby eliminated from air emissions and circulation in society with by-product acid. *4: 98% reduction potential only if filter dust is not re-introduced in cement kiln.
Integrated analysis of quantified measures

The starting point for considering a combination of measures is the measures which a global agreement is likely to include. With negotiations ongoing, the final outcome is not known, however the assessment considers some alternative outcomes and estimates the implication on costs and reduction of mercury in circulation and emitted to air. The main scenario made includes all the demand measures\(^4\) that have been analysed and the specific measures to reduce air emissions.

As with any market, the price of mercury is determined by supply and demand and hence, measures which reduce the demand by requiring users to substitute mercury, may lead to reduced mercury prices. Measures that put restriction on the supply will tend to increase the mercury price. The price of mercury is important for the substitution away from using the substance. In principle, the higher the price, the lower is the additional cost of substitution for any given application.

Overall, it is mainly the effectiveness of the education programme for the small scale gold miners (ASGM) which will be affected by changes in the mercury price, while the substitution of dental amalgam and measuring and control devices may be affected to some degree. All these changes primarily affect developing countries and care should be taken to minimise negative effects there on poverty and health care.

---

\(^4\) Measures reducing mercury demand on the global market.
If supply reduction measures would be implemented, they would in principle achieve the reduction of the quantities of mercury in circulation or emitted to air in a cost effective manner. The reduced supply would drive the price up until the demand has been reduced to the level of the reduced supply. The mercury applications with the lowest substitution costs would change to the mercury-free alternatives and no further specific demand regulation would in principle be needed.

If demand measures are implemented, they will lead to a decrease in the mercury price, which will then result in lower supply, or less desirable: Increased demand in ASGM activities due to reduced incentives for good mercury housekeeping. The dedicated mercury mining is the supply source for which the production costs are highest. The other types of supply are by-product mercury from non-ferrous mining or from recycling of mercury, and therefore these quantities of mercury will be offered for sale even at low prices (as far as permanent mercury disposal is more expensive).

The combined scenario includes all the demand measures and in order to balance supply and demand, also the supply measures are included.

The total estimated demand is at the level of 4.500 tonnes per year, so if this global agreement scenario would be implemented, the reduction in mercury demand would be about 3.400 tonnes/year, or a little more than 75% of the current total demand.

In order to reduce supply with the same amount, the following supply measures could be implemented. Other combinations could be selected provided the overall reduction was maintained under this scenario. This selection however minimise new introduction of primary mercury into the economy and makes use of mercury already in circulation in society, while mercury-free alternatives are being developed further for remaining allowed mercury uses.

<table>
<thead>
<tr>
<th>Supply measures</th>
<th>Estimated supply, t/y</th>
<th>Unit costs (disposal), EUR/kg Hg</th>
<th>Reduced supply, t/y</th>
<th>Remaining supply, t/y</th>
<th>Total costs, million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated mercury mining</td>
<td>1.450</td>
<td>0</td>
<td>1.450</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-ferrous metals production*1</td>
<td>500</td>
<td>13</td>
<td>500</td>
<td>0</td>
<td>6,5</td>
</tr>
<tr>
<td>Recycled Hg - from chlor-alkali facilities</td>
<td>800</td>
<td>2</td>
<td>194</td>
<td>606</td>
<td>0,3</td>
</tr>
<tr>
<td>Recycled Hg - recycling of Hg catalysts, wastes and products*2</td>
<td>700</td>
<td>2</td>
<td>-</td>
<td>700</td>
<td>0,0</td>
</tr>
<tr>
<td>Supply from commercial stocks*2</td>
<td>1.007</td>
<td>2</td>
<td>1.007</td>
<td>0</td>
<td>1,5</td>
</tr>
<tr>
<td>Total</td>
<td>4.457</td>
<td>3.151</td>
<td>1.306</td>
<td>8,3</td>
<td></td>
</tr>
</tbody>
</table>

Table 0-5 Supply measures that reduce the amount of Hg in circulation (whole World; based on medium estimates and annualised costs).
Note to table above: *1: Disposal costs for the non-ferrous metal sector are higher per kg of mercury, because part of the waste includes other materials. The full cost is here allocated to mercury, which can be discussed; this affects the overall results little however.*2: Note that the total demand is above the most recent available supply estimates (2007 numbers from Maxson (2009). Additional supply is assumed delivered from commercial stocks.

Note that the total demand is above the most recent available supply estimates (2007 numbers from Maxson (2009). Additional supply is assumed delivered from commercial stocks. The amount supplied from each source is subject to some uncertainty so the mining and recycling might provide slightly higher quantities while changes in stocks provide less. In any case, if demand is reduced by more than 75% it will drive the price down and make dedicated mining unprofitable.

The costs of reducing the supply are here indicated as the costs of permanent environmentally sound disposal of the mercury as regards the by-product from the non-ferrous metals production and most mercury stocks. The costs of ceasing the dedicated mining activities would relate to closing of the mines. These costs have not been estimated.

The distribution effects are important in relation to the supply measures. The mining companies and others with income from sale of mercury will lose that income. It is not a loss to society as it is balanced by increased income to those selling the alternatives to mercury. The distribution effects may typically affect the political feasibility of measures. If the price of mercury as estimated in Section 4 is assumed at around 28 EUR per kg, the total loss of revenue for mercury suppliers globally of reducing supply by around 3.200 tonnes would be around 90 million EUR.

In addition to the demand and supply measures there are measures that focus directly at reducing mercury emissions to air. All the measures combined will have the effects on quantities and costs shown in Table 0-6, where the reductions are attributed to the demand measures.

Note that the costs displayed here and above in this sub-section are the annualised costs. Costs related to the financing needs are illustrated in other sections of the report. The two cost concepts show different results for example if a measure involves an up-front investment. In effect, the only differences are for cost estimates for the measures targeting ASGM and the chlor-alkali sector, as the costs for investment in emission reduction devices are annualised in both concepts in this study.
Table 0-6  Combined effects of the scenario (World excl. EU and North America; based on medium estimates and annualised costs)

<table>
<thead>
<tr>
<th></th>
<th>Reduced Hg in circulation, t/y</th>
<th>Reductions of air emissions, t/y</th>
<th>Total costs, million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand measures</td>
<td>3.151</td>
<td>724</td>
<td>5.300</td>
</tr>
<tr>
<td>Other measures that reduce circulation or air emissions</td>
<td>340</td>
<td>521</td>
<td>8.100</td>
</tr>
<tr>
<td>Supply measures</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>3.491</td>
<td>1.246</td>
<td>13.000</td>
</tr>
<tr>
<td>% of total circulation or air emissions</td>
<td>73%</td>
<td>55%</td>
<td></td>
</tr>
</tbody>
</table>

The estimation of the impacts above has been based on the medium estimates regarding the unit costs of the measures. If costs are instead at the low end of the range, the total annualised costs would be about 3 billion EUR/year, instead of about 13 billion EUR/year. Assuming the high cost estimates would double the total annualised costs to about 26 billion EUR/year. The discrepancy between these numbers and the sums shown in
Table 0-2 above are caused by slightly differing calculation methods at the aggregate level; the differences are however minor considering the associated uncertainties.

The costs for the demand measures are dominated by the costs of substitution for the products: batteries and dental amalgam. An alternative scenario could be to exclude these two mercury applications. The medium costs would in this case be significantly reduced to about 8 billion EUR/year, while the reduction in mercury circulation is changed from 73% to 61%. The reduction in air emissions is more limited, from 55% to 53%, due to the character of the products and their lifecycle. However, air emissions from the lifecycle of these products may be underestimated in existing global inventories.

As mentioned above, the sensitivity analysis for the costs of substitution of batteries and dental amalgam showed that using slightly different assumptions in the calculations would yield 40-70% lower medium costs. These options however remain among the relative more costly in terms of reductions per kg mercury. Should the main results however prove to be most realistic, it could, seen from a purely economical perspective, be considered most beneficial to omit the substitution of batteries and dental amalgam from the convention requirements. Other considerations may however play an important part too, for example the protection of developing countries with a weak waste management infrastructure and weak regulation of products containing hazardous substances.

Societal benefits of mercury reductions
In this study, the effectiveness has been assessed in terms of money per kg mercury reduced. For comparison, the societal benefits in terms of reduced damage costs from IQ reductions caused by mercury intake has however been summarised based on study performed by Pacyna et al (2010). This Nordic Council of Ministers study "Socio-economic costs of continuing the status quo of mercury pollution" estimated the global damage costs of loss of IQ (intelligence) due to intake of mercury from ingestion and inhalation. Note that only this adverse effect was included in the estimate and not other human health and environmental effects. They estimated the damage cost in a "Status quo" mercury release scenario for 2020. This was a "business as usual" scenario with no additional mercury reduction measures implemented, but anticipating an increasing economic activity. The global damage costs assuming a value of IQ loss as in Europe was estimated at 22 billion EUR/y, while the same results adjusted for lower life income etc, in other parts of the World yielded an adjusted damage cost of 8 billion EUR/y.

Taking into account all effects of mercury on human health and the environment, the real damage cost may be several times higher than the estimate mentioned above. With the significant associated uncertainty of both estimated damage costs and the estimated total costs of mercury reductions calculated in this study, it appears that the societal benefits and reduction costs are in the same range, and that the reductions quantified in the current study would reduce these damages significantly.
Major data gaps and uncertainties

It should be noted that this assessment does not include quantifications for all mercury release sources relevant for the negotiation of a mercury convention. Aspects not covered quantitatively in this assessment due to data gaps include:

- Residential heating and industrial boilers
- Pig iron production
- Waste incineration and open waste burning
- Waste disposal
- Contaminated sites
- Additional intentional uses: Lamps, electric/electronic appl., other minor uses.
- Changes in operation cost after substitution of mercury in chlor-alkali production
- Releases to media other than air (indirectly covered as mercury inputs)

Due to data gaps and complexity, some significant uncertainties are associated with the quantitative estimates made. Major uncertainties in the quantifications made include (for details, see report):

- Comparative price level (CPL) factor used
- Coal fired PP: Price and type of reduction systems
- Non-ferrous metal: Current presence of wet gas cleaning
- ASGM cost estimates
- Batteries and dental amalgam: Global market size and substitution prices
- Life cycle management costs for dental amalgam
- Underestimated Hg releases from product waste
1 Introduction

This study analyses the costs and effectiveness of options for a global legally binding instrument on mercury. It takes its outset in the current draft texts for such an instrument (agreement, convention) negotiated in the International Negotiating Committee (INC) constituted by representatives of governments and intergovernmental organisations with UNEP as secretariat. The options selected for mercury release reductions, here termed "measures", are based on the March 2012 draft convention text (UNEP, 2012).

While this study seeks to describe the global situation, this is done with the perspective of the European Union, and the costs and effectiveness assessment is primarily focused on developing regions and countries in economic transition, as well as, for some reduction options, the geographical territory of EU27.

The measures currently covered in the draft negotiation text are the following (not original numbering):

1 Mercury supply
2 International trade in mercury
3 Products and processes
4 Artisanal and small scale gold mining (ASGM)
5 Emissions and releases
6 Storage, wastes and contaminated sites
7 Awareness-raising, research and monitoring, and communication of information
8 Other elements: Institutional arrangements, settlement of disputes, further development of the convention and final provisions.

The measures here numbered 1 through 6 are dealt with individually in this study, and the remaining measures are dealt with on an overview level as depicted below.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Coverage in this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury supply</td>
<td>Yes: Costs of permanent environmentally sound storage of obsolete Hg (+ value of foregone Hg sales)</td>
</tr>
<tr>
<td>International trade in mercury</td>
<td>Yes</td>
</tr>
<tr>
<td>Products and processes</td>
<td>Batteries, dental amalgam, measuring devices, VCM, chlor-alkali</td>
</tr>
<tr>
<td>Artisanal and small scale gold mining (ASGM)</td>
<td>Yes</td>
</tr>
<tr>
<td>Emissions and releases</td>
<td>Coal fired power plants, non-ferrous metal, large scale gold, cement production(others qualitatively)</td>
</tr>
<tr>
<td>Storage, wastes and contaminated sites</td>
<td>Permanent storage of mercury and compounds (other wastes covered qualitatively)</td>
</tr>
<tr>
<td>Awareness-raising, research and monitoring, and communication of information</td>
<td>Covered as &quot;others&quot;</td>
</tr>
<tr>
<td>Other measures: Institutional arrangements, settlement of disputes, further development of the convention and final provisions.</td>
<td>Covered as &quot;others&quot; (incl. administrative elements of all other measures)</td>
</tr>
</tbody>
</table>

Before the cost effectiveness assessment of the individual measures, the geographical scope of the study is discussed in Section 2 and the current state of knowledge of global mercury demand and releases is described in Section 3. The latter is the baseline for the assessment of effectiveness of the individual measures.

Note that continental decimal comma is used in this report, and that all conversions between US dollar (USD) and Euro (EUR) are based on the exchange rate of 1.3191 USD/EUR. This was the exchange rate stated by ECB (2012) for 9 March 2012; a rate which was close to the average for the four month period of November 2011 to February 2012.

Limitations of this study
This study was performed under a contract including about 10 fee-weeks of work, involving also non-assessment activities. It has therefore been necessary to limit the assessment to easily available data and adapting a "best quick estimates" approach. As shown, many of the estimations made are associated with significant uncertainties, which could perhaps have been decreased had more time been available. All results of this study should be considered in this light.
2 Geographical scope and other definitions

This assessment seeks to examine the costs and effectiveness of a global agreement on mercury for each of two geographical scopes: 1) Developing countries plus countries in economic transition, and 2) where relevant and feasible, the EU.

No official definition of developing countries exists within the UN system. Indicative definitions used in UN statistics exist however, see below. Probably the most accurate distinction between developed and developing countries is whether the country is an OECD member or not, as the OECD includes most countries with a high GDP per capita, independent of geographical region. This distinction is used in this study in some cases where source data have been grouped in this way.

In many cases however, data have only been available by geographical region. Using this distinction, Europe and North America (USA and Canada) have been considered here as developed and the rest of the world has been considered here under "developing countries plus countries in economic transition" (or better "the world excluding Europe and North America"). This obviously is not a precise distinction, as several countries outside Europe and North America have high GDP per capita economies and would probably not be eligible for funding by the mercury instrument. It should also be noted that Mexico has been included in available mercury release estimates for North America. The non-availability of more detailed data has dictated the use of these distinctions in the calculations made for this assessment.

Furthermore, some mercury-related data is given for Europe (excluding the Russian Federation), while other data have been given for the EU25 or the EU27. As it has not been possible, within the framework of this report, to collect more detailed data, all these geographical designations have been used as a proxy for EU27. The uncertainties induced by this approximation are considered moderate compared to most other uncertainties involved in the analysis.
United Nations Statistics Division’s indicative definitions of developing regions and regions in economic transition are shown in Table below (UNSD, 2011).

Table 2-1 UN indicative definitions of developing regions and regions in economic transition (UNSD, 2011).

<table>
<thead>
<tr>
<th>Developed and developing regions c/</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing regions</td>
</tr>
<tr>
<td>002  Africa</td>
</tr>
<tr>
<td>019  Americas excluding Northern America (numerical code 021)</td>
</tr>
<tr>
<td>029  Caribbean</td>
</tr>
<tr>
<td>013  Central America</td>
</tr>
<tr>
<td>005  South America</td>
</tr>
<tr>
<td>142  Asia excluding Japan</td>
</tr>
<tr>
<td>009  Oceania excluding Australia and New Zealand (numerical code 053)</td>
</tr>
<tr>
<td>Developed regions</td>
</tr>
<tr>
<td>021  Northern America</td>
</tr>
<tr>
<td>150  Europe</td>
</tr>
<tr>
<td>392  Japan</td>
</tr>
<tr>
<td>033  Australia and New Zealand</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transition countries d/</th>
</tr>
</thead>
<tbody>
<tr>
<td>172  Commonwealth of Independent States</td>
</tr>
<tr>
<td>051  Armenia</td>
</tr>
<tr>
<td>031  Azerbaijan</td>
</tr>
<tr>
<td>112  Belarus</td>
</tr>
<tr>
<td>298  Kazakhstan</td>
</tr>
<tr>
<td>417  Kyrgyzstan</td>
</tr>
<tr>
<td>498  Republic of Moldova</td>
</tr>
<tr>
<td>662  Russian Federation</td>
</tr>
<tr>
<td>762  Tajikistan</td>
</tr>
<tr>
<td>795  Turkmenistan</td>
</tr>
<tr>
<td>604  Ukraine</td>
</tr>
<tr>
<td>660  Uzbekistan</td>
</tr>
</tbody>
</table>

**Transition countries of South-Eastern Europe**

| 008  Albania                                |
| 070  Bosnia and Herzegovina                 |
| 191  Croatia                                |
| 498  Montenegro                             |
| 660  Serbia                                |
| 807  The former Yugoslav Republic of Macedonia |

a/ The designation sub-Saharan Africa is commonly used to indicate all of Africa except northern Africa, with the Sudan included in sub-Saharan Africa.

b/ The continent of North America (003) comprises Northern America (021), Caribbean (029), and Central America (013).

c/ There is no established convention for the designation of "developed" and "developing" countries or areas in the United Nations system. In common practice, Japan in Asia, Canada and the United States in northern America, Australia and New Zealand in Oceania, and Europe are considered "developed" regions or areas. In international trade statistics, the Southern African Customs Union is also treated as a developed region and Israel as a developed country; countries emerging from the former Yugoslavia are treated as developing countries and countries of Eastern Europe and of the Commonwealth of Independent States (code 172) in Europe are not included under either developed or developing regions.

d/ "Countries in transition from centrally planned to market economies" is a grouping used for economic analysis.
OECD members

The energy statistics reported by the International Energy Agency, IEA, which are also used in this assessment, refer to a distinction of OECD members and non-OECD members as follows:

OECD members currently (February 2012) include: Australia, Austria, Belgium, Canada, Chile (since 2010), Czech Republic, Denmark, Estonia (since 2010), Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel (since 2010), Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia (since 2010), Spain, Sweden, Switzerland, Turkey, United Kingdom, United States (OECD, 2012).

Note that OECD members coincide with the regions indicated as developed in the UN Statistics indicative definitions above, except Mexico, the Republic of Korea and the new members Chile and Israel.

2.1 Regional price differentiation

In this report most of the estimated costs were calculated based on prices in the EU or North America, because these prices were the only available and comparable prices. For certain specified measures, additional cost estimates were calculated adjusted for the differences in price levels in the EU/North America and the rest of the world.

The price levels in the EU and in North America are considered as roughly the same in this study. As an approximation to average price levels in the rest of the world, a comparative price level index (CPL) derived by the OECD for Turkey was used. The CPL for Turkey was index 59 in 2011 where the average CPL for OECD members was index 100. Turkey had the lowest CPL among OECD members and was thus deemed the most relevant proxy for the average situation for the world excluding EU and North America. CPL’s were not available for non-OECD countries. The average CPL for the World excluding the EU and North America is thus not known, but it may deviate from the value of Turkey, and this number may be seen as a root to major uncertainty on the overall results of the assessment.

2.2 Interest rate and discounting principles

In all discounting of investments, an interest rate of 4% pro anno was used.

As per general economic theory, one time investments with infinite effect (as the cessation of mercury use in chlor-alkali conversion) is discounted with 4% of the investment per year infinitely.
3 Current mercury demand and releases

This section presents the currently best available estimates for mercury demand by application and for mercury releases to the atmosphere. These data form the basis for the assessment of mercury reduction potentials in this study. Unless otherwise noted, the data are estimates for 2005. The data sources for most of the data are either UNEP/AMAP (2008) or UNEP (2010b); for other sources; see table notes.

Note that data for atmospheric emissions from by-product sources and waste treatment are given for Europe, while data for mercury demand and atmospheric releases for most (but not all) intentional uses are given for the EU25. In the analysis of this study, EU25 and Europe are used as covering approximately the EU27, as the available data do not allow for a more precise distinction. This inaccuracy is deemed to induce a moderate uncertainty to the analysis made.

In the assessment, data from Table 3-1 was used for by-product sources (such as coal fired power plants), whereas Table 3-2 was used for intentional mercury use sources. There is a certain overlap between the tables. They were however kept in this display to show and summarise over each of the two inventory approaches used in the data sources. By-product sources in Table 3-1 include coal and oil combustion, non-ferrous metal production (Zn+Pb+Cu+ large scale gold), pig iron and steel production and cement production. Intentional mercury use sources in the tables include mercury production (not a use, but done to supply mercury to intentional use), ASGM, VCM production, chlor-alkali production with mercury cells, batteries, dental amalgam, measuring and control devices with mercury added, fluorescent lamps etc., electrical and electronic devices with mercury added and "other intentional uses" (porosimetry, PUR catalysts and various minor uses).

Waste incineration and "other waste" are actually in a mixed category because the mercury originates from both intentional use and from the un-intentional trace content of many materials. In the source documents, UNEP/AMAP (2008) or UNEP (2010b), they are reported with the by-product sources.

Current global estimates for mercury releases to other environmental media are not available at present.
### Table 3-1 Anthropogenic mercury releases to the atmosphere from major sources (data sources, see table notes).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Region</th>
<th>Releases to air 2005, t/y*1</th>
<th>Air rel. globally, range (t/y) and remarks*2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal and oil combustion in power plants/industrial boilers</td>
<td>World (excl. Eur+Na)</td>
<td>732,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>76,6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>71,2</td>
<td></td>
</tr>
<tr>
<td>- Including from fossil fuel combustion in power plants</td>
<td>World</td>
<td>880</td>
<td>Large (339-657), residential and other small (257-506)</td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>396</td>
<td>(237-555)</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>498</td>
<td>Large (339-657)</td>
</tr>
<tr>
<td>- Including from residential heating and industrial boilers</td>
<td>World</td>
<td>371</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Non-ferrous metal production (Zn+Pb+Cu)</td>
<td>World (excl. Eur+Na)</td>
<td>114</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>5,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>132</td>
<td>(80-185)</td>
</tr>
<tr>
<td>Pig iron and steel production</td>
<td>World (excl. Eur+Na)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>14,4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>61</td>
<td>(35-74)</td>
</tr>
<tr>
<td>Cement production</td>
<td>World (excl. Eur+Na)</td>
<td>160</td>
<td>(85-234)</td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>18,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>10,9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>189</td>
<td>(114-263)</td>
</tr>
<tr>
<td>Gold production (large scale)</td>
<td>World (excl. Eur+Na)</td>
<td>98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>12,9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>111</td>
<td>(66-156)</td>
</tr>
<tr>
<td>ASGM</td>
<td>World (excl. Eur+Na)</td>
<td>657</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>Mercury production</td>
<td>World (excl. Eur+Na)</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>9</td>
<td>(5-12)</td>
</tr>
<tr>
<td>Waste incineration (incomplete/large scale from developed countries only)</td>
<td>World (excl. Eur+Na)</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>10,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>15,1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>42</td>
<td>(57-627*6)</td>
</tr>
<tr>
<td>Chlor-alkali production</td>
<td>World (excl. Eur+Na)</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>6,3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>6,5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>46,8</td>
<td>(29-64)</td>
</tr>
<tr>
<td>Other quantified sources</td>
<td>World (excl. Eur+Na)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>14,7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>7,2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>26</td>
<td>(?)</td>
</tr>
<tr>
<td>Other waste</td>
<td>World</td>
<td>74</td>
<td>(57-156? *7)</td>
</tr>
<tr>
<td>Crematoria (dental amalgam)</td>
<td>World</td>
<td>37</td>
<td>(?)</td>
</tr>
<tr>
<td>Total for these sectors</td>
<td>World (excl. Eur+Na)*8</td>
<td>1,966</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe (excl. Russia), &quot;Eur&quot;</td>
<td>146</td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td></td>
<td>World*9</td>
<td>2,257</td>
<td></td>
</tr>
</tbody>
</table>

Notes to table above: *1: Air emissions 2005 from UNEP/AMAP GAMA tech, background report, 2008, except for numbers in bold which were derived (new global data minus old from EUR and NA) from updates in §29 study by
Table 3-2 Mercury demand (input) and atmospheric releases for intentional uses of mercury (sources, see table notes).

<table>
<thead>
<tr>
<th>Hg application</th>
<th>Region</th>
<th>Quantiﬁed Hg input to sector 2005, t/y</th>
<th>Air rel. 2005 *1, t/y</th>
<th>Air rel: globally, range (t/y) /remarks*1,</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>ASGM*2</td>
<td>World (excl. EU25+Na)</td>
<td>1.458</td>
<td>1.195</td>
<td>1.791</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>1.465</td>
<td>1.200</td>
<td>1.800</td>
</tr>
<tr>
<td>VCM production</td>
<td>World (excl. EU25+Na)</td>
<td>770</td>
<td>715</td>
<td>825</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>770</td>
<td>715</td>
<td>825</td>
</tr>
<tr>
<td>Dental*3,*5</td>
<td>World (excl. EU25+Na)</td>
<td>257</td>
<td>225</td>
<td>290</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>175</td>
<td>155</td>
<td>195</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>60</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>492</td>
<td>435</td>
<td>550</td>
</tr>
<tr>
<td>Batteries</td>
<td>World (excl. EU25+Na)</td>
<td>323</td>
<td>240</td>
<td>408</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>28</td>
<td>20</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>19</td>
<td>17</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>370</td>
<td>277</td>
<td>463</td>
</tr>
<tr>
<td>Dental*3,*5</td>
<td>World (excl. EU25+Na)</td>
<td>227</td>
<td>193</td>
<td>261</td>
</tr>
<tr>
<td></td>
<td>EU25 (data from 10 countries)</td>
<td>95</td>
<td>85</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>40</td>
<td>35</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>362</td>
<td>313</td>
<td>411</td>
</tr>
<tr>
<td>Measuring and control devices</td>
<td>World (excl. EU25+Na)</td>
<td>264</td>
<td>250</td>
<td>280</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>38</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>48</td>
<td>40</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>350</td>
<td>320</td>
<td>380</td>
</tr>
<tr>
<td>Lamps</td>
<td>World (excl. EU25+Na)</td>
<td>85</td>
<td>79</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>25</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>25</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>135</td>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>Electrical and electronic devices (other)</td>
<td>World (excl. EU25+Na)</td>
<td>125</td>
<td>115</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>15</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>60</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>200</td>
<td>180</td>
<td>220</td>
</tr>
<tr>
<td>Other*6</td>
<td>World (excl. EU25+Na)</td>
<td>110</td>
<td>90</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>113</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>90</td>
<td>60</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>313</td>
<td>225</td>
<td>400</td>
</tr>
<tr>
<td>Totals for these applications</td>
<td>World (excl. EU25+Na)</td>
<td>3.621</td>
<td>3.785</td>
<td>5.199</td>
</tr>
<tr>
<td></td>
<td>EU25</td>
<td>492</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>North America, &quot;Na&quot;</td>
<td>344</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>World</td>
<td>4.457</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4 Mercury supply

Summary of the key features of the measure and its potential impacts
The objective of the measure is to restrict global mercury supply as much as possible to match demand for mercury uses, which are allowed under the convention and ensure environmentally sound storage of surplus mercury. The exact wording of the measure is under discussion in the INC and several alternatives are under consideration. Another objective is the environmentally sound storage of mercury and selected mercury compounds from the list of current supplier categories given in Annex A to the draft convention text (see list below).

The global supply situation has substantial influence on the consumption and releases of mercury, especially in artisanal and small scale gold mining and other activities in the developing world. Reduction of supply is expected to increase the price and reduce the availability of mercury and thereby discourage consumption and improve the mercury "house-holding" practices in these activities. Reduction of supply has the potential to reduce global mercury releases significantly and this measure can be considered a key measure of the convention.

4.1 Who will be affected?

Annex A of the draft convention text includes the mercury sources listed below. The supply sources retained in the final convention text cannot be predicted at this stage. Brackets from the original document indicate (additional) suggestions for sources to be included or alternative wording.
A ban of dedicated mercury mining is proposed in the draft convention text. The few current producers of primary mercury from dedicated mercury mining are local or national scale companies in Kyrgyzstan and China.

The producers of by-product mercury from production of other non-ferrous metals are primarily a relatively small number of multinational mining companies, but also some local and national scale companies exist. As mercury is a natural constituent of the ores processed, it would need to be environmentally soundly disposed of, to the extent it cannot be sold for allowed uses. While some non-ferrous metal production plants may already have such disposal facilities, others may need to improve their facilities to meet the standards to be defined by the COP of the convention. In this assessment, we have assumed that these standards would approach the current standards for such waste in the EU. As regards the internal EU situation, the provisions of the Regulation (EC) No 1102/2008 on mercury export ban and safe storage do not yet include criteria for permanent disposal of these waste types, so only temporary storage is allowed.

Local populations as well as the global population and environment will benefit from mercury release reductions in the sector. Non-ferrous metal extraction may have significant local environmental effects and the sector contributes significantly to the global mercury pool in the biosphere.

Compared to the rest of the world, the EU is rather advanced in the management of global mercury supply. EU primary (dedicated) mercury production has ceased with the closure of the Almadén mining activities in 2003, and according to Regulation (EC) No 1102/2008, metallic mercury extracted from cinnabar ore, by-product mercury from non-ferrous metal extraction and the cleaning of natural gas, and mercury no longer in use in the chlor-alkali industry shall be considered waste and be disposed of as of 15 March 2011. Import and EU produced recycled mercury from other sources are thus the only remaining allowed mercury supply
sources within the EU. Regulation (EC) No 1102/2008 will probably cover much of the scope of the current draft convention text in terms of supply provisions. The convention may however go beyond the scope of the current EU ban, for example by including more mercury-containing compounds. If this would be the case, EU industry may be affected.

As regards extra-EU costs, that is, costs in the World except EU and North America, there may be a need for assisting local or national scale companies in the re-direction of by-product mercury from being placed on the market to environmentally sound waste disposal. This may be in the form of demonstration or implementation projects in selected countries, or as loans/grants.

As for dedicated mercury mining there will be a need for promotion of alternative sources of income.

UNEP (2011a) summarises the permanent storage provision of the measure and the needs for funding as shown below.

<table>
<thead>
<tr>
<th>Function</th>
<th>Support needed for</th>
<th>Magnitude of need</th>
<th>Magnitude of funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Reducing the global mercury supply through the environmentally sound storage of elemental mercury;</td>
<td>Environmentally sound permanent/long-term storage of elemental mercury - Establishing temporary/interim/new storage facilities, possibly at national and/or regional/sub-regional levels. For most Parties, these facilities would be small. - Enhancing existing storage facilities.</td>
<td>From data collected through activities of the mercury supply and storage partnership area, it is estimated that the total worldwide mercury supply will exceed demand, between 2010 and 2050, by between 28,000 and 46,000 tonnes, or an average of between 700 and 1,150 tonnes per year. Provision will need to be made for this excess to be removed from the market and placed in storage. Temporary or interim storage might be required at the national level prior to transport for final storage or disposal. Most Parties would need to store only small quantities of mercury, and costs could be reduced by arranging temporary storage at existing hazardous waste facilities or at the mining and industrial facilities responsible for generating mercury releases. Regional and sub-regional storage facilities may be envisaged as a cost-effective way of ensuring sufficient storage capacity.</td>
<td>Low: To establish or enhance existing hazardous waste facilities for temporary storage at the national level. High: For regional and subregional storage, unless existing facilities can be used. Various stabilization technologies are being developed, which may make it easier, safer and less costly to manage, transport, store and dispose of excess mercury, although such stabilization may increase the volume of material to be stored.</td>
</tr>
</tbody>
</table>

4.2 Potential barriers to implementation

Mining companies are an important economic sector globally. The sector may react to supply reduction schemes, and the companies involved may request compensation for foregone sales of mercury and for costs associated with environmentally sound storage of mercury containing wastes.
A lack of uniform regulation globally, if some countries do not become parties to a mercury convention, would induce market distortions, and this could be highly sensitive for the competitiveness of the sector.

4.3 Background information

The distribution of mercury supply by source type has been estimated by Maxson (2009). The global supply estimates are shown in Table 4-1 below.

<table>
<thead>
<tr>
<th>Mercury supply, by main sources*1</th>
<th>Supply, t Hg/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated mercury mining</td>
<td>1.300-1.600</td>
</tr>
<tr>
<td>By-product mercury from non-ferrous metal sector</td>
<td>400-600</td>
</tr>
<tr>
<td>Recycling/re-use from chlor-alkali facilities</td>
<td>700-900</td>
</tr>
<tr>
<td>Recycling of mercury from catalysts, production wastes and products</td>
<td>600-800</td>
</tr>
<tr>
<td>Commercially available mercury stocks</td>
<td>As needed (+)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.000-3.900+</strong></td>
</tr>
</tbody>
</table>

Note: *1: Recent update for mercury demand for ASGM indicates that the current mercury supply may be higher

As shown in the table, primary mercury mining and by-product mercury from other mining activities constituted the major sources of mercury supply in 2007, and this is likely still the case. With the demand reduction measures included in this study, this means that by-product mercury sources, recycled mercury and/or obsolete mercury from various stocks will also be affected by efforts to reduce supply; see section 11.1.

The USGS (2011) estimated the following supply and reserves of mercury globally for 2009 and 2010. Note that export from the European Union has been prohibited since March 2011, as a consequence of the new EU export ban.
Table 4-2  Estimated global mine production of mercury according to USGS (2011, 2012), t/y.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>United states</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Chile (by-product)</td>
<td>NA</td>
<td>173</td>
<td>100</td>
</tr>
<tr>
<td>China</td>
<td>1,400</td>
<td>1,600</td>
<td>1,400</td>
</tr>
<tr>
<td>Kyrgyzstan</td>
<td>250</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Mexico (reclaimed)</td>
<td>NA</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>Peru (by-product)</td>
<td>140</td>
<td>102</td>
<td>35</td>
</tr>
<tr>
<td>Spain</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Other countries</td>
<td>130</td>
<td>100</td>
<td>130</td>
</tr>
<tr>
<td>World (rounded)</td>
<td>1,920</td>
<td>2,250</td>
<td>1,930</td>
</tr>
</tbody>
</table>

Notes: e: Estimated; 5: reference to USGS definitions of reserves; see reference for explanation.

4.4 Mercury inputs and air emissions

Table 4-3  Overview of baseline mercury turnover related to the measure, World.

<table>
<thead>
<tr>
<th>Measure/options</th>
<th>Input of Hg, t/y</th>
<th>Hg releases to atmosphere, t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg supply</td>
<td>3,100-3,900</td>
<td>931 (at least; from intentional Hg use)</td>
</tr>
</tbody>
</table>

4.5 Expected costs

The primary additional societal costs associated with the implementation of the supply measure are the costs of environmentally sound disposal of by-product mercury from the non-ferrous metal sector.

The costs for cleanup of the mercury mining facilities and their surroundings to an acceptable environmental standard have not been included due to the lack of data on the actual local needs and associated costs.

The measure involves several distributional effects, i.e. where some actors will face reduced incomes while others will have increased income. The major cost in this category is the cost of foregone sales of commodity mercury. As this cost may have importance for the negotiations, it is quantified here.

Note that the costs for mercury users resulting from the need to substitute with mercury-free technologies are covered in Section 6 on products and processes, and the costs associated with public administration of the supply measure in the Parties to the convention is dealt with in Section 10 on other measures.
Cost of foregone profits from mercury sales

UNEP (2010a) described the potential cost of reduction of primary mining as follows: "The costs for abatement of mercury emissions via reduction in mercury mining will vary according to local conditions. As an example, the mercury mine in Algeria was put out of use in 2003 due to unprofitability, not environmental reasons (MBM, 2005). But mercury is an important metal for some purposes, and easy access to this metal might be considered important for economic growth in some regions, for example China. From the production side, foregone profits if terminating a mercury mine might be offset by other investment opportunities, but the major part of the costs will be born by mercury buyers who are short of substitutes for mercury." With higher mercury prices, the incentives for dedicated mercury production may rise in case a ban is not introduced in the convention.

The European Commission (2011a) described the expected mechanisms involved in the price development of mercury in case of changes in supply and demand:

"The price of mercury will, everything else being equal, go up with decreases in supply (mines closing, export bans, etc.). The price of mercury will go down with restrictions on demand (product and process use bans), or when more cost-effective alternatives to mercury are available.

The demand for mercury, and thus its price, is also influenced by the demand for those products and processes that use mercury.

It is not possible to say with certainty what the effect on the direction of prices (increase/decrease) of simultaneously introducing restrictions on supply and demand will be, as those restrictions will work in opposite directions. The final effect on the price of mercury will depend on the extent of those restrictions but as well as on how responsive aggregate supply and demand are to changes in mercury prices."

US Geological Survey’s mineral commodity summary for mercury (USGS, 2011) quotes Platts Metals Week on average prices per mercury flask in the US as shown in Table 4-4. The 2010 prices were estimated, yet the price in October 2010 was USD 1.450 per flask. The higher price is explained as resulting from increased gold prices and the export bans in the EU and US. Following the EU export ban entry into force in March 2011, prices averaged USD 1,950 per flask. It should be noted that prices can vary significantly and frequently depending on demand, quality and amounts sold.

Given that the global market for mercury is not fully competitive and that the price for mercury is dependent on the specific quantity and quality being traded, the observed trading price for individual trades can vary significantly. The US Geological Survey price data is used in what follows in a range of USD 600 (2009) to USD 1,950 (2011) per flask (USD 17 to 57 per kg Hg).

---

5 One flask = 34.5 kg Hg
Table 4-4  

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average price, USD/flask</td>
<td>670</td>
<td>530</td>
<td>600</td>
<td>600</td>
<td>1.076</td>
<td>1.950</td>
</tr>
</tbody>
</table>

The European Commission (2011a) used these prices and projections of the mercury demand to estimate the value (in ranges) of the total global supply of mercury as shown in Table 4-5. According to the European Commission, "the value figures are in real terms for 2007 prices and October 2010 prices respectively, but no discount rate has been applied. The aggregate market for mercury supplies is expected to experience a sharp reduction in value in 2011 as the EU export ban comes into force. The US ban is not included in the supply figures. The EU export ban restrictions on supplies could be expected to lead to a higher price for mercury. This effect is to an extent reflected in the high price scenario of October 2010." Note also that the consequences of a global convention on mercury are not reflected in either the projected supply numbers or the derived sales value estimates.

It should also be noted that the values derived are total sales values, and not profits, and thus the costs for production and marketing of the mercury should ideally be subtracted to find the real value of the foregone mercury sales.

An idea of the fluctuation of mercury prices can also be established by analysing trade statistics for mercury import to and export from EU27 as shown in Table 4-6, Table 4-7 and Figure 4-1. The prices registered by the customs authorities may likely reflect bulk sales of mercury. It is worth noting a considerable price difference between imports and exports. The possibility of errors and bias in the registered values cannot be ruled out, but the value of exports seems to be relatively persistently at slightly above the double of the import value. The difference may indicate that the expenses associated with mercury production and trade most likely represent less than half of the sales value on the world market.
Figure 4-1 Development of mercury prices 2002-2010 derived from EU trade statistics.

Table 4-6 Import to and export from the EU27 of mercury and derived mercury prices.

<table>
<thead>
<tr>
<th>Export</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total EXTRA-EU27, tonnes</td>
<td>1.287</td>
<td>804</td>
<td>684</td>
<td>403</td>
<td>265</td>
<td>598</td>
<td>599</td>
<td>1.206</td>
<td>966</td>
</tr>
<tr>
<td>Export EUR/flask</td>
<td>207</td>
<td>234</td>
<td>320</td>
<td>739</td>
<td>694</td>
<td>413</td>
<td>470</td>
<td>399</td>
<td>638</td>
</tr>
<tr>
<td>USD/flask</td>
<td>267</td>
<td>302</td>
<td>414</td>
<td>955</td>
<td>896</td>
<td>534</td>
<td>607</td>
<td>515</td>
<td>824</td>
</tr>
<tr>
<td>Import</td>
<td>2,002</td>
<td>2,003</td>
<td>2,004</td>
<td>2,005</td>
<td>2,006</td>
<td>2,007</td>
<td>2,008</td>
<td>2,009</td>
<td>2,010</td>
</tr>
<tr>
<td>Total EXTRA-EU27, 1000 EUR</td>
<td>473</td>
<td>416</td>
<td>1,000</td>
<td>1,862</td>
<td>2,257</td>
<td>1,354</td>
<td>1,781</td>
<td>1,184</td>
<td>1,971</td>
</tr>
<tr>
<td>Total EXTRA-EU27 tonnes</td>
<td>166</td>
<td>174</td>
<td>518</td>
<td>276</td>
<td>258</td>
<td>275</td>
<td>251</td>
<td>396</td>
<td>99</td>
</tr>
<tr>
<td>Import EUR/flask</td>
<td>98</td>
<td>82</td>
<td>67</td>
<td>233</td>
<td>302</td>
<td>170</td>
<td>245</td>
<td>103</td>
<td>687</td>
</tr>
<tr>
<td>USD/flask</td>
<td>126</td>
<td>106</td>
<td>86</td>
<td>301</td>
<td>390</td>
<td>219</td>
<td>316</td>
<td>133</td>
<td>887</td>
</tr>
</tbody>
</table>

Table 4-7 Average mercury prices derived from EU27 trade statistics for the period 2002-2010.

<table>
<thead>
<tr>
<th>Export</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Export EUR/flask</td>
<td>207</td>
<td>739</td>
<td>457</td>
</tr>
<tr>
<td>USD/flask</td>
<td>273</td>
<td>975</td>
<td>603</td>
</tr>
<tr>
<td>Difference to average in % of average</td>
<td>-55%</td>
<td>62%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Import</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Import EUR/flask</td>
<td>67</td>
<td>687</td>
<td>221</td>
</tr>
<tr>
<td>USD/flask</td>
<td>88</td>
<td>907</td>
<td>291</td>
</tr>
<tr>
<td>Difference to average in % of average</td>
<td>-70%</td>
<td>211%</td>
<td></td>
</tr>
</tbody>
</table>

The value of foregone sales of mercury on the world market can be estimated at 19-110 million EUR/y depending on the price development and the amount of mercury not sold, based on the data summarised in Table 4-8.
Table 4-8  Estimated value of foregone mercury sales.

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS Hg price quotes, 2009/2011, USD/kg Hg</td>
<td>17</td>
<td>57</td>
</tr>
<tr>
<td>- Do, EUR/kg Hg (effectiveness, Hg eliminated from circulation)</td>
<td>13</td>
<td>43</td>
</tr>
<tr>
<td>Hg amounts not sold (short/long term), t/y</td>
<td>1.700</td>
<td>3.300</td>
</tr>
<tr>
<td>Value of foregone Hg sales, mill. EUR/y*1 (rounded)</td>
<td>22</td>
<td>140</td>
</tr>
</tbody>
</table>

Notes: *1: Based on USGS price quotes shown above, as trade statistics may have higher uncertainty.

The value of the foregone Hg sales is primarily a distribution effect, as is some the effects of price changes. If the reduction of Hg supply results in increased prices, those that still supply mercury will see their profits increase. The intended effect of reducing the supply is to increase the price and thereby give incentive to reduce the use of mercury in the various applications.

Increased prices of mercury may affect the prices of remaining products produced with or containing mercury, and thus ultimately be paid by consumers. The effects of increased mercury prices on the price of mercury-added products may be expected to be minimal, as mercury in most cases constitute only a minor fraction of the mercury-added product. Increased mercury prices are however a desired driver for reduced mercury releases from diffuse or un-regulated mercury usage such as illegally performed ASGM, as well as for pushing consumers towards buying mercury-free alternative products.

Costs of environmentally sound disposal of mercury from the nonferrous metal sector

Assuming that primary mercury mining would be terminated upon the entering into force of a supply ban of a global mercury convention, only excess mercury from other supply sources will have to be stored safely instead of being marketed. We here distinguish between primary (new) mercury extracted from the underground as by-product from non-ferrous metal production, and excess recycled mercury metal which has already been in circulation in society (including strategic and other stocks of mercury).

As regards by-product mercury, it should also be kept in mind that a cessation of mercury marketing from by-product sources may in the long run affect the choice of technology employed to retain mercury from being released or contaminating other products (sulphuric acid, etc.) from the non-ferrous metals sector. New mining operations increasingly use hydrometallurgical extraction methods (direct leach) where mercury and other contaminants need not be retained from process gases, but remain in waste sludges, which need to be disposed under environmentally sound conditions.

As described below, the costs of permanent disposal of pure or almost pure mercury in Europe under conditions considered environmentally sound are around
0.9-2 EUR/kg, depending on the specific treatment and conditions. These prices may likely exceed costs of depositing locally generated mercury-containing waste on on-site tailings and sludge deposits of the non-ferrous metal extraction industry outside Europe and North America. The prices are however used as a best available estimate.

Mercury-containing solid waste fractions from primary non-ferrous metal production based on sulphidic ore concentrates (zinc, lead, large scale gold, copper) generally have relatively high mercury concentrations. Outotec (2012) gives the following examples of what they consider typical ranges for the mercury content in the drained sludge from the wet gas cleaning of non-ferrous smelters (counted as weight-% on dry matter basis). Please see Section 8.4.2 for further explanation of the fate of mercury in the non-ferrous metal sector.

**Table 4-9 Examples of typical mercury concentrations in waste types from non-ferrous metal smelters.**

<table>
<thead>
<tr>
<th>Waste type</th>
<th>Typical Hg concentration (% of dry weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calomel (mercury-chloride) from Hg removal with Boliden Nordzink process</td>
<td>85%</td>
</tr>
<tr>
<td>Drained sludge from the wet gas cleaning of zinc smelters</td>
<td>10-60%</td>
</tr>
<tr>
<td>Drained sludge from the wet gas cleaning of lead smelters</td>
<td>1 - 10%</td>
</tr>
<tr>
<td>Drained sludge from the wet gas cleaning of copper smelters</td>
<td>0.1 - 5%</td>
</tr>
</tbody>
</table>

According to Outotec (2012), mercury in wet gas cleaning sludges from non-ferrous smelters is present as mercury selenide and mercury sulphide, both with low solubility in the diluted sulphuric acid slurry produced in the gas cleaning devices. In the bleed from the wet gas filter system, in most cases the suspended particles are separated as sludge before the liquid phase continues to an effluent treatment plant. This sludge has high concentrations of heavy metals and is often deposited separately.

Based on the above, it is assumed here that the mercury in wet gas cleaning sludges need not to be stabilised further, prior to permanent deposition.

As regards the calomel (mercury chloride) produced from the dominating mercury specific removal method, the stabilisation with sulphur yielding the more stable mercury sulphide before permanent storage, is already practised in some non-ferrous metal smelters. For example in the Boliden Odda Zinc smelter in Norway (formerly Norzink), where the resulting mercury sulphide is deposited in secured caverns in the mountains close to the smelter. One of the less used methods available for mercury removal from non-ferrous smelters, the thiosulphate method, actually produces mercury sulphide as the end product. This method is however
somewhat more expensive than the dominating Boliden-Nordzink process described in Section 8.4.2 and is mainly used where very low residual concentrations of mercury in the produced sulphuric acid are needed (a few plants currently; Outotec, 2012). Accordingly, costs for stabilisation of the mercury in calomel from mercury removal are included in the overall cost estimates for environmentally sound disposal of by-product mercury from the non-ferrous smelter sector.
Table 4-10 below presents cost estimates for the environmentally sound permanent disposal of mercury containing waste from the non-ferrous metal sector in case all such waste with mercury is deposited instead of the mercury being marketed, and assuming an equal distribution of the deposited mercury between 1) wet gas cleaning sludge and 2) calomel and similar products of specific mercury removal from the sector.
### Table 4-10 Cost estimation for environmentally sound permanent disposal of mercury containing waste from non-ferrous smelters.

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Hg amount to be deposited, t/y</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>Assumed Hg fraction of above in calomel t/y</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Assumed Hg fraction in gas cleaning sludges t/y</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>Typical Hg concentration in gas cleaning sludge *1:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- from zinc production</td>
<td>0.1</td>
<td>0.6</td>
</tr>
<tr>
<td>- from lead production</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>- from copper production</td>
<td>0.001</td>
<td>0.05</td>
</tr>
<tr>
<td>Estimated amount of gas cleaning sludge weighted according to global production of Zn, Pb, Cu and Au, t/y</td>
<td>800</td>
<td>8000</td>
</tr>
<tr>
<td>Price for permanent disposal of calomel; with or without sulphur stabilisation, EUR/kg Hg *2</td>
<td>0.9</td>
<td>2</td>
</tr>
<tr>
<td>Price for permanent disposal of gas cleaning sludge, EUR/kg Hg *3</td>
<td>0.9</td>
<td>2</td>
</tr>
<tr>
<td>Costs for permanent disposal of calomel; with or without sulphur stabilisation, million EUR/y</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Costs for permanent disposal of gas cleaning sludge, million EUR/y</td>
<td>0.72</td>
<td>16</td>
</tr>
<tr>
<td>Total cost estimate for permanent disposal, million EUR/y</td>
<td>1.0</td>
<td>16</td>
</tr>
<tr>
<td>Estimated cost in EUR/kg Hg,</td>
<td>1.7</td>
<td>40</td>
</tr>
<tr>
<td>CPL adjusted results:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total cost estimate for permanent disposal, million EUR/y, CPL adjusted</td>
<td>0.59</td>
<td>9.4</td>
</tr>
<tr>
<td>Estimated cost in EUR/kg Hg, CPL adjusted</td>
<td>1.0</td>
<td>24</td>
</tr>
</tbody>
</table>

Costs of environmentally sound disposal of excess mercury from other supply sources

The following pertains to the permanent disposal (retirement) of surplus metallic mercury from non-mining supply sources, that is: pure mercury or other waste material with very high mercury concentration.

Assuming, as currently expected, that primary mercury mining would be terminated upon the entering into force of a supply ban of a global mercury convention, only excess mercury from other supply sources will have to be stored
safely instead of being marketed. We here distinguish between primary (new) mercury extracted from the underground as by-product from non-ferrous metal production, and excess recycled mercury metal which has already been in circulation in society (including strategic and other stocks of mercury).

Environmentally sound disposal of mercury containing waste basically means disposal which effectively prevents spreading of the mercury from the deposited waste to the environment. Mercury releases from waste can happen with air through mercury evaporation, with water, dissolved or suspended, or with physical movement of the waste through human activity for example during construction works on former waste deposits, or through natural geological processes including for example ice movements during ice ages. The working environment of persons operating the deposit must also be secured.

A range of different disposal options are described and assessed in the European Commission study entitled "Requirements for facilities and acceptance criteria for the disposal of metallic mercury" (BIPRO, 2010). Based on their economic and environmental assessment the following options were recommended:

- Pre-treatment (Sulphur stabilisation) of metallic mercury and subsequent permanent disposal in salt mines (highest level of environmental protection, acceptable costs).
- Pre-treatment (Sulphur stabilisation) of metallic mercury and subsequent permanent disposal in a hard rock underground formation (high level of environmental protection, acceptable costs).
- Permanent Disposal of metallic mercury in salt mines (high level of environmental protection, most cost effective option).

Pre-treatment of metallic mercury with a subsequent permanent disposal in above ground facilities was also assessed in the study, but was not found as environmentally safe for permanent mercury disposal as the sub-terrain deposition options (BIPRO, 2010). As for the internal EU situation Regulation (EC) No 1102/2008 now regulates this area; criteria on final disposal are however yet to be defined.

One of the operators of large scale permanent mercury disposal in Europe charges 2 EUR/kg mercury for sulphur stabilisation, handling and final disposal in a salt mine (DELA, 2012). In this process, the mercury is stabilised as mercury sulphide, also called cinnabar, the mineral from which mercury is extracted. According to BIPRO (2010), this stabilisation ranges among the least expensive stabilisation methods and it has been tested by several companies. An alternative is deposition of securely packed metallic mercury in salt mines (not stabilised). No facilities in the EU had permits for this deposition in 2010, but several had permits to deposit mercury containing waste such as “fluorescent tubes and other mercury-containing waste” (EU waste code 20 01 21*). Permanent disposal as metallic mercury in salt mines with specified safety measures can be done at around 0,9-2 EUR/kg Hg including appropriate packaging. Both of these terminal disposal methods were screened as environmentally safe and economically feasible by BIPRO (2010).
From a Danish study of the feasibility of an environmentally safe permanent surface facility for disposal of low-grade radioactive waste, a cost estimate relevant for non-radioactive hazardous material was derived here at around 2 EUR/kg of waste, or around 1 EUR/m$^3$ of waste (derived from Danish Decommissioning, 2011).

These prices captures the current conditions in the developed world, which is the current source of most recycled/re-usable mercury, but may likely exceed costs of similar operations run (in the future) in most other parts of the world due to regional costs structures.

It should be noted that the above mentioned prices for permanent disposal do not include packaging of the metal mercury waste at the customer and transport from the customer to the treatment facility. It has not been possible to assess such costs within the framework of this study. It is however assumed that such costs will generally be well below the costs of the permanent disposal mentioned above.

A summary of costs and effectiveness for permanent retirement of mercury from other sources than primary mining is given in Table 4-11.

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-mining mercury to be stored, t/y</td>
<td>1.300</td>
</tr>
<tr>
<td>Disposal costs, EUR/kg Hg</td>
<td>0.9</td>
</tr>
<tr>
<td>Estimated disposal costs, World, mill. EUR/y</td>
<td>1.2</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>1.300</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>0.9</td>
</tr>
</tbody>
</table>

4.6 Summary of costs and effectiveness of the measure

Based on the deliberations of the European Commission (2011a) described above, the costs of the foregone sales of mercury, taking into account possible remaining allowed uses in the short and medium term, the costs of the measure on reduction of mercury supply can be summarised as follows. Note that costs of public administration of the measures are dealt with under Section 10 on "other measures".
Table 4-12  Summary of costs and effectiveness (whole World for this measure).

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Reduction potential, t Hg eliminated from circulation /y</th>
<th>Estimated cost per kg of Hg eliminated, EUR/kg Hg</th>
<th>Estimated global costs, mill. EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forgone profits of Hg sale (distribution effect only)</td>
<td>1.700-3.300</td>
<td>13-43</td>
<td>22-140</td>
</tr>
<tr>
<td>Environmentally sound disposal of by-product Hg in the non-ferrous metal sector</td>
<td>400-600</td>
<td>1-24</td>
<td>0,6-9</td>
</tr>
<tr>
<td>Environmentally sound disposal of Hg from other sources</td>
<td>1.300-1.700</td>
<td>1-2</td>
<td>1-3</td>
</tr>
<tr>
<td>Total estimated costs (rounded)</td>
<td>-</td>
<td>-</td>
<td>21-140</td>
</tr>
</tbody>
</table>

4.6.1 Uncertainties and gaps

Major uncertainties influencing global costs calculations:

› Mercury amounts actually eliminated from circulation depend on ambition level of the negotiations on mercury reductions.

› Variation in mercury prices is significant (see above).
5 International trade in mercury

Summary of the key features of the measure and its potential impacts
The objective of the measure is to restrict international mercury trade to the import of mercury for environmentally sound disposal and for uses allowed for the parties under the convention, and to secure prior informed consent from the importing country (and creating national licensing systems). Reducing international trade of mercury is a support measure to the supply measure and it has the potential for reducing global mercury releases significantly, though the precise reduction potential cannot reasonably be quantified individually for this measure.

5.1 Who will be affected?
As the EU does not currently have an import restriction on mercury, this measure may affect industrial users of mercury by restricting the number of sources of mercury supply, which again may affect mercury prices in the EU. The use of mercury in the EU is however heavily restricted already, and with the convention, the use of mercury for manufacturing products for export out of the EU (see Section 6) may potentially be restricted beyond current regulation. Any remaining mercury usage in, and export of, products from the EU would likely be such covered by the definition of "allowable uses" or uses with long transition periods (probably such as light sources, etc.), and would thus be acceptable under the convention. In conclusion, this measure would likely have minimal overall consequences within the EU, besides the administrative burden of the prior informed consent procedures considered under this measure.

As regards extra-EU elements, that is, costs in the World except EU and North America, this measure primarily involves legal set-up and administrative burdens in developing countries and countries in transition. The prior informed consent element for mercury export/import may best be implemented nationally by adding it to already established procedures for the Rotterdam (PIC) Convention, or by setting up similar procedures specifically for mercury, if this is more practical. The need for assistance with this measure may be considered minor compared to other measures.
5.2 Potential barriers to implementation

The setup of effective national systems for administration of the mercury trade may prove a challenge in many countries. The development of a standardised system in the form of a computer interface in a commonly available programme format, such as for example MS Access or MS Excel, which could be made available free of charge to developing countries and countries with economies in transition, could be a help to promote uniform and functioning administrative practices. The system could from the start be suited to feed into a global database on mercury trade, but should probably not be online with global system due to a possible need to respect national proprietary information.

The development of such an IT-based solution could be promoted by financial and technical support.

5.3 Expected costs

The Rotterdam convention on prior informed consent (PIC) has some resemblance with what is discussed for international trade of mercury (though not duplicating it).

The costs for running a PIC procedure includes costs for central, global administration of the procedure, including ensuring exchange of globally relevant information, as well as a national component of running the PIC procedure within each party to the convention.

As regards the central, global component, the budget of the Rotterdam Convention can be taken as an indication of the implied costs. The Rotterdam Convention's annual budget includes a regular component paid by Parties and host countries for COP meetings. This component has an annual budget of about 4 million USD/year in the period 2009-2013 (Rotterdam Convention, 2011).

Besides the regular budget, the Rotterdam Convention works with a voluntary budget for support activities to developing countries and countries with economies in transition for their implementation of the national component. The voluntary part works with a budget of about 2 million USD/year in the period 2009-2013 (Rotterdam Convention, 2011).

We do not have specific information on other elements of the national component, but it can be considered covered under expenses here termed as "other measures", see Section 10.

5.3.1 Uncertainties and gaps

Data on major elements of the costs for national administration of the prior informed consent procedure and licensing of traders are incomplete.
6 Products and processes

Summary of the key features of the measure and its potential impacts
The aim of the measure is to impose restriction on the import, manufacture, production and export of "mercury-added" products (with intentional mercury use) as well as on processes using mercury. The restriction will likely work with the concept of "allowed uses", meaning uses for which it has been agreed among the Parties, that technically-feasible and economically viable mercury free alternatives are not yet available. The allowed uses are to be defined in the convention and may include defined grace periods. It should be noted that the current draft measures text presents several alternative options on regulating products and processes.

6.1 Who will be affected?
The intentional use of mercury in the EU is already heavily restricted and some Member States have restrictions going beyond EU legislation. Depending on the level of ambition in the negotiations, the result may not go beyond current EU legislation, and would thus have little impact on intra-EU circumstances. Many remaining mercury uses in the EU would in this case probably be covered by "allowed use" exemptions under the convention. On the other hand, technically viable alternatives do exist for more product and process uses than currently covered by EU legislation, and if a broader scope of the measure is decided upon by the INC process, this measure could have some effect on the industries currently producing mercury-added products or using mercury in processes.

As regards extra-EU cost elements, that is, costs in the World except EU and North America, the needed assistance could include awareness-raising campaigns, technical assistance to inform of, and introduce, mercury-free alternatives, demonstration project for implementation of mercury-free production processes, as well as actual implementation costs for mercury-free technologies and products.

A potentially positive cost element in this respect is the possible boost in exports of mercury-free alternative products developed or manufactured in the EU.
6.2 Potential barriers to implementation

The creation of trade barriers is traditionally a very sensitive subject in international negotiations, and major producer countries outside the EU and North America may have problems accepting binding substitution requirements. However, some such producer countries have the necessary capacity for technology changes and normally cope well with changing market demands, also those imposed by environmental legislation in the importing countries. By way of example, mercury-free button cell batteries and digital clinical thermometers are already produced in China. In such cases, the effects of product or process restrictions are primarily a re-distribution of the market from some actors to others, or from some technologies to others within the same companies.

On the other hand, some developing countries have production of older types of products, such as clinical mercury-in-glass thermometers, and may not necessarily have the infrastructure for a quick change to electronic products. In such cases, individual countries could be affected negatively by product or process restrictions, and loans or grants could facilitate conversion to mercury-free techniques.

Another factor involved in substitution efforts is the availability of the relevant raw materials at relevant costs and in relevant amounts. This is for example an issue in the VCM production in China, as the existing and widely used mercury-free production process, employed in most other places in the world, is using oil derivatives as raw materials, whereas the technology applying mercury catalysts uses the more readily available coal as the primary raw material. Instead, alternative catalysts have recently been introduced for the process using coal as raw material (see below).
6.3 Mercury inputs and air emissions

<table>
<thead>
<tr>
<th>Measure/options</th>
<th>Input of Hg to society, t/y</th>
<th>Hg releases to atmosphere, t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>370</td>
<td>22</td>
</tr>
<tr>
<td>Dental amalgam (air rel. crematoria only)</td>
<td>362</td>
<td>27</td>
</tr>
<tr>
<td>Measuring and control devices</td>
<td>350</td>
<td>54</td>
</tr>
<tr>
<td>VCM production</td>
<td>770</td>
<td>15</td>
</tr>
<tr>
<td>Hg-cell chlor-alkali production</td>
<td>492</td>
<td>47</td>
</tr>
<tr>
<td>Lamps</td>
<td>135</td>
<td>21</td>
</tr>
<tr>
<td>Electrical and electronic (other)</td>
<td>200</td>
<td>37</td>
</tr>
<tr>
<td>Others</td>
<td>313</td>
<td>44</td>
</tr>
</tbody>
</table>

6.4 Cost and effectiveness by mercury use/sector

6.4.1 Mercury-added products

Batteries
A number of battery types may contain mercury; these include some button cell types as well as some other battery shapes and types (see below). Average mercury content of the button cells is based on experience from the EU (BIOS, 2012). It should be noted mercury concentrations in button cells and other batteries are regulated in the EU Battery Directive, and thus the situation here could differ from the situation in some other regions of the world. As the data are most updated and complete here, we have however used EU data as the background for the costs estimation and adjusted for lower prices in other regions with the CPL factor.

For the EU27 the following basic data regarding button cells are provided. The average mercury content of the three types of button cells containing mercury on the EU market (weighted by market share) was 0,010 g Hg/unit. While the mercury content will vary with the cell weight, the average mercury content is most likely a material constant within each battery type, and it is expected to be within the range of 0,009-0,011 g Hg/average unit. The average weighted unit price of button cells containing mercury was estimated at 1,80 EUR/unit, with an assumed range of +/- 20% or around 1,4-2,2 EUR/unit. The study estimated the price of mercury-free button cells to be approximately 10% higher than that of mercury-containing cells, here assumed in the range of 5-15%, corresponding to an average unit price of the mercury-free cells of 1,98 EUR/unit. The BIOS (2012) report indicates an average extra price of 0,13 EUR/unit, but this average concerns all button cells including the lithium cells, which do not contain mercury. Note that the total mercury content of button cells placed on the EU market in 2010 is estimated at 8,4 tonnes (range: 2,3-14,4 tonnes) according to BIOS (2012).
Table 6-2  Background data for button cell batteries on the European market (derived from BIOS, 2012).

<table>
<thead>
<tr>
<th>Button cell type</th>
<th>Weight, g/unit</th>
<th>Mercury content, %</th>
<th>Mercury content, g/unit</th>
<th>Market share, %</th>
<th>Average price, EUR/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
<td>Average</td>
<td>Average</td>
<td></td>
</tr>
<tr>
<td>Zinc air</td>
<td>1,2</td>
<td>0,3-1,9</td>
<td>1</td>
<td>0,012</td>
<td>34</td>
</tr>
<tr>
<td>Alkaline</td>
<td>2,1</td>
<td>0,8-3,3</td>
<td>0,5</td>
<td>0,011</td>
<td>8</td>
</tr>
<tr>
<td>Silver oxide</td>
<td>1,3</td>
<td>0,3-2,3</td>
<td>0,45</td>
<td>0,006</td>
<td>12</td>
</tr>
<tr>
<td>Lithium</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>Not indicated</td>
</tr>
</tbody>
</table>

The costs for battery substitution are calculated in two steps. First, the incremental price for non-mercury batteries is divided by the mercury content of each battery. The result is the cost effectiveness in terms of EUR/kg Hg eliminated from circulation with batteries. Secondly, this figure is multiplied with the amount of mercury applied in the world excluding the EU and North America to yield the total substitution cost for the same part of the world.

The cost estimation here is based on the different button cell battery types, which are considered here to constitute the major part of the global consumption of mercury for batteries. However, actual substitution costs for batteries may likely be lower, as a significant amount of mercury is used in other, less expensive battery types. According to NRDC (2006, citing CRC data), the total mercury consumption for battery production in China in 2004 was 154 tonnes/year, of which 104 tonnes were used for button cell batteries. The other 50 tonnes/year, or 33 percent, were used for paste type zinc manganese cylinder batteries (majority of consumption), paperboard zinc manganese cylinder batteries and alkaline manganese cylinder batteries, which are sold on the national market and perhaps other markets with no restrictions on mercury concentration in batteries (i.e. Asia, Africa, South America), as well as small amounts to mercury oxide batteries. This mercury use for other battery types was expected to decrease by the time of the NRDC/CRC study, but newer data have not been found for the present study.

Button cells is a high-price product used for specific technical purposes, whereas the other mercury containing product types in Chinese production are the lowest priced battery types available, satisfying primarily low-demand purposes for customers not prioritising long battery life. In the developed region markets, these battery types are more or less substituted by long-lasting, and slightly more expensive cylindrical alkaline batteries. We do not have data for prices of such low-grade batteries and their alternatives in China or other developing world markets, and can therefore not reasonably estimate the costs of substituting for these with mercury-free batteries of the same types. We can only assume that the costs for this substitution would be lower than for button cells, and thus the total calculated costs for battery substitution may be over-estimated.
It should be noted that the introduction of mercury-free button cell batteries is a rather new development and that the prices may fall considerably over the coming years, meaning that the costs of mercury-substitution in this field will also become lower.

The size in terms of revenue of the global dry battery market was found which indicates that the total costs of substitution here has been over-estimated. It has however not been possible to further validate these data within the current project.

Lifecycle management costs of mercury containing batteries
The total costs of disposal of the button cells include costs of consumer information, collection, transport and final treatment of the cells.

In the Netherlands, the procedure for collecting and recycling used batteries is laid down by law and businesses which import, manufacture or sell batteries and products containing batteries are required to contribute to the final disposal of the batteries (extended producer responsibility - EPR - scheme). The collection and disposal is organised by the organisation Stibat (Stibat 2012). Stibat organises collection from consumers (22,000 collection points) whereas button cells from professional users to some extent is covered by professional waste dealers in cooperation with Stibat. The collection efficiency for all batteries is according to the annual report of the organisation estimated at 86% of the batteries disposed of. No specific data for button cells are provided.

Producers and importers of batteries pay a fee for each battery they sell on the Dutch market: the “management fee”. Stibat uses this money to pay for collecting, transporting, sorting and recycling of used batteries. Stibat collects the returned batteries at the various collection points and arranges the sorting and recycling. Stibat has a coordinating role, enabling all parties to collaborate in collecting used batteries. The management fee also covers the cost of developing publicity campaigns. This role includes providing information on the relevant legislation and regulations, an administration programme and a collection service for discarded batteries. Stibat also runs publicity campaigns to promote consumer participation with regard to battery collection.

The fee may here be considered as an approximation of the aggregated costs of collection and disposal/treatment of the button cells. The fee for button cells by January 1 2012 is 0.003 EUR/cell (excl. VAT). Assuming an average mercury content per unit of 0.01 g Hg/unit, the aggregated costs of waste management can be estimated at 300 EUR/kg Hg, or around 2% of the estimated medium substitution costs of 18,000 EUR/kg Hg eliminated from circulation, i.e. an insignificant cost compared to the uncertainties involved (0.003 EUR per cell/0.00001 kg Hg per cell = 300 EUR/kg Hg).

The button cells which are not collected are in the Netherlands most probably disposed of to municipal solid waste incineration. The costs of preventing all releases of mercury from the cells not collected have not been included in the estimation applied here.
EU regulation stipulate recycling of waste batteries, but this may not necessarily be the case for the rest of the world under a future mercury convention. The costs are however considered indicative for the cost range for lifecycle management of mercury in button cell batteries.

An overview of estimated costs and effectiveness of mercury substitution in batteries can be seen in Table 6-3.

Table 6-3 Summary of costs and effectiveness for substitution of batteries.

<table>
<thead>
<tr>
<th>Batteries</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated substitution costs, World (excl EU and NA), mill. EUR/y</td>
<td>1.700</td>
<td>15.000</td>
<td>6.000</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>240</td>
<td>408</td>
<td>323</td>
</tr>
<tr>
<td>Reduction potential, 100% of air emissions, t Hg/y</td>
<td>16</td>
<td>26</td>
<td>22</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>7.000</td>
<td>37.000</td>
<td>18.000</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>110.000</td>
<td>580.000</td>
<td>270.000</td>
</tr>
</tbody>
</table>

Results, CPL adjusted:

| Estimated substitution costs, World (excl EU and NA), mill. EUR/y       | 1.000  | 8.900   | 3.500   |
| Calculated effectiveness, elimination from circulation, EUR/kg Hg       | 4.100  | 22.000  | 11.000  |
| Calculated effectiveness, reduced air emissions, EUR/kg Hg               | 65.000 | 340.000 | 160.000 |

Sensitivity analysis, batteries

The calculated cost estimates are very sensitive to the expected incremental price of mercury free batteries. Alternative calculations based on a 0-10% price increase, which could possibly be a future scenario, yielded the following CPL adjusted results (
Table 6-4; not including minimal lifecycle costs of mercury in batteries):
Table 6-4  Results, sensitivity analysis, with 0-10% price increase only*1.

<table>
<thead>
<tr>
<th>Batteries, alternative: 0-10% price increase, CPL adjusted</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated substitution costs, World (excl EU and NA), mill. EUR/y</td>
<td>0</td>
<td>5.900</td>
<td>1.800</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>0</td>
<td>14.000</td>
<td>5.000</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>0</td>
<td>220.000</td>
<td>80.000</td>
</tr>
</tbody>
</table>

Note: *1: Not including reduced minimal lifecycle costs of mercury in batteries.

As expected, this lowers the medium total costs and cost effectiveness numbers to the half of the main result.

If the costs of substitution of non-button cell batteries (assumed 33% of Hg consumption for batteries) was hypothetically considered as zero, the costs of substitution of (button cell) batteries would be reduced with a further 33% in any of the two scenarios depicted above.

Dental amalgam
BIOS (2012) provides data on the costs of dental amalgam fillings and mercury-fillings borne by the patients in 18 EU Member States. The costs to the patient vary considerably depending on the differences in labour costs and in the amount reimbursed by national health insurance schemes. The total costs including the reimbursement is not indicated, but it is indicated that in most Member States the reimbursement is the same for both types of fillings, and the incremental costs to the patients can be used as an indication of the total extra costs. The differences in price of the filling material represent only a small part of the extra costs, and the labour cost represents the major difference as composite fillings (or at least the larger ones) are reported to take a bit more time to apply. On average the material cost for an amalgam filling is estimated at 1 EUR whereas the average material cost for a composite or glass ionomer filling is estimated at 5 EUR.

Based on the UNEP Mercury inventory toolkit (UNEP, 2011b), it is assumed that on average the mercury use per filling is 0,8 (0,7-0,9) g mercury, and the total number of fillings made is estimated with this number in combination with the total mercury demand estimate for dental amalgam use in the World excluding the EU and North America (see demand in Section 3).

As average for the EU27 Member States the incremental price are estimated at 14,8 EUR/filling corresponding to extra 46% on the price of an amalgam filling. The price levels differs among the EU15 (Western Europe) and EU12 (mainly Central and Eastern Europe) with an incremental price of 18,1 EUR/filling in EU 15 and 9,3 EUR in EU12. The EU average increment was used in the cost assessment.
Table 6-5 Background data for dental amalgam for the EU marked (derived from BIOS, 2012).

<table>
<thead>
<tr>
<th></th>
<th>Average dental restoration costs borne by the patient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dental amalgam filling, EUR</td>
</tr>
<tr>
<td>EU 27</td>
<td>32,2</td>
</tr>
<tr>
<td>EU15 (Western Europe)</td>
<td>49,7</td>
</tr>
<tr>
<td>EU12 (Central and Eastern Europe)</td>
<td>14,7</td>
</tr>
</tbody>
</table>

It should be noted that the so-called a-traumatic restoration technique (ART) may become a major alternative to dental amalgam in developing countries. The method involves no drilling, only hand tools, and typically applies the filling material glasionomer, which chemically bonds to dental material and some types leak flour reducing new dental decay near the filling. ART is reported to be less costly than alternatives (Dorri et al., 2009), probably primarily because of the lower labour and equipment need; no quantitative price data have however been found in this study. Glasionomer fillings (with traditional drilling) have been tested in developed countries also, and have so far been reported to have lower durability than amalgam and composite fillings (Nordic Council of Ministers, 2010). They are however sometimes used for young children due to the simpler application procedure and less demand for durability in young children's teeth. A widespread application of ART as a substitute for dental amalgam may result in lower substitution costs than calculated in this study based on data from the EU, where ART likely currently has limited use.

Lifecycle management costs of dental amalgam

The negative externalities of the use of mercury in dental amalgam can be estimated at several levels:

1) The actual costs of measures taken in order to prevent the major releases of mercury to the environment;

2) Costs of preventing all releases of mercury to the environment as consequence of the use of mercury in amalgam.

The costs of actual measures implemented in many countries include (but are not necessarily limited to):

› Costs of amalgam separators in clinics;

› Costs of management of mercury-containing waste from the clinics;

› Costs of flue gas treatment in crematories;
Costs of sewage sludge management in the case that high Hg content prevent the disposal of the sludge on agricultural land.

In case all releases should be prevented, various other costs should be added: costs of flue gas control in municipal waste incinerators (MSWI), thermal treatment of ash and residues from MSWI, capture of Hg in exhaust gases from dental clinics, thermal treatment of soil from cemeteries, etc.

In a recent report published by three NGOs, the total costs of preventing an additional 90% of the dental mercury from entering the environment in the USA are estimated at 41-47 USD/filling (Concorde, 2012) corresponding to 32-37 EUR/filling. These costs are the costs beyond the costs of measures already taken, which remove 13 tonnes of the 42 tonnes entering the waste stream. The major costs elements are in the assessment estimated to be recycling of the amalgam waste (of waste with less than 50 ppm Hg), thermal treatment to remove elemental mercury from ash/residues of municipal waste incinerators, incineration of waste with flue gas control and flue gas control of emissions from crematoria, see Appendix 2.

Some costs of preventing the releases of mercury in dental amalgam are provided by COWI (2008) and BIOS (2012), but none of the studies provide the basis for estimates of the total costs. COWI (2008) estimates the costs of applying high efficiency amalgam filters at 1,400-1,800 EUR/kg Hg reduced releases to the sewage system, and the costs of having mercury filters on all crematoria at approx. 17,000 EUR/Hg reduced releases to air, but do not provide these data in terms of costs per tons of Hg used.

Some cost elements included in the Concorde (2012) study could appear to be in the high end of what would realistically be implemented to eliminate mercury in the environment, yet probably relevant for the scope of the Concorde study. Based on an assessment of the cost elements included by Concorde (2012), the cost elements shown in Table 6-6 were included in the estimation of life cycle management costs of mercury in dental amalgam. These costs elements were used here to estimate roughly alternative costs per dental amalgam filling and per kg mercury used. The results are also shown in Table 6-6. The selection of cost elements included and not included from the Concorde study can be seen in Appendix 2.
Table 6-6  Lifecycle management costs for dental amalgam (data for USA, derived from Concorde, 2012).

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hg filters on small waste incinerators (large are assumed equipped already)</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Incineration with Hg filters of previously landfilled waste</td>
<td>112</td>
<td>224</td>
</tr>
<tr>
<td>Hg filters on sewage sludge incinerators</td>
<td>36</td>
<td>72</td>
</tr>
<tr>
<td>Hg filters on air from medical waste handling</td>
<td>1</td>
<td>1,5</td>
</tr>
<tr>
<td>Hg filters on crematoria</td>
<td>99</td>
<td>165</td>
</tr>
<tr>
<td>Hg filters on air from dental clinics</td>
<td>0,5</td>
<td>0,75</td>
</tr>
<tr>
<td>Land filling of Hg waste on hazardous waste deposits</td>
<td>0,0183</td>
<td>0,02135</td>
</tr>
<tr>
<td>Thermal treatment to remove Hg from dental waste</td>
<td>1,2</td>
<td>2,4</td>
</tr>
<tr>
<td>Safe disposal of Hg wastes, including solid residues from flue gas control</td>
<td>0,0372</td>
<td>0,434</td>
</tr>
<tr>
<td>- Do, recovered metal Hg</td>
<td>0,1434</td>
<td>0,239</td>
</tr>
<tr>
<td>Sum of above costs, rounded</td>
<td>252</td>
<td>470</td>
</tr>
<tr>
<td>&quot;Indicative waste management, manipulation and handling costs&quot; (= all other costs associated with above activities)*1</td>
<td>252</td>
<td>470</td>
</tr>
<tr>
<td><strong>Total for above costs</strong></td>
<td><strong>504</strong></td>
<td><strong>940</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concorde grand total, mill. USD</td>
<td>2.086</td>
</tr>
<tr>
<td>Share of Concorde total included above</td>
<td>24%</td>
</tr>
<tr>
<td>Concorde cost/filling, USD</td>
<td>41</td>
</tr>
<tr>
<td><strong>Cost/filling for above cost types, USD</strong></td>
<td><strong>10</strong></td>
</tr>
<tr>
<td>- Do, EUR/filling</td>
<td>8</td>
</tr>
<tr>
<td>kg Hg/filling (UNEP Toolkit, 2001b)</td>
<td>0,0007</td>
</tr>
<tr>
<td><strong>Cost EUR/kg Hg for sum of above cost types</strong></td>
<td><strong>11.000</strong></td>
</tr>
<tr>
<td>‘-Do, inversely CPL adjusted (for sensitivity analysis)</td>
<td>6.490</td>
</tr>
</tbody>
</table>

Note: *1: As suggested by Concorde (2012); see appendix and reference.
An overview of estimated costs and effectiveness of mercury substitution in dental amalgam can be seen in Table 6-7.

Table 6-7  Summary of costs and effectiveness for substitution of dental amalgam.

<table>
<thead>
<tr>
<th>Dental</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated substitution costs, World (excl EU and NA), mill. EUR/y</td>
<td>1.800</td>
<td>12.000</td>
<td>5.700</td>
</tr>
<tr>
<td>Estimated costs for substitution minus saved Hg life cycle costs, mill. EUR</td>
<td>-270</td>
<td>8.000</td>
<td>2.500</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>193</td>
<td>261</td>
<td>227</td>
</tr>
<tr>
<td>Reduction potential, 100% of air emissions (only crematoria emis. included here), t Hg/y*1</td>
<td>21</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>-1.400</td>
<td>29.900</td>
<td>11.200</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg*1</td>
<td>-13.000</td>
<td>370.000</td>
<td>120.000</td>
</tr>
</tbody>
</table>

Results, CPL adjusted:

| Estimated costs for substitution minus saved Hg life cycle costs, World (excl EU and NA), mill. EUR/y | -160     | 4.700   | 1.500   |
| Calculated effectiveness, elimination from circulation, EUR/kg Hg | -830     | 18.000  | 6.600   |
| Calculated effectiveness, reduced air emissions, EUR/kg Hg*1       | -7.700   | 220.000 | 70.000  |

Notes: *1: Actually more air emission inputs should have been included here, resulting in lower per kg Hg costs, but the relevant air emission estimates are not available.

Sensitivity analysis, dental amalgam

Alternative base data for the cost estimation for substitution of dental amalgam could be used. In the cost estimates for substitution of dental amalgam above, average EU prices for amalgam fillings and incremental prices for alternatives were used, and the results were CPL adjusted for lower price levels outside the EU and North America. If instead the lower average price for amalgam fillings and the higher incremental prices for substitution (see Table 6-5) from EU12 were used (not CPL adjusted due to lower cost level than general EU) in combination with CPL adjusted lifecycle costs for dental amalgam in the USA (see Table 6-6), it would yield the following results:
Table 6-8 Results, sensitivity analysis, EU12 price data and CPL adjusted lifecycle costs.

<table>
<thead>
<tr>
<th>Dental amalgam, alternative: EU12 base data; CPL adjusted lifecycle costs for amalgam</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated costs for substitution minus saved Hg life cycle costs, mill. EUR</td>
<td>-330</td>
<td>3.000</td>
<td>800</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>-1.700</td>
<td>11.400</td>
<td>3.600</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>-15.000</td>
<td>140.000</td>
<td>40.000</td>
</tr>
</tbody>
</table>

When comparing with the CPL adjusted results in Table 6-7, medium total cost and cost-effectiveness under the alternative price scenario are a bit above half of the results of the main scenario in Table 6-7.

**Measuring devices**

No breakdown of the global mercury consumption for measuring devices by types of devices have been identified, neither have estimates of the global market of each product type in question. A similar estimation process as for other products above have thus been applied, making use of the available data for typical mercury content in the individual product types, assumptions about their mutual distribution in the product group, and available estimates of total global mercury demand for the product group.

The major application areas of mercury in measuring devices in the EU in 2007 were medical thermometers (16% of total), other thermometers (9%), sphygmomanometers and other manometers (39%), and barometers (29%) representing together 93% of the total. Mercury for hanging drop electrodes (redox laboratory analysis in chemical research and industry) account for the main part of the remaining 7%. Barometers and sphygmomanometers are here pooled together, as they contain approximately the same amount of mercury, and the replacement costs per kg of mercury is for both devices relatively low.

The mercury content and the substitution of the four types of measuring devices is quite different and it will here roughly be assumed that the distribution for North America is similar to the distribution for the EU indicated above. For the rest of the world it is assumed that the medical thermometers takes up a larger part and other thermometers less, and the following distribution will be assumed: medical thermometers (30% of total), other thermometers (5%), sphygmomanometers, barometers and other manometers (60%), and other devices (5%).

Average mercury content of medical thermometers, other thermometers, and sphygmomanometers is derived from the UNEP's mercury inventory toolkit (UNEP, 2011b) if nothing else is mentioned. Barometers used for households
contain approximately the same amount of mercury as sphygmomanometers while barometers for professionals contain more.

For the sphygmomanometers, other manometers and barometers group data on prices have been derived from the REACH Annex XV restriction report prepared by the European Chemicals Agency (ECHA, 2010). According to the analysis, manometers and barometers can be replaced by mercury free meters without extra costs. The average factory gate price of a mercury sphygmomanometer is approximately 40 EUR. The price to the customer is not indicated but a price of 60 EUR is indicated by COWI (2008). Shock resistant aneroid sphygmomanometers are available at approximately the same price, but the average lifetime is shorter, while more expensive electronic devices have the same lifetime as the mercury devices. In this assessment, the incremental annualised price in percentage of the annualised price of the mercury devices will be used. The annualised price of the less expensive alternatives is here considered 0-50% higher than the price of the mercury device. The customer price of 60 EUR/unit will be used for the EU and NA, while the in the EU factory gate price of 40 EUR/unit will be used as best estimate for the rest of the world. As other manometers and barometers can be replaced without extra costs it will be assumed that the price of alternatives for the whole group is approximately 30% higher than the mercury devices.

The Lowel Centre reports for UNEP (2011c) indicate that there are net savings in substitution of mercury sphygmomanometers if lifecycle management of mercury is included. Very little data exist on substitution prices including life cycle management.

Medical thermometers. A technical guidance from WHO from 2001 on replacement of mercury thermometers and sphygmomanometers in health care, notes that extra costs of mercury-free thermometers vary with location, model and number, but that hospitals that have substituted mercury in a number of countries including Argentina, Mexico and the Philippines report cost savings using the alternative digital devices instead of mercury-thermometers (WHO, 2011). The incremental price is therefore considered here as 0%, with a range of -10% to +10%. The price for mercury-in-glass medical thermometers was estimated at 1,34 EUR/piece (in developing countries) based on CPL adjustment of a bulk price (hospital's price) in India of 55 INR/piece (0,79 EUR/piece) (Toxics Link, 2012). The Indian price was used in the cost assessment for the World except the EU and North America.

Other thermometers. Other thermometers are mainly used in industry, laboratories or for measuring ambient air temperature. The latter can be replaced without extra costs with alcohol- in-glass thermometers, but for thermometers used in industry and laboratories the prices of alternatives in general are higher than the mercury thermometers, yet they also provide extra functions, for example such as data-logging over time. An average for thermometers for laboratories and for industry is here used as indicator for the whole group. The mercury content may typically range from 1 to 40 g/unit, but the average is assumed to be within 5-15 g/unit. The REACH Annex XV restriction report uses a price of 40 EUR and 23EUR per device, without and with mercury respectively, but in fact the calibration costs during the lifetime exceed the purchase costs. For some purposes
mercury-free liquid-in-glass thermometers, which are slightly cheaper than the mercury-thermometers can be used. For other thermometers the annualised extra costs are estimated at 3% using electronic laboratory thermometers as substitute for mercury-thermometers, and 394% for electronic devices as compared to mercury-thermometers in industry. Note that the electronic devices have some extra functionalities. As a rough average it will be assumed that the price of the thermometers in this group is 30 EUR/unit and the price of the alternative is about twice the price of the mercury thermometer.

Porosimeters, while being measuring instruments, are not included here because the mercury in the porosimeter is not an integral part of the meter, but is an auxiliary material in the measurement (mercury is pressed into the porous specimen and disposed of with it after analysis).

An overview of estimated costs and effectiveness of mercury substitution in dental amalgam can be seen in Table 6-9.

<table>
<thead>
<tr>
<th>Measuring and control devices:</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated substitution costs, World (excl EU and NA), mill. EUR/y</td>
<td>2</td>
<td>230</td>
<td>63</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>250</td>
<td>280</td>
<td>264</td>
</tr>
<tr>
<td>Reduction potential, 100% of air emissions, t Hg/y</td>
<td>25</td>
<td>59</td>
<td>43</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg (Hg-weighted mean)</td>
<td>9</td>
<td>880</td>
<td>252</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>90</td>
<td>4.200</td>
<td>1.600</td>
</tr>
</tbody>
</table>

**Results, CPL adjusted:**

<table>
<thead>
<tr>
<th>Measuring and control devices:</th>
<th>Low</th>
<th>High</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated substitution costs, World (excl EU and NA), mill. EUR/y</td>
<td>1</td>
<td>140</td>
<td>37</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>5</td>
<td>520</td>
<td>149</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>53</td>
<td>2.500</td>
<td>940</td>
</tr>
</tbody>
</table>

### 6.4.2 VCM production

VCM (vinylchlorid monomer) is the monomer molecule from which PVC is made. The majority of VCM production in the world is based on oil derivatives (ethylene) and does not use mercury in the production. In China the majority of the
production is however based on carbide from coal, applying the so-called acetylene process, in which mercury-chloride is used as a catalyst (CRC of MEP, 2011). Also in Russia 3-4 facilities are reported to use this process. One facility in the Slovak Republic also uses this process in parallel to the mercury-free ethylene process.

In 2008, according to CRC of MEP (2011) there were 89 PVC manufacturers producing VCM in China applying the acetylene hydrochlorination process with a total capacity of 11.605 million tonnes and total output of 6,20 million tonnes. In 2011 the mercuric chloride concentration of the mercury catalyst used by most enterprises was around 12.5%. The annual use of mercury is about 574-803 t of which about 206-289 t mercury remains in the waste catalyst and the rest is in the activated carbon, waste acid, emissions to the environment and other wastes from the process. As such VCM production is among the largest intentional uses of mercury globally.

According to the European Commission (2011), by the end of 2010, production capacity from acetylene in China had reached 16 million tonnes/year (81% of the total PVC production capacity in China), the capacity of PVC production from ethylene was about 3 million tonnes/year (15%), while another 750,000t/y (4%) used a combination of both processes. The use of mercury for VCM production is expected to increase as China expands its VCM production.

One way of reducing the mercury usage, and thereby presumably also the mercury releases to the environment, is to lower the concentration of mercury in the catalyst. This move is currently in process in China.

Another way, which seems more desirable in the long run, taking the perspective of mercury reductions, is the implementation of a new mercury-free catalyst based on precious metals, which according to Teirlinck and van Haandel (2011) has already been developed. The catalyst has been pilot tested with technical success in one or more Chinese VCM production facilities.

Higher catalyst costs, 5-15 USD per ton of PVC produced, are to be compensated to a great extent by achieving a higher yield. As the PVC production cost are estimated to around 400 USD/t PVC produced and market price is estimated to around 900 USD/t, the higher costs of the catalysts only represent around 1-2% of the PVC production price, and around 1-4% of the PVC market price. The catalyst is reported to be usable directly in existing VCM production facilities designed for the acetylene process (European Commission, 2011).

According to the developers of the catalysts, the current mercury catalyst costs less than 1% of total PVC production costs. These costs do not include costs for mercury release reduction efforts. The costs of the mercury-free catalyst are estimated to be below 2% of total PVC production costs. Precious metal can be either purchased or leased. Precious metal recycling is included in the cost estimates given (Teirlinck and van Haandel, 2011).

A rough estimate of the total cost of substituting the mercury catalyst in the Chinese PVC production is derived from the data summarised in Table 6-10. With a total PVC production using the acetylene process in China of 16 million
tonnes/year, the total costs for substituting the mercury-containing catalyst would be around 80-240 million USD annually, or around 60-180 million EUR /y. Note that this calculation does not take into account costs saved from eliminating the need for mercury lifecycle management (waste management, Hg release reductions).

Considering the associated uncertainty of the cost estimate and the fact that only a few facilities outside China uses the acetylene process for VCM production, this estimate is here considered as covering the total costs for the world.

<table>
<thead>
<tr>
<th>Table 6-10</th>
<th>Calculation of cost estimate for substitution of mercury catalyst in PVC production in China*1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Additional cost of catalyst, USD/t PVC produced</td>
<td>5</td>
</tr>
<tr>
<td>Production cost of PVC, USD/t</td>
<td>400</td>
</tr>
<tr>
<td>Market price of PVC, USD/t</td>
<td>900</td>
</tr>
<tr>
<td>Catalyst cost in % of PVC market price</td>
<td>1%</td>
</tr>
<tr>
<td>Catalyst cost in % of PVC production cost</td>
<td>1%</td>
</tr>
<tr>
<td>2010 PCV production with acetylene process in China, mill. t/y</td>
<td>16</td>
</tr>
<tr>
<td>Additional costs for full substitution with new catalyst 2010, Mill USD/y</td>
<td>80</td>
</tr>
<tr>
<td>Additional costs for full substitution with new catalyst 2010, Mill EUR/y</td>
<td>60</td>
</tr>
</tbody>
</table>

Note: *1: Note that this calculation does not take into account costs saved from eliminating the need for Hg lifecycle management (waste management, Hg release reductions).
Table 6-11  Summary of costs and effectiveness for substitution of mercury catalyst in VCM production with the acetylene method.

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional costs for full substitution with new catalyst 2010, Mill EUR/y</td>
<td>60</td>
<td>180</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>770</td>
<td>770</td>
</tr>
<tr>
<td>Reduction potential, 100% of air emissions, t Hg/y</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>80</td>
<td>230</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>3.900</td>
<td>12.000</td>
</tr>
</tbody>
</table>

6.4.3 Mercury-cell chlor-alkali production

Chlor-alkali production applying the mercury cell technology (MCCAP) is acknowledged as an obsolete technology by the industry, and there are no reports of new construction of mercury-cell facilities globally. Yet, a substantial part of the global production of chloride and alkali (sodium hydroxide - NaOH, potassium hydroxide - KOH, etc.) is still produced on existing mercury-cell facilities. About two thirds of the remaining global production capacity based on the mercury-cell technology is situated in Europe (and the EU), as this has been the dominant process used historically in this region. The main alternative production process to mercury cells is the membrane process commonly considered more cost effective for most conditions. The operating costs are however here calculated conservatively as equal to those for the mercury cell process.

EuroChlor, the European industry organisation for the chlorine industry, has signed a voluntary agreement to phase out mercury-cell technology in the EU by 2020.

Table 6-12 presents an overview of global mercury-cell based production capacity as of 2010 as well as planned conversions or closures 2010-2015 and recent converted or closed down capacity (UNEP Chlor-alkali partnership, 2012). The data source contains more detailed information about the production plants in question.
Table 6-12  Global mercury-cell chlor-alkali production capacity, planned and recently executed conversions or closures, 1000 t/y (based on UNEP Chlor-alkali partnership, 2012).

<table>
<thead>
<tr>
<th>Country</th>
<th>2010 Mercury cell chlorine capacity</th>
<th>Closure or conversion plans quantified 2010-2015</th>
<th>Known mercury capacity reductions since 2005 due to plant closures or conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>420</td>
<td>420</td>
<td></td>
</tr>
<tr>
<td>Czech Republic</td>
<td>197</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>42</td>
<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>690</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Germany*1</td>
<td>870</td>
<td>290</td>
<td>478</td>
</tr>
<tr>
<td>Greece</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>137</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poland</td>
<td>125</td>
<td>125</td>
<td>80</td>
</tr>
<tr>
<td>Romania</td>
<td>186</td>
<td>186</td>
<td></td>
</tr>
<tr>
<td>Serbia &amp; Montenegro</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>732</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>120</td>
<td>120</td>
<td>95</td>
</tr>
<tr>
<td>Switzerland</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>277</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe total</td>
<td>3,949</td>
<td>1,508</td>
<td>699</td>
</tr>
<tr>
<td>EU27 total</td>
<td>3,912</td>
<td>1,508</td>
<td>699</td>
</tr>
<tr>
<td>North America</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td>437</td>
<td></td>
<td>694</td>
</tr>
<tr>
<td>Rest of world</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Algeria</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angola</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td>122</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>145</td>
<td>145</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td>217</td>
<td></td>
<td>115</td>
</tr>
<tr>
<td>China</td>
<td>81</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Columbia</td>
<td>22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuba</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>0</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>India</td>
<td>188</td>
<td>188</td>
<td>453</td>
</tr>
<tr>
<td>Indonesia</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iran</td>
<td>332</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>Iraq</td>
<td>68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>42</td>
<td>42</td>
<td>294</td>
</tr>
<tr>
<td>North Korea</td>
<td>25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Libya</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morocco</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myanmar</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pakistan</td>
<td>33</td>
<td></td>
<td>170</td>
</tr>
<tr>
<td>Peru</td>
<td>76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Philippines</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td>401</td>
<td></td>
<td>102</td>
</tr>
<tr>
<td>Syria</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turkmenistan *2</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uruguay</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rest of world total</td>
<td>2,072</td>
<td>383</td>
<td>1,154</td>
</tr>
<tr>
<td>Grand total</td>
<td>6,458</td>
<td>1,891</td>
<td>2,547</td>
</tr>
</tbody>
</table>
Notes to Table 6-12: *1: There are currently two plants in Germany that use a mercury process to produce sodium methylate. Together these plants produce about 100,000 tonnes of sodium methylate per year. *2: According to authorities there should be one small electrolysis unit with mercury technology.

Over the last several decades, chlor-alkali facilities in several countries have worked to reduce mercury releases with various technical measures. UNEP (2010a) summarises this as follows: "The existing MCCAPs use various control techniques to reduce mercury emissions, including: 1) gas stream cooling, 2) mist eliminators, 3) scrubbers, and 4) adsorption on activated carbon or molecular sieves (e.g. US EPA, 1995). Gas stream cooling is often used as the primary mercury control technique or as a preliminary removal step to be followed by a more efficient control device. Mist eliminators can be used to remove mercury droplets, water droplets, or particulate matter from the cooled gas streams. Scrubbers are used to absorb the mercury chemically from both the hydrogen stream and the end box ventilation streams. Sulfur- and iodine-impregnated carbon adsorption systems are commonly used to reduce the mercury levels in the hydrogen gas stream if high removal efficiencies are desired. This method requires pre-treatment of the gas stream by primary or secondary cooling followed by mist eliminators to remove about 90 % of mercury content of the gas stream."

UNEP (2010a) presents the costs and benefits of conversion of mercury-based chlor-alkali plants as follows: Besides the health benefits of reduced mercury releases, […] "the analysis by Concorde (2006) also assesses the costs and benefits (especially energy savings, reduced costs of mercury monitoring and waste disposal, etc) to industry of converting a typical MCCAP to the membrane process. There are various cases of actual conversions that have generated an attractive two-to three-year return on investment. However, it was pointed out that an EU industry investment on average in conversion of the MCCAP process to membrane process may not show an attractive bottom-line return until close to 10 years. The Concorde (2006) study concludes that combining the considerable “bottom-line” benefits of MCCAP conversion with even a conservative estimate of the public health benefits, it can be expected that the overall benefits, even when accumulated over only 5 years, are nearly twice the costs associated with the technology transition. Therefore, the conversion of MCCAPs should be regarded as a high priority when discussing the whole range of public health and other benefits associated with industrial development of chemical industry."

Such mercury reduction measures have been valuable in the past and may be pursued further as long as mercury cells exist. Considering the analysis by Concorde East/West (2006) described above, combined with the fact that mercury-cell technology is recognised as obsolete, in many cases not the most economically beneficial, and as mercury releases are inevitable in the lifecycle of the mercury used in the chlor-alkali sector, it may be concluded that conversion of mercury-cells may be the primary path to pursue in the efforts to reduce mercury releases from this sector. As industry has in several cases indicated that new chlor-alkali facilities will likely not be based on mercury-cell technology, the costs of conversion may be significantly reduced, if industry is given some time for phase-out and conversion.
Some individual investment cost elements of converting a mercury-cell plant to membrane technology are exemplified in Table 6-13, which is based on the EU best available techniques (BAT) reference document for the production of chlor-alkali (EC CAK BREF, 2011). Note that costs for decommissioning of the old mercury-cell plant and some other costs are not included in this table. EC CAK BREF (2011) also reports observed investment costs of conversion of mercury-cell plants to membrane technology at 190-670 EUR/t annual chlorine capacity depending on the needed changes and local conditions, including some environmental clean-up elements (examples from 1992-2009). Investment costs of around 1,000 EUR/t annual chlorine capacity are reported for new plants with membrane technology. The investment costs for conversion thus represents some 20-60% of the investment costs for a new plant.

Table 6-13 Examples of investment costs for the conversion of a mercury-cell plant with 100 kt/y chlorine capacity (and an electric current density of 5 kA/m²) (from EC CAK BREF (2011), citing EuroChlor (2010)).

<table>
<thead>
<tr>
<th>Cost object</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell room and electric supply (5 kA/m²)</td>
<td>69</td>
<td>227</td>
</tr>
<tr>
<td>Peripherals (electrolytes circuits)</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Causitic concentration (3 effects)</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Intermediate buffer tank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brine circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polishing filters</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Hardness removal</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Dechlorination</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Chlorate removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulphate removal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine circuit (liquefaction)</td>
<td></td>
<td>27</td>
</tr>
<tr>
<td>Hydrogen cooling</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Cooling water</td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Total for equipment and installation</td>
<td>140</td>
<td>403</td>
</tr>
<tr>
<td>Engineering</td>
<td>36</td>
<td>51</td>
</tr>
<tr>
<td>Proratable and start-up costs</td>
<td>10</td>
<td>28</td>
</tr>
<tr>
<td>Miscellaneous (10 %)</td>
<td>18</td>
<td>45</td>
</tr>
<tr>
<td>Escalation and financial costs</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>Total conversion</td>
<td>214</td>
<td>553</td>
</tr>
</tbody>
</table>

NB: Costs for decommissioning of the old mercury cell plant and costs for replacement or refurbishing of other equipment are not included.

Source: [232, Euro Chlor 2010]
The overall assessment made by Concorde East/West (2006) of costs and benefits of the conversion of mercury-cell chlor-alkali production in Europe is summarised in Table 6-14. Note that the calculation of health benefits is based on an estimated atmospheric release of on average 4-5 g mercury per tonne chlorine production capacity, which is somewhat higher than normally stated by the Chlor-alkali sector. This emission level is based on an inclusion of mercury-amounts reported as "unaccounted for" in industry reporting, and the further argumentation for this assessment is presented in the reference. Note also that the health benefits only include neuro-toxic effects on humans and no other observed effects on humans or the environment.

<table>
<thead>
<tr>
<th>Combined benefits and costs (billion euro at 2004)</th>
<th>Estimated annual benefits &amp; costs</th>
<th>During 5 yrs.</th>
<th>During 10 yrs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present value – total conversion costs, including: Investment cost, cleanup, etc.</td>
<td>2.6 one-time</td>
<td>2.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Present value total benefits, including:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Industry benefits</td>
<td>various</td>
<td>4.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Health benefits*</td>
<td>0.7 annual</td>
<td>3.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Environmental benefits</td>
<td>significant</td>
<td>not included</td>
<td>not included</td>
</tr>
<tr>
<td>Ratio of total benefits/costs</td>
<td>1.9</td>
<td>1.7</td>
<td>3.2</td>
</tr>
</tbody>
</table>

Assumptions for conversion of European MCCAPs to the membrane process:
- annual chlorine production capacity ≈ 6 million tonnes
- 10-15% of capacity will close rather than convert
- annual atmospheric mercury emissions ≈ 4.5 g Hg per tonne chlorine capacity ≈ 25-30 tonnes mercury total
- annual health benefits >25 euro per gram of mercury emissions eliminated
- annual environmental benefits may be similar to health benefits, but are not quantified here

Note:
* Health benefits are based on estimates of neuro-developmental impacts – specifically loss of intelligence – of methylmercury exposure in the US due to fish consumption, although there is evidence of other health effects as well. The figure of 25 euro per gram of mercury emissions eliminated (multiplied by 25-30 tonnes of mercury emissions eliminated upon full conversion) is a conservative estimate based on two key sources: one assuming human methylmercury exposure from consumption of both marine and freshwater fish, and the other assuming exposure from consumption of freshwater fish only.

Extrapolating the costs of mercury-cell conversion in Europe to the World (excl. Europe and North America) the rough costs estimate shown in Table 6-15 can be derived. Note that these cost estimates include at least some elements of costs for environmental clean-up of the production sites.

Based on the remaining mercury-cell production capacity, the observed costs of conversions in the EU described above, and the calculated error of mean of the costs reported (+/- 15% derived from EC CAK BREF, 2011), the investment costs for conversion from mercury to membrane technology in EU can be roughly estimated at around 1.5-1.9 billion EUR (one time investment), not adjusted for expected savings on operation costs. It can however be discussed if such costs should be assigned to the mercury convention as the EU based chlor-alkali industry has already committed themselves to a voluntary conversion.
Similarly, but assuming double uncertainty on the estimate, the investment cost for the world (excl. EU and North America) can be roughly estimated to 600-1,200 million EUR (one time investment), not adjusted for expected savings on operation costs. As mentioned above, the operation costs for the membrane technology are normally substantially lower than for the mercury-cell technology, and a return on investment in 2-10 years (outer ranges, and not including environmental benefits).

Table 6-15  Roughly estimated costs of conversion of chlor-alkali production to mercury-free membrane technology.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU 27 Hg-based Cl prod. capacity, 1000 t/y</td>
<td>3.912</td>
</tr>
<tr>
<td>World (excl. Europe and North America) Hg-based Cl prod. capacity, 1000 t/y</td>
<td>2.072</td>
</tr>
<tr>
<td>Observed investment costs for conversion in the EU, EUR/t annual Cl prod. capacity (EC CAK BREF, 2011)</td>
<td>190-670</td>
</tr>
<tr>
<td>Average investment costs, EUR/t annual Cl prod. capacity</td>
<td>430</td>
</tr>
<tr>
<td>Calculated uncertainty of cost average, +/- (8 observations)</td>
<td>15%</td>
</tr>
<tr>
<td>Calculated estimated cost, Europe, mill. EUR</td>
<td>1.700 (1.500-1.900)</td>
</tr>
<tr>
<td>Calculated estimated cost, World (excl Europe and North America), mill. EUR (uncertainty assumed +/- 30%)</td>
<td>900 (600-1,200)</td>
</tr>
</tbody>
</table>

Table 6-16  Summary of costs and effectiveness for substitution of Hg-cells in chlor-alkali production outside the EU and North America.

<table>
<thead>
<tr>
<th>Chlor-alkali production</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calculated estimated cost, World (excl Europe and North America), mill. EUR</td>
<td>600</td>
<td>1,200</td>
</tr>
<tr>
<td>Estimated annualised costs, World (excl Europe and North America), mill. EUR</td>
<td>24</td>
<td>48</td>
</tr>
<tr>
<td>Reduction potential, 100% Hg eliminated from circulation in environment, t Hg/y</td>
<td>257</td>
<td>257</td>
</tr>
<tr>
<td>Reduction potential, 100% of air emissions, t Hg/y</td>
<td>21</td>
<td>46</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation, EUR/kg Hg</td>
<td>90</td>
<td>190</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>1,000</td>
<td>1,100</td>
</tr>
</tbody>
</table>
6.5 Summary of costs and effectiveness of the measure

Table 6-17  Summary of costs and effectiveness, World excl. EU and North America.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Reduction potential (circulation), t Hg/y*1</th>
<th>Estimated cost per kg of Hg (circulation), EUR/kg Hg</th>
<th>Estimated global costs, mill. EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries</td>
<td>240-408</td>
<td>4.100-22.000</td>
<td>1.000-8.900</td>
</tr>
<tr>
<td>Dental amalgam</td>
<td>193-261</td>
<td>(-830)-18.000</td>
<td>(-160)-4.700</td>
</tr>
<tr>
<td>Measuring and control devices</td>
<td>250-280</td>
<td>5-540</td>
<td>1-140</td>
</tr>
<tr>
<td>VCM production</td>
<td>770</td>
<td>80-230</td>
<td>60-180</td>
</tr>
<tr>
<td>Hg-cell chlor-alkali production</td>
<td>257</td>
<td>90-190</td>
<td>600-1.200</td>
</tr>
<tr>
<td>Total estimated costs</td>
<td>1.710-1.976</td>
<td>-</td>
<td>1.501-15.120</td>
</tr>
</tbody>
</table>

Notes: For air emission reductions and cost effectiveness related to air emissions, see tables above.

6.5.1 Uncertainties and gaps

It should be noted that mercury concentrations in button cells and other batteries are regulated by the EU Battery Directive, and thus the situation here could differ from the situation in some other regions of the world. As the data are most updated and complete here, we have however used EU data as the background for the costs estimation.
7 Artisanal and small scale gold mining (ASGM)

Summary of the key features of the measure and its potential impacts
The aim of the measure is to reduce, and if possible eliminate, the use of mercury in ASGM, and promote good mercury house-holding practices to reduce mercury releases from this activity. As several hundred tonnes of mercury is consumed in ASGM annually, and a significant part is emitted to air, this measure has a significant potential for mercury release reductions with a global perspective.

7.1 Who will be affected?
This measure will give very little cost impacts within the EU, as ASGM is only performed in some limited EU territories outside Europe (such as French Guyana, where it is illegal). There is on the other hand a significant need for support to awareness-raising, training in release reduction methods, etc. among miners globally, and this may be challenging elements of a future convention on mercury. The miners are many, spread over large remote areas, loosely or not at all organised in groups, and often the operations are illegal. The Artisanal Gold Council and other experts are positive that substantial reductions can be made, and valuable experience with the needed types of activities has been gained through the UNIDO Global Mercury Project, and similar activities. A manifold increase in dedicated efforts is however needed.

UNEP (2011a) presents the issue as follows: "Artisanal and small-scale gold mining (ASGM) remains the largest demand sector for mercury globally. Best estimates put global mercury use in the sector in the range of 1300 tonnes in 2011. Virtually all of the mercury used is released to the environment. Conservative estimates suggest that ASGM accounts for 13 per cent of the world’s gold production per annum and directly involves an estimated 10-15 million miners globally. From this, the current value of annual artisanal and small-scale gold production in 2010 and 2011 is around USD10.5 billion. With the price of gold rising to over USD1,700 per ounce in 2011, a gold rush involving a growing number of poverty-driven miners is currently under way."
It is believed that ASGM is practiced in almost 70 countries around the world, of which 14 are in Asia and the Pacific, 17 in Latin America and the Caribbean and 32 in Africa.

Artisanal and small-scale gold mining is a complex global development issue that presents challenges and opportunities in many countries. Technical options for reducing mercury use and releases exist [...]. Lack of access to formal credit markets as a result of the informal nature of the sector, however, is a barrier to change.

[...] The specific requirements [...] will vary from situation to situation, but in all cases will require stakeholder engagement, financial and technical support, access to markets, capacity building and training."

Note that since then, the mercury demand estimate has been increased, see below.

### 7.2 Potential barriers to implementation

As the sector is largely informal, geographically spread, and with little education and infrastructure, it requires local outreach and training in all affected regions to implement the available, low-cost and effective cleaner low-tech solutions. The activity is poverty-driven and the number of miners is expected to grow with rising gold prices and ever-present humble means of alternative livelihoods.

Local governments in developing countries may have moderate means and incentives to promote better mercury management in the ASGM regions, and can not be expected to secure effective mercury reductions in this activity field without significant support. It is therefore deemed of paramount importance that adequate financial and technical support is made available for this "sector", even if it may not be agreed to make binding, global measures on this aspect. In order to be effective, training efforts should likely be backed by rising mercury prices to increase the incentive for release reduction and better mercury "house-holding practices". This again links to the requirement for reduced global mercury supply.

UNEP(2010a) states the following in relation to the situation for small scale miners: "Given a recent price relation between gold and mercury of 1:1000, it would require an extremely large price reduction in gold before gold production via ASGM technologies would become less profitable than alternative income sources for the community. Another effect is that the disposable income would become even smaller for the miners and their community. If mercury price was increased, the income could become smaller for the miners, resulting in a poorer financial situation, although increasing mercury prices may provide an incentive for miners to use less mercury (by using processes to concentrate the ore prior to amalgamation), or to ensure efficient capture and recycling of mercury.

The implementation of suitably designed micro credits could encourage the use of mercury-free technologies which increases the potential benefit of this abatement
option, since no use of mercury has a higher benefit than control of mercury emissions via technical solutions."

### 7.3 Mercury inputs and air emissions

<table>
<thead>
<tr>
<th>Measure/options</th>
<th>Input of Hg to society, t/y</th>
<th>Hg releases to atmosphere, t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASGM</td>
<td>1,465</td>
<td>660</td>
</tr>
</tbody>
</table>

### 7.4 Expected costs

Figure 7-1 summarises expert assessments of the reduction potential of known technologies and practices in ASGM. The figure was based on a previous estimate of mercury demand for the activity, but depicts the expected potential of a 90% decrease in demand from the introduction of low-tech solutions based on training.

The following extracts from (UNEP, 2010a) capture the key features of the needed activities and the associated costs:
"There are a number of technologies available to reduce the use or release of mercury associated with ASGM. The use of mercury vapour capture technologies in gold shops is estimated to be quite efficient since it involves relatively large scale operations and allows for increased income for the users of the technology. The estimated costs are relatively low. A quick estimate is a cost less than USD 19 per kg reduced mercury emission (not considering education or disposal costs). Telmer (2008) indicates that the installation of vapour capture equipment in a gold shop would cost USD 35 and capture 90% of the mercury vapour.

The use of mercury retorts by miners depends on information and education and there are a vast number of miners in need of education, so the use of retorts is estimated as costly, although the unit cost of each retort is low. The efficiency of the measure depends on the application of the retorts. [...] Micro credits have proven themselves as very effective as a tool to reduce poverty in other circumstances in the world (Yunus 2006, Grameen Bank). This could provide the opportunity to the gold miners to increase their long term thinking when engaging in gold mining. Furthermore, given that this is a loan, implementation costs can be reduced as loans are repaid.

[...] In a 2-year project, community mining groups have been trained and are purchasing and using retorts, each of which costs about USD 5 when purchased in bulk. 500 miners have been trained and to date, upwards of 80 percent, as self-reported by the miners, are using the retorts. A retort has a maximum potential of capturing 90% of the mercury vapour. [...] The costs following this effort are estimated at USD 5 per retort and USD 100 per person for education (based on EU experience cited above).

According to Telmer, (2012), education is critical to decreasing the use of mercury. Past efforts have been fettered by barriers such as a lack of awareness of the realities of mining communities and a poor understanding of their motivations. However, more recent efforts have shown that education can be highly effective at lowering mercury use and ultimately eliminating it. Part of this education is in technical training that allows miners to accomplish two important outcomes: (1) lowering or eliminating mercury use through recycling and/or more efficient amalgamation through activation, or replacing mercury use through more efficient concentration techniques - this saves money by reducing the costs of mercury; (2) increasing gold recovery - this refers to education that allows miners to process the same amount of material but recover more gold allowing them to invest in low or zero mercury methods. Importantly, although a higher mercury price does present an incentive for miners to use less mercury, this is most true for the intensive mercury users (using whole ore amalgamation) and much less true for low intensity mercury use (concentrate amalgamation) which is still extremely widespread. For example, most of Africa practices low intensity mercury use where an elevated cost of mercury will not be as strong an incentive to lower use as education about health effects and education about alternative higher gold recovery practices. Using up-scaling methods of education and outreach, a cost of USD 100/miner for 10 million miners for a total of 1000 million dollars would be highly effective according to Telmer (2012).
According to Telmer (2012), estimates of mercury release to the environment were 1,000 tonnes/year in 2008 with 40% of that being emitted to the atmosphere. In 2011, the global mercury demand estimate for ASGM was raised to 1,425 tonnes/year (Telmer, 2011). More recent estimates from Telmer (2012) suggest that the releases may be as high as 1,600 tonnes/year with 45% or 720 tonnes released to the atmosphere through amalgam heating. The use of retorts could potentially capture 90% of this or 650 tonnes.

Based on the above considerations, the costs for a 90% reduction of mercury input to and releases from ASGM from the implementation of these initiatives are thus estimated roughly at 1,000 million USD for education efforts plus 5*10 = 50 Million USD for the purchase of retorts or other low-tech solutions, summing up to 1,050 million USD or 800 million EUR (no attempt was made here to estimate the uncertainty of this cost). According to Telmer (2012), more miners can in fact use the same retort, so actual costs might be slightly lower, but this estimate was used in the assessment in light of the associated uncertainty. A practical implementation time of 10 years for this educational process is used in the overall assessment, and the effect is for simplicity assumed to be indefinite (adopted practices would be passed on to future miners).

A summary of costs and effectiveness is given in Table 7-2 below.

<table>
<thead>
<tr>
<th>Table 7-2</th>
<th>Summary of costs and effectiveness of the measure on ASGM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>World excl EU+NA</td>
<td>Medium</td>
</tr>
<tr>
<td>Estimated costs (education; low tech devices assumed included), million USD</td>
<td>1,050</td>
</tr>
<tr>
<td>- do, million EUR</td>
<td>800</td>
</tr>
<tr>
<td>Annualised/discounted costs - indefinite lifetime assumed, mill. EUR/y</td>
<td>42</td>
</tr>
<tr>
<td>Reduction potential, 90% Hg eliminated from circulation in environment, t Hg/y</td>
<td>1,310</td>
</tr>
<tr>
<td>Reduction potential, 90% of air emissions, t Hg/y</td>
<td>590</td>
</tr>
<tr>
<td>Calculated effectiveness, eliminated from circulation, EUR/kg Hg</td>
<td>32</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>71</td>
</tr>
</tbody>
</table>

### 7.5 Summary of costs and effectiveness of the measure

The costs and effectiveness of the measure are summarised in the section above.
7.5.1 Uncertainties and gaps
The estimate is associated with substantial uncertainty mainly as regards the need for education of miners, and it is not known with any certainty if the measure will ensure lasting reductions in mercury demand and releases. This likely largely depends on the development in mercury and gold prices.
8 Emissions and releases

Summary of the key features of the measure and its potential impacts

The aim of this measure is to reduce mercury releases from the major sources of atmospheric emissions and major sources of mercury releases to land and water. Examples of major atmospheric mercury release sources covered are coal fired power plants, non-ferrous metals smelters, waste incineration, etc. Examples of major release sources to land and water covered are production using mercury intentionally, non-ferrous metal production, waste incineration, etc. There is a significant potential for mercury release reductions with this measure, which can be considered a key measure of the convention.

Limitation in scope

The quantifications made in this section focuses primarily on atmospheric releases. This is because most of the data needed for quantification of costs and effectiveness related to releases to other media are not available or not aggregated sufficiently to be included here within the framework of this study.

8.1 Who will be affected?

The owners of the facilities affected will face costs for the introduction of BAT/BEP techniques, notably filter systems which retain mercury from the flue gas in solid or liquid residues.

Many of the affected facilities are either publicly owned or are local or national scale privately owned companies. As mentioned above the non-ferrous metals sector is constituted primarily by a relatively small number of multinational mining companies, but also some local and national scale companies exist.

Local producers of mercury-added products in the developing world will be affected by costs for mercury filters. These costs are however considered as probably relatively minor in the global perspective and they have not been quantified in this study due to this and the complexity of the issue.
Depending on the level of ambition in the negotiations, this measure could have substantial impact on mercury release sources within the EU. Quite likely however, the level of mercury release reductions attained in the EU may serve as a model for the rest of the world, and the measure would in this case not necessarily impose large changes for EU industry/facilities. Options for mercury reduction beyond the present EU level are however available for some sources, and controls already implemented on some source types in the EU could be applied on other similar sources (e.g. activated carbon injection in coal fired power plants and flue gas desulphurisation on industrial coal fired boilers). Such options are considered in the current draft elements paper in general terms, and should they become a part of a convention, this measure could have substantial impacts within the EU, warranting more detailed study of the intra-EU costs of this measure.

Also, the application of available and more effective specific emission controls for mercury in coal fired power plants, the largest global source of atmospheric mercury emissions, could become an issue in the negotiations in order to reach desired global reductions in this field. It should however be kept in mind that the planned reductions of greenhouse gas emissions (from the EU and elsewhere) may likely reduce mercury releases from the power sector. This is because the mercury emissions are closely related to the amounts of coal combusted.

As regards extra-EU costs, that is, costs in the World except EU and North America, this measure will likely require substantial support for developing countries and countries in transition. This may be financial support for implementation projects, and notably technical support (like the current EU funded UNEP Coal fired power plants project).

A potentially positive cost element in this respect is the possible boost in export of mercury reduction controls developed and manufactured in the EU. Because of the long experience with these technologies, the European industry is among the frontrunners of the global market.

### 8.2 Potential barriers to implementation

**Non-ferrous metal sector:** See section 4.2. Additional technical barriers: Several of the currently most effective and economic technologies for mercury removal suited for the non-ferrous metal sector are owned by one company, with the resulting potential limitations for competition and reduced prices (UNEP,2011c).

**Coal fired power plants:** The availability of inexpensive power is seen as a major component in material growth and the sector is thus sensitive to increased prices. The ongoing negotiations of a renewed protocol on climate change also addresses this sector, and any progress in reducing carbon dioxide emissions from coal fired power plants will also reduce mercury releases from the sector.
8.3 Mercury inputs and air emissions

<table>
<thead>
<tr>
<th>Measure/options</th>
<th>Input of Hg to society, t/y</th>
<th>Hg releases to atmosphere, t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal fired power plants</td>
<td>NA</td>
<td>396</td>
</tr>
<tr>
<td>Residential heating and industrial boilers</td>
<td>NA</td>
<td>382</td>
</tr>
<tr>
<td>Non-ferrous metal production (Zn, Pb, Cu, Au large scale)</td>
<td>NA</td>
<td>243</td>
</tr>
<tr>
<td>Cement production</td>
<td>NA</td>
<td>189</td>
</tr>
<tr>
<td>Pig iron and steel production</td>
<td>NA</td>
<td>61</td>
</tr>
<tr>
<td>Large scale controlled waste incineration</td>
<td>-</td>
<td>42</td>
</tr>
</tbody>
</table>

NA = Not available.

8.4 Costs and effectiveness by sector

8.4.1 Coal fired power plants (CFP)

Cost estimate data

The most recent examples of costs estimates identified are given in the so-called §29 study (UNEP, 2010) and presented in Table 8-2 and Table 8-3 below.

As shown, the total prices for mercury reduction per MWh electricity produced varies by a factor 50 depending on which technology is already present in the CFP and which technology is chosen for additional mercury removal. The general pattern is that the more advanced (multi-pollutant) abatement technology already installed, the lower the cost for achieving additional mercury retention. This is because the mercury-specific removal systems require high efficiency dust filters to capture the mercury-containing reagents/dust.

Multi-pollutant flue gas cleaning systems are normally introduced to lower concentrations of dust (with soot and heavy metals), SO\(_{X}\) and NO\(_{X}\). These systems do generally not retain the part of the mercury present as elemental mercury gas. The fraction of the mercury present as elemental mercury gas varies with coal type and combustion conditions primarily depending on the presence of other trace elements (Cl, Br, etc.) which can oxidise elemental mercury gas into ionic mercury which associates with dust in the flue gas and thereby can be captured in dust filters present. The retention of mercury in highly efficient dust filters like fabric filters (FF) and high-end electrostatic precipitators (ESP) vary from around 10% to above 90% depending on coal type and conditions, but on average they are considered to retain about 50% (UNEP, 2011b).

Two key principles are employed to reach additional mercury retention: 1) Activated carbon injection (ACI), often with carbon impregnated with halogens to increase mercury adsorption which yields the highest retention rates, and 2)
injection of oxidising reagents into the flue gas stream to enhance mercury oxidation and thereby increase mercury retention in high-end dust filters.

Multi-pollutant flue gas cleaning systems are present in most coal fired power plants in the EU (assumed 90%), while they are generally absent in the world outside the EU and North America (and Japan, Rep. of Korea and Australia). The presence is reported to be 48% of facilities in China (Wang et al., 2010) and assumed 10% in other regions of this group of countries; yielding an overall presence of 21% in these regions. Activated carbon injection performed on a routine basis in coal fired power plants has not been reported to take place outside the USA, while it is regularly practiced in other sectors, notably in waste incineration, in the EU and perhaps other places.

Activated carbon injection can work without the presence of advanced multi-pollutant systems like flue gas desulfurization (FGD) or selective catalytic reduction (SCR) (only a high end filter is needed). Installing ACI alone (including needed filters) can also be less expensive than installing a full advanced multi pollutant system, and some countries with low-sulphur coal dominating their power sector may wish to install ACI only, if mercury release reductions are desired. ACI has therefore been chosen as the example of a mercury-specific reduction technique for which costs and related effectiveness were calculated.

Depending on the agreements made on mercury reduction targets for coal fired power plants in the negotiations of a global agreement, the EU may not necessarily be required to install ACI, because substantial mercury release reductions have already been acquired with multi-pollutant systems.

Note that in the calculations made, it has been taken into account that for coal fired power plants with existing advanced multi-pollutant retention systems, on average 50% of the mercury is already being retained and therefore the resulting extra retention of mercury with ACI will be lower (for example 80% of remaining 50% = 40% Hg retention).

Table 8-2 Examples of emission control costs and removal efficiencies for coal combustion from Pacyna et al (2010).

<table>
<thead>
<tr>
<th>Emission control technology</th>
<th>Estimated Hg reduction (per cent)</th>
<th>Costs (USD 2008/MWhe)*2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Investment cost</td>
</tr>
<tr>
<td>Dry ESP</td>
<td>&gt; 63</td>
<td>0,5</td>
</tr>
<tr>
<td>Fabric filter (FF)</td>
<td>&gt; 93</td>
<td>0,5</td>
</tr>
<tr>
<td>FF+wet or dry scrubber+sorbent injection</td>
<td>&gt; 98</td>
<td>2,7</td>
</tr>
<tr>
<td>Dry ESP + wet or dry scrubber + sorbent injection</td>
<td>&gt; 98</td>
<td>2,7</td>
</tr>
</tbody>
</table>

Notes: *1: Annual operating costs of about USD 20/MWh electricity (MWhe) could be expected for emerging technologies such as Electro-catalytic Oxidation or Integrated Gasification Combined Cycle. *2: The accuracy of cost estimates in the table is within ± 50 per cent.
Table 8-3  Examples of capital and operating & maintenance costs, as well as removal efficiencies for different configurations of mercury specific emission controls. Based on data from Sloss (2008) and NESCAUM (2010).

<table>
<thead>
<tr>
<th>Existing equipment configuration</th>
<th>New equipment configuration</th>
<th>Capital cost (year 2010 USD/MWhe)</th>
<th>O&amp;M cost (year 2010 USD/MWhe)</th>
<th>Removal efficiency (per cent) / plant capacity (MW)</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1= lignite coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2= sub-bituminous coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cESP</td>
<td>+ACI</td>
<td>0,15</td>
<td>4,06</td>
<td>80 /</td>
<td>Sloss, 2008</td>
</tr>
<tr>
<td>cESP+FGD</td>
<td>+ACI</td>
<td>0,15</td>
<td>4,06</td>
<td>80 /</td>
<td>Sloss, 2008</td>
</tr>
<tr>
<td>Dry scrubber+FF</td>
<td>+ACI</td>
<td>0,02</td>
<td>0,32</td>
<td>80 /</td>
<td>Sloss, 2008</td>
</tr>
<tr>
<td>ESP¹</td>
<td>+ACI</td>
<td>0,04</td>
<td>0,09-1,16</td>
<td>90 / 220</td>
<td>NESCAUM, 2010</td>
</tr>
<tr>
<td>ESP²</td>
<td>+ACI</td>
<td>0,06-0,07</td>
<td>0,14-1,06</td>
<td>90 / 240 and 140</td>
<td>NESCAUM, 2010</td>
</tr>
<tr>
<td>ESP+wFGD¹</td>
<td>+ CaBr₂</td>
<td>0,01</td>
<td>0,07</td>
<td>73 / 500</td>
<td>NESCAUM, 2010</td>
</tr>
<tr>
<td>ESP+wFGD²</td>
<td>+ CaBr₂</td>
<td>0,01</td>
<td>0,07</td>
<td>73 / 500</td>
<td>NESCAUM, 2010</td>
</tr>
<tr>
<td>ESP+wFGD¹</td>
<td>+ Pd catalyst</td>
<td>0,02</td>
<td>Not available</td>
<td>73 / 500</td>
<td>NESCAUM, 2010</td>
</tr>
<tr>
<td>ESP+wFGD²</td>
<td>+ Au catalyst</td>
<td>0,03</td>
<td>Not available</td>
<td>73 / 500</td>
<td>NESCAUM, 2010</td>
</tr>
</tbody>
</table>

Using the prices in bold in Table 8-3 above as illustrative examples of the price range and using the 2005 mercury emission estimates for coal fired power plants presented in Section 3, the following annual costs and mercury reduction potentials can be calculated.

Appendix 2 presents an overview of other data used and results calculated for cost and effectiveness of ACI for additional reductions of mercury releases to the atmosphere.

A summary of costs and effectiveness of the introduction of ACI on large coal fired power plants is given in Table 8-4 below.
Table 8-4  Summary of costs and effectiveness of mercury capturing filters on coal fired power plants.

<table>
<thead>
<tr>
<th>Summary of costs and effectiveness</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated costs, World (excl EU and NA), mill. EUR/y</td>
<td>1.200</td>
<td>14.000</td>
</tr>
<tr>
<td>Reduction potential, reduced air emissions, t Hg/y</td>
<td>170</td>
<td>400</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>3.000</td>
<td>82.000</td>
</tr>
</tbody>
</table>

Results, CPL adjusted*1:

| Estimated costs, World (excl EU and NA), mill. EUR/y | 710  | 8.300 |
| Calculated effectiveness, reduced air emissions, EUR/kg Hg | 1.800 | 48.000 |

8.4.2 Non-ferrous metal production

To our knowledge global estimates of costs and effectiveness of mercury release reductions have not previously been reported, and this section is largely based on original data collected for this study. A more detailed description than made in other sections of the report was therefore deemed necessary.

Mercury mass balance and release abatement in the non-ferrous metal sector

The description here focuses on the production of zinc, copper, lead and large scale gold from ore, or more precisely from concentrated ore, so-called concentrate (except for gold, which is produced directly from ore). The production of these metals have the highest potential for mercury releases, as large part of these metals are produced from sulphidic ore with relatively high mercury concentrations.

According to Outotec, the dominating global supplier of release reduction equipment for the non-ferrous metal sector, in general one can say that practically all zinc and lead smelters (with the pyrometallurgical process) have such amounts of mercury in the feed that they need mercury removal systems. There are exceptions, with cleaner feed metal concentrates, but they are few. For copper smelters it is the opposite. But, it seems that there are more and more copper concentrates which will contain some mercury. For gold smelters it varies. Some concentrates contain very high levels of mercury, e.g., in Nevada and Australia.

The major part of the direct mercury release take place when the concentrate is roasted at high temperatures to remove the sulphur and oxidise the metal mineral to make it available for the downstream leaching processes (in the so-called pyrometallurgical method process). In the roasting, almost all the mercury present evaporates and follows the gas phase.

Note that some modern non-ferrous metal operations use the direct-leach hydrometallurgical extraction process, where the ore concentrate is not roasted but
leached in aqueous solutions of chemicals, and the mercury is directed to waste sludges, which also need environmentally sound disposal.

In Figure 4-1 below, a typical mercury balance for a zinc smelter is illustrated by the dominating producer of mercury retention equipment and other process systems for the non-ferrous metal sector (Outotec, 2012).

*Figure 8-1 Typical mercury balance for a zinc smelter (Outotec, 2012).*

<table>
<thead>
<tr>
<th>Capacity:</th>
<th>330,000 ton/year of zinc concentrate equal to a production of approx. 165,000 ton/year of zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury content of the concentrate:</td>
<td>65 ppm, equal to 21,450 kg./year</td>
</tr>
</tbody>
</table>

Almost all large pyrometallurgical smelters treating sulphidic raw materials have acid plants, where the SO₄ in the off-gas from the roasting process is exploited to produce sulphuric acid, and at the same time reduce the adverse effect of acidification in the environment. For the acid plant to function properly, dust and humid mist needs to be captured from the off-gas and for this a series of filters and scrubbers concluding with a wet electrostatic precipitator is employed. A substantial part, but not all, of the mercury present in the off-gas is retained as
aqueous sludge in this wet gas cleaning sequence. The sludge is deposited locally, or further processed to extract contained metals, including mercury.

In some non-ferrous metal smelters with acid plants, a dedicated mercury removal step is introduced before the acid plant. In other smelters this is not the case, and as shown in Figure 8-1, most of the remaining mercury is retained in the produced, and normally marketed, sulphuric acid, while a minor part (~5% in figure) will be released directly to the atmosphere. Some uses of sulphuric acid require mercury concentrations to be low or even very low, and for production of such acid qualities from non-ferrous metal smelters, the use of a mercury removal system is necessary. Industry standards exist, which specify mercury threshold concentrations.

Other technical uses of sulphuric acid are not technically vulnerable to mercury impurities, and there is a substantial market for such low-grade acid. The further fate of the mercury in the sulphuric acid is largely an un-described aspect of the lifecycle of mercury in the non-ferrous metal sector. A part of it may likely be used in open processes where part of the mercury is released to the environment. This is, for example, the case when the sulphuric acid is used in industrial fertilisers for agricultural application.

Two factors are thus important drivers for reduction of mercury releases to the atmosphere from the non-ferrous metal sector: 1) The economical and environmental incentives for establishing an acid plant, and 2) technical/economical and environmental incentives for mercury removal. If there is a market for sulphuric acid with high concentrations of mercury impurity, the producer has no economical incentives for retaining the mercury. This choice can be influenced by requiring environmental standards for mercury release reduction or by requiring standards dictating low mercury concentrations in sulphuric acid.

Where a mercury removal step is included, almost all of the remaining mercury is retained, and the air emissions are reduced to a minimum (~0.1 parts per thousand of the input in figure). The mercury retention rates with the most effective methods are very close to 100% (EC NFM BREF, 2001). With the most widely used technology, the so-called Boliden Norzinc process (also called the Outotec Chloride Scrubber), the residue produced is mercury chloride (="calomel"), which may be sold for processing elsewhere, may be refined to metal mercury, or may be deposited locally, depending on company policy, environmental regulation, the market price of mercury and the price for local deposition.

The Boliden Norzink process is the most economic of the effective mercury removal techniques and it is implemented in about 80% of the existing mercury removal systems in the sector. The technique requires the presence of a wet off-gas cleaning system to operate satisfactorily (Outotec, 2012). Other techniques exist for mercury removal in the non-ferrous metals sector, but most are more expensive and are also produced by Outotec (mostly for specialty applications). We therefore focus on the Boliden Norzink process in the derivation of cost effectiveness estimates.

There are exceptions where acid plants are not present, especially in some remote areas (such as parts of Canada, Russia and Australia) where it is difficult to
transport the sulphuric acid to the market. Precise numbers are not available, but a major producer of pollution prevention systems for non-ferrous facilities (Outotec, 2012) estimates that at least 90-95% of all smelters with a normal industrial scale size have acid plants. Not counted then are extremely small smelters, for example in China. Obviously most of these are very small and probably with a very limited gas cleaning only, if any (Outotec, 2012).

Some modern "smelters" use an alternative "direct leach" process (hydrometallurgical process), where the concentrate is not roasted, but instead is processed in a series of aqueous media. This process produces no or minimal direct atmospheric mercury releases, but instead directs all the mercury to wet sludges, which can be deposited in local tailings deposits, or further processed to produce metal mercury for the market.

Secondary non-ferrous metal production (from recycled metal) also releases mercury, but to a much smaller degree, and not much data are available on this subject. For these operations, activated carbon filters are among the techniques used for mercury retention (Outotec, 2012).

As for other non-ferrous metals, the major mercury emitting production is that of gold production, which is dealt with in other sections. Many small-scale and a few medium-scale gold miners employ mercury for the gold extraction with the amalgamation process (see Section 7). Large scale gold production using cyanidation and other related processes (and no intentional mercury addition) are also major sources of mercury releases in the global perspective. The gold ore naturally contains moderate to major concentrations of mercury.

The production of other non-ferrous metals may also release mercury, but to a smaller degree, and these sectors are poorly described in the mercury literature and are therefore not dealt further with in this study.

The key producer countries of zinc, copper, lead and gold, and their annual production of these metals are shown in Table 8-5.
Table 8-5  Global mine production of zinc, copper, lead and gold in 2010, tonnes/year (USGS, 2012*1).

<table>
<thead>
<tr>
<th>Country</th>
<th>Zinc</th>
<th>Copper</th>
<th>Lead</th>
<th>Gold</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>748.000</td>
<td>1,110.000</td>
<td>369.000</td>
<td>231</td>
</tr>
<tr>
<td>Australia</td>
<td>1,480.000</td>
<td>870.000</td>
<td>625.000</td>
<td>261</td>
</tr>
<tr>
<td>Bolivia</td>
<td>411.000</td>
<td></td>
<td>73.000</td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td></td>
<td></td>
<td></td>
<td>58</td>
</tr>
<tr>
<td>Canada</td>
<td>649.200</td>
<td>525.000</td>
<td>65.000</td>
<td>91</td>
</tr>
<tr>
<td>Chile</td>
<td>5,420.000</td>
<td></td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>China</td>
<td>3,700.000</td>
<td>1,190.000</td>
<td>1,850.000</td>
<td>345</td>
</tr>
<tr>
<td>Ghana</td>
<td></td>
<td></td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>India</td>
<td>700.000</td>
<td>343.000</td>
<td>95.000</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td></td>
<td>872.000</td>
<td></td>
<td>120</td>
</tr>
<tr>
<td>Ireland</td>
<td>342.000</td>
<td></td>
<td>45.000</td>
<td></td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>500.000</td>
<td>380.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mexico</td>
<td>518.000</td>
<td>260.000</td>
<td>158.000</td>
<td>73</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td></td>
<td></td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>Peru</td>
<td>1,470.000</td>
<td>1,250.000</td>
<td>262.000</td>
<td>164</td>
</tr>
<tr>
<td>Poland</td>
<td></td>
<td>425.000</td>
<td>70.000</td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td>703.000</td>
<td>97.000</td>
<td>192</td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
<td>50.000</td>
<td>189</td>
</tr>
<tr>
<td>Sweden</td>
<td></td>
<td></td>
<td>60.000</td>
<td></td>
</tr>
<tr>
<td>Uzbekistan</td>
<td></td>
<td></td>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Zambia</td>
<td></td>
<td>690.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other countries</td>
<td>1,490.000</td>
<td>1,900.000</td>
<td>320.000</td>
<td>559</td>
</tr>
<tr>
<td>World total (rounded)</td>
<td>12,000.000</td>
<td>15,900.000</td>
<td>4,140.000</td>
<td>2,560</td>
</tr>
<tr>
<td>% of total (Zn+Pb+Cu)</td>
<td>37%</td>
<td>50%</td>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>


Additional mercury removal potential

Based on their background knowledge of the global non-ferrous metals sector, Outotec (2012) has estimated roughly the remaining potential for mercury removal from primary non-ferrous metal production in the major producer-countries of these metals. The estimates are associated with uncertainties, especially due to varying concentrations of mercury in the feed materials, but do however provide important information about the current situation. The table also presents Outotec's current knowledge of existing mercury removal systems in the country.

Note that the description and estimates in the table includes large-scale gold production.
Table 8-6 Prevalence of dedicated mercury removal systems in the non-ferrous metal sector and estimated remaining mercury removal potential in major mining countries of the world (Outotec, 2012).

<table>
<thead>
<tr>
<th>Country</th>
<th>Non-ferrous smelters</th>
<th>Mercury removal systems</th>
<th>Rough estimate of the remaining potential for mercury removal in the non-ferrous metal sector with main technologies (ton per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>There are at least two zinc smelters and several copper smelters</td>
<td>No systems installed</td>
<td>15</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>Several copper-and zinc smelters</td>
<td>No systems installed to our knowledge</td>
<td>Difficult to say, maybe 10</td>
</tr>
<tr>
<td>Uzbekistan</td>
<td>At least one copper- and one zinc smelter</td>
<td>No systems installed to our knowledge</td>
<td>Difficult to say, 0-10</td>
</tr>
<tr>
<td>India</td>
<td>There are many zinc-, copper- and lead smelters.</td>
<td>There are a number of Boliden Norzink plants installed in the zinc smelters, but they have never been started up due to no incentive for Hg removal.</td>
<td>20</td>
</tr>
<tr>
<td>China</td>
<td>Many zinc-, copper- and lead- and gold smelters.</td>
<td>4-5 systems installed. Probably there are several more smelters needing mercury removal.</td>
<td>Very difficult to say, maybe 20</td>
</tr>
<tr>
<td>Chile</td>
<td>Numerous copper smelters</td>
<td>Two smelters have the Boliden Norzink process installed. But, they are not in operation as there is a large sulphuric acid market in Chile for leaching of oxidic copper ore and for this application there does not seem to be any concern about mercury.</td>
<td>15</td>
</tr>
<tr>
<td>Mexico</td>
<td>There are zinc-, copper- and lead smelters.</td>
<td>No systems installed to our knowledge</td>
<td>10</td>
</tr>
<tr>
<td>Brazil</td>
<td>There are at least zinc- and copper smelters.</td>
<td>No systems installed to our knowledge; one is in advanced planning</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>Peru</td>
<td>There are zinc-, copper- and lead smelters.</td>
<td>No installation of mercury removal plants, as far as we know.</td>
<td>Probably 5-15</td>
</tr>
<tr>
<td>Iran</td>
<td>There are at least lead- and copper smelters.</td>
<td>One Boliden Norzink process installed at a lead smelter. Not operated presently due to little mercury in the raw material.</td>
<td>Difficult to say 0-10</td>
</tr>
<tr>
<td>Indonesia</td>
<td>There is a copper smelter.</td>
<td>No installation of mercury removal plants, as far as we know.</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>Philipinnes</td>
<td>There is a copper smelter.</td>
<td>No installation of mercury removal plants, as far as we know.</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>Thailand</td>
<td>There are zinc-, copper- and lead smelters.</td>
<td>The Boliden Norzink technology is installed for copper-and zinc smelter.</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>Zambia</td>
<td>There are copper smelters.</td>
<td>No installation of mercury removal plants, as far as we know.</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>South Africa</td>
<td>Many non-ferrous smelters.</td>
<td>No installation of mercury removal plants, as far as we know.</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>USA</td>
<td>Many different smelters.</td>
<td>Three Boliden Norzink plants installed (one for a zinc roaster and two for gold roasting).</td>
<td>Little 0-5</td>
</tr>
<tr>
<td>Country</td>
<td>Non-ferrous smelters</td>
<td>Mercury removal systems</td>
<td>Rough estimate of the remaining potential for mercury removal in the non-ferrous metal sector with main technologies (ton per year)</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td>Five Boliden Norzink plants installed (four for zinc roasters and one for copper smelter).</td>
<td>Probably little 0-5</td>
</tr>
<tr>
<td>Australia</td>
<td>There are zinc-, copper- and lead smelters.</td>
<td>One Boliden Norxink plant installed at a zinc smelter. There are at least one gold smelter and one lead smelter without mercury removal, in spite of substantial mercury load.</td>
<td>10</td>
</tr>
<tr>
<td>Japan</td>
<td>Many different smelters.</td>
<td>Boliden Norzink and other technologies are installed.</td>
<td>Probably little 0-2</td>
</tr>
<tr>
<td>South Korea</td>
<td>Many different smelters.</td>
<td>Boliden Norzink technology installed.</td>
<td>Probably little 0-2</td>
</tr>
<tr>
<td>Poland</td>
<td>There are at least copper- and zinc smelters.</td>
<td>No mercury removal plants installed, as far as we know. Reported that only little mercury in the concentrates.</td>
<td>Probably little 0-2</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>There are zinc-, copper- and lead smelters.</td>
<td>Boliden Norzink technology installed for a zinc plant.</td>
<td>Probably little 0-2</td>
</tr>
<tr>
<td>Rest of Europe</td>
<td>Many different smelters.</td>
<td>Practically all smelters who need it have mercury removal technology.</td>
<td>Probably little 0-2</td>
</tr>
</tbody>
</table>

|                                                                 |                                                                 | Total estimate for these countries: | ~ 120-170 (sum of ranges 105-185)     |
|                                                                 |                                                                 | Total global estimate calculated here based on Outotec input above and global production*1 | ~140-200     |

Notes: *1: The countries in this table cover approximately 87% of global production of Zn+Pb+Cu+Au; see Table 8-5.

Cost estimate data
The most recent examples of costs estimates identified in the literature are given in the so-called §29 study (UNEP, 2010) and are presented in Table 8-7 below.

Note that these data do not include the mercury-specific removal methods applied in the sector. Costs data have therefore been collected from Outotec (2012). Cost data from Outotec are shown in Table 8-8 further below.
Table 8-7  Examples of emission control costs and efficiencies for non-ferrous metal and cement production from (UNEP, 2010b).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Specific activity indicator (SAI)</th>
<th>Emission control technology</th>
<th>Hg red. (per cent)</th>
<th>Costs a (USD 2008/SAI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Investment costs</td>
</tr>
<tr>
<td>Primary lead</td>
<td>metric ton primary lead</td>
<td>Dry ESP</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>metric ton primary lead</td>
<td>FF</td>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>metric ton primary lead</td>
<td>Activated carbon injection +FF+FGD</td>
<td>90</td>
<td>2.5</td>
</tr>
<tr>
<td>Primary zinc</td>
<td>metric ton primary zinc</td>
<td>Dry ESP</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>metric ton primary zinc</td>
<td>FF</td>
<td>10</td>
<td>4.5</td>
</tr>
<tr>
<td>Primary copper</td>
<td>metric ton primary copper</td>
<td>FF</td>
<td>5</td>
<td>1.8</td>
</tr>
<tr>
<td></td>
<td>metric ton primary copper</td>
<td>Fabric filters – state-of-the-art</td>
<td>10</td>
<td>3.9</td>
</tr>
<tr>
<td>Secondary lead</td>
<td>metric ton secondary lead</td>
<td>Dry ESP</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>metric ton secondary lead</td>
<td>FF</td>
<td>10</td>
<td>6.8</td>
</tr>
<tr>
<td>Secondary zinc</td>
<td>metric ton secondary zinc</td>
<td>Dry ESP</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>metric ton secondary zinc</td>
<td>FF</td>
<td>10</td>
<td>0.1</td>
</tr>
<tr>
<td>Secondary copper</td>
<td>metric ton secondary copper</td>
<td>Dry ESP</td>
<td>5</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>metric ton secondary copper</td>
<td>FF</td>
<td>10</td>
<td>6.6</td>
</tr>
</tbody>
</table>

a The accuracy of cost estimates in the table is within ± 50 per cent.

Outotec (2012) note to their price estimates shown in Table 8-8 that a very conservative technical life of 15 years was used in the calculation. Technical life is normally substantially longer for a Boliden Norzink installation; 25 years at least, and actual prices may thus be lower. For a Boliden Norzink mercury removal plant the cost is practically independent of the content of mercury in the gas (the main design factor is the gas flowrate going through the plant); the only variable cost is the chlorine gas consumption and the cost of this is only about 1% of the total cost. Therefore, if the mercury content in the feed would be the double compared with the examples shown in the table, the cost per kg mercury removed would be half, and opposite, if the mercury content was only half, the cost per kg mercury removed would be the double of the shown value. The smelting capacities used in the examples are believed to be typical sizes. The mercury content of copper- and lead concentrates are normally lower than for zinc; below we have assumed 30 ppm for both cases. As mentioned above, in many cases copper concentrates
contain only small amounts of mercury (well below 30 ppm) when they are based on other ore types than sulphidic ore.

Note that the prices per kg mercury removed in the tables, are per total kg of mercury captured before the acid plant in the smelter. Similar prices based on kg mercury prevented from being emitted directly to the environment from the smelter would be about 10 times higher, because as shown in Figure 8-1, about 90% of this mercury would have been contained in the produced acid, had it not been removed upstream of the acid plant (as mentioned above, mercury in the acid may very well be released to the atmosphere where the acid is used).

Table 8-8 Estimated prices for mercury removal with the Boliden Norzink process (chloride scrubber; Outotec, 2012)*1

<table>
<thead>
<tr>
<th>ZINK SMELTING</th>
<th>Mercury removal costs, expressed in alternative ways</th>
<th>Unit</th>
<th>Investment costs</th>
<th>Operation &amp; Maintenance costs</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- per kg Hg removed, or</td>
<td>USD/kg</td>
<td>56</td>
<td>22</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>- per ton zinc produced, or</td>
<td>USD/ton</td>
<td>3,5</td>
<td>1,4</td>
<td>4,9</td>
<td></td>
</tr>
<tr>
<td>- per ton sulphuric acid produced</td>
<td>USD/ton</td>
<td>1,8</td>
<td>0,7</td>
<td>2,5</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>COPPER SMELTING</th>
<th>Mercury removal costs, expressed in alternative ways</th>
<th>Unit</th>
<th>Investment costs</th>
<th>Operation &amp; Maintenance costs</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- per kg Hg removed, or</td>
<td>USD/kg</td>
<td>79</td>
<td>30</td>
<td>109</td>
<td></td>
</tr>
<tr>
<td>- per ton copper produced, or</td>
<td>USD/ton</td>
<td>3,9</td>
<td>1,5</td>
<td>5,4</td>
<td></td>
</tr>
<tr>
<td>- per ton sulphuric acid produced</td>
<td>USD/ton</td>
<td>1,3</td>
<td>0,5</td>
<td>1,8</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LEAD SMELTING</th>
<th>Mercury removal costs, expressed in alternative ways</th>
<th>Unit</th>
<th>Investment costs</th>
<th>Operation &amp; Maintenance costs</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>- per kg Hg removed, or</td>
<td>USD/kg</td>
<td>131</td>
<td>45</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>- per ton lead produced, or</td>
<td>USD/ton</td>
<td>3,2</td>
<td>1,1</td>
<td>4,3</td>
<td></td>
</tr>
<tr>
<td>- per ton sulphuric acid produced</td>
<td>USD/ton</td>
<td>4</td>
<td>1,4</td>
<td>5,4</td>
<td></td>
</tr>
</tbody>
</table>

Notes: *1: The estimations were made in SEK (Feb/Mar, 2012) and converted to USD with the exchange rate 6,7 SEK/USD. Prices here do not include wet off-gas cleaning system. See other information of the basis for the cost estimation in Table 8-9 below.
Table 8-9  Basis for the cost estimation in Table 8-8 (Outotec, 2012)

<table>
<thead>
<tr>
<th></th>
<th>ZINK SMELTING</th>
<th>COPPER SMELTING</th>
<th>LEAD SMELTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacities:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Concentrate feed</td>
<td>330.000 ton/year</td>
<td>500.000 ton/year</td>
<td>165.000 ton/year</td>
</tr>
<tr>
<td>- Mercury content of feed concentrate</td>
<td>65 ppm</td>
<td>30 ppm</td>
<td>30 ppm</td>
</tr>
<tr>
<td>- Base metal produced (Zn/Cu/Pb)</td>
<td>165.000 ton/yea</td>
<td>150.000 ton/yea</td>
<td>100.000 ton/yea</td>
</tr>
<tr>
<td>- Sulphuric acid production</td>
<td>330.000 ton/year</td>
<td>450.000 ton/year</td>
<td>80.000 ton/year</td>
</tr>
<tr>
<td>- Mercury removed in mercury removal plant</td>
<td>10.335 kg/year</td>
<td>7.400 kg/year</td>
<td>2.400 kg/year</td>
</tr>
<tr>
<td>Technological life of plant</td>
<td>15 years (actual =/&gt; 25)</td>
<td>15 years (actual =/&gt; 25)</td>
<td>15 years (actual =/&gt; 25)</td>
</tr>
<tr>
<td>Interest rate</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Summarising across the prices above one can see that the total cost for mercury removal counted per ton of metal produced does not differ so much between the three metals:

<table>
<thead>
<tr>
<th></th>
<th>Total estimated cost for mercury removal (USD/ton metal produced)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>4,9</td>
</tr>
<tr>
<td>Copper</td>
<td>5,4</td>
</tr>
<tr>
<td>Lead</td>
<td>4,3</td>
</tr>
</tbody>
</table>

Wet gas cleaning is a prerequisite to running an acid plant, and it is therefore anticipated that 100% of the smelters with acid plants have good wet gas cleaning. Wet gas cleaning could thus with good reason be economically allocated to the cost of running an acid plant, which is in itself profit-driven (except in rare cases of very remotely situated smelters), and is therefore not driven by the need for reducing mercury releases to the environment. Some smelters may have wet gas cleaning, but no acid plant and no Hg removal plant. Also, some smelters which do not have either of these plants could reduce their mercury releases (and other pollutants) by introducing a wet gas cleaning system. As the major mercury sources in the non-ferrous sectors are based on the use of sulphidic ore concentrates, it is however anticipated that much of the mercury reduction potential is covered - or can be covered - by mercury-specific removal systems such as the Boliden Norzink process. As wet gas cleaning contributes significantly to the removal of mercury from the off-gas (see Figure 8-1), the costs of wet gas cleaning are however included here.

Prices for wet gas cleaning systems for non-ferrous metal smelters were collected for this study from Outotec (2012), who are also a supplier of such systems (among several).
The off-gases from smelters treating sulphidic raw materials contain some SO$_3$ (formed from the SO$_2$) and with the humidity in the gas a fine sulphuric acid mist is formed. This acid mist, in addition to other impurities such as dust, must be removed to achieve a good mercury removal (and in case of acid production they must also be removed to protect the acid plant). Removal of acid mist requires the use of wet electrostatic precipitators (the mist is so fine that it goes through for example a fabric filter). The normal wet gas cleaning train in non-ferrous smelters is comprised of:

- Humidifying tower (saturation of the gas with water),
- Scrubber (for bulk removal of, e.g., dust)
- Gas cooler (for removal of water vapour to enable production of concentrated sulphuric acid; low temperature is also needed for the mercury removal), and
- wet electrostatic precipitators (for removal of acid mist and fine dust).

In the previously described mercury removal cost estimations for zinc, copper and lead, plant sizes with capacities of 165,000, 150,000 and 100,000 ton per year of the respective metal were used. A rough investment cost (+/- 30%) for the corresponding wet gas cleaning plants would be:

- Zinc smelter: 20 million USD
- Copper smelter: 20 million USD, and
- Lead smelter: 9 million USD.

This is calculated in SEK, and converted to USD with the exchange rate 6.7 SEK/USD, using a (very conservative) 15 year technical life and 4% annual interest rate. In fact the wet gas system should normally last as long as the mercury removal systems - at least 25 years. There should not be any difference between the zinc, copper and lead metals in this aspect.

Expressed as USD/ton metal produced including operation and maintenance the prices are calculated as shown in Table 8-10 below.

<table>
<thead>
<tr>
<th>Estimated wet gas cleaning costs for different metals</th>
<th>Unit</th>
<th>Investment costs</th>
<th>Operation &amp; Maintenance costs</th>
<th>Total costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>USD/ton metal produced</td>
<td>10,2</td>
<td>9,9</td>
<td>20,1</td>
</tr>
<tr>
<td>Copper</td>
<td>USD/ton metal produced</td>
<td>11,2</td>
<td>10,9</td>
<td>22,1</td>
</tr>
<tr>
<td>Lead</td>
<td>USD/ton metal produced</td>
<td>7,8</td>
<td>6,9</td>
<td>14,7</td>
</tr>
</tbody>
</table>

As shown in the table, the prices for wet gas cleaning systems are considerably higher than those for mercury removal systems. The reason for the lower costs for lead is that the amount of off-gas generated per ton of metal produced is much lower than for copper and zinc.
It should also be pointed out that the wet gas cleaning generates an aqueous sludge containing the various impurities removed, including mercury. These are present both in dissolved and suspended form. It requires an extensive treatment to generate a liquid clean enough for discharge to a recipient and separation of the impurities in a form which is acceptable for disposal. Costs for this are not included in the wet gas cleaning cost estimates shown above. As mentioned mercury is just one of the pollutants which need to be treated for to secure environmentally sound discharge and disposal. The prices for environmentally sound disposal of mercury from the non-ferrous metal sector are dealt with in Section 4.5.

When combining Outotec’s assessment of remaining global mercury removal potential (Table 8-6) and their estimated prices for mercury-specific removal calculated as USD per kg of mercury, a cost estimate for global implementation of mercury-specific removal systems in the non-ferrous metals sector covering the remaining reduction potential can be calculated with the results shown in Table 8-11.

![Table 8-11 Cost estimates for mercury-specific removal of remaining global reduction potential based on Outotec’s (2012) assessment of remaining mercury removal potential and their prices per kg mercury removed](image)

The estimated average costs in USD per kg mercury removed were derived from the costs data shown in Table 8-8, using the global metal production data shown in Table 8-5 and applying our assessment of a likely uncertainty range for the real average price based on the data shown in Table 8-12.

![Table 8-12 Support data used in estimation of uncertainty range of average prices in Table 8-11](image)
Note that the estimated global cost of 9-19 million EUR/y is relatively small, but it corresponds to the investments and running of approx. 15-30 new mercury-specific removal plants. A lot has already been done to reduce mercury releases from the sector, so today there are an accumulated amount of approx. 50 mercury removal plants installed (also including other technology than Boliden Norzink). In that context, it seems reasonable that there should be a potential for 15-30 more (Outotec, 2012).

Calculating similar cost for implementation of wet gas cleaning systems in the smelters, which do not have them already, would require detailed data on the number of smelters of each type with and without (respectively) such systems. As mentioned above, some of the smelters which still lack mercury-specific removal systems already have wet gas cleaning systems (because they have acid plants). If this fact is ignored considering the expected low number of incidents, a rough estimate of the cost of implementing wet gas cleaning systems can however be calculated using the data provided above in this section. Considering 15-30 "typical" smelters, distributed on zinc, copper and lead according to the relative share of the global sum production of these three metals, and using the production capacities shown in Table 8-9 and the price estimates in Table 8-8, the following estimation of the global costs can be calculated as shown in Table 8-13. As mentioned above, the total calculated costs may slightly overestimate the actual situation, as some of these plants may have wet gas cleaning already.

<table>
<thead>
<tr>
<th></th>
<th>Zn</th>
<th>Cu</th>
<th>Pb</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 (15-30) smelters distributed on Zn, Cu, Pb; approx. number remaining based on global production distribution</td>
<td>9</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>Typical production capacity used in price estimates; t/y</td>
<td>330.000</td>
<td>500.000</td>
<td>165.000</td>
</tr>
<tr>
<td>Wet gas cleaning; typical total costs per tonne produced metal, (2012) USD/t</td>
<td>20,1</td>
<td>22,1</td>
<td>14,7</td>
</tr>
<tr>
<td>Wet gas cleaning; typical total costs per tonne produced metal, EUR/t (at 1,3191 USD/EUR)</td>
<td>15,2</td>
<td>16,8</td>
<td>11,1</td>
</tr>
<tr>
<td>Cost per metal, EUR/y</td>
<td>45.144.000</td>
<td>92.400.000</td>
<td>5.494.500</td>
</tr>
<tr>
<td>Total cost estimate, Mill. EUR/y, rounded (range)</td>
<td>140 (100-180)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The calculation of precise mercury reduction potentials and associated costs require detailed knowledge of the state of mercury removal technologies in the industry. As this knowledge is not fully present in an aggregated state, rough estimates have to be made as done above based on the mentioned assumptions. As mentioned, the number of non-ferrous smelters with no wet gas cleaning is not known. Wet gas cleaning is technically compulsory when running an acid plant in non-ferrous smelters, and incurred costs could thus be attributed to the commercially beneficial acid production. Some smelters do however not have acid plants and wet gas cleaning, and for these, the establishing of wet gas cleaning systems has a significant reduction potential for atmospheric mercury releases. For all facilities without specific mercury removal systems (Boliden-Nordzink process and others),
the introduction of such systems has a significant potential for reductions of mercury circulation with produced sulphuric acid (and later indirect releases to the environment). It also has some reduction potential for direct releases to the atmosphere, especially for smelters with no acid plant, but also with smelters with an acid plant.

As a conservative approach, it is here chosen to include the costs of introducing both technologies in the remaining smelters not hitherto equipped with these technologies.

The additionally captured mercury (as compared to today) needs to be environmentally soundly disposed off. This cost element is also included in the table on summary of costs and effectiveness below. The unit price for disposal of mercury from the non-ferrous metal sector derived in Section 4.5 on supply was used here also.

A summary of the costs and effectiveness of introducing wet gas cleaning plus specific mercury removal in remaining smelters is given in Table 8-14 below.

<table>
<thead>
<tr>
<th>Wet gas cleaning + specific Hg removal + disposal</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs, Hg-specific gas cleaning, mill. EUR/y</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>Costs, general wet gas cleaning, under assumtions made, mill. EUR/y</td>
<td>100</td>
<td>180</td>
</tr>
<tr>
<td>Cost for permanent env. sound disposal of captured Hg amount, CPL adjusted, mill. EUR/y</td>
<td>0.28</td>
<td>9.6</td>
</tr>
<tr>
<td>Estimated total cost, World, mill. EUR/y</td>
<td>110</td>
<td>210</td>
</tr>
<tr>
<td>Reduction potential, Hg eliminated from circulation (deposited), t Hg/y</td>
<td>280</td>
<td>400</td>
</tr>
<tr>
<td>Reduction potential, air emissions, t Hg/y</td>
<td>30</td>
<td>185</td>
</tr>
<tr>
<td>Calculated effectiveness, elimination from circulation (deposited), EUR/kg Hg</td>
<td>390</td>
<td>530</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>1,100</td>
<td>3,700</td>
</tr>
</tbody>
</table>

Note that mass balance calculations in combination with UNEP (2010) release estimates and global mercury supply estimates from the sector (see Section 4) indicate that the mercury circulation reduction potential, and thereby the total costs, may in reality be slightly higher than indicated in the results given in Table 8-14.
8.4.3 Ferrous metal production
Cost estimates for technologies for mercury release reductions from flue gases in ferrous metal production was not found readily available for use in this study and consequently quantification of cost and effectiveness were not performed. The sector is characterised by a large number of facilities with relatively modest mercury emissions per facility. The original mercury sources are particularly the fuels used in the process, but also minor concentrations in some ore types used.

8.4.4 Cement production
The original source of mercury in cement production is both raw materials, particularly lime, and the fuels used. In some cement production plants, wastes are used as fuels and the use of certain wastes types may increase the mercury input considerably (UNEP Toolkit, 2011b).

Besides the mercury inputs with raw materials and fuels, two factors decide the fate of the mercury in a cement production facility: The presence of filters which can capture mercury in the exhaust gasses, and the management of the collected filter dust. In cement kilns, the chemical conditions seem to favour oxidation of the mercury gasses and consequently high retention rates - almost 100% - can be attained with effective dust filters, for example fabric filters (see table below). Aggregated information on the prevalence and quality of dust filters in the sector globally has not been identified, and thus an estimated prevalence in the world excluding EU and North America of 10-30% has been assumed in the quantifications made here. The costs cover implementation and maintenance of optimised fabric filters, a mid range cost technique with high mercury retention.

As regards filter dust management, the dust is often re-introduced in the kiln to make use of the material. In this case a steady state for mercury will prevail, and the mercury will partly be emitted to the atmosphere, partly be incorporated in the produced cement. If all the filter dust is mixed into the produced cement, the mercury will follow the cement and be partially immobilised there and probably partially released later in the lifecycle of the cement. The only way to eliminate the further spreading of the mercury is to deposit the filter dust in an environmentally safe manner. In the quantifications made, it is presumed that safe deposition of filter dust must be done to attain the described reductions of air emissions.

Cost estimate data
Cost and effectiveness of various filter retention techniques for cement production are shown in Table 8-15.
### Table 8-15
Examples of emission control costs and efficiencies for cement production (from UNEP 2010b).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Specific activity indicator (SAI)</th>
<th>Emission control technology</th>
<th>Hg red (per cent)</th>
<th>Annualised costs*1 (USD 2008/SAI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Investment costs</td>
</tr>
<tr>
<td>Cement production</td>
<td>metric ton cement</td>
<td>FF</td>
<td>5</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>metric ton cement</td>
<td>FF – optimized</td>
<td>98</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>metric ton cement</td>
<td>Wet FGD</td>
<td>90</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Notes: *1: The accuracy of cost estimates in the table is within ± 50 per cent. An interest rate of 4% p.a. and a technical lifetime of filters are assumed in the reference document.

### Table 8-16
Summary of costs and effectiveness of dust filters and management practices for cement production.

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs optimised fabric filters, USD/t cement produced</td>
<td>0.4</td>
<td>1.2</td>
</tr>
<tr>
<td>Cement production, World excl EU+NA, mill. t/y</td>
<td>1.900</td>
<td>2.100</td>
</tr>
<tr>
<td>Assumed existing prevalence of filter technology, % of facilities</td>
<td>10%</td>
<td>30%</td>
</tr>
<tr>
<td>Estimated costs, World excl EU+NA, mill. EUR/y</td>
<td>530</td>
<td>2.300</td>
</tr>
<tr>
<td>Reduction potential, reduced air emissions, t Hg/y*1</td>
<td>58</td>
<td>210</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>9.100</td>
<td>11.000</td>
</tr>
<tr>
<td>Results, CPL adjusted*2:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated costs, World (excl EU and NA), mill. EUR/y</td>
<td>310</td>
<td>1.360</td>
</tr>
<tr>
<td>Calculated effectiveness, reduced air emissions, EUR/kg Hg</td>
<td>5.400</td>
<td>6.500</td>
</tr>
</tbody>
</table>

Notes: *1: Assuming all filter material is deposited as waste and not re-fed into cement kiln (which it often is today). 2*: It is assumed that the filter technology is supplied also from countries outside the EU+NA regions.
8.4.5 Residential heating and other fossil fuel combustion
While source category contribute with very significant atmospheric emissions, it is composed by a variety of smaller release sources, and is thus very complex to reduce emissions from, let alone quantify costs for. The origin of the mercury input is fossil fuels, primarily coal but also oil products. The category also includes single house heating and other very small units for which mercury release abatement would likely be very costly to reduce, unless by introduction of alternative low mercury/non-mercury energy sources. Climate change mitigation efforts such as energy optimisation, house insulation and introduction of alternative energy sources may be the most effective way to reduce releases from this source category. No attempts were made to quantify costs of mercury release reductions from this source category.

8.4.6 Waste incineration
Large scale waste incineration is almost solely done in Europe and North America (and maybe a few other countries). This sector is rather strictly regulated in the EU and the employment of filters capturing mercury in the flue gas is common in this region. Mercury releases from this sector have previously been substantial (and still are to a certain degree), and the widespread waste-to-energy practice in these regions has been one of the driving forces for pursuing reductions of mercury releases by prevention measures, i.e. the substitution of mercury in products and materials. There is likely still a potential for mercury release reductions from this sector in Europe and North America, but no quantification for this has been attempted in this assessment.

Outside the EU and North America, a demand for mercury retention would therefore primarily affect future facilities. While efforts for waste minimisation are considered environmentally effective, and some developing countries have hesitated with the introduction of this technique due to infrastructure and regulatory issues, the utilisation of waste for energy production may gain more momentum worldwide in the future, and a rise in the number of large waste incineration facilities could be expected. In such new facilities, the employment of mercury retaining techniques is recommended during the coming decades in spite of efforts for mercury substitution in products and materials, because products and materials already in use in the society will still be circulating for years to decades, and because some mercury uses are likely to be considered "allowed" for a foreseeable time in a future global agreement on mercury (or any similar national measures).

On-landfill open waste burning and informal waste heap burning ("backyard-burning") are widespread practices in many developing countries, and these practices are likely a substantial and hitherto underestimated mercury release source. With the prevailing lack of environmentally sound collection schemes for hazardous waste in most developing countries, the most effective - and perhaps the only viable - way of reducing mercury releases from waste burning is the substitution of mercury in products and materials, as targeted in the products and processes measure of the draft mercury convention text.
Table 8-17 below shows price examples for mercury retention in the flue gas of large scale waste incineration facilities. Quantification of overall costs for employing these techniques has not been attempted for the reasons mentioned above in combination with an expected lack of reliable global waste production numbers.

Table 8-17  Example of emission control costs and removal efficiencies for waste incineration from (UNEP, 2010b).

<table>
<thead>
<tr>
<th>Emission Control Technology</th>
<th>Hg reduction (per cent)</th>
<th>Annual costs*1 (USD 2008/metric ton of waste)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Investment costs</td>
</tr>
<tr>
<td>Wet scrubber with alkaline additives – medium efficiency if emission control</td>
<td>20</td>
<td>0.1</td>
</tr>
<tr>
<td>Waste separation – medium</td>
<td>60</td>
<td>0.6</td>
</tr>
<tr>
<td>Dry ESP</td>
<td>70</td>
<td>1.8</td>
</tr>
<tr>
<td>ESP+wet scrubber+activated carbon with lime+FF</td>
<td>99</td>
<td>2.3</td>
</tr>
<tr>
<td>Two-stage scrubber+wet ESP –</td>
<td>90</td>
<td>2.3</td>
</tr>
<tr>
<td>Activated carbon injection +FF</td>
<td>80</td>
<td>2.2</td>
</tr>
<tr>
<td>Activated carbon injection +venturi scrubber+ESP –</td>
<td>95</td>
<td>5.3</td>
</tr>
<tr>
<td>Activated carbon injection +venturi scrubber with lime milk+caustic soda+FF</td>
<td>99</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Notes: The accuracy of cost estimates in the table is within ± 50 per cent.
8.5 Summary of costs and effectiveness of the measure

Table 8-18 Summary of costs and effectiveness.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Reduction potential, air emissions, t Hg/y</th>
<th>Estimated cost per kg of Hg (air) EUR/kg Hg</th>
<th>Estimated global costs, mill. EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal fired power plants</td>
<td>170-400</td>
<td>3.000-82.000</td>
<td>710-8.300</td>
</tr>
<tr>
<td>Non-ferrous metal production</td>
<td>30-185</td>
<td>1.100-3.700</td>
<td>110-210</td>
</tr>
<tr>
<td>Cement production</td>
<td>58-210</td>
<td>9.100-11.000</td>
<td>310-1.360</td>
</tr>
<tr>
<td>Total estimated costs</td>
<td>-</td>
<td>-</td>
<td>1.130-9.870</td>
</tr>
</tbody>
</table>

8.5.1 Uncertainties and gaps

The existing presence of the suggested filter equipment in the regions of the world is uncertain for both coal fired power plants, the non-ferrous metal sector and for cement production.

Especially for coal fired power plants, the price range for available filter solution is rather wide, and refining of this element may affect the cost estimates calculated.
9 Storage, waste and contaminated sites

Summary of the key features of the measure and its potential impacts

The first part of this measure is aimed at securing that mercury in interim storage of mercury should be made in an environmentally sound manner according to guidelines or provisions defined later by the Conference of the Parties (COP) of the Convention. Perhaps more important, the measure promotes environmentally sound waste handling and disposal of mercury-containing waste, which is largely absent in most parts of the world today. This also includes metallic mercury and mercury compounds not intended for allowed uses. There is a significant potential for mercury release reductions with this measure in a global perspective, as it may prevent substantial amounts of obsolete mercury from being re-marketed, as well as in the longer run to prevent mercury in waste from being spread further in the environment. In many parts of the world, mercury-containing (and other hazardous waste) is not only not collected and treated separately, but is also deposited on un-secured waste dumps where it is often burned in the open to reduce the waste amounts, and from where it can also be spread to the ground water.

The second part of the measure proposes that remediation of mercury contaminated sites could be encouraged (and/or the spreading of the contamination could be prevented) according to guidelines to be developed by the COP.

9.1 Who will be affected?

The storage and waste sub-measures seem, based on a preliminary assessment, to be covered by the provisions of the EU Regulation (EC) No 1102/2008 on the banning of exports of metallic mercury and certain mercury compounds and mixtures and the safe disposal of metallic mercury, in conjunction with EU waste regulation. If this is the case, a convention would introduce no major additional changes as regards the intra-EU situation.

As regards the sub-measure on remediation of mercury contaminated sites, this issue appears to be still largely outstanding when it comes to older contaminations in the EU, while present legislation likely covers new contamination situations.
This sub-measure may have significant effects on mercury release reductions, especially in the areas directly affected by the contamination, such as former mercury mining sites and chemical industry sites.

As regards extra-EU activities, that is, costs in the World except EU and North America, there is a substantial need for awareness-raising about mercury containing hazardous waste management in developing countries, as well as for technical and financial support for the establishment of mercury containing hazardous waste management infrastructure such as collection, treatment and disposal systems. Even though hazardous waste management is by far no new subject, the infrastructure for managing it is largely non-existing in developing countries today, as well as in many countries in transition. Also, the draft convention text mentions the need for regional cooperation and coordination in order to secure regional facilities for final disposal of mercury waste. Such cooperation and coordination may need financial and technical support to operate effectively.

The EU could also choose to assist in the development of drafts for the above mentioned guidelines on disposal and storage of waste mercury and remediation of contaminated sites, respectively (both to be developed by the COP). The issue of disposal has already been dealt with extensively in the DG ENV (BIPRO) 2010 report, in EU stakeholder conferences and in other activities. The development of a guideline for remediation of contaminated sites could build on extensive experience in this field in the EU, and could be of use both intra-EU and extra-EU.

### 9.2 Potential barriers to implementation

See above.

### 9.3 Mercury inputs and air emissions

<table>
<thead>
<tr>
<th>Measure/options</th>
<th>Input of Hg to society, t/y</th>
<th>Hg releases to atmosphere, t/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste deposition and open waste burning</td>
<td>-</td>
<td>74++</td>
</tr>
<tr>
<td>Contaminated sites</td>
<td>-</td>
<td>70-110</td>
</tr>
</tbody>
</table>

Note: ++ means likely much more, as open waste burning on landfills and elsewhere is likely underestimated.
Table 9-2  Total estimated mercury releases to the atmosphere (A) and hydrosphere (H, aquatic environments) from contaminated sites; from UNEP/AMAP (2008).

<table>
<thead>
<tr>
<th>Contaminated site</th>
<th>Atmosphere (t/year)</th>
<th>Hydrosphere (t/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury mining</td>
<td>5-20</td>
<td>10-50</td>
</tr>
<tr>
<td>Chlor-alkali industry</td>
<td>1-3</td>
<td>2-5</td>
</tr>
<tr>
<td>Non-ferrous metal processing</td>
<td>1-5</td>
<td>-</td>
</tr>
<tr>
<td>Precious metal processing</td>
<td>2-10</td>
<td>5-10</td>
</tr>
<tr>
<td>Artisanal and small scale gold mining (ASGM)</td>
<td>50</td>
<td>5-100</td>
</tr>
<tr>
<td>Other industrial and urban sites</td>
<td>10-20</td>
<td>-</td>
</tr>
<tr>
<td>Total</td>
<td>70-110</td>
<td>70-165</td>
</tr>
<tr>
<td>Total (A+H)</td>
<td>140-275</td>
<td></td>
</tr>
</tbody>
</table>

9.4  Expected costs

9.4.1  Interim storage

The potential costs for interim storage have not been included in the assessment as the need is hard to quantify. Focus has instead been on permanent disposal which is dealt with in Section 4.

9.4.2  Waste

Waste with even quite low concentrations of mercury is considered hazardous according to the EU waste regulation; for example waste fluorescent lamps with mercury concentrations around 200 mg/kg Hg are considered hazardous waste with high precaution requirements for transport and treatment/disposal. The EU waste regulation works with mercury containing waste categories as criteria and not with concentrations of mercury in the waste. Waste categories and concentration thresholds are also discussed in the INC work.

The costs for treatment and deposition of mercury containing waste vary significantly depending on the type of waste and the concentration of mercury in the waste. By way of example indicative price ranges for some waste types containing mercury are listed in Table 9-3 (Kommunekemi, 2012).
Table 9-3 Examples of prices (gate fees) for treatment of mercury containing waste in Denmark (Kommunekemi, 2012).

<table>
<thead>
<tr>
<th>Waste fraction</th>
<th>Price range, EUR/kg waste</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermometers, manometers, etc. with fluid metal mercury</td>
<td>12-15</td>
<td>Labour intensive segregation of Hg plus refining of Hg abroad</td>
</tr>
<tr>
<td>Inorganic filter cake from flue gas cleaning</td>
<td>0,1-0,3</td>
<td>Deposition in German salt mines</td>
</tr>
<tr>
<td>Dental filter sludge (high in organics)</td>
<td>0,7-2</td>
<td>Incinerated in own facility with high-performance filter technology and secure deposition of solid residues</td>
</tr>
<tr>
<td>Activated carbon filters</td>
<td>0,7-2,7</td>
<td>Incinerated with high-performance filter technology and secure deposition of solid residues</td>
</tr>
</tbody>
</table>

Market price examples for different mercury-containing waste fraction from mercury-cell chlor-alkali production/decommissioning are given in Table 9-4 (DELA, 2012). According to DELA these costs are rather independent of the mercury concentration in these kinds of waste. The prices include extraction of the mercury in the waste and final disposal/treatment of the non-mercury residues. The price for terminal disposal of the extracted mercury is however not included and must be added (see prices in Section 9.4.1 above). The extracted mercury could in principle be re-used, but this option is not considered here.

Table 9-4 Examples of market prices for treatment of mercury-containing waste fractions from mercury-cell chlor-alkali production/decommissioning (excluding terminal disposal of the extracted mercury; DELA; 2012).

<table>
<thead>
<tr>
<th>Waste fraction</th>
<th>Price range, EUR/kg waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sludge</td>
<td>0,65-0,75</td>
</tr>
<tr>
<td>Soil</td>
<td>0,25-0,35</td>
</tr>
<tr>
<td>Activated carbon</td>
<td>0,45-0,55</td>
</tr>
</tbody>
</table>

Besides the costs for treatment of mercury-containing waste, additional costs are associated with the segregation and collection of such waste, as well as for the transport and packaging of the waste prior to the final waste treatment. Transport costs for regional (lorry) transport are generally low compared to the costs for safe treatment/deposition.

As mentioned earlier, on-landfill open waste burning and informal waste heap burning ("backyard-burning") are widespread practices in many developing countries, and these practices are likely a substantial and hitherto underestimated mercury release source. With the prevailing lack of environmentally sound collection schemes for hazardous waste in most developing countries, the most effective - and perhaps the only viable - way of reducing mercury releases from waste disposal is the substitution of mercury in products and materials, as targeted in the products and processes measure of the draft mercury convention text.
Due to the complexity of the issue, it has not been attempted to calculate global cost estimates for environmental sound disposal of waste with low to moderate concentrations of mercury.

The draft Technical guidelines for the environmentally sound management of waste consisting of elemental mercury and wastes containing or contaminated with mercury (Basel Convention, 2010) recommend extended producer responsibility (EPR) schemes to secure the collection of mercury containing waste products, under certain conditions. EPR can also be used to assign the life cycle costs of management of the mercury in the products to the product sales price. EPR procedures are becoming more common in the EU for various products requiring special waste treatment. The use of EPR programmes however require a transparent and well regulated economy and established collection systems for hazardous waste to function properly, and it should therefore likely not stand alone as a mercury management measure in developing countries.

9.5 Summary of costs and effectiveness of the measure

No costs were quantified for this measure. Costs for environmentally safe permanent disposal of some high-concentration mercury wastes are estimated in Section 4 on the mercury supply measure.

9.5.1 Uncertainties and gaps

Costs of environmentally sound disposal of waste with moderate mercury concentrations (as high concentration waste is covered under permanent disposal), including for the establishment of the national and global infrastructure needed for waste segregation at consumers, separate collection and treatment, and hazardous waste deposits.

Amounts of mercury to be stored intermittently and associated costs.

Costs of preventing further spreading of mercury from contaminated sites.
10 Other measures of the draft convention text

This section of the report covers all the draft convention measures covering institutional and administrative aspects of the convention, as well as most of the administrative elements of all other elements covered above.

10.1 Summary of the key features of the measure and its potential impacts

Financial resources and technical and implementation assistance
This measure pertains to the commitment from developed countries to assist financially and technically developing countries and countries in transition, and the development of suitable mechanisms to administer such assistance. In this report, this important aspect of the instrument is dealt with under each of the other measures above, and is therefore not described separately.

Awareness-raising, research and monitoring, and communication of information
The objective of this measure is to promote the development and availability of appropriate information on effects, exposure routes, releases, alternatives, reduction technologies, etc. of mercury. Research and development and communication of information on mercury are key components in reducing mercury consumption, releases, and human and environmental exposures.

Apart from the information aspects covered in the discussion of other measures above, the EU already plays an important role in the research and development and communication of information on mercury. The information developed in the EU is made available on Commission websites, via UNEP's mercury websites, via the BREF notes website, and in other fora. It is likely that the creation of a convention on mercury may increase the need for the development and provision of such information from the EU, and that the EU could have an important role to play
globally in making such information available and target-oriented, and in spreading it to relevant Parties and stakeholders worldwide.

The measure also includes provisions for the Parties' planning of their implementation of a convention and their reporting on compliance. The measure also mentions the COP's creation at its first meeting of a tool for use by the Parties in their implementation work. Again, the EU could choose to be of assistance in the creation of such a draft tool. A similar tool is available for the Stockholm Convention, and this could perhaps serve as a paradigm for an implementation planning tool for mercury.

Other elements of the draft convention text
The remaining elements of the draft convention text pertain to institutional arrangements, settlement of disputes, further development of the convention and final provisions. These measures are not dealt with in detail in this report. The EU may wish to take a proactive part in the involved preparation work and/or support financially the work of the convention secretariat.

10.2 Who will be affected?
In effect all Parties to the convention will be affected, but the burden of administration, research, outreach etc. may be relatively heavier for developing countries.

10.3 Potential barriers to implementation
The financial support to developing countries is a key point for success in the coming to an agreement of a global mercury convention. This also influences the choice of financial mechanisms to be established to funnel support from donors to developing countries, the key subject of interest seeming to be the extent of influence from developing countries on which policy areas and specific projects should receive funding.

The implementation of existing agreements on global chemicals management including, among others, the Stockholm Convention, the Rotterdam Convention and the Basel Convention may have paved the way for a more smooth implementation of a global mercury convention, and all necessary efforts should be made to seek synergies between the instruments and thereby reduce the implementation costs of a global mercury convention.

10.4 Mercury inputs and air emissions
While this section deals with important aspects of a future mercury convention, the measures and sub-measures covered are to a high degree to be considered
supporting measures to the other measures described above, and it is thus difficult to allocate specific release reduction potentials to these measures.

10.5 Expected costs

Stockholm Convention

The global costs for implementing these "other" measures would be challenging to quantify at the present stage. However, there are clear similarities between the measures considered for mercury in the INC negotiations with those in place for Persistent Organic Pollutants (POPs) in the Stockholm Convention. The Stockholm convention also includes provisions for reduction of releases from major sources, reductions in intentional use of certain POP chemicals, management of stocks of obsolete chemicals and trade restrictions, and also the provisions for the general measures which are not specific to the chemicals covered are similar to those considered for mercury. The latter are the focus of our analysis in this section.

Table 10-1 provides an overview of the total estimated costs of implementation of the Stockholm Convention over a 10-years period in four countries (12 years for India). The estimated costs are based on the budgeted costs indicated in the countries’ National Implementation Plans (NIPs) for implementing the convention. The costs indicate the total of the estimated baseline and incremental costs. The countries aggregate in their NIPs the costs in different ways. In order to prepare an overview across countries, the costs have here been roughly broken down into major action areas, on the basis of the description of each action in the NIPs.

The total costs per capita vary from 0.5 USD/capita in India to 17.5 USD/capita in Uruguay. The costs of the different activities likely reflect actual differences in the POPs situation in the countries and differences in the priorities between the countries. It cannot be ruled out however, that the methodology for the estimation in the different countries differ.

Averaging the per capita total costs shown in Table 10-1 and extrapolating it to the global situation using population data however yields total costs close to the total costs for developing country Parties and parties with economies in transition estimated by the Secretariat of the Stockholm Convention of around 8 billion USD for the period 2004-2014 (UNEP/POPs, 2009). That estimate was derived based on a broader evaluation of National Implementation Plans.

The total costs per capita of the actions which are not addressing the management of specific substances, i.e. capacity building, legal development, monitoring and public awareness and training, is more or less the same in Morocco, India and China (from 0.09 to 0.17 USD/capita). Uruguay differs significantly from this with costs of 10.5 USD/capita for these action areas. See Table 10-2.

The total estimated costs of institutional capacity building and legal framework development is about 40 millio USD in the two large countries, India and China.
For the two smaller countries it varies from 3.2 to 12 million USD, and the costs do not reflect the size of the country, but rather national priorities.

Monitoring of POPs including development of the analytical infrastructure varies from 1.3 million USD in Morocco to 179 million USD in China and reflects to some extent the size of the countries.

In Table 10-2 the estimated sum of costs for institutional capacity building, legal framework establishment, monitoring including analytical capacity, awareness raising and training are extracted from Table 10-1. The same costs are shown per capita. Using an average for Morocco, India and China of the per capita cost estimates for these activities per year, and extrapolating with number of inhabitants, a total cost estimate for the World excluding, the EU27, USA and Canada can be calculated to 60 million EUR/year. Note that this population figure includes several countries which are not considered developing countries or countries in economic transition.

This number may likely be considered a low end estimate as costs for smaller countries will be relatively higher, because some of these expense types are more or less independent of the number of inhabitants in the country.
Table 10-1  Total estimated costs of implementation of the Stockholm Convention over a 10-years period, as estimated in the national implementation plans *

<table>
<thead>
<tr>
<th>Action area</th>
<th>Total implementation costs, Mill. USD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Morocco</td>
</tr>
<tr>
<td>2006-2015</td>
<td></td>
</tr>
<tr>
<td>Institutional capacity building, strategy development</td>
<td>3,2</td>
</tr>
<tr>
<td>Legal framework development</td>
<td>0,04</td>
</tr>
<tr>
<td>Human health assessments, epidemiological studies, food safety</td>
<td>0,6</td>
</tr>
<tr>
<td>General waste management incl. waste dumps</td>
<td>0,5</td>
</tr>
<tr>
<td>PCB management and disposal</td>
<td>13,6</td>
</tr>
<tr>
<td>Management and disposal of obsolete pesticides</td>
<td>4,5</td>
</tr>
<tr>
<td>Management of current pesticide use</td>
<td>1,0</td>
</tr>
<tr>
<td>Abatement of unintentional produced POPs (dioxins)</td>
<td>-</td>
</tr>
<tr>
<td>Contaminated sites, identification of POPs stockpiles</td>
<td>-</td>
</tr>
<tr>
<td>Monitoring of POPs including analytical infrastructure</td>
<td>1,3</td>
</tr>
<tr>
<td>Public awareness and training</td>
<td>0,2</td>
</tr>
<tr>
<td>Other costs</td>
<td>0,1</td>
</tr>
<tr>
<td>Total</td>
<td>24,9</td>
</tr>
<tr>
<td>Population, million inhabitants</td>
<td>32</td>
</tr>
<tr>
<td>Total costs, USD per capita</td>
<td>0,8</td>
</tr>
</tbody>
</table>

**Table 10-2** Estimated costs for institutional capacity building, legal framework establishment, monitoring including analytical capacity, awareness raising and training for the implementation of the Stockholm Convention on POPs.

<table>
<thead>
<tr>
<th></th>
<th>Morocco</th>
<th>Uruguay</th>
<th>India</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs for institutional, legal, monitoring, awareness and training for 10 years (India 12 y), Mill. USD</td>
<td>4,69</td>
<td>30,09</td>
<td>111,84</td>
<td>224,46</td>
</tr>
<tr>
<td>- Do, per capita, USD</td>
<td>0,15</td>
<td>9,07</td>
<td>0,09</td>
<td>0,17</td>
</tr>
<tr>
<td>- Do, per capita per year, USD/y</td>
<td>0,015</td>
<td>0,907</td>
<td>0,008</td>
<td>0,017</td>
</tr>
<tr>
<td>World (excl EU, USA, Canada); average of Morocco, India and China extrapolated; Mill. USD/y</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>World (excl EU, USA, Canada); average of Morocco, India and China extrapolated; Mill. EUR/y</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Administrative and other measures of a mercury agreement

It should be noted that the capacity building, legal framework and other related activities performed for the implementation of the Stockholm Convention may also contribute to the similar implementation efforts for a mercury convention, and this group of expenses for a mercury convention may thus perhaps be lower than those for the Stockholm Convention.

Considering the possible differences (and co-benefits) between the Stockholm Convention and a global convention on mercury, as well as the uncertainties associated with the analysis made above, the costs for implementing a mercury convention as regards measures relating to institutional capacity building, legal framework establishment, monitoring including analytical capacity, awareness raising and training in developing countries and countries with economies in transition are here estimated roughly at around 40-80 million EUR/year.

In addition to this amount, there will be a need for funding of the central administration of the secretariat for the mercury agreement, as well as costs for administering an economical mechanism for providing economical assistance to developing countries and countries with economies in transition. UNEP (2011a) summarises the costs for administering an economical mechanism.

The Global Environmental Facility (GEF) administers funding for implementation of the Stockholm Convention, and recently also funding for preparatory activities for a global agreement on mercury. GEFs budgets for the fiscal years 2006, 2007, 2008, and 2009 (which included funding for the secretariat, Scientific and Technical Advisory Panel, the GEF Trustee, the GEF Evaluation Office and various special initiatives) totalled 92.9 million USD, which was about 2.97 per cent of the replenishment (the total funding available for economical support to countries). The Multilateral Fund administers funding for supporting countries compliance with the Montreal Protocol on ozone depleting substances. The fifth Multilateral Fund replenishment amounted to 470.4 million USD for the triennium
2006–2008. The budgeted costs for administering the Fund and its Executive Committee during that triennium totalled 16.1 million USD. Thus, the budgeted administrative costs were equivalent to about 3.43 per cent of the replenishment amount.

Without going into a deeper analysis of the subject, this information indicates that costs for central, global administration of a mercury agreement, including COP’s and other necessary meetings might be at the level of some 20-40 million USD/year. This estimate is of course uncertain, especially seen in the light of the lack of a deeper analysis of the needs here.

### 10.6 Summary of costs and effectiveness of the measure elements

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Reduction potential, t Hg/y</th>
<th>Estimated cost per kg of Hg EUR /kg Hg</th>
<th>Estimated global costs, mill. EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>National implementation aspects on: Institutional capacity building, legal framework establishment, monitoring including analytical capacity, awareness raising and training.</td>
<td>-</td>
<td>-</td>
<td>40-80</td>
</tr>
<tr>
<td>Central, global administration of a mercury agreement</td>
<td>-</td>
<td>-</td>
<td>20-40</td>
</tr>
<tr>
<td>Total estimated costs*1,2</td>
<td>-</td>
<td>-</td>
<td>60-120</td>
</tr>
</tbody>
</table>

### 10.6.1 Uncertainties and gaps

The actual costs of these convention elements will be hard to estimate with any accuracy at the current point, where many objects of the draft convention text are still to be settled.
11 Integrated analysis of inter-dependent measures

The assessment has analysed the possible measures and their expected effects. The measures have so far been described individually. Here, the effect of combining the measures is assessed and discussed.

The starting point for considering a combination of measures, are the measures which the global agreement is likely to include. With negotiations ongoing, the final outcome is not known, however the assessment will consider alternative outcomes and estimate the implication on costs and reduction of mercury in circulation and emitted to air.

The main scenario will include all the demand measures that have been analysed and the specific measures to reduce air emissions.

11.1 Supply and demand measures

The main challenge in assessing a combined scenario is the interaction between supply and demand on the price of mercury and how the price affects the costs and effects of the measures.

As with any market the price of mercury is determined by supply and demand and hence, measures which reduce the demand by requiring users to substitute mercury with other substances or processes, will lead to reduced mercury prices. Measures that put restriction on the supply will tend to increase the mercury price.

The price of mercury is important for the substitution away from using the substance. In principle, the higher the price, the lower is the additional cost of substitution for any given application.

Qualitatively, the sensitivity of each measure to changes in the mercury price can be assessed as follows:
Batteries: Here, the cost of substitution is mainly related to finding alternative substances that have the same properties as mercury. The content of mercury is small in each button cell battery, so the price of mercury is not the main factor why mercury is used. Therefore price change will not affect the cost of substitution in a significant way.

Dental amalgam: Similarly as for batteries, the impact of changes in the mercury price is not expected to affect the substitution costs significantly in developed countries, while it may do so in developing countries. The reason is the influence of the labour costs in the dental clinic, which are the dominating cost elements, at least in the developed countries.

Measurement and control instruments: Here, the price of mercury could have some effect as the mercury content is relatively high.

VCM production: While mercury constitutes a large part of the catalyst used in VCM production, the mercury costs are presumable minor in relation to the total costs of PVC production (for which VCM is used).

Chlor-alkali: Here the cost of the alternative is related to change a different technology, where the operational costs are not higher once the new technology has been introduced. Therefore, the cost of replacing mercury in this application is not sensitive to the mercury price.

ASGM: This application is the one where the price of mercury could have the largest impact on the effectiveness of the proposed measure. The programme to train the small scale goldmines to better mercury housekeeping is likely to be more effective the more expensive mercury is. It is not possible to estimate quantitatively how this relationship could be.

Overall, it is mainly the effectiveness of the education programme for the small scale gold miners which will be affected by changes in the mercury price, while the substitution of dental amalgam and measuring and control devices may be affected to some degree. All these changes primarily affect developing countries and care should be taken to minimise negative effects there on poverty and health care.

If supply reduction measures would be implemented they would in principle achieve the reduction of the quantities of mercury in circulation or emitted to air in a cost effective manner. The reduced supply would drive the price until the demand has been reduced to the level of the reduced supply. The mercury applications with the lowest substitution costs would change to the mercury-free alternatives and no further specific demand regulation would be needed.

If demand measures are implemented, they will lead to a decrease in the mercury price, which will then result in less supply, or less desirable: Increased demand in ASGM activities due to reduced incentives for good mercury housekeeping. The dedicated mercury mining is the supply where the production costs are the highest. The other types of supply are by-product mercury from non-ferrous mining or from recycling of mercury, and therefore these quantities of mercury will be offered for sale even at low prices (as far as permanent mercury disposal is more expensive).
The combined scenario includes all the demand measures and in order to balance supply and demand, also the supply measures are included.

Table 11-1 Demand measures that reduce the quantities of mercury in circulation (World excl. EU and North America; based on medium estimates and annualised costs).

<table>
<thead>
<tr>
<th>Demand measures</th>
<th>Unit costs, EUR/kg Hg</th>
<th>Reduction t Hg/y</th>
<th>Total costs million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries, substitution</td>
<td>11.000</td>
<td>323</td>
<td>3.600</td>
</tr>
<tr>
<td>Dental amalgam, substitution</td>
<td>6.600</td>
<td>227</td>
<td>1.500</td>
</tr>
<tr>
<td>VCM production, Hg substitution</td>
<td>160</td>
<td>770</td>
<td>120</td>
</tr>
<tr>
<td>Measuring and control devices, substitution</td>
<td>150</td>
<td>264</td>
<td>40</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution</td>
<td>140</td>
<td>257</td>
<td>36</td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed divided on 10 years</td>
<td>32</td>
<td>1.310</td>
<td>42</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3.151</td>
<td>5.300</td>
</tr>
</tbody>
</table>

The total estimated demand is at the level of 4.500 tons per year so if this global agreement scenario would be implemented, the reduction of demand would be a little more than 75%.

In order to reduce supply with the same amount, the following supply measures should be implemented.

Table 11-2 Supply measures that reduce the amount of Hg in circulation (globally; based on medium estimates and annualised costs).

<table>
<thead>
<tr>
<th>Supply measures</th>
<th>Estimated supply, t/y</th>
<th>Unit costs (disposal), EUR/kg Hg</th>
<th>Reduced supply, t/y</th>
<th>Remaining supply, t/y</th>
<th>Total costs, million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dedicated mercury mining</td>
<td>1.450</td>
<td>0</td>
<td>1.450</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-ferrous metals production</td>
<td>500</td>
<td>13</td>
<td>500</td>
<td>0</td>
<td>6,5</td>
</tr>
<tr>
<td>Recycled Hg from chlor-alkali facilities</td>
<td>800</td>
<td>2</td>
<td>194</td>
<td>606</td>
<td>0,3</td>
</tr>
<tr>
<td>Recycled Hg - recycling of Hg catalysts, wastes and products</td>
<td>700</td>
<td>2</td>
<td>-</td>
<td>700</td>
<td>0,0</td>
</tr>
<tr>
<td>Supply from commercial stocks*1</td>
<td>1.007</td>
<td>1.007</td>
<td>0</td>
<td>1,5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.457</td>
<td>3.151</td>
<td>1.306</td>
<td>8,3</td>
<td></td>
</tr>
</tbody>
</table>
Note: *1: Note that the total demand is above the most recent available supply estimates (2007 figures from Maxson (2009). Additional supply is assumed delivered from commercial stocks.

The amount supplied from each source is subject to some uncertainty so it might be that the mining and recycling provides slightly higher quantities and less is changes in stocks. In any case, if demand is reduced by more than 70% it will drive the price down and make dedicated mining unprofitable. It will also mean that most of the recycled mercury would have to be stored, if it should be avoided that it is being made available at low price to ASGM activities.

The costs of reducing the supply are here indicated as the costs of permanent environmentally sound disposal of the mercury as regards the by-product from the non-ferrous metals production and the recycled mercury. The costs of ceasing the dedicated mining activities would eventually relate to closing of the mines. These costs have not been estimated.

The distribution effects are important in relation to the supply measures. The mining companies and others with income from sale of mercury will lose that income. It is not a loss to society as it is balanced by increased income to those selling the alternatives to mercury. The distribution effects typically affect the political feasibility of measures. If the price of mercury as estimated in Section 4 is assumed at around 28 EUR per kg the total loss of revenue for mercury suppliers globally of reducing supply by around 3.400 tones would be around 95 million EUR.

In addition to the demand and supply measures there are measures that focus directly at reducing mercury emissions to air.

| Table 11-3 Measures to reduce air emissions (World excl. EU and North America; based on medium estimates and annualised costs). |
| --- | --- | --- |
| | Unit costs, EUR/kg Hg | Reductions of air emissions, t/y | Total costs, million EUR/y |
| Coal fired power plants, activated carbon injection (ACI) | 24.900 | 280 | 7.000 |
| Cement production, optimised fabric filters | 5.950 | 134 | 800 |
| Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning | 2.400 | 107 | 260 |
| Total | | 521 | 8.100 |

The cleaning of off-gas from non-ferrous metal production will in addition to the reduction of air emissions also reduce the quantity of mercury in circulation by about 230 tonnes - in total it reduced the amount in circulation by 340 tonnes of which 107 is estimated to be emission to air.
All the measures combined will have the following effects on quantities and costs, where the reductions are attributed to the demand measures.

Note that the costs displayed here and above are the annualised costs. Costs related to the financing needs are illustrated in other sections of the report. The two cost concepts show different results for example if a measure involves an up-front investment. In effect, the only differences are for cost estimates for the measures targeting ASGM and the chlor-alkali sector, as the costs for investment in emission reduction devices are annualised in both concepts in this study.

Table 11-4  Combined effects of the scenario (World excl. EU and North America; based on medium estimates and annualised costs).

<table>
<thead>
<tr>
<th></th>
<th>Reduced Hg in circulation, t/y</th>
<th>Reductions of air emissions, t/y</th>
<th>Total costs, million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand measures</td>
<td>3.151</td>
<td>724</td>
<td>5.300</td>
</tr>
<tr>
<td>Other measures that reduce circulation or air emissions</td>
<td>340</td>
<td>521</td>
<td>8.100</td>
</tr>
<tr>
<td>Supply measures</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>3.491</td>
<td>1.246</td>
<td>13.000</td>
</tr>
<tr>
<td>% of total circulation or air emissions</td>
<td>73%</td>
<td>55%</td>
<td></td>
</tr>
</tbody>
</table>

The estimation of the impacts above has been based on the medium estimates regarding the unit costs of the measures. The effects of assuming either the low or the high end of cost range are shown below. If costs are instead at the low end the total annualised costs would only about 3 billion EUR/year instead of about 13 billion EUR/year. Assuming the high cost estimates would double the total annualised costs to about 26 billion EUR/year. The discrepancy between these numbers and the sums shown in
Table 0-2 in the extended executive summary are caused by slightly differing calculation methods at the aggregate level; the differences are however minor considering the associated uncertainties.

Table 11-5  Sensitivity of unit cost assumptions, million EUR/y (World excl. EU and North America; based on annualised costs).

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand measures</td>
<td>1.200</td>
<td>5.300</td>
<td>11.600</td>
</tr>
<tr>
<td>Other measures that</td>
<td>1.300</td>
<td>8.100</td>
<td>14.700</td>
</tr>
<tr>
<td>reduce circulation or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>air emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply measures</td>
<td>2</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>2.500</td>
<td>13.000</td>
<td>26.000</td>
</tr>
</tbody>
</table>

The costs for the demand measures are dominated by the costs of substitution for the products: batteries and dental amalgam. An alternative scenario could be to exclude these two mercury applications. As sensitivity assessment, the effects of not including these two demand measures are illustrated.

Table 11-6  Combined effects of scenario without batteries and dental amalgam substitution (World excl. EU and North America; based on medium estimates and annualised costs).

<table>
<thead>
<tr>
<th></th>
<th>Reduced Hg in circulation, t/y</th>
<th>Reductions of air emissions, t/y</th>
<th>Total costs, million EUR/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand measures</td>
<td>2.601</td>
<td>681</td>
<td>200</td>
</tr>
<tr>
<td>Other measures that</td>
<td>340</td>
<td>521</td>
<td>8.100</td>
</tr>
<tr>
<td>reduce circulation or</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>air emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply measures</td>
<td></td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>2.941</td>
<td>1.203</td>
<td>8.000</td>
</tr>
<tr>
<td>% of total circulation</td>
<td>61%</td>
<td>53%</td>
<td></td>
</tr>
<tr>
<td>or air emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The medium costs would in this case be significantly reduced to about 8 billion EUR/year, while the reduction in mercury circulation is changed from 73% to 61%. The reduction in air emissions is more limited, from 55% to 53%, due to the character of the products and their lifecycle. However, air emissions from the lifecycle of these products may be underestimated in existing global inventories.
As shown in Section 6.4.1, the sensitivity analyses for costs for substitution of batteries and dental amalgam showed, that using slightly different assumptions in the calculations would yield 40-70% lower medium costs. These options however remain among the relative more costly in terms reductions per kg mercury. Should the main results however prove to be most realistic, it could, seen from a purely economical perspective, be considered most beneficial to omit the substitution of batteries and dental amalgam from the convention requirements. Other considerations may however play an important part too, for example the protection of developing countries with a weak waste management infrastructure and weak regulation of products containing hazardous substances.

11.2 Demand and waste measures

Measures which reduce mercury demand, and thereby the amount of mercury brought into circulation in society, will also ultimately reduce the costs for environmentally sound disposal of mercury containing waste. This development will however only happen over longer time, until all intentional mercury use has ceased. In a hypothetical situation where all intentional use stopped today, it would perhaps take one decade before most of the mercury would be out of circulation in society, and perhaps two-three decades before almost all mercury will be eliminated from circulation. In the most likely situation after the eventual introduction of global demand measures, some mercury uses would still be allowed under the convention for a period, perhaps a decade or two, until alternatives were developed and commercially matured for almost all intentional mercury use. Any remaining uses with specific exemptions could preferably be of a character where releases could be eliminated entirely and mercury containing wastes could be collected and handled in closed systems.
12 Societal benefits of mercury reductions

For comparison, the reduction costs quantified in this study can be seen in relation to existing estimates of the damage costs of the adverse effects of mercury in the environment. The societal benefits of mercury reduction equal the reductions in damage costs from mercury.

The Nordic Council of Ministers study "Socio-economic costs of continuing the status-quo of mercury pollution" (Pacyna et al., 2008) estimated the global damage costs of loss of IQ (intelligence) due to intake of mercury from ingestion and inhalation. Note that only this adverse effect was included in the estimate and not other human health and environmental effects. They estimated the damage cost in a "Status quo" mercury releases scenario for 2020. This is a "business" as usual scenario with no additional mercury reduction measures implemented but an expected increase in economic activity was taken into account. The global damage costs assuming a value of IQ loss as in Europe was estimated at 22 billion EUR/y, while the same results adjusted for lower life income, etc., in other parts of the world yielded an adjusted damage cost of 8 billion EUR/y.

Taking into consideration that the actual total damage costs including all effects of mercury on human health and the environment, the real damage cost may be several times higher than the estimate mentioned above.

With the significant associated uncertainty of both estimated damage costs and the estimated total costs of mercury reductions calculated in this study, it appears that the societal benefits and reduction costs are in the same range, and that the reductions quantified in the current study would reduce these damages significantly.

As regards the damages included Pacyna et al. (2008) state that: "The damage costs are related directly to the dose of Hg received through inhalation of contaminated air and the ingestion of polluted food. This relation has been previously presented as the slope factor, linking IQ changes with intake of Hg containing food during pregnancy. The total damage cost related to welfare parameters of changes in development impairment have been reviewed in the DROPS project. This cost includes the cost related to loss of earnings, loss of education, as well as
opportunity cost while at school (Scasny et al., 2008). Furthermore, the reduction in IQ might have a direct and indirect effect on earnings. The direct effect of reduced IQ is traced through its impact on job attainment and performance, i.e. lower IQs decrease job attainment and performance. Reduced IQ may also result in two indirect effects: reduced educational attainment, which, in turn, affects earnings and change in labour market participation. 

The adjustment for lower lifetime income etc. outside Europe was calculated using the relative difference in Gross Domestic Product (GDP) per capita expressed as Purchasing Power Parity (PPP) as a weighting factor. The method is called benefit transfer. The costs are dependant on the GDPppp per capita level in the studied country. Thus, a country with low GDPppp will have a lower IQ cost and vice versa for a country with a high GDPppp. For example, in the case of inhalation, the amount of 0.8582 € (USD 1.2873) per 1 kg of Hg (value for Poland) was used for the countries in Asia (except Japan), Eastern Europe, Africa and South America, while 1.419 € (USD 2.1285) per 1 kg of Hg was used for the rest of the world (Pacyna et al., 2008).
Acronyms and abbreviations

% - Per cent

ACI - Activated carbon injection (mercury specific filter type)

ASGM - Artisanal and small scale gold mining

Au - Gold

BAT - Best available techniques

BEP - Best environmental practices

COP - Conference of the Parties

CPL - Comparative price level

Cu - Copper

EC - European Commission

ECB - European Central bank

ECHA - European Chemicals Agency

ESP - Electrostatic precipitator (dust filter)

EU - European Union

EU27 - European Union, 27 Member States

EUR - Euro

Eur. - Europe
Excl. - Excluding

FGD - Flue gas desulphurisation (filter type)

g - Gram

GDP - Gross domestic product

GEF - Global Environment facility

Hg - Mercury

INC - International Negotiating Committee

IQ - Intelligence quotient

kg - Kilogram

MCCAP - Mercury cell chlor-alkali plant

Mill. - Million

MS - Microsoft

Na - North America

OECD - Organisation for Economic Co-operation and Development

Pb - Lead (metal)

PIC - Prior informed consent

POPs - Persistent organic pollutants

PPP - Purchasing power parity

PVC - poly vinyl chloride (plastic)

Rel. - Releases

RP - Reduction potential

SCR - Selective catalytic reduction (filter type)

SEK - Swedish crowns

t - tonnes (metric tons)

UN - United Nations
UNEP - United Nations Environment Programme
USD - United States dollars
USGS - United States Geological Survey
VCM - Vinyl chloride
WHO - World Health organisation
y - year
Zn - Zinc
References

Artisanal Gold Council; http://www.artisanalgold.org/.


DELA (2012): Personal communication and submitted material, Susanne Kummel, March and April, 2012. DELA, Germany.


Kommunekemi (2012). Personal communication. Bjarne Damsgaard, Kommunekemi (hazardous waste treatment facility), Denmark, April 2012.


Toxics Link (2012): Personal communication, June 2012. Based on price quotations received from an Indian hospital in 2012.


UNEP, 2010a: Potential costs and benefits associated with each of the provisions listed in paragraph 27 of Governing Council decision 25/5. UNEP(DTIE)/Hg/INC.1/INF/8, UNEP, April 2010.

UNEP, 2011a: Further comparative analysis of options for financial mechanisms to support the global legally binding instrument on mercury. UNEP(DTIE)/Hg/INC.3/4. UNEP, Aug 2011.


UNEP/POPs, 2009: Report on the assessment of funding needs of Parties that are developing countries or countries with economies in transition to implement the provisions of the Convention over the period 2010–2014; UNEP/POPS/COP.4/27, January 2009.


Appendix 1

Summary of cost effectiveness quantified without CPL adjustment for lower implementation costs in developing regions. Note that only some reduction measures were adjusted, while others were either deemed dependent on developed world technology or originally quantified for developed countries only.

<table>
<thead>
<tr>
<th>Reduction option</th>
<th>World (excl EU+NA)</th>
<th>Red</th>
<th>Medium RP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EUR/kg Hg eliminated from circulation</td>
<td>t Hg eliminated from circulation/y</td>
<td></td>
</tr>
<tr>
<td>Batteries, substitution*1</td>
<td>18000</td>
<td>7000</td>
<td>37000</td>
</tr>
<tr>
<td>Dental amalgam, substitution*1,2</td>
<td>11200</td>
<td>-1400</td>
<td>29900</td>
</tr>
<tr>
<td>Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning, combined*3</td>
<td>460</td>
<td>390</td>
<td>530</td>
</tr>
<tr>
<td>Measuring and control devices, substitution*1</td>
<td>252</td>
<td>9</td>
<td>910</td>
</tr>
<tr>
<td>VCM production, Hg substitution*1</td>
<td>155</td>
<td>80</td>
<td>230</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution*1</td>
<td>140</td>
<td>90</td>
<td>190</td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed divided on 10 years</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Supply, value of Hg not supplied for allowed uses*1 (distributional effect only)</td>
<td>25</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>Non-ferrous metals production, env. sound Hg waste storage</td>
<td>21</td>
<td>1,7</td>
<td>40</td>
</tr>
<tr>
<td>Permanent env. sound storage of Hg from other supply sources</td>
<td>1,5</td>
<td>0,9</td>
<td>2</td>
</tr>
<tr>
<td>Cement production, optimised fabric filters*4</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
<tr>
<td>Coal fired power plants, activated carbon injection (ACI)</td>
<td>NR</td>
<td>NR</td>
<td>NR</td>
</tr>
</tbody>
</table>

Notes: *1: Cost for lifecycle management of Hg wastes not subtracted. *2: Air emissions in calculation only include crematoria emissions; real emissions are higher and thus the price per kg Hg will actually be lower. *3: If Hg deposited; thereby eliminated from air emissions and circulation in society with by-product acid. *5: Attributed to reduced air emissions from non-ferrous metal smelters + permanent storage of other Hg supply.
<table>
<thead>
<tr>
<th>Reduction option</th>
<th>Medium</th>
<th>Low</th>
<th>High</th>
<th>Medium RP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batteries, substitution*1</td>
<td>270.000</td>
<td>110.000</td>
<td>580.000</td>
<td>22</td>
</tr>
<tr>
<td>Dental amalgam, substitution*1,2</td>
<td>180.000</td>
<td>-13.000</td>
<td>370.000</td>
<td>21</td>
</tr>
<tr>
<td>Coal fired power plants, activated carbon injection (ACI)</td>
<td>43.000</td>
<td>3.000</td>
<td>82.000</td>
<td>280</td>
</tr>
<tr>
<td>Cement production, optimised fabric filters*4</td>
<td>10.000</td>
<td>9.100</td>
<td>11.000</td>
<td>134</td>
</tr>
<tr>
<td>VCM production, Hg substitution*1</td>
<td>8.000</td>
<td>3.900</td>
<td>11.690</td>
<td>15</td>
</tr>
<tr>
<td>Non-ferrous metals production, Hg-specific gas cleaning and wet gas cleaning, combined*3</td>
<td>2.400</td>
<td>1.100</td>
<td>3.700</td>
<td>107</td>
</tr>
<tr>
<td>Measuring and control devices, substitution*1</td>
<td>2.200</td>
<td>90</td>
<td>4.300</td>
<td>42</td>
</tr>
<tr>
<td>Chlor-alkali production, Hg substitution*1</td>
<td>1.050</td>
<td>1.000</td>
<td>1.100</td>
<td>34</td>
</tr>
<tr>
<td>ASGM, education and low tech devices, costs assumed divided on 10 years</td>
<td>71</td>
<td>71</td>
<td>71</td>
<td>590</td>
</tr>
<tr>
<td>Supply, value of Hg not supplied for allowed uses*1 (distributional effect only)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Non-ferrous metals production, env. sound Hg waste storage</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Permanent env. sound storage of Hg from other supply sources</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Notes: *1: Cost for lifecycle management of Hg wastes not subtracted. *2: Air emissions in calculation only include crematoria emissions; real emissions are higher and thus the price per kg Hg will actually be lower. *3: If Hg deposited; thereby eliminated from air emissions and circulation in society with by-product acid. *4: 98% reduction potential only if filter dust is not re-introduced in cement kiln.
### Appendix 2

Costs elements included in the analysis of lifecycle costs for dental amalgam conducted by Concorde East/West (2012). Budget items included in the current assessment (see Section 6.4.1) are marked in yellow colour.

<table>
<thead>
<tr>
<th>Key pathways of dental mercury to the environment</th>
<th>Mercury (ton)</th>
<th>End-of-pipe or other preventative mechanism</th>
<th>Approx. cost range ($/kg mercury removed)</th>
<th>Approximate cost ($/US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal solid waste incinerator (large) emissions to the atmosphere</td>
<td>6.2</td>
<td>Assumes flue gas controls are already present on all large incinerators</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Municipal solid waste incinerator (smaller) emissions</td>
<td>6.1</td>
<td>flue gas controls</td>
<td>20,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Municipal solid waste incinerator ash &amp; residues to treatment (50ppm Hg)</td>
<td>1.0</td>
<td>thermal treatment to remove elemental Hg from ash/residue</td>
<td>160,000</td>
<td>240,000</td>
</tr>
<tr>
<td>Municipal solid waste (low Hg) previously landfilled</td>
<td>5.6</td>
<td>incineration of waste with flue gas controls</td>
<td>30,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Municipal wastewater sludge incinerator emissions</td>
<td>5.8</td>
<td>flue gas controls</td>
<td>20,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Municipal wastewater sludge (low Hg) previously landfilled</td>
<td>1.1</td>
<td>incineration of sludge with flue gas controls</td>
<td>20,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Municipal wastewater sludge to agricultural and other land disposal (100ppm)</td>
<td>5.5</td>
<td>thermal treatment to remove elemental Hg before land disposal</td>
<td>80,000</td>
<td>120,000</td>
</tr>
<tr>
<td>Biomedical waste process emissions to the atmosphere</td>
<td>5.0</td>
<td>capture mercury in exhaust gases with activated carbon filters</td>
<td>1,000</td>
<td>1,500</td>
</tr>
<tr>
<td>Biomedical waste process water treatment</td>
<td>6.3</td>
<td>chemical treatment of process wastewater</td>
<td>160,000</td>
<td>240,000</td>
</tr>
<tr>
<td>Biomedical waste to treatment and disposal (50ppm Hg)</td>
<td>1.3</td>
<td>thermal treatment to remove elemental Hg</td>
<td>10,000</td>
<td>20,000</td>
</tr>
<tr>
<td>Cemetery releases to the soil</td>
<td>4.2</td>
<td>thermal treatment of soil to remove elemental Hg</td>
<td>2,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Cremation emissions to the atmosphere</td>
<td>3.9</td>
<td>flue gas controls (specialized)</td>
<td>30,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Dental clinic occupational emissions to the atmosphere</td>
<td>6.5</td>
<td>ventilation and capture mercury in exhaust gases with activated carbon filters</td>
<td>1,000</td>
<td>1,500</td>
</tr>
<tr>
<td>Dental clinic wastewater emissions to the atmosphere</td>
<td>6.9</td>
<td>capture mercury in exhaust gases with activated carbon filters</td>
<td>1,000</td>
<td>1,500</td>
</tr>
<tr>
<td>Human exhalation to the atmosphere</td>
<td>6.2</td>
<td>none feasible</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>Hazardous waste to landfill or safe disposal</td>
<td>6.3</td>
<td>secure/landfill or safe disposal</td>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>Recycling amalgam waste (service contract)</td>
<td>6.0</td>
<td>thermal treatment to remove elemental Hg</td>
<td>300</td>
<td>600</td>
</tr>
<tr>
<td>Recycling amalgam waste (50ppm Hg)</td>
<td>1.2</td>
<td>thermal treatment to remove elemental Hg</td>
<td>160,000</td>
<td>240,000</td>
</tr>
<tr>
<td>Emissions to the atmosphere during recycling</td>
<td>6.1</td>
<td>flue gas controls (specialized)</td>
<td>30,000</td>
<td>50,000</td>
</tr>
<tr>
<td>Total environmental releases</td>
<td>42.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safe storage/disposal of elemental mercury and mercury waste generated in the above processes, including:</td>
<td>32.4</td>
<td>secure/landfill or safe disposal</td>
<td>3</td>
<td>35</td>
</tr>
<tr>
<td>Filtration from flue gas controls</td>
<td>28.9</td>
<td>long-term above-ground safe storage</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

Total waste treatment cost (multiplied by 90%) = $1,043,099,029 | $1,701,077,850

Total waste management, manipulation and handling costs = $1,043,099,029 | $1,701,077,850

Total waste management and treatment costs = $2,086,198,029 | $3,422,155,700

Total waste management and treatment costs per filling (allocated over 51 million amalgam fillings) = $540.91 | $966.71
Appendix 3

Overview of data involved in the estimation of costs and effectiveness for coal fired power plants. Costs are not CPL adjusted here.
Cost data used for coal fired power plants.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Cost input (text; currency, remarks)</th>
<th>Cost EUR/unit</th>
<th>Unit</th>
<th>Regional price adj. factor</th>
<th>Regional cost, EUR/unit</th>
<th>Activity rate (in unit)</th>
<th>Nego- tiations adj. factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal fired power plants (with exist. cESP+FGD); add ACI (80% mercury removal)</td>
<td>4,21 USD/MWh electricity produced</td>
<td>3,19157001</td>
<td>USD/MWH electricity produced</td>
<td>1</td>
<td>3,19157</td>
<td>4.498.258</td>
<td>849.327</td>
</tr>
<tr>
<td>Coal fired power plants (with exist. Dry scrubber+FF); add ACI (80% Hg removal)</td>
<td>0,34 USD/MWh electricity produced</td>
<td>0,257751497</td>
<td>USD/MWH electricity produced</td>
<td>1</td>
<td>0,2577515</td>
<td>4.498.258</td>
<td>849.327</td>
</tr>
</tbody>
</table>
Effectiveness; data and results for coal fired power plants.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Release pathway</th>
<th>Basic Hg turnover, 2005 t/y</th>
<th>Reduction potential of add. measure</th>
<th>Hg reduction potential, t Hg/y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>World (excl EUR+NA)</td>
<td>EU</td>
<td>World (excl EUR+NA)</td>
<td>World (excl EUR+NA)</td>
</tr>
<tr>
<td>Coal fired power plants (with exist. cESP+FGD); add ACI (80% Hg removal)</td>
<td>Air</td>
<td>396</td>
<td>42</td>
<td>0,71</td>
</tr>
<tr>
<td>Coal fired power plants (with exist. Dry scrubber+FF); add ACI (80% Hg removal)</td>
<td>Air</td>
<td>396</td>
<td>42</td>
<td>0,71</td>
</tr>
</tbody>
</table>

Cost estimates for coal fired power plants.

<table>
<thead>
<tr>
<th>Cost element</th>
<th>Total cost, Mill. EUR/y</th>
<th>Calculated costs, EUR/kg Hg</th>
<th>Total cost, Mill. USD/y</th>
<th>Calculated costs, USD/kg Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>World (excl EUR+NA)</td>
<td>EU</td>
<td>World (excl EUR+NA)</td>
<td>World (excl EUR+NA)</td>
</tr>
<tr>
<td>Coal fired power plants (with exist. cESP+FGD); add ACI (80% Hg removal)</td>
<td>14.000</td>
<td>2.700</td>
<td>50.000</td>
<td>150.000</td>
</tr>
<tr>
<td>Coal fired power plants (with exist. Dry scrubber+FF); add ACI (80% Hg removal)</td>
<td>1.200</td>
<td>220</td>
<td>4.300</td>
<td>12.000</td>
</tr>
</tbody>
</table>