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Mercury substitution priority working list

An input to global considerations on mercury management

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Content

Executive summary

Mercury (Hg) is among our most serious health and environmental hazards. Anthropogenic emissions of Hg result in direct human exposure and a build-up in the global environment and subsequent transfer to humans via consumed fish. The supply chain from virgin mined Hg over Hg-added products to final disposal is long. While the adverse environmental impacts are globally acknowledged, the understanding and mitigation of the problem is delayed, maybe because consumers and other public and private stakeholders are not always aware of the risks, and because environmental costs are, generally, not considered in the market price for devices containing Hg. To reduce or eliminate the risks, Hg substitution is one viable option. Here we present an input to global considerations on mercury management by presenting a mercury substitution priority working list; or: An identification of the least essential mercury uses. This may be used as inspiration for reducing intentional mercury uses globally, if politically desirable, by furnishing the list to stakeholders globally as an input to constructive discussions currently undertaken under auspices of UNEP towards reducing Hg releases. The list includes all identified intentional uses of Hg, the availability of relevant alternatives, and proposed Hg substitution order, and major challenges ahead.

No doubt, implementation of substitution of mercury in developing countries worldwide will need careful consideration of the potential impacts of mercury substitution, and probably substantial technical and financial support in some areas. However, the results of this study illustrate that significant mercury reductions may indeed be within reach, and that a reduction process involving a step-wise substitution approach taking major socio-economic challenges into consideration could be a way forward.

Almost two thirds, or 43 out of the 72 identified uses of mercury, are deemed readily substitutable because alternatives are compatible and even dominate the market in many countries already. Many of these mercury uses are already used in marginal amounts in the global perspective, and restrictions of further input of these to society may therefore perhaps have relatively small economical consequences in the present situation. Some readily substitutable mercury uses do however represent significant inputs of mercury to society, which could be avoided without major technical difficulties (e. g. mercury-oxide batteries, certain other regionally sold old-type primary batteries and thermostats, and manometers). Other uses have alternatives available or well on the way, but face institutional (or structural), social or technical challenges indicating a need for longer phase-out periods. These are for example hospital and laboratory equipment, which use is often required in quite rigid standards, which take

time to change. Finally, a limited number of Hg uses (10 out of 72 identified) face substantial, but likely not insurmountable, challenges for mercury substitution or phase-out. In most cases, the socio-economic challenges are the main reasons; examples are small scale gold mining, everyman's fluorescent energy-saving lights, and dental amalgam.

In short, the results of our assessment indicate that:

- Many mercury uses may today be readily eliminated, if politically desired.
- Global mercury demand may be reduced significantly by substitution of the least essential uses.
- Applying a prioritized phase-out work list may help focusing on the main problems in mercury reductions and thereby securing a cost effective phase-out process.

Based on these findings we recommend that:

A prioritised phase-out work list for intentional mercury uses is discussed and developed further in international cooperation, for example as part of the Open-ended Working Group considering legal and other initiatives on mercury established under the auspices of the United Nation's Environment Programme (UNEP). This could serve:

- As a valuable tool in mutual communication and discussion of possible global mercury reductions
- As a tool for a step-wise reduction development, if desired politically
- As part of forming a common vision for global mercury reductions.

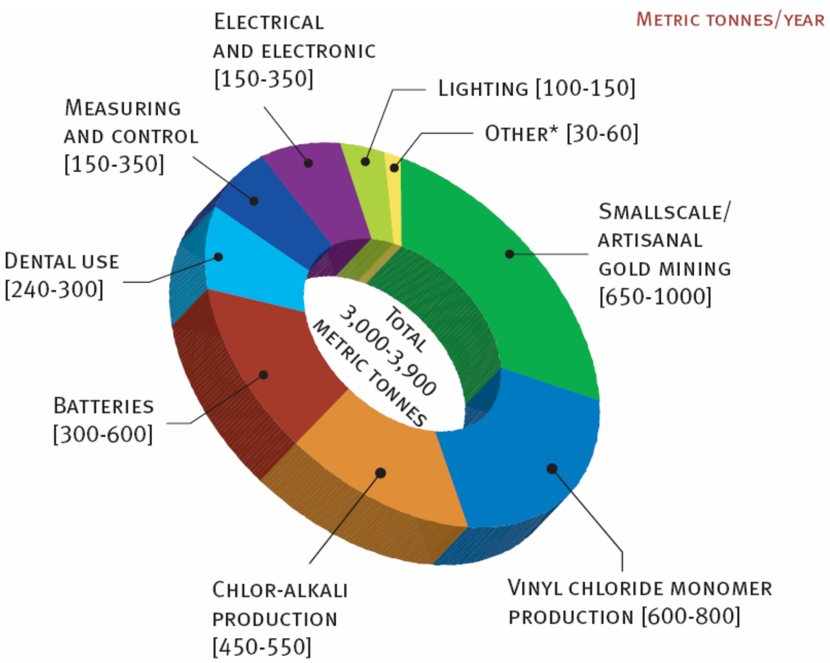
1. Background

Mercury is scientifically demonstrated and politically acknowledged as a global pollutant (UNEP, 2002, 2005, 2006, 2007; The Madison Declaration on Mercury Pollution, 2007). Elemental Hg is unique when compared to other trace metals found in the atmosphere, in that it is predominantly in the gaseous elemental form (Slemr et al. , 1985; Schroeder and Munthe, 1998), where other metals, e. g. lead, are primarily spread in the atmosphere with aerosols. The characteristics of gaseous metallic Hg, such as low aqueous solubility, mean that it has relatively low reactivity and is quite stable. Therefore, gaseous elemental mercury has a long atmospheric residence time, enabling global transport. Its vapour pressure and biological processes allows it to be deposited and reemitted from land, vegetation and aquatic surfaces. All of these factors contribute to its spreading throughout the globe to areas where there are very little natural or local man-made Hg releases. Hg accumulation in aquatic food resources deserve special attention, considering that the growing world population needs increasing food supplies and cannot risk that such a nutritious food resource as fish and other sea and fresh water food turns unsuitable for human consumption due to anthropogenic emissions of Hg. In virtually all regions of the world – including such remote areas as the Arctic – fish and other aquatic foods with mercury concentrations too high for frequent human consumption have been found (UNEP, 2002). For the general population, the most critical toxic effect from mercury is damage to the central nervous system, notably the developing brain of the foetus (UNEP, 2002). In many countries women of childbearing age and small children are advised to avoid eating certain fish species often – or not at all – due to mercury contamination (NMR, 2007).

The three dominating sources of anthropogenic emissions of Hg are burning of fossil fuels, non-ferrous metal smelters and intentional use of mercury in small scale gold mining, industry, households, and health care ([Pirrone *et al.* , 1996, 2001, as cited in UNEP, 2002; Hylander and Meili, 2003, 2005). While atmospheric Hg emissions at burning of fossil fuels and metal smelters may be drastically reduced by appropriate flue gas cleaning technology, emissions from intentional use of mercury is generally more difficult to curb, because Hg is released from many and geographically scattered sources and at many stages, starting at mining and continuing with manufacturing, use and disposal far beyond the end of life of Hg containing products. Releases, especially to air but also to water and land have been, and still are, large when mining and processing Hg bearing ores (Ferrara et al. , 1998; Hylander and Meili, 2003; ACAP, 2005; UNEP, 2005). Further emissions are evoked by fabricating Hg

containing compounds, products and equipments such as dental amalgam, batteries, thermometers, and sphygmomanometers for measuring blood pressure, or when Hg is being used in production processes such as the production of chlorine and alkali with Hg cells and at gold mining by artisanal and small-scale miners using the Hg amalgamation method. Often, the emissions continue when using the products, such as Hg continuously emitted during all the life time of fillings with dental amalgam (Skare and Engqvist, 1994; Sörme and Lagerkvist, 2002). At the end of life, Hg is generally released to one or more of the media air, soil, and water. This can be an abrupt release of Hg encapsulated, such as when breaking a Hg containing thermometer by accident in the sink or a fluorescent tube in the waste bin. It can be through waste incineration predominant in some developed countries or in open burning of waste taking place in many developing countries, or the releases may be more slow (and poorly identified) such as in land filled Hg containing wastes.
The figure below presents a picture of the most current knowledge of reported mercury consumption with intentional uses in products and processes globally. The figure shows a split on the main use categories; note however that a more detailed quantitative split on individual applications is not available, and therefore this study works with indicative notations for the consumptions of each mercury application (see description under "methods" below).

Reduction of mercury releases to the environment has gained high priority globally during the last few years, and negotiations on how to address this issue have been performed at the UNEP Governing Council meetings in 2003, 2005 and in February 2007 (UNEP, 2007, and earlier decisions). New ideas may be of paramount importance in the pursuit of significant support for efficiently addressing mercury release reductions. Releases from intentional uses of mercury are significant globally. While prioritized lists have been developed nationally in a few countries and in some cases as part of regional conventions and strategies, a prioritised list for reducing intentional mercury uses globally had not – to our knowledge – been developed prior to the initiation of this study. During the course of this study, a prioritised phase-out plan for mercury was presented by the NGO's active in the mercury issue (Bender, 2006).



Mercury consumption globally
The diagram shows the estimated distribution of mercury use among key sectors globally in 2005 (data: Maxson, 2006). Although there are alternatives to most uses of mercury, it continues to be used in some parts of the world. Waste treatment is a major mercury release source; while some countries have waste management systems that reduce releases, many countries worldwide do not have such waste management systems, and practices like open waste burning and informal dumpsites are not uncommon (NMR, 2007).
** Laboratory, pharmaceutical, cosmetic, cultural/traditional uses, etc.*

Objectives

The objectives of the present study were to create a first draft concept of a mercury substitution priority working list with global relevance to serve as:

- A help in mutual communication and discussion of possible global mercury reductions;
- A tool for a step-wise reduction development, if desired politically;
- An input to creating a common vision for global mercury reduction work with initial suggestions for timing of their global substitution/phase-out and the parameters proposed for assessing the possible, relative prioritization/timing of substitution.

The list is intended to serve as a first draft concept to be further discussed and evaluated by interested parties, including relevant authorities in charge, for example as a part of the work of the Open-ended Working Group considering legal and other initiatives on mercury established under the auspices of the United Nation's Environment Programme (UNEP).

2. Methods

To serve these objectives, efforts were made to identify and list all known uses of Hg. We evaluated the state of Hg substitution for each application in developed countries (primarily OECD countries which are best described in existing literature), and listed potential major challenges for global substitution and proposed a Hg substitution order and relevant considerations.

2.1 Inputs

We used the following data types as input to our assessment:

1) We extracted lists of intentional mercury uses worldwide from UNEP's Mercury inventory Toolkit, the Global Mercury Assessment report, and other recent review sources, which we combined with our background knowledge.

2) We looked at the state of substitution in developed countries, because international review literature almost only describes the state of Hg substitution in these countries. Based on major reviews, selected original literature and our background knowledge, we indicated our understanding of the state of substitution with an index of 0 – 4, where 0 means no/low substitution and 4 means full substitution, as defined below. The actual state of substitution is not known for most uses – at least not at an international level – so this categorization should be considered indicative only, and additional, country specific studies may be warranted prior to implementing new regulation or other major changes on the issue. The substitution level indices used were defined as follows:

	Key to assigned substitution level indices:
Index	Description of substitution level
0	No substitution indicated in assessed data sources; development often underway
1	Alternatives are in commercial maturation, or are present on the market but with marginal market shares
2	Alternatives are commercially matured and have significant market shares, but do not dominate the market
3	Alternatives dominate the market, but new production with mercury also have significant market shares
4	Mercury use is fully, or almost fully, substituted
N	Not enough data found to assign an indicator
?	Indicator uncertain due to limited data

As supporting information only, we have reviewed a limited number of references to see which Hg uses were reported as banned or severely restricted in countries, in (sub-federal) states in the USA, and in the European Union, giving indications that the Hg uses in question have been found readily substitutable (UNEP, 2002; ECOS, 2005; EU RoHs Directive[1] (2003;) and Battery Directives (2006). .

In cases where the reviewed information indicated that the level of substitution varied markedly among the developed countries described, a range was entered to describe the variation (for example "2–4"). Ranges were also used where the given information indicated uncertainty as to the state of substitution for the specific Hg use.

In a few production processes where mercury is consumed continuously as an auxiliary material, the production method applying mercury is widely accepted as outdated and new facilities built in developed countries are based on mercury-free technology (for example chlor-alkali facilities with Hg cells, and VCM production with Hg catalysts). In these cases, the Hg substitution level is indicated based on the share of production capacity using Hg versus capacity using alternatives, even though the facility design type is considered fully outdated in developed countries, and new Hg cell facilities will not be build.

3) We also indicated our assessment of the current main challenges for substitution globally based on the studied reviews and our background knowledge. For this aspect we included the following aggregate indicators:

Indicator	Focus of needed substitution efforts
P:	Prices of mercury free alternatives are presently markedly higher when environmental and health costs are not considered.
T:	Need for technical development of alternatives.
S:	Uses with social implications, such as in small scale gold mining where mercury use is currently vital to some, but not all, gold mining communities.
I:	Institutional (or structural) implications such as in standardized chemical laboratory analyses.
0, or [empty]:	No major hurdles identified (other than perhaps resistance in the market to adopt new products/processes).

Note that the price indicator does not include a total economical assessment of life cycle costs for alternatives vs. mercury use/mercury added products e. g. waste handling.

4) As a separate data type, we indicated the difference in sales price of the alternatives and the mercury uses as follows, where this information was available in the assessed reviews:

Indicator	Price difference; Hg free alternative vs. Hg use
-	Sales price of alternative smaller than Hg use
=	Approximately same price
+	Sales price of alternative larger than Hg use
?	Limited or no data on sales prices available in assessed reviews

[1] The EU RoHs Directive covers most electronic and electrical equipment; for example some Hg containing light sources and some measuring instruments are not covered (2003).

5) We indicated the magnitude of global mercury consumption with each mercury use in question. Except for the major uses, this information is not readily available, so we chose to use four indicative categories of relative magnitude globally:

Indicator	Relative magnitude of global Hg consumption
0?	Next to no consumption
x	Small consumption
xx	Medium consumption
xxxx	Large consumption
[x/xx]?	Indicated magnitude uncertain

Finally, it must be mentioned that it has been beyond the scope of this study to assess the health- and environmental impacts of available mercury-free alternatives.

2.2 Additional expert assessments

As additional data input and a further qualification of the main authors' (Hylander and Maag) assessment of the general substitution level in developed countries, the list of aggregated substitution level indices where sent to a number of experts (the co-authors) with an invitation to submit their expert assessment of the substitution level for identified Hg uses in their homelands, Belgium, Italy, Japan and the United States[2], based on their background knowledge (the individual expert assessments received are presented in Appendix 2).

2.3 Synthesis

Based on the input elements outlined above, we assigned proposed time spans for what we call a "99 percent" phase-out, where the introduction of Hg products on the market has ceased, except for the necessary special exemptions such as Hg as a standard in Hg analysis, or military and individual dispensations that often occur.

The three time spans we used were:

- Short term phase-out (illustrated with 8 years, counted as if a global agreement on substitution was made in 2007)
- Medium term phase-out (illustrated with 12 years)
- Long term phase-out (illustrated with 25 years)

[2] (in alphabetical order).

Similar time spans have been used in the Montreal Protocol on ozone-depleting substances, in the Kyoto Protocol on climate change and in the Heavy Metals Protocol of the Convention on Long-Range Transboundary Air Pollution (LRTAP convention).
It is important to note that these time frames were considered by the authors as realistic based on a pragmatic judgment, if global mercury substitution is politically agreed on. Faster substitution may be practically possible, in case this should be backed politically and the necessary resources for implementation and assistance would be allocated.
To assign a relevant phase-out time span to a mercury application, we used the following four criteria:

- Are mercury-free alternatives technically matured and readily available on the marked? If so, and if there were no other major factors involved, a short time span was suggested.
- Are there significant social implications, especially for developing countries? If so, longer time spans were suggested.
- Are there institutional implications that take time to change? If so, longer time spans were suggested.
- Are there major long-life investments that would realistically make long transition periods necessary? If so, longer time spans were suggested.

3. Results and discussion

3.1 Categorization of Hg uses by proposed transition time

Tables 1–3 below show our suggested categorization of mercury uses according to the expected time needed for global substitution, should this be desired politically. It is important to note that these suggestions are based on an overview of a limited number of reviews and the results should be taken as illustrative of the substitution potential only. It is equally important to emphasize that this categorization is primarily based on observations of the success with substituting mercury uses in developed countries. These observations can – to our opinion – be used to indicate the technical and practical possibilities for implementing mercury substitution, but do not give an adequate description of the social, economical and environmental impacts of substitution under local conditions in a developing country. No doubt, to implement substitution of mercury in developing countries worldwide, will need careful consideration of these impacts, and would probably need substantial technical and financial support in some areas. As mentioned earlier, it is important to note that the suggested time frames were considered by the authors as realistic based on a pragmatic judgment, if global mercury substitution was politically agreed on. Faster substitution could perhaps be practically possible, in case this should be backed politically and the necessary resources for implementation and assistance would be allocated.

As shown in Table 1, almost two thirds, or 43 out of the 72 identified uses (/use groups) of mercury are deemed readily substitutable, provided this is politically desired. Many of these mercury uses are already used in marginal amounts in the global perspective, and restrictions of further input of these to society may therefore have relatively small economical consequences in the global context. Some readily substitutable mercury uses do however represent significant inputs of mercury to society, which could be avoided without major technical difficulties, for example mercury oxide batteries, old-fashioned primary batteries sold on some national/regional markets, level switches and manometers.

Table 2 lines out a number of mercury uses for which alternatives are available or well on the way, but institutional (or structural), social or technical challenges indicate a need for longer phase-out periods. These are for example hospital and laboratory equipment, which use is often required in quite rigid standards, which take time to change. The category also include examples of Hg uses with emerging alternatives in sectors which have so far shown a good potential for technical advancement, such as batteries and LCD flat screens.

Table 3 lists a limited number of Hg uses with substantial, but likely not insurmountable, challenges for mercury substitution or phase-out. In most cases, the main reason is the socio-economic challenges, as is the case for small scale gold mining, every-man's fluorescent energy-saving lights, or dental amalgam which may still have an époque for use as a tooth restoration material in countries where decayed teeth presently are extracted (unless patients and dentists globally see other benefits in working with the available alternatives, which technically face most or all needs). Some of the more challenging Hg uses are discussed further in the next section.

An overview of review results grouped by Hg use category, including references used for each application and explanatory remarks for some uses, is given in Appendix 1.

Appendix 2 gives an overview of the individual additional expert assessments of the substitution situation in selected countries (Belgium, Italy, Japan, and the United States of America).

Table 1: Mercury uses which may be most readily substitutable in a global perspective

Hg use	Time proposed for "99%" global phase-out, years	General substitution level (over-all assess-ment)	Focus of future substi-tution efforts	Price of Hg-free vs. Hg product /process	Relative magnitude of Hg consump-tion globally
Least essential Hg uses in global perspective(?)					
Industrial processes:					
Acetaldehyde production with mer-cury-sulphate (HgSO4) as catalyst	8	4	S	?	x
Vinyl acetate production (Hg catalysts)	8	4	0	?	0?
Production of the cube (1-amino anthrachion) colours /pigments with Hg catalyst	8	4	0	?	0?
Products:					
Skin lightening creams and soaps	8	4	S	?	x?
Thermometers, switches and relays					
Hygrometer/psychrometer (thermome-ter-based)	8	2–4	0	0	0
Pyrometers (high range thermometers)	8	3–4	0	0	0
Level switches (in sewer pumps, float switches, pressure switches, car hoods, movement detectors, alarms, in various apparatus, etc.)	8	2–3	0	=	xx
Multiple pole level switches in excava-tion machines	8	4	0	=	0?
Mercury-wetted contacts (in electron-ics)	8	3	0	=	x
Data transmission relays or "reed relays"	8	3	0	=	x
Displacement (or "plunger") relays	8	2–4	0	0	0
Thermo-switches (thermostats)	8	3–4	0	=	x
ABS brake activators and airback activators in cars	8	3–4	0	?	x?
Continuous conductors in rotating seam welding wheels	8	1–2	0	?	x
Ignitrons and Hg-arc rectifiers in AC/DC converters	8	2–3	0	?	x
Lamps and batteries					
Head lamps in some car brands	8	3	0	?	x
Mercury oxide /mercury zinc batteries (cylindrical and button)	8	4	0	=,+	xx
Alkaline cylindrical batteries (contain-ing mercury)	8	4	0	=	x
Zinc-manganese batteries (paste and paper types)	8	4	S	=	xx
Biocides and pesticides					
Agricultural pesticides (seed dressing, dipping sugar cane and grape seed-lings, spraying insecticides etc.)	8	4	0	=?	x
Slimicides/fungicides used in paper and paper pulp factories	8	4	0	?	0?

Preservation of wood (other than wood for paper production)	8	4	0	?	0?
Latex and other paints for shelf life preservation and hindering mould on painted surfaces in humid conditions.	8	4	0	=?	x?
Antifouling paints for boats	8	4	0	0	0?
Biocides for preservation of eye cosmetics and in liquids for exchange-able eye lenses	8	3	0	=?	x
Various measuring, control and health care equipment					
Manometers/pressure controls for industrial uses, district heating, etc.	8	3–4	0	-,=	xx
Barometers, meteorological	8	3–4	0	?	x
Flow meters (gas flows etc. , applying a manometer)	8	4	0	0	x
Manometers for educational purposes	8	4	0	-,=	xx
Gyroscopes/gyro compasses with mercury	8	4	0	?	0?
Vacuum pumps with mercury	8	3–4	0	?	0?
Mercury in large bearings of rotating mechanic part in for example older waste water treatment plants	8	3–4	0	?	0?
Esophageal dilators (Bogie tubes) and gastrointestinal tubes with Hg	8	3–4	0	?	0?
Hydrometer (measuring density of liquids)	8	4	0	?	0?
Miscellaneous					
Tanning,	8	4	0	?	0?
Pigment (vermilion, HgS)	8	4	0	?	0?
Browning and etching steel	8	4	0	?	0?
Gilding	8	4	0	?	0?
Certain colour photograph paper types	8	4	0	?	0?
Recoil softeners in rifles	8	4	0	?	0?
Mercury fulminate, Hg(ONC)2, used as detonators for explosives, in am-munition and in fireworks	8	4	0	?	0?
Fireworks	8	4	0	?	0?
Executive toys	8	4	0	?	0?

Note: Key to annotation, see section 3, Methods

Table 2: Mercury uses which may need intermediate transition time

Hg use	Time proposed for "99%" global phase-out, years	General substitution level (overall assessment)	Focus of future substitu-tion efforts	Price of Hg-free vs. Hg product /process	Relative magnitude of Hg consump-tion globally
Uses needing intermediate transition time(?)					
VCM (vinyl-chlorid-monomer) production with mercury-dichloride (HgCl2) as catalyst	12	4	S	?	xxxx
Polyurethane production (Hg catalysts)	12	2–3	0	?	x?
Medical thermometers	12	2–4	S,I	+	xx
Other glass thermometers (laboratory, educational, etc.)	12	2–3	I	=	xx
Other (non-glass) mercury thermometers (industrial, marine diesel engines, etc.)	12	2–3	I	=,+	xx
Street advertisement with fluorescent neon tubes of certain colours	12	1	T	?	x
High pressure Hg and Na lamps (for street lighting etc.)	12	1	T	?	x
Backlight in LCD flat screens	12	1	T	?	x
Exit signs (green signs in public buildings etc.)	12	2–3	0	0	0
Alkaline button cell batteries (containing mercury)	12	1	T	=?	xx
Zinc-air button cell batteries	12	1–2	T	=?	x
Silver oxide button cell batteries	12	1–2	T	=?	x
Pharmaceuticals for human and veterinary uses, including biocides in vaccines, in eye drops, some herbal medicines, disinfectants, etc.	12	3	S,I	?	x
Blood pressure gauges (sphygmomanometers)	12	2–3	S,I	=,+	xx
Blood pressure "strain gauge plethysmographs"	12	1–2?	I	0	x
Specialized laboratory apparatus (Coulter Counters, tensiometers, and others)	12	3–4?	I	?	x
Chemical reactants for analysis (COD analysis, Kjeldahl analysis (nitrogen analysis), Nesslers reagent, etc.)	12	2–3	I	=?	x
Porosimetric analysis (pore size distribution)	12	1	I,T	?	x
Marine navigation lights in light houses (in some types the lens/lamp unit floats on mercury)	12	2–4	I	?	x

Note: Key to annotation, see section 3, Methods. See also additional details and remarks in appendices.

Table 3: Mercury uses which may need longer transition time, and uses for which data were lacking in reviewed literature

Hg use	Time proposed for "99%" global phase-out, years	General substitution level (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product /process	Relative magnitude of Hg consumption globally
Uses needing longer transition time(?)					
Chlor-alkali production with mercury cells	25	3	S	=, +	xxxx
Small scale gold and silver mining	25	4	S,T	?	xxxx
Dental amalgam fillings	25	2–4	I,S,P,T	-,=,+	xx
Linear fluorescent lamps	25	1	T	?	xx
Compact fluorescent lamps (CFL, commonly called energy saving lamps/bulbs)	25	1	T	=/+?	xx
Laboratory atomic absorption spectrometry lamps	25	0–1?	I	?	x
Electrodes and references for physio-chemical measurements, such as calomel electrodes, references for Hg analysis etc.	25	2–3	I	?	x
Ethnic/cultural/ritualistic uses and folklore medicine	25	4	S,I	?	x
Infra-red light detection semiconductors	?	N	0	?	x?
Neutron source in synchrotron light establishments and perhaps other high-intensity physical instruments	?	N	?	?	x

Note: Key to annotation, see section 3, Methods. See also additional details and remarks in appendices.

3.2 Hg uses with special challenges for substitution

As shown in Table 3 above, the number of Hg uses for which long transition periods would be expected facing global substitution plans is quite limited. Below, the main challenges for substitution of Hg with these uses are discussed briefly. For additional description and discussion, see the referenced documents (with Appendix 1 as a key to identification of relevant references).

Dental amalgam

Dental amalgam is among the largest uses of mercury globally. Mercury-free alternatives to almost all uses of dental amalgam are however commercially available today, and are widely used in some developed countries in combination with preventive measures to combat tooth decay. The use of amalgam fillings is severely restricted in a number of countries (UNEP, 2002). For example in Denmark, it is only allowed in adult molar teeth with high wearing, and in Sweden it is almost substituted and is not subsidized by the public health insurance system. A high awareness of the risks to environment and health among both patients and some dentists, as well as the availability of alternatives has facilitated the phase-out. . Esthetical considerations have also reduced the demand for amalgam fillings. Investigations of the possibilities for restrictions have also been initiated by the European Commission. While the consumer prices for alternative dental fillings have been reported to vary both below and above the prices of amalgam fillings (UNEP, 2002), the most common alternative material in North Europe (polymer/ceramic composites) currently have higher consumer prices than Hg amalgam. The full environmental costs of dental amalgam are however not reflected in these price differences, because the polluter pays principle is not brought to effect (Hylander and Goodsite, 2006). A concrete example is that the cost of Hg removal from crematoria flue gases is not restricted to the amalgam bearers, but carried by the general taxpayers in the actual countries. Also the cost to clean Hg from the wastewater of dental clinics is collectively born, if at all performed (Hylander et al. , 2006a, 2006b).

Similar to other health related issues, a tendency has been observed among some dentists to prefer the well known technology to newer technologies with fewer years to prove themselves adequate.

Because of the institutional tendency to prefer the well known amalgam, the sometimes higher prices, and an expected political desire not to hinder increased dental care in developing countries combined with amalgam producers' marketing efforts in developing countries as amalgam sales decrease in developed countries, a long phase-out time is expected to be realistic. It could be claimed an advantage for developing countries to avoid repeating the environmental mistakes already made in developed countries, by basing increased dental care on mercury-free filling materials, but a deeper discussion of this issue is, however, beyond the scope of this study.

Certain laboratory uses

Some specific laboratory uses, including for example electrodes and references for physio-chemical measurements (calomel electrodes, references for Hg analysis, atomic absorption spectrometry lamps for Hg analysis) appear difficult or impossible to substitute directly for technical reasons, and because they serve as references. The use of these references can however probably be restricted to few and specialized users, and the mercury consumption is expected to be very minimal in the global context. These uses could perhaps even be candidates for specific exemptions to sales bans. As a consequence, they have been categorized in the group with a long phase-out time.

Artisanal and small scale gold mining

Gold extraction using the mercury amalgamation process is a special challenge to global Hg substitution. The use has been abandoned for commercial production many decades ago in the developed countries. It is economically and technically disadvantageous compared to modern gold extraction technologies (often using cyanide) because of low extraction efficiency (Hylander et al. , 2007). The method causes very severe environmental effects where it is used. Due to the simplicity of the method when neglecting environment protection and work safety, it is used by millions of individuals in developing countries with gold reserves on their territory. UNIDO has estimated that of 10–15 million of small-scale miners, most are engaged in gold mining, often using the Hg amalgamation method, and that about 100 million people worldwide are directly or indirectly economically dependent on this activity (UNIDO, 2006a, 2006b). Rudimentary yet effective methods exist (retorts) to reduce mercury releases markedly from the process, and for some ore types, Hg-free small scale technology is available. Because of the extreme number of miners and dependants involved, because of their low income and limited education, because the sector is largely informal (sometimes illegal), and because of economic interests among Hg and gold dealers profiting from the present situation, advocating less polluting extraction methods is an enormous challenge.

The industrialized alternative and a more efficient extraction method such as cyanidization, is also associated with severe environmental and work safety problems, especially if not used in highly controlled industrial settings requiring investments high above small scale miners' reach. Cyanide is acutely toxic to humans (compared to Hg's generally chronic and long-term toxic effects), yet simplistic use of the method is often employed by small scale miners in combination with Hg amalgamation, with multiple work safety and environmental hazards as consequences. In fact, gold recovery would increase by using cyanidation alone and not in combination with or preceded by Hg. This would also eliminate reactions between cyanide and Hg, increasing the hazards of Hg. Cyanide itself is in nature degraded to non toxic carbon and nitrogen compounds.

UNIDO has emphasized the urgent need for awareness raising at all levels from the miners, over local and national authorities, to the global community, as well as other actions to promote cleaner production of gold globally. The UNIDO is however optimistic, that if the necessary assistance and funding is made available, Hg releases can be reduced by more than half over a decade from the present estimated releases of 650–1000 tonnes Hg per year from artisanal and small scale gold mining (UNIDO, 2006a, 2006b). The long term goal is a total phase out of Hg amalgamation for technologies less invasive to environment and health.

Part of the background for the European Unions present pursuit of reduced global supply of mercury is the wish to minimize the associated environmental impacts and raise the mercury price to motivate miners for reductions of the mercury use. The health and environmental risks related to the releases and exposures of mercury are well known and understood and priority should be given to concrete measures for reducing these risks (EC, 2006a, 2006b). Urgent action is needed to reduce both supply and demand of mercury in gold mining, being a dominant end consumer of Hg. Gold miners, as well as other economic activities, are sensitive to pricing of produced goods as well as of input resources, and react instantly to changes in profit. This has been demonstrated by the increased gold price in the 1980's, causing the onset of the present gold mining boom, spurred by a further increased gold price in the 21^{st} century (UNIDO 2006a and b). Similarly, the increased Hg price in 2003 and 2004 reduced Hg use among gold miners having to pay for the commodity and the increase also stimulated their interest in Hg free technologies, since Hg is often a major production cost besides labour (Hylander et al. , 2007).

Chlor-alkali production with mercury cells

Europe has historically had a dominating position in the global production capacity for chlorine and alkali, and approximately half of the European capacity is still based on mercury cells. In the global context this industry has for many decades been the largest single consumer of Hg, and has therefore been an important driving force for the supply and trade circulation of mercury. Since 1 October 2007, European Union legislation requires that, in general, environmental permits are based on best available technology (membrane or asbestos free diaphragm cells) for chlor-alkali production, implying the conversion or closure of mercury cell facilities (IPPC, 2000). Also, a 1990 OSPAR Convention agreement aims at a phase-out of mercury cells in chlor-alkali facilities by 2010. Euro Chlor, at the other hand, has agreed to phase out most European Hg cell capacity by 2020 (Euro Chlor, 2006).

As substantial amounts of mercury (10. 000 tonnes Hg or more in West Europe) are in use as the operating stock in the European chlor-alkali sector, the fate of this mercury has also been taken into consideration through the European Commission's 2006 proposal for an export ban and requirements for safe storage of mercury (EC, 2006a). The rationale is that mercury taken out of use in Europe for environmental reasons should not be exported and released to the global atmosphere/environment from other regions.

For the global context, the long time span for finalization of Hg use in chlor-alkali industry is however considered most realistic, mainly because of the relatively large investments bound in these facilities combined with a probably political desire to avoid too strong effects on the socio-economic situation of developing and developed countries affected (from demanding a fast change).

Hg containing light sources

A number of energy-efficient light sources, of which straight fluorescent tubes and "low energy bulbs" (or compact fluorescent lamps, CFL's) are sold in largest quantities, are currently dependent on mercury as a gas-phase light emitter. Over the last decades, no commercial and equally energy-efficient alternatives have been available (while many with higher energy demand), and technological front-runners' efforts have been concentrated on reducing the amount of Hg used per lamp. Thereby, mercury consumption in the best available lamps has been reduced to almost a tenth of the amounts used earlier in standard fluorescent lamps. Much of the global supply is however produced at low price with less focus on Hg reductions.

Mercury-free low energy lamps have recently been introduced on the market (diode based lighting for standard sockets; Jula, 2007) or are technically ready for introduction (field emission lamps; Baltscheffsky, 2007). For the diode lamps, development is ongoing to increase the light quality further to meet domestic and other needs (Ingeniøren, 2007).

Low energy lighting is currently a highly prioritized issue due to the pursuit of reductions of energy demand with a view to minimizing global climate change. Many countries have implemented awareness raising campaigns on this issue during the last decade or more, and Australia and California are now considering to ban the use of incandescent lamps for energy reasons, and also EU is discussing restrictions for them. With the currently attainable modest recycling rates for spent Hg lamps (see e. g. Ny Teknik, 2002; Asari et al. , 2005), more mercury will be released from lamp disposal in the future[3].

The increased focus on energy saving lamps could be taken as an opportunity to support and enhance the development and marketing of Hg-free energy efficient lamps, and thereby perhaps give Hg reductions in this sector a substantial boost.

For the general consumer lamps, a long phase-out time was suggested because of considerations for the socio-economic impacts of a faster implementation in developing countries. This is at least the case regarding linear fluorescent lamps, where the whole electric-light fittings probably must be replaced at transition to Hg free lamps, while transition to Hg-free alternatives to CFL's may be accomplished faster. While mercury-free alternatives are emerging in developed countries, fluorescent lamps are produced nationally and regionally, and investments in manufacture

[3] While, at the same time, any reduction in the production of coal-based electricity will reduce Hg releases from power plants.

of the technically different alternatives, and initially increased sales prices, would affect many people in these countries.

LCD backlights: In spite of the only early developments of alternatives (LED's) in backlights for flat LCD screens for computers, and flat TV's, a medium phase-out time were suggested because of the very fast technical development observed so far in this high-tech sector, and the global market character of such products.

Ethnic/cultural/ritualistic uses and folklore medicine

This is a diverse mercury application group including for example the use of mercury in personal talismans, oral intake of metal mercury, key rings and statues filled with mercury, and traditional (non-allopathic) medicals. Much of this mercury use may be difficult to address because it is informal, sometimes illegal, and often linked to religious values which may be more difficult to affect than average consumer behaviors. As long as mercury can be obtained, some of these uses may likely go on, legally or not. Awareness raising among the users may perhaps affect some users; this has been attempted in some countries. For these reasons, long time is expected to be needed to affect this use.

4. Conclusions

The results of our assessment indicate that:

- Many mercury uses may today be readily eliminated, if politically desired.
- Global mercury demand may be reduced significantly by substitution of the least essential uses.
- Applying a prioritized phase-out work list may help focusing on the main problems in mercury reductions and thereby securing a cost effective phase-out process.

Based on these findings we recommend that: A prioritised phase-out work list for intentional mercury uses is discussed and developed further in international cooperation, for example as part of the Open-ended Working Group considering legal and other initiatives on mercury established under the auspices of the United Nation’s Environment Programme (UNEP). This could serve:

- As a valuable tool in mutual communication and discussion of possible global mercury reductions
- As a tool for a step-wise reduction development, if desired politically
- As part of forming a common vision for global mercury reductions.

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Resumé på dansk (summary in Danish)

Kviksølv er blandt de stoffer der udgør den største risiko for miljø og sundhed. Menneskeskabte kviksølvudledninger resulterer i direkte eksponering af mennesker, samt indirekte via ophobning i det globale miljø og indtagelse med fisk i diæten. Forsyningskæden for kviksølv – fra minerne via kviksølvholdige produkter til affaldsbortskaffelse – er lang. Selvom kviksølvs miljøeffekter er anerkendt global, synes forståelsen heraf og udbedring af problemet at gå langsomt. Dette kan måske skyldes at forbrugere og andre offentlige og private interessenter ikke altid er opmærksomme på risikoen, samt at miljøomkostningerne i almindelighed ikke er indregnet i forbrugerpriserne for kviksølvholdige produkter. Substitution er en af tilgængelige muligheder for reduktion eller eliminere af denne risiko. Vi præsenterer her et indlæg til de globale overvejelser om håndtering af kviksølvproblemet, i form af en prioriteret arbejdsliste for kviksølv substitution, eller med andre ord: en udpegning af de mindst essentielle anvendelser af kviksølv. Dette kan forhåbentligt tjene som inspiration for reduktion af den globale anvendelse af kviksølv, såfremt dette ønskes politisk, ved spredning af listen til interessenter verden over som bidrag til konstruktive diskussioner om kviksølv, der pågår i UNEP's regi. Listen indeholder alle identificerede anvendelser af kviksølv, den angiver i hvilken grad alternativer er tilgængelige, samt hvilke udfordringer der ligger forud, og den foreslår en mulig rækkefølge for global substitution af kviksølv.

Der vil uden tvivl være behov for en nøje granskning af, hvilke mulige effekter gennemførelse af en substitution af kviksølv vil få i udviklingslande verden over. Ligeledes vil der i visse regioner formodentligt være behov for betydelig teknisk og finansiel bistand til substitutionens gennemførelse. Resultaterne af denne undersøgelse illustrerer imidlertid, at betydelige reduktioner af kviksølv-anvendelsen er indenfor rækkevidde, samt at en trinvis reduktions-proces, der tager vigtige socioøkonomiske overvejelser i betragtning, kunne være en mulig vej frem.

Op imod to tredjedele, eller 43 ud af 72 fundne anvendelser af kviksølv, forventes at kunne substitueres umiddelbart, fordi alternativerne er dækkende og i mange lande allerede dominerer markedet. Mange af disse kviksølv-anvendelser bruges allerede i dag kun i mindre mængder, hvorfor begrænsninger i deres markedsførelse forventes kun ville få ret begrænsede økonomiske konsekvenser i den aktuelle situation. Visse umiddelbart substituerbare kviksølv-anvendelser udgør imidlertid betydelige bidrag til forbruget af kviksølv, bidrag der kunne undgås uden større tek-

niske vanskeligheder (fx kviksølv-oxid batterier, visse regionalt solgte ældre batterityper, termostater samt manometre). For visse andre anvendelser er alternativer ligeledes tilgængelige, eller på vej, men institutionelle (eller strukturelle), sociale eller tekniske udfordringer antyder behovet for længere udfasningsperioder. Eksempler på disse er hospitals- og laboratorieudstyr, hvis anvendelse dikteres af faste standarder, som det tager tid at ændre. Endelig er der nogle få anvendelser af kviksølv (10 af 72), for hvilke der er betydelige, om end ikke uovervindelige, udfordringer for substitution. I de fleste tilfælde skyldes dette overvejende socio-økonomiske udfordringer. Eksempler på sådanne anvendelser er lavteknologisk guldudvinding, de udbredte energibesparende lysstofrør, samt amalgam tandfyldninger.

I korte træk indikerer resultaterne således at:

- Mange kviksølv-anvendelser i dag uden videre kan elimineres, såfremt dette ønskes politisk
- Den globale efterspørgsel af kviksølv kan mindskes betydeligt ved substitution af de mindst vigtige kviksølv-anvendelser
- Anvendelsen af en prioriteret arbejdsliste for udfasningen kan bidrage til at der kan fokuseres på hovedproblemerne ved kviksølv-substitution, hvorved der sikres en kost-effektiv udfasningsproces.

På denne baggrund anbefaler vi, at en prioriteret arbejdsliste for udfasning af bevidst anvendelse af kviksølv diskuteres og videreudvikles i internationalt samarbejde, for eksempel som led i arbejdet i den såkaldte Åbne Arbejdsgruppe, der er etableret under FN’s Miljøprogram (UNEP) med den opgave at overveje retslige og andre initiativer vedrørende kviksølv. Arbejdslisten vil kunne tjene som:

- Et værdifuldt værktøj til gensidig kommunikation og diskussion af mulighederne for globale kviksølv-reduktioner
- Et værktøj til en trinvis reduktionsproces, hvis det ønskes politisk
- Som et led i udformningen af en fælles global vision for reduktion af kviksølvs anvendelse.

Appendix 1: Overview of review results by Hg use category

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Intentional use of mercury in industrial/manufacturing processes	0,1,2,3,4,N,?	P,T,S,I	-,=,+	0,x,xx, xxxx	8,12,25,?		
Chlor-alkali production with mercury cells	3	S	=, +	xxxx	25	2, 21, 51, 53, 39	Substitution index given pertains to Hg consumption. For the infrastructure, the index is 4, as no new Hg cell facilities are being build, and Hg-free alternative membrane technology is widely accepted as state of the art for new facilities.
VCM (vinyl-chlorid-monomer) production with mercury-dichloride ($HgCl_2$) as catalyst	4	S	?	xxxx	12	2, 21, 37, 52, 53	New plants employing Hg are not built in OECD countries. Note the large expansion in China of VCM.
Acetaldehyde production with mercury-sulphate ($HgSO_4$) as catalyst	4	S	?	x	8	2, 21, 52	New plants employing Hg are not built in OECD countries.
Polyurethane production (Hg catalysts)	2–3	0	?	x?	12	2, 21, 26, 52	0
Vinyl acetate production (Hg catalysts)	4	0	?	0?	8	2, 52	New plants employing Hg are not built in OECD countries

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Production of the cube (1-amino anthrachion) colours /pigments with Hg catalyst	4	0	?	0?	8	52	0
Small scale gold and silver mining	4	S,T	?	xxxx	25	2, 21, 22, 37, 51, 52, 55, 56	Some weekend panners (hobbyists) in North America are still using Hg.
Consumer products with intentional use of mercury	0	0	0	0	0		0
Dental amalgam fillings	2–4	I,S,P,T	-,=,+	xx	25	2, 17, 18, 19, 21, 28, 30, 32, 49, 51, 53	Hg in <4% of fillings made in Japan, <5% of fillings made in Sweden (based on Hylander and Meili, 2003; SOU 2003:53, Dental materials and health, Stockholm, Sweden, 2003; and KemI, 2004). As regards the need for further technical development, some consider Hg-free alternatives fully adequate for all dental restoration situations, while others deem that amalgam fillings are so far still needed for some specialized uses. Currently, composite filling are considered by some to have somewhat shorter life time than amalgam. Technical development may be needed to further reduce the price and application technology for the alternatives in order to enhance their use in developing countries.
Skin lightening creams and soaps	4	S	?	x?	8	21, 51, 52, 53	0
Thermometers containing mercury:	0	0	0	0	0	2, 53	0
Medical thermometers	2–4	S,I	+	xx	12	5, 15, 21, 28, 32, 51, 52, 59	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Other glass thermometers (laboratory, educational, etc.)	2–3	I	=	xx	12	15, 21, 28, 31, 32, 52	0
Other (non-glass) mercury thermometers (industrial, marine diesel engines, etc.)	2–3	I	=,+	xx	12	5, 31	0
Hygrometer/psychrometer (thermometer-based)	2–4	0	0	0	8	15	0
Pyrometers (high range thermometers)	3–4	0	0	0	8	15	0
Electrical and electronic switches, contacts and relays with mercury:	4	0	0	0	0	2, 28, 53	0
Level switches (in sewer pumps, float switches, pressure switches, car hoods, movement detectors, alarms, in various apparatus, etc.)	2–3	0	=	xx	8	5, 15, 21, 28, 32, 52	Many alternatives, price vary with application
Multiple pole level switches in excavation machines	4	0	=	0?	8	5, 15, 52	0
Mercury-wetted contacts (in electronics)	3	0	=	x	8	5, 15, 52	0
Data transmission relays or "reed relays"	3	0	=	x	8	5, 15, 32, 52	0
Displacement (or "plunger") relays	2–4	0	0	0	8	15	0
Thermo-switches (thermostats)	3–4	0	=	x	8	5, 15, 52	0
Infra-red light detection semiconductors	N	0	?	x?	?	5, 28	0
ABS brake activators and airback activators in cars	3–4	0	?	x?	8	5, 28	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Continuous conductors in rotating seam welding wheels	1–2	0	?	x	8	28	Hg substituted for straight, but not curved weldings. Kemi (2004) and the Swedish industry has deemed substitution within 2014 possible.
Ignitrons and Hg-arc rectifiers in AC/DC converters	2–3	0	?	x	8	15, 28	0
Light sources with mercury:	0	0	0	0	0	2	0
Linear fluorescent lamps	1	T	?	xx	25	2, 11, 21, 32, 38, 44, 51, 52, 57, 58	Hg free alternatives in the form of light emitting diodes arranged in lines, coupled to a transformer, have been introduced on the Swedish market in 2007 for bench lighting and for working light with extension cords (www.jula.se;ClasOhlsson.se).
Compact fluorescent lamps (CFL, commonly called energy saving lamps/bulbs)	1	T	=/+?	xx	25	2, 3, 11, 21, 51, 52, 57, 58	LED lamps and field emission lamps fit for ordinary sockets.
Street advertisement with fluorescent neon tubes of certain colours	1	T	?	x	12	2, 21, 28, 51, 52	No direct alternatives for blue colour neon tubes, but LED street signs are taking over market shares
High pressure Hg and Na lamps (for street lighting etc.)	1	T	?	x	12	2, 5, 21, 32, 51	Low pressure Na lamps with less intensive light are Hg-free (RPA, 2002), and could perhaps substitute for some Hg containing lamps.
Backlight in LCD flat screens	1	T	?	x	12	2, 11, 51, 53	Also LED's for back-light in small computers, mobile phones (UNEP, 2006)
Laboratory atomic absorption spectrometry lamps	0–1?	I	?	x	25	51	0
Head lamps in some car brands	3	0	?	x	8	51	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Exit signs (green signs in public buildings etc.)	2–3	0	0	0	12	16, 23	Favoured by industry in some countries due to lower energy consumption
Batteries containing mercury:	0	0	0	0	0	2	0
Mercury oxide /mercury zinc batteries (cylindrical and button)	4	0	=,+	xx	8	2, 10, 21, 32, 37, 52	Batteries substituted in the 1980's and 1990's in OECD countries.
Alkaline cylindrical batteries (containing mercury)	4	0	=	x	8	2, 21, 32, 37, 52	Hg substituted in the 1980's and 1990's in OECD countries.
Zinc-manganese batteries (paste and paper types)	4	S	=	xx	8	2, 10, 21, 32, 37	Hg substituted in the 1980's and 1990's in OECD countries.
Alkaline button cell batteries (containing mercury)	1	T	=?	xx	12	2, 10, 21, 32, 37, 52	Button cell batteries witout Hg are under development or recently introduced on market. Some button cells can substitute for each other across type. USA's battery industry has comitted to substitute Hg before 2011 according to (NRDC, 2006).
Zinc-air button cell batteries	1–2	T	=?	x	12	2, 10, 21, 32, 37, 52	See above
Silver oxide button cell batteries	1–2	T	=?	x	12	2, 10, 21, 32, 37, 52	See above
Biocides and pesticides containing mercury:	0	0	0	0	0	53, 2	0
Agricultural pesticides (seed dressing, dipping sugar cane and grape seedlings, spraying insecticides etc.)	4	0	=?	x	8	2, 21, 32, 51, 53	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Slimicides/fungicides used in paper and paper pulp factories	4	0	?	0?	8	21, 32, 35	0
Preservation of wood (other than wood for paper production)	4	0	?	0?	8	21, 35	0
Latex and other paints for shelf life preservation and hindering mould on painted surfaces in humid conditions.	4	0	=?	x?	8	21, 51, 53	0
Antifouling paints for boats	4	0	0	0?	8	21, 35, 51	0
Pharmaceuticals for human and veterinary uses, including biocides in vaccines, in eye drops, some herbal medicines, disinfectants, etc.	3	S,I	?	x	12	2, 21, 28, 53	Many types of Hg-free biocides exist, but have (perhaps) not been documented to the same degree for these pharmaceutical uses. So the sustained need for Hg biocides is here considered primarily as institutional/structural
Biocides for preservation of eye cosmetics and in liquids for exchangeable eye lenses	3	0	=?	x	8	5, 28	0
Manometers and pressure gauges:	0	0	0	0	0	2, 32, 53	Expensive alternatives have higher performance than Hg use
Blood pressure gauges (sphygmomanometers)	2–3	S,I	=,+	xx	12	15, 21, 29, 31, 59	Hg-free substitutes accepted as equally accurate and less hazardous by WHO (2005) among others.
Blood pressure "strain gauge plethysmographs"	1–2?	I	0	x	12	29, 31, 46	Sels Instruments, 2007 (Gallium/Indium gauge available on WWW)
Manometers/pressure controls for industrial uses, district heating, etc.	3–4	0	-,=	xx	8	28, 21, 15, 31	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Barometers, meteorological	3–4	0	?	x	8	15, 28, 31	0
Flow meters (gas flows etc. , applying a manometer)	4	0	0	x	8	15, 28	0
Manometers for educational purposes	4	0	-,=	xx	8	21, 28, 31	0
Laboratory chemicals and equipment:	0	0	0	0	0	2	0
Specialized laboratory apparatus (Coulter Counters, tensiometers, and others)	3–4?	I	?	x	12	5, 28, 51	Hg-free tensiometers available. Hg function in Coulter Counter seems substitutable, if the market demand is large enough(?).
Chemical reactants for analysis (COD analysis, Kjeldahl analysis (nitrogen analysis), Nesslers reagent, etc.)	2–3	I	=?	x	12	5, 21, 28, 32, 51	Substitution level different for different uses
Electrodes and references for physio-chemical measurements, such as calomel electrodes, references for Hg analysis etc.	2–3	I	?	x	25	5, 21, 28, 51	Though some uses can be substituted by other techniques, some basic references are still needed. Could even be a candidate for dispensations beyond 25 years.
Porosimetric analysis (pore size distribution)	1	I,T	?	x	12	28, 33, 42	Alternatives available for some pore sizes, but so far apparently not for all sizes
Other mercury metal uses:	0	0	0	0	0		0
Marine navigation lights in light houses (in some types the lens/lamp unit floats on mercury)	2–4	I	?	x	12	21, 51, 52	0
Ethnic/cultural/ritualistic uses and folklore medicine	4	S,I	?	x	25	51, 52	0
Gyroscopes/gyro compasses with mercury	4	0	?	0?	8	21, 28, 51, 52	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Vacuum pumps with mercury	3–4	0	?	0?	8	51, 52	0
Mercury in large bearings of rotating mechanic part in for example older waste water treatment plants	3–4	0	?	0?	8	51, 52	0
Miscellaneous products/processes not mentioned above:	0	0	0	0	0		0
Esophageal dilators (Bogie tubes) and gastrointestinal tubes with Hg	3–4	0	?	0?	8	15, 51	0
Hydrometer (measuring density of liquids)	4	0	?	0?	8	15, 51	0
Tanning,	4	0	?	0?	8	51	0
Pigment (vermilion, HgS)	4	0	?	0?	8	51, 21	0
Browning and etching steel	4	0	?	0?	8	51	0
Gilding	4	0	?	0?	8	6, 14, 21	0
Certain colour photograph paper types	4	0	?	0?	8	51	0
Recoil softeners in rifles	4	0	?	0?	8	51	0
Mercury fulminate, Hg(ONC)2, used as detonators for explosives, in ammunition and in fireworks	4	0	?	0?	8	21, 32, 51	0
Fireworks	4	0	?	0?	8	2, 21, 51	0
Executive toys	4	0	?	0?	8	51	0

Hg use (table continued over several pages)	General substitution level in developed countries (overall assessment)	Focus of future substitution efforts	Price of Hg-free vs. Hg product/ process	Relative magnitude of Hg consumption globally	Time proposed for "99%" global phase-out, years	References (other than back ground knowledge of the authors)	Remarks
Neutron source in synchrotron light establishments and perhaps other high-intensity physical instruments	N	?	?	x	?	16	Tens of tons of Hg in each unit. Just a few units (about 5) around the globe. No emissions at normal operation. Alternatives are reported available, but not used for economical reasons

Note: Key to annotation, see section 3, Methods

Appendix 2: Overview of additional expert assessments

Hg use (table continued over several pages)	**Synthesis originally presented to experts (Maag and Hylander; adjustet later)**	**Expert assessment for Belgian conditions (Maxson)**	**Expert assessment for Italian conditions (Pirrone)**	**Expert assessment for USA's conditions (Brooks /Gilkeson)**	**Expert assessment for USA's conditions (Smith)**	**Expert assessment for Japanese conditions (Asari)**	**Final synthesis of general substitution level in developed countries**
	0,1,2,3,4,N,?	0,1,2,3,4,N,?	0,1,2,3,4,N,?	0,1,2,3,4,N,?	0,1,2,3,4,N,?	0,1,2,3,4,N,?	0,1,2,3,4,N,?
Intentional use of mercury in industrial/manufacturing processes							
Chlor-alkali production with mercury cells	2–3	2	2	2–3	3–4	4	3
VCM (vinyl-chlorid-monomer) production with mercury-dichloride (HgCl2) as catalyst	4	4	3–4	4	4	4	4
Acetaldehyde production with mercury-sulphate (HgSO4) as catalyst	4	4	3	4	?	4	4
Polyurethane production (Hg catalysts)	4	?	3–4	2–3	?	?	2–3
Vinyl acetate production (Hg catalysts)	4	4	4	4	?	4	4
Production of the cube (1-amino anthrachion) colours /pigments with Hg catalyst	4	?	4	?	?	?	4
Small scale gold and silver mining	4	4	?	4	4	not present	4
Consumer products with intentional use of mercury							
Dental amalgam fillings	2–4	2	2	2	2	4	2–4
Skin lightening creams and soaps	4	4	4	4	4	not present	4
Thermometers containing mercury:						3	
Medical thermometers	2–4	2–3	2–3	3–4	3		2–4
Other glass thermometers (laboratory, educational, etc.)	3	2–3	2	2–3	3		2–3

Hg use (table continued over several pages)	Synthesis originally presented to experts (Maag and Hylander; adjustet later)	Expert assessment for Belgian conditions (Maxson)	Expert assessment for Italian conditions (Pirrone)	Expert assessment for USA's conditions (Brooks /Gilkeson)	Expert assessment for USA's conditions (Smith)	Expert assessment for Japanese conditions (Asari)	Final synthesis of general substitution level in developed countries
Other (non-glass) mercury thermometers (industrial, marine diesel engines, etc.)	3	2–3	3	?	3		2–3
Hygrometer/psychrometer (thermometer-based)	4	?	3–4	2–3	4		2–4
Pyrometers (high range thermometers)	4	?	3–4	?	3		3–4
Electrical and electronic switches, contacts and relays with mercury:	4		4			3	4
Level switches (in sewer pumps, float switches, pressure switches, car hoods, movement detectors, alarms, in various apparatus, etc.)	3	3	2–3	2–3	3		2–3
Multiple pole level switches in excavation machines	4	?	3	?	?		4
Mercury-wetted contacts (in electronics)	3	3	3	3	3		3
Data transmission relays or "reed relays"	3	3	4	3	?		3
Displacement (or "plunger") relays	4	4	4	2–3	?		2–4
Thermo-switches (thermostats)	4	4	4	3–4	3		3–4
Infra-red light detection semiconductors	N	?	?	?	?		N
ABS brake activators and airbag activators in cars	3	3	3–4	4	3		3–4
Continuous conductors in rotating seam welding wheels	1	?	2	?	?		1–2
Ignitrons and Hg-arc rectifiers in AC/DC converters	3	?	2–3	2–3	?		2–3
Light sources with mercury:						1	
Linear fluorescent lamps	1	1	1	1	1		1
Compact fluorescent lamps (CFL, commonly called energy saving lamps/bulbs)	1	1	1	1	1		1
Street advertisement with fluorescent neon tubes of certain colours	1	1	1	0–2	1		1

Hg use (table continued over several pages)	**Synthesis originally presented to experts (Maag and Hylander; adjustet later)**	**Expert assessment for Belgian conditions (Maxson)**	**Expert assessment for Italian conditions (Pirrone)**	**Expert assessment for USA's conditions (Brooks /Gilkeson)**	**Expert assessment for USA's conditions (Smith)**	**Expert assessment for Japanese conditions (Asari)**	**Final synthesis of general substitution level in developed countries**
High pressure Hg and Na lamps (for street lighting etc.)	1	?	1	1	1		1
Backlight in LCD flat screens	1	1	1	1	1		1
Laboratory atomic absorption spectrometry lamps	N	?	1	0–1	1		0–1?
Head lamps in some car brands	3	3	2–3	3	3		3
Exit signs (green signs in public buildings etc.)	2	2	3	2–3	2		2–3
Batteries containing mercury:						3	
Mercury oxide /mercury zinc batteries (cylindrical and button)	4	4	4	4	4		4
Alkaline cylindrical batteries (containing mercury)	4	4	4	4	4		4
Zinc-manganese batteries (paste and paper types)	4	4	4	?	4		4
Alkaline button cell batteries (containing mercury)	1	1	2	1	2		1
Zinc-air button cell batteries	2	2	2	1	2		1–2
Silver oxide button cell batteries	2	2	2	1	2		1–2
Biocides and pesticides containing mercury:						4	
Agricultural pesticides (seed dressing, dipping sugar cane and grape seedlings, spraying insecticides etc.)	4	4	4	4	4		4
Slimicides/fungicides used in paper and paper pulp factories	4	4	4	4	4		4
Preservation of wood (other than wood for paper production)	4	4	4	4	4		4
Latex and other paints for shelf life preservation and hindering mould on painted surfaces in humid conditions.	4	4	4	4	4		4
Antifouling paints for boats	4	4	4	4	?		4

Hg use (table continued over several pages)	Synthesis originally presented to experts (Maag and Hylander; adjustet later)	Expert assessment for Belgian conditions (Maxson)	Expert assessment for Italian conditions (Pirrone)	Expert assessment for USA's conditions (Brooks /Gilkeson)	Expert assessment for USA's conditions (Smith)	Expert assessment for Japanese conditions (Asari)	Final synthesis of general substitution level in developed countries
Pharmaceuticals for human and veterinary uses, including biocides in vaccines, in eye drops, some herbal medicines, disinfectants, etc.	3	3	3	3	3		3
Biocides for preservation of eye cosmetics and in liquids for exchangeable eye lenses	3	3	3	3	3		3
Manometers and pressure gauges:							
Blood pressure gauges (sphygmomanometers)	3	2–3	3–4	2–3	3		2–3
Blood pressure "strain gauge plethys-mographs"	0	?	?	?	?		1–2?
Manometers/pressure controls for industrial uses, district heating, etc.	4	?	3–4	3	3		3–4
Barometers, meteorological	4	?	3–4	3	4		3–4
Flow meters (gas flows etc. , applying a manometer)	4	?	4	3	3		4
Manometers for educational purposes	4	?	4	3	4		4
Laboratory chemicals and equipment:							
Specialized laboratory apparatus (Coulter Counters, tensiometers, and others)	?	?	3	3–4	?		3–4?
Chemical reactants for analysis (COD analysis, Kjeldahl analysis (nitrogen analysis), Nesslers reagent, etc.)	2	?	2	2–3	2		2–3
Electrodes and references for physio-chemical measurements, such as calomel electrodes, references for Hg analysis etc.	2	?	2–3	2–3	2		2–3
Porosimetric analysis (pore size distribution)	1	?	?	?	?		1
Other mercury metal uses:						?	
Marine navigation lights in light houses (in some types the lens/lamp unit floats on mercury)	3	?	2–3	4	4		2–4

Hg use (table continued over several pages)	Synthesis originally presented to experts (Maag and Hylander; adjustet later)	Expert assessment for Belgian conditions (Maxson)	Expert assessment for Italian conditions (Pirrone)	Expert assessment for USA's conditions (Brooks /Gilkeson)	Expert assessment for USA's conditions (Smith)	Expert assessment for Japanese conditions (Asari)	Final synthesis of general substitution level in developed countries
Ethnic/cultural/ritualistic uses and folklore medicine	4	?	4	N	2		4
Gyroscopes/gyro compasses with mercury	4	?	4	?	4		4
Vacuum pumps with mercury	4	?	4	3–4	4		3–4
Mercury in large bearings of rotating mechanic part in for example older waste water treatment plants	4	?	4	3	4		3–4
Miscellaneous products/processes not mentioned above:							
Esophageal dilators (Bogie tubes) and gastro-intestinal tubes with Hg	3	?	4	4	3		3–4
Hydrometer (measuring density of liquids)	4	?	4	?	4		4
Tanning,	4	?	4	4	4		4
Pigment (vermilion, HgS)	4	?	4	4	4		4
Browning and etching steel	4	?	4	4	4		4
Gilding	4	?	4	4	4		4
Certain colour photograph paper types	4	?	4	4	?		4
Recoil softeners in rifles	4	?	4	3	3		4
Mercury fulminate, Hg(ONC)2, used as detonators for explosives, in ammunition and in fireworks	4	?	4	4	4		4
Fireworks	4	?	3	4	?	4	4
Executive toys	4	?	4	?	4		4
Neutron source in synchrotron light establishments and perhaps other high-intensity physical instruments	?	?	?	?	?	?	N

Note: Key to annotation, see section 3, Methods