THE REAL €O$T OF DENTAL MERCURY

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AUSTRALIANS FOR MERCURY FREE DENTISTRY

CAMPAIGN FOR MERCURY FREE DENTISTRY A PROJECT OF CONSUMERS FOR DENTAL CHOICE

EUROPEAN ENVIRONMENTAL BUREAU

Mercury Policy Project

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Disclaimer

Table of Contents

Executive summary

While its use has essentially been eliminated in many countries, dental amalgam is now being considered for a global phase-out in the ongoing mercury treaty negotiations[1] and in the European Union (BIO 2012) because of significant environmental concerns. The negative effects of mercury releases related to amalgam use are widely recognized in countries where its use has been prevalent: it is often the largest source of mercury in municipal wastewater as well as an increasing source of mercury air pollution from crematoria. On the other hand, high-quality mercury-free alternatives have long been available. While most dental professionals charge lower prices for amalgam fillings than for mercury-free alternatives, this paper shows that when factoring in "external" environmental and societal costs,[2] amalgam is a higher-priced dental material by far (Hylander and Goodsite 2006). Ultimately, society pays for mercury releases related to amalgam use through additional pollution control costs, the loss of common (public-owned) resources, and the health effects associated with mercury releases and contamination (MPP 2008).

According to the United Nations Environment Programme, the use of mercury in tooth fillings represents some 10% of global mercury consumption, thus being among the largest consumer uses of mercury in the world (AMAP/UNEP 2008). In the U.S., as demonstrated in this report, mercury use in dentistry amounts to over 32 tons[3] annually, which is considerably more than some recent estimates.[4] For comparison, in the European Union dental applications comprise the second largest use of mercury, amounting to some 20-25% of the annual consumption of mercury in the EU. With something less than twice the population of the U.S., the EU use of mercury in dentistry is somewhat more than twice the U.S. consumption (BIO 2012).

Although the relative health risks due to direct human mercury exposure from amalgams are still being debated, the significant releases to the environment of dental mercury in waste and through other pathways, as well as its persistence once it reaches the environment, are well established:

- to the soil via wastewater sludge to land disposal, burial of deceased persons with fillings, atmospheric deposition following cremation or wastewater sludge incineration, etc.,
- to the atmosphere via cremation, etc.,[5]

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[1] See, for example, http://www.unep.org/hazardoussubstances/MercuryNot/MercuryNegotiations/tabid/3320/language/en-US/Default.aspx

[2] "External" environmental and societal costs and/or benefits include such things, for example, as the human health and environmental costs of dental mercury released to the wastewater system, or discarded to municipal waste and then incinerated; or the benefit of retaining more healthy tooth material when placing a mercury-free filling.

[3] Many of the calculations that appear in this report are denominated in pounds and U.S. tons (or simply "tons," equal to two thousand pounds). In the cases where the metric system is used, the metric ton (or "tonne," equivalent to one thousand kilograms) will be used.

[4] See especially the IMERC database at www.newmoa.org/prevention/mercury/imerc/factsheets/dental_amalgam.pdf

[5] The Cremation Society of Great Britain provides rather comprehensive statistics on cremations in the 27 EU member countries (EU-27), amounting to nearly one-third of all EU deaths and emitting about 4.5 tonnes of mercury to the atmosphere in 2005. Since then the rate of cremation has increased further due to: 1) a rise in the average number of fillings per person cremated (due to individuals keeping more and more of their original teeth), and 2) a rise in the frequency of cremation. To take the UK example, it has been estimated that the amount of mercury from cremations will increase by two-thirds between 2000 and 2020, accounting potentially for between 11% and 35% of all UK mercury emissions to the air in 2020 (EEB 2007).

- to surface waters, and
- eventually to the groundwater.

With a specific focus on the situation of the United States, this report demonstrates that the basic cost to the patient of an "equivalent" amalgam filling in the U.S is $144 compared to $185 for an "equivalent" composite filling. However, the report then demonstrates that when the real cost (to the environment and society at large) of amalgam is accounted for, composite turns out to be significantly less costly than amalgam as a filling material. Based on conservative assumptions, the following table summarizes the real cost of an amalgam filling in the U.S., presented in the form of two alternative approaches for calculating the "external" costs of using mercury in dentistry:

1. The first approach, which is more conservative than the second, is to estimate the additional cost (i.e., beyond measures already being taken) required to keep dental mercury out of the environment, or at least to minimize the amount that reaches the environment.[6] These include measures such as removing mercury from the flue gases of incinerators and crematoria, removing mercury from wastewater sludges before disposal to agricultural land, collecting and recycling dental amalgam waste and sequestering the recovered mercury, etc. Since there is an international consensus that the global pool of mercury circulating in the biosphere needs to be greatly reduced, it is logical to calculate the cost of ensuring that additional mercury does not enter the environment from dental uses. Using this approach, the cost of keeping 90% of 2009 mercury releases associated with amalgams out of the environment adds an extra $41-67 to the commercial cost of an amalgam filling.

2. The second approach quantifies the benefits for people and the environment that would result from a phase-out of mercury use in dentistry. These would include such benefits as reduced health costs, reduced environmental effects, additional jobs created, etc. In most cases these benefits are simply the same as "avoided costs." Using this approach, the annual benefits that would be accrued if composite fillings were placed instead of amalgam amounts to $3.1-6.5 billion. When allocated over the roughly 51 million amalgams placed in 2009, this amounts to $60-128 for each amalgam avoided, raising the real cost of amalgam even higher than under the first scenario.

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[6] Once dental mercury has been used, there are a number of "end-of-pipe" techniques to prevent it from entering the environment, but each comes at a (sometimes very high) cost, and may not be as effective as intended. Further, the actual implementation of "end-of-pipe" techniques remains limited, including with regard to mercury abatement from cremation, the incidence of which is increasing (Cain *et al.* 2007; Cowi/Concorde 2008).

Average dental clinic fee vs. the real cost of an average ("equivalent") amalgam filling

	Rear tooth "equivalent" composite filling	Rear tooth "equivalent" amalgam filling
Average private clinic fee	$185	$144
Methodology 1 – "External" costs of preventing toxic dental materials from being released into the environment*	$0 – minimal**	$41-67
Total real cost (Methodology 1)	**~$185**	**$185-211**
Methodology 2 – Benefits to health and society of phasing out dental amalgam	$0 – minimal**	$60-128
Total real cost (Methodology 2)	**~$185**	**$204-272**
* In the case of mercury, this is the cost of preventing 90% of dental mercury from entering the environment. ** See discussion in Section 1.		

While this report focuses on amalgam use only in the U.S., this case should serve as a valuable example for other nations that are contemplating the future of dental amalgam in their own countries. Clearly, the general trend is in the direction of mercury-free dentistry.

The Swedish ban on amalgam effective 1 June 2009 has proven that there are few if any cases where amalgam fillings are necessary (KEMI 2010). As amalgam is similarly banned in Norway and Denmark, and severely restricted in Germany, Finland, Bulgaria, Mongolia, Vietnam, Thailand (WHO 2010) and Japan, among others, the mercury-free experience in these countries clearly demonstrates that amalgam is no longer necessary in most clinical situations.[7]

Support for mercury-free dentistry is gaining momentum internationally, with a recent World Health Organization report recognizing the environmental concerns of amalgam and the need "to prepare for a treaty on mercury use," including support for use of dental material alternatives to amalgam (WHO 2010). Leading up to and during the 3rd Intergovernmental Negotiating Committee meeting (November 2011) for a legally binding agreement on mercury, the Nordic Council, Switzerland and the African Region all expressed support for a dental amalgam phase-out. The Council of Europe has also recently passed a resolution calling on nations to take measures "restricting or prohibiting the use of amalgam for dental fillings" (Council 2011).

Among other scientific assessments, the Scientific Committee on Emerging and Newly Identified Health Risks has concluded that modern mercury-free alternatives "have facilitated a radical change in the concepts of restorative dentistry through the introduction of more minimally invasive techniques and the associated retention of more tooth substance when treating caries" (SCENIHR 2008).

In summary, the methodical research presented in this report confirms that amalgam is by no means the least expensive filling material when the external costs are taken into account. Clearly, adverse effects on the environment and society over the whole life cycle of dental amalgam – mercury production, preparation of filling materials, removal of old fillings and placement of new

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[7] This is further confirmed by U.S. dentists, at least half of whom claim to no longer place amalgam fillings (TWD 2007).

ones, environmental and health impacts from mercury recycling, discharges to wastewater, solid waste disposal, emissions from crematoria and releases from cemeteries – can only be sustainably avoided by phasing out amalgam as a dental restorative material and switching to mercury-free alternatives.[8] Since high quality and cost-effective alternatives – including composites, glass ionomers and "compomers" – are readily available, this report therefore concludes, from a full cost perspective, that dental amalgam should be phased out.[9]

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[8] It should be noted here that, although a number of studies have identified a range of human health effects that are or may be linked to dental amalgam (Mutter 2011), this study does not recommend that intact amalgam fillings should be replaced by mercury-free fillings unless the patient shows clinically significant signs of hypersensitivity to mercury. On the other hand, the study does categorically recommend that government authorities, industry, dental professionals and the public work together to ensure that new and replacement fillings are mercury-free.

[9] For purposes of reaching a broad consensus, a " phase out" of dental amalgam may include, at least in the near term, a mechanism for exemption in cases of special medical need. However, it should be noted that in Sweden the exemption was invoked in less than 10 cases during the first year after the ban (KEMI 2010). Hence, as of July 2012, amalgam is no longer permitted in Sweden even for exceptional medical reasons.

The Real Cost of Dental Mercury

1 Purpose

It is often claimed by proponents of dental amalgam that the cost of amalgam is lower than that of composites. This begs the obvious question, "Why does composite[10] cost more?" This paper demonstrates that while the cost of the materials and related equipment is slightly higher for composite than for amalgam, the vast majority of the cost differential is due to the increased time it takes for the average dentist to place a typical composite filling in a rear tooth. Even dentists who have relatively little experience placing composite fillings report that they are able to place composite in a front tooth in less time than amalgam, while those with more extensive experience using composites say the time difference to place fillings in rear teeth may also be largely eliminated.[11]

Nevertheless, assuming that the average composite filling will remain more expensive to the patient than the average amalgam for the foreseeable future, the "cost" justification for favoring the amalgam option is suspect for several reasons:

- First, in many cases the patient does not pay for dental care. Public health clinics, Medicaid providers and other healthcare providers (Children's Health Insurance Program (CHIP), Indian Health Service, Military Dental Services, the Office of Dentistry in the U.S. Department of Veterans Affairs, etc.) offering services for which the cost of care is borne by the taxpayer rather than the patient would clearly not experience a decline in patient numbers if amalgam were no longer available.
- Second, a composite filling is, on average, more expensive than amalgam (for fillings in rear teeth) only if one goes by the commercial fee charged by the dentist. However, when one considers as well the additional costs to the environment and human health of using mercury in dental fillings – "external" costs that are ultimately borne by society – the real cost of amalgam becomes more clear.

The purpose of this paper is to shed light on these "external" costs in two steps: first, by showing how much of the mercury used for dental amalgam is ultimately released to the environment; and second, to examine the costs associated with those releases, as well as other quantifiable benefits of phasing out the use of amalgam.

2 Mercury in the environment

Mercury is a naturally occurring metal – most of it lying in geological deposits that are not part of the biosphere. It enters the environment via natural events, such as volcanic eruptions, but more

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[10] There are a number of mercury-free alternative filling materials that are used. Composites, professionally known as "resin-based composite materials," or RBC, are the most common.

[11] Nearly half of all practitioners appear to have abandoned the use of amalgam altogether. Ref. http://thewealthydentist.com/survey/surveyresults/16_MercuryAmalgam_Results.htm

so through human activities. Mercury analyses from the tissues of Arctic indicator species show that current-day levels of mercury in the biosphere are some 10 times the levels preceding the industrial revolution (Dietz *et al.* 2009)..[12]

Mercury is a well-known neurotoxin, especially damaging to the brain and nervous system of the developing fetus, infant and young child.

Mercury entering water bodies either from runoff or from air deposition can be transformed into methylmercury, an even more toxic form of mercury that bioaccumulates in fish and other animals to levels that pose a continuing and unacceptable environmental and public health risk.

A National Research Council report in 2000 estimated that annually more than 60,000 children in the U.S. may be born with permanent, irreversible neurological problems due to methylmercury exposure from their mothers' consumption of fish. Moreover, data from the U.S. Centers for Disease Control show that hundreds of thousands of newborns are annually exposed to mercury above the U.S. EPA recommended safe level, while there is more recent evidence of risk from exposures even below the U.S. EPA recommended safe level.

Predominantly anthropogenic mercury releases to the environment have contaminated fresh and saltwater fisheries to such an extent that all 50 states, one U.S. territory and three Native American tribes have issued health advisories warning of the dangers of consuming fish caught in their waters due to elevated concentrations of mercury.

Mercury pollution is both a local issue, as in the case of local "hotspots," and a global issue, as when it is transported in the atmosphere from one country or continent to another. Moreover, mercury pollution exported from the U.S. in the atmosphere may return to the U.S. in the form of contaminated fish, just as mercury exports from the U.S. may return as manufactured products.

The widely documented effects of mercury exposure on human health and wildlife have driven a great range of efforts, in the U.S. and overseas, to significantly reduce the level of this toxic, persistent, and bio-accumulative metal in the environment.

The dental industry, among others, has helped to make dental practitioners aware of the hazards. Encapsulated dental amalgam is typically shipped from manufacturers in packaging with a "skull and crossbones" symbol affixed next to the words: *"Poison, contains metallic mercury."* Amalgam manufacturers – Kerr, Vivadent and Dentsply, among others – clearly for health reasons, consistently advise dentists against placing amalgam in the teeth of pregnant women, nursing mothers, children under six, and anyone with kidney disease.

However, these warnings are generally not passed along to the public – according to the results of a national poll conducted by Zogby International which discovered that:

- most Americans (76 percent) don't know mercury is the primary component of "silver" amalgam fillings;
- 92 percent of Americans prefer to be informed of their options with respect to mercury and non-mercury dental filling materials prior to treatment; and
- 77 percent of Americans would choose to pay more for fillings that do not contain mercury, if given the choice (MPP *et al.* 2006).

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[12] See http://www.unep.org/gc/gc22/Document/UNEP-GC22-INF3.pdf

3 Dental clinic mercury consumption and wastes

3.1 Consumption of mercury in dental applications

The most accurate way to determine U.S. consumption of mercury for dental applications is to calculate it based on the number of restorations carried out, and the type and size of each restoration. For a number of years the American Dental Association has carried out extensive surveys designed to gather precisely this kind of information. The broad-based ADA survey published in 2007, which examined the last three quarters of 2005 and the first quarter of 2006, generated the data shown in Table 1.

Table 1 Annual restorative procedures carried out by private practitioners, 2005-6

Restoration type	Number of restorations
Amalgam – 1 surface	16,763,750
Amalgam – 2 surfaces	22,972,950
Amalgam – 3+ surfaces	12,455,470
Resin – 1 surface (front tooth)	19,432,890
Resin – 2 surfaces (front tooth)	15,115,060
Resin – 3+ surfaces (front tooth)	11,619,760
Resin – 1 surface (rear tooth)	33,623,950
Resin – 2 surfaces (rear tooth)	29,196,240
Resin – 3+ surfaces (rear tooth)	13,679,050
Source: ADA (2007)	

According to the authors of the survey, the total number of amalgams reported above represents only the activities of dentists in private practice. Table 1 does not include services provided by dentists practicing in the military, correctional facilities, dental school clinics, hospitals, the Public Health Service (e.g. Medicaid), and other federal, state and local government-funded clinics that cater to many people with limited means. Therefore, at least an additional 10%, and perhaps closer to 20% more fillings than those presented in Table 1 are placed annually in the U.S.

It is estimated that the number of amalgam fillings placed in the U.S., which are virtually all placed in rear teeth, is decreasing by 3.5-4% per year (Beazoglou *et al.* 2007). If we take 2009 as our base year, we could assume a decline from 2005-6 of approximately 15% in the number of amalgam filings placed. If we further assume that the total number of fillings placed in the U.S. is roughly the same in 2009 as in 2005-6, and that the decline in amalgam fillings (assuming they are all placed in rear teeth) is balanced by a corresponding increase in the number of resin fillings in rear teeth,[13] we obtain the data in the first three columns of Table 2.

If we then assume that another 10-20% of the restorative procedures are carried out in venues other than private practices, as mentioned above, we get a reasonable estimate of the total fillings placed in 2009, as in the last column of Table 2.

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[13] In fact, as the use of amalgams has declined, the substitute restorative materials used from 1992-2004 have been 81% composites and 19% crowns (Beazoglou *et al.* 2007), but this does significantly change the conclusions to be drawn from Table 2.

Table 2 Estimated annual restorative procedures, 2009

Restoration type	Private practice restorations 2005-6	Private practice restorations 2009	All restorations 2009
Amalgam restorations	52,192,170	44,363,345	51,017,846
Resin restorations (front teeth)	46,167,710	46,167,710	53,092,867
Resin restorations (rear teeth)	76,499,240	84,328,066	96,977,275
Total restorations	174,859,120	174,859,120	201,087,988
Source: ADA (2007)			

It should be kept in mind that a dentist placing an amalgam filling cannot afford to run short of amalgam during the procedure, because the amalgam initially prepared will harden while preparing more. Therefore, the dentist will normally prepare more amalgam than needed for a given filling. Routinely, then, in addition to the excess amalgam that is carved away as the filling is shaped, there is additional amalgam that goes directly to waste (referred to as "non-contact scrap" since it has not been in direct contact with the patient). The amalgam that is carved away may be spit into the chairside sink, it may be suctioned from the mouth into the wastewater system, or it may be swallowed. Meanwhile the "non-contact scrap" may go into a hazardous waste bag for proper disposal – or not. Cain *et al.* (2007) found that a significant amount of dental amalgam waste ends up as "normal" waste in the municipal waste stream, and a smaller percentage simply ends up in "burn barrels" or the equivalent.

Typically, based on clinical experience, a 1-surface filling will require one "spill" of amalgam (400mg of mercury mixed with metal powders of approximately the same weight) to be prepared at the chair for use, a 2-surface filling will require two spills (including 600mg of mercury) to be prepared and a 3+surface filling three spills (including 800mg of mercury). Clearly some fillings might require more and some less, but on average these quantities provide a sound basis for estimating overall amalgam use and mercury consumption.

Assuming a similar distribution of amalgams among 1-surface, 2-surface and 3+surface fillings in 2009 as in 2005-6, Table 3 calculates the amount of mercury (i.e., "new" mercury introduced by the dental practitioner, as opposed to "old" mercury already contained in a damaged filling that may be removed during the procedure) used in dental practices in 2009 at nearly 30 metric tonnes, or about 32.8 U.S. tons. This is equivalent to 583.5mg of mercury used per filling on average, including some "new" mercury that goes directly to waste (as described above).

Table 3 Estimated annual dental mercury use in the U.S. (2009)

Amalgam Restoration size	Fillings 2005-6	Percentage distribution 2005-6 & 2009	Fillings 2009	Mercury used (mg) per filling	Total mercury (kg)	Total mercury (tons)
1 surface	16,763,750	32.1%	16,386,566	400	6,555	7.225
2 surfaces	22,972,950	44.0%	22,456,059	600	13,474	14.852
3+ surfaces	12,455,470	23.9%	12,175,222	800	9,740	10.737
Total	**52,192,170**	**100.0%**	**51,017,846**		**29,768**	**32.814**

3.2 Mercury waste generated by dental clinics

As described above, of the 32.8 tons of "new" mercury consumed in 2009 by dental clinics, some of that was amalgam carved away (~7%) or discarded as non-contact scrap (~26%) during typical clinical procedures – averaging some 33% of the total "new" mercury used.[14] However, most of the mercury waste that is generated in a clinic results not from "carving" a new filling or discarding unused amalgam, but rather from drilling out damaged amalgam in order to make room for the new filling.

Considering that around 70% of all fillings placed are replacements of previous fillings (MPP *et al.* 2006, citing the American Dental Association), and that probably at least 80% of amalgam fillings placed are replacements of previous fillings, and that the total amount of amalgam used is decreasing every year (Beazoglou *et al.* 2007), and that the average amalgam filling may be estimated to last at least 10 years,[15] the total mercury carried in the dental fillings of living Americans in 2009 is estimated to be in the range of 500-600 tons. All of this mercury will potentially enter the environment unless it is otherwise dealt with.

One may then calculate that the mercury drilled out of old fillings and remaining in extracted teeth will become dental waste each year, plus around 33% of the new mercury prepared for fillings that is carved off or otherwise discarded (Fleming 2010), for a total of about 32 tons of mercury in waste generated annually by dental practices. Therefore, for each average amalgam filling requirement of 583.5mg of fresh mercury, a roughly similar quantity of mercury in waste is presently generated in dental clinics.

Outside of dental clinics, however, there are further mercury wastes and releases due to the use of dental amalgam, such as releases to the air and wastewater from the clinics themselves, emissions from incinerated municipal waste and wastewater sludge, emissions from crematoria, losses due to abrasion and corrosion of fillings, etc. These are discussed below.

4 Dental mercury wastes and emissions

This section of the report discusses the types of mercury wastes and releases from the use of dental amalgam, while Section 5 deals more specifically with the quantities of mercury involved.

Figure 1 below shows the diverse pathways taken by mercury wastes and emissions directly associated with dental amalgam use. As indicated, dental mercury may ultimately end up in the atmosphere, surface water, wastewater (sometimes after being trapped in the plumbing for many years), groundwater or soil. These pathways are described further below.

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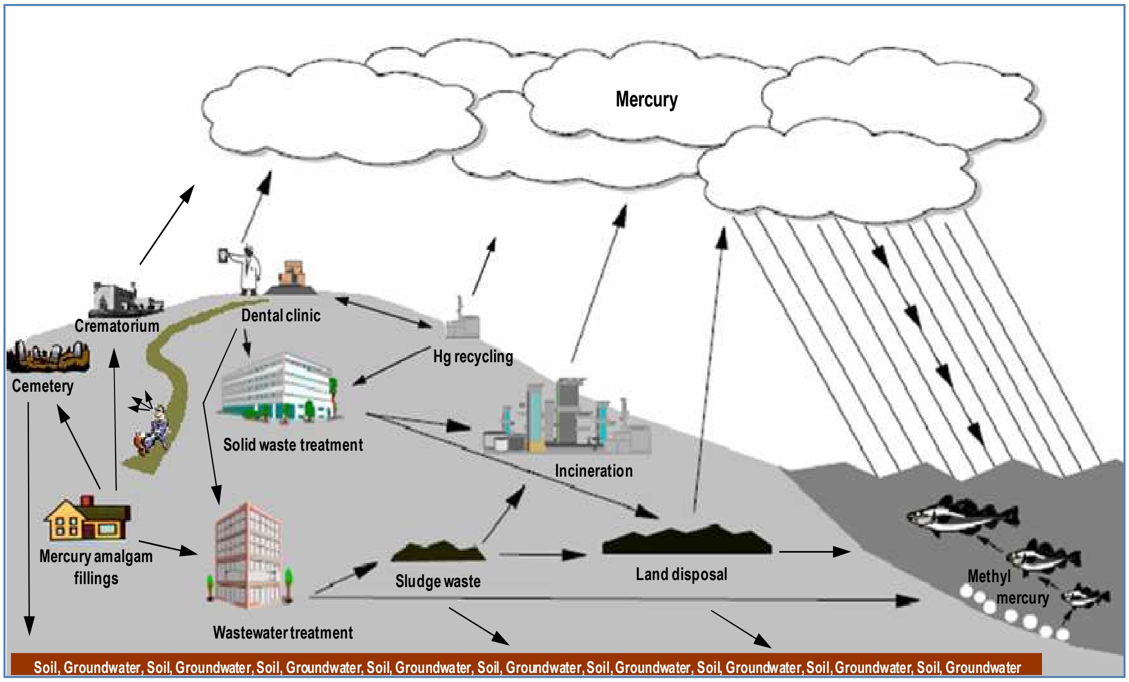
[14] Estimate based on clinical measurements (Fleming 2010, Barron 2006). Note that "squeeze cloths" are often still used to express excess mercury before placement of the filling. With this method the prepared ball of amalgam, while still soft, is placed into a cheesecloth and twisted. Mercury is expressed through the cloth and onto a tray or into a container that should subsequently be disposed of as medical waste, recycled or suctioned out. Many dentists continue to follow this procedure even though the metal powders and mercury are supposed to be properly proportioned in the manufactured capsules (Fleming 2010). Note that this excess mercury is included here in the 33% going to waste.

[15] In a US Geological Survey report published in 2000, it was reported that the average life of an amalgam filling is from 5 to 8 years, while a 1995 article in a Swiss dental medical journal reported the average life to be 10 years. Other estimates have ranged as high as 10-20 years (Reindl 2007). While some fillings last even longer, many fillings also have shorter lives due to fracture of the tooth, etc. It is interesting to note that the skill of the dentist placing a filling has likewise been found to be a significant factor in the durability of the filling (Sunnegårdh-Grönberg *et al.* 2009).

Figure 1 The myriad pathways of dental mercury into the environment



Source: EEB (2007)

4.1 Pathways to the environment

The primary sources of mercury waste that originate in the dental clinic include

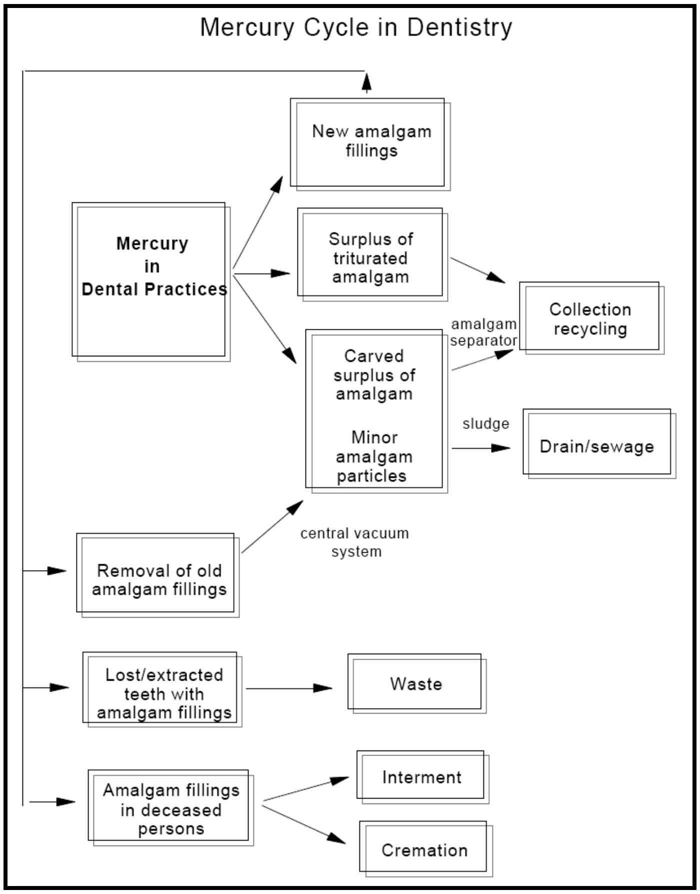
- mercury waste generated during the preparation of more amalgam than the filling requires;
- the excess material carved from new amalgam fillings;
- the removal of damaged amalgam fillings;
- the removal of teeth containing amalgam;
- other mercury going to solid waste or wastewater;
- mercury emissions and particulate matter going directly to the air, especially from drilling procedures;
- the traps, filters and other devices in dental clinics intended to remove mercury from the wastewater and sometimes from the clinic's ventilation system – and the "downstream" flows of mercury from there.

Other waste streams related to the use of amalgam will also be discussed below, such as emissions during incineration of amalgam waste, releases to domestic wastewater from chewing and abrasion of amalgams, etc.

Most dental mercury waste results from the removal of damaged previous fillings from patients' teeth. Together with waste from new fillings, removed teeth, etc., these dental wastes typically follow several main paths. They may be captured for subsequent recycling or disposal, they may be washed down drains that lead to the general municipal wastewater system, they may be placed in special containers as medical waste, or they may be simply discarded as municipal waste.

Figure 2 is a simplified illustration of the general flow of mercury through the dental clinic and "downstream." As a simplified model it does not show, for example, that mercury may be caught in the plumbing system, or released to the air both within the clinic and to the air directly from the clinic wastewater system, nor does it make clear that mercury may be released by certain dental techniques (e.g. cleaning or polishing amalgams) even when fillings are not placed or removed. Some of these releases are, nevertheless, included in the subsequent analysis.

Figure 2 - Simplified flow of mercury through the dental clinic



Source: Horsted-Bindslev *et al.* (1991), as cited by the Wisconsin Mercury Sourcebook (1999)

Next to each dental chair most dental facilities have a basic chairside filter (or trap) in the small sink leading to the wastewater system to capture the larger amalgam particles, and some have secondary vacuum filters just upstream of the vacuum pump. In addition, separator technologies are available that can theoretically remove over 95% of the mercury from wastewater.

Dental mercury may enter the environment from a number of paths. For example, when mercury waste enters the municipal waste stream, some mercury may eventually be released into the atmosphere from landfill emissions, or the mercury will vaporize if the waste is incinerated. Mercury that bypasses clinic traps or filters and travels as suspended matter through the wastewater system will typically adhere to wastewater sludge, where it has the potential to volatilize when the sludge is later disposed of or incinerated. Mercury evaporates easily to the atmosphere, especially as the temperature increases, after which some is deposited locally and the rest is transported through the atmosphere in a vaporized state (Wisconsin Mercury Sourcebook 1999).

One should also be aware of the less traveled but all too common pathways that some waste follows. For example, some amalgam waste is still incinerated in “burn barrels” or discarded in unauthorized landfills, septic systems operate where wastewater systems are unavailable (Cain *et al.* 2007), wastewater “exceptions” and overflows are common, and dental clinics face a range of challenges with regard to the proper installation and maintenance of separators (Hylander *et al.* 2006a and 2006b). In these and similar instances, dental mercury wastes are especially problematic.

Once mercury is deposited from the atmosphere or other sources into lakes and streams, in the open ocean, or to the soil (especially in wetland habitats), it becomes rapidly available for methylation (Harris *et al.* 2007), which is a process by which bacteria convert some of the mercury into an organic form – methylmercury. This is an especially toxic form of mercury that humans ingest primarily through eating fish, although some communities suffer methylmercury exposure through the consumption of marine mammals as well. Wildlife also ingest methylmercury through eating fish or lower-order organisms. Methylmercury is particularly hazardous because it biomagnifies in the food chain, which means that the level of methylmercury in fish tissue increases as larger fish or animals consume smaller ones (Wisconsin Mercury Sourcebook 1999).

The quantity of amalgam related mercury that is eventually methylated is extremely difficult to predict because the extent of methylation depends on the species and quantity of mercury entering a specific ecosystem, the manner in which the mercury is deposited such as by precipitation, the ecological characteristics of that ecosystem such as the acidity of the soil, the moisture level, etc. For this reason we may find elevated methylmercury levels in relatively distinct geographical areas. As a rough approximation, however, we may assume that the extent of methylation of dental mercury deposition from the atmosphere is generally similar to the extent of methylation of mercury deposition related to coal combustion emissions.

It should also be noted that methylmercury may result from the methylation of amalgam-related mercury in the oral cavity or gastro-intestinal tract (Leistevuo *et al.* 2001), although this pathway is not quantified in this analysis.

The extent of the methylmercury problem is evident from the many fish advisories in the United States. The total number of advisories issued by the U.S. EPA warning of fish contamination with mercury has gradually increased to more than 4,000 in 2008, covering more than 16 million acres of lakes and more than 1.3 million miles of river (US EPA 2009).

4.2 Wastewater releases

4.2.1 Municipal wastewater system

Research has demonstrated that most municipal wastewater systems encounter significant levels of mercury, and it has been determined that 50% or more of that mercury may originate from dental clinics (AMSA 2002a), corrosion of fillings, abrasion from chewing, etc. (Skare and Engqvist 1994; Hylander *et al.* 2006b). Some reported mercury loads in municipal wastewater are summarized in Table 4 below.

Table 4 Dental mercury in wastewater systems

City	Wastewater mercury load from dental practices
Duluth, MN	36%
Seattle, WA	40-60%
Palo Alto, CA	83%
Greater Boston Area, MA	13-76%
Sources: AMSA 2002a	

The amount of dental mercury going to wastewater systems from dental clinics and domestic releases has been quantified in this report, but most municipal wastewater treatment systems are not designed to treat or remove mercury from the wastewater stream. Most of the mercury entering the wastewater stream will be concentrated in the sewage sludge or "biosolids,"[16] and a fraction will be discharged to downstream surface waters along with the treated effluent. If a wastewater treatment plant incinerates its sludge, and operates with a wet scrubber system, mercury from amalgam may even be carried from the scrubber back to the headworks of the treatment plant. In this case, mercury that came into the plant in one form may later be discharged to the receiving water in another form.

It is important to note that various conditions during the wastewater treatment process may also be favorable to the methylation of mercury.[17] Furthermore, since the majority of sludge waste is disposed of by spreading it on agricultural or other land, or by incineration, there is the further likelihood of mercury and possibly methylmercury following the pathway to surface water runoff, or incinerator emissions of mercury to the atmosphere, followed by deposition, possible methylation and uptake in the food chain.

Alternatively one could consider a process to remove mercury from sewage sludge before disposal, but as we will see below, the cost would be substantially higher than if we were to avoid mercury reaching the wastewater plant in the first place.

4.2.2 Dental clinic and piping system

Over many years the piping systems in dental clinics tend to accumulate mercury that settles to low parts of the system, sumps, etc., or attaches itself to the inside of metallic pipes. The slow dissolution and re-release of this mercury is often sufficient, even after dental clinic emissions have been greatly reduced, to exceed wastewater discharge standards, and may serve as a long-term source of mercury to a wastewater treatment facility. For example, substantial amounts of mercury were recovered (average 1.2 kg per clinic) during the remediation of 37 abandoned dental clinics in Stockholm in 1993–2003 (Engman, 2004). Similar accumulations were observed during work in another Swedish dental clinic (Hylander *et al.* 2006a). These studies indicate that thorough maintenance work on a dental clinic wastewater system is necessary to ensure that all pipes and plumbing fixtures are cleaned and/or replaced since they can constitute an ongoing source of mercury releases.

4.2.3 Septic tanks

In areas lacking a public wastewater system, dental practices are often connected to septic systems. As in parts of wastewater treatment systems, conditions may exist in a septic system that promote the methylation of mercury, which may contaminate local soils and groundwater. Likewise, septic tank sludges may be periodically removed and dispersed over agricultural and other soils, or contribute to the mercury loading at wastewater treatment facilities.

While mercury releases to wastewater should clearly be avoided, most methylmercury is generated following the deposition of mercury emitted from the combustion or heating of mercury-containing

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[16] U.S. estimates of the percentage of mercury in municipal wastewater retained in sewage sludge are in excess of 90%. However, this percentage may refer only to wastewater passing through sewage treatment plants as an ICON (2001) estimate of 70-80% and Danish investigations showing an average of only 53% may also include mercury in municipal wastewater that evades any treatment plant.

[17] In fact, studies have demonstrated that even within the dental clinic wastewater system a certain portion of dental mercury becomes bioavailable, and may constitute a significant source of risk to human health and the environment (Stone *et al.* 2005).

materials. The emission of mercury by combustion occurs in a variety of settings, including municipal incinerators, sludge waste incinerators, hazardous waste incinerators, cremation chambers, etc. The typical recycling process for dental wastes is thermal reprocessing, which also generates atmospheric emissions.

4.3 Solid waste generated

Mercury-containing solids and sludges removed from clinic traps and filters are increasingly recycled or disposed of as hazardous waste.

4.3.1 Municipal landfill and incineration

However, despite regulations regarding the characterization and disposal of mercury bearing hazardous wastes, many solid dental wastes still follow the low-cost route of disposal as municipal solid waste and are subsequently sent to landfills or incinerators. Depending on the characteristics of the landfill, dental amalgam may decompose over time and the mercury may enter the leachate (which may itself be disposed of in a manner that allows the mercury to be released), groundwater, soils, or volatilize into the atmosphere. Studies have documented methylmercury in gases emitted from landfills (Lindberg *et al.* 2001). Municipal incinerator operators will not accept mercury waste if they are able to identify it in advance, but it often enters the solid waste stream unmarked and undetected.

4.3.2 Hazardous waste landfill and incineration

The regulations for hazardous waste treatment are stricter and more closely monitored than those for municipal waste. Therefore, both hazardous waste landfills and incinerators are equipped to deal with mercury wastes, and to minimize releases. On the other hand, because this disposal path is typically more expensive than recycling, dental professionals have sometimes been reticent to send dental wastes to hazardous waste disposal.

4.4 Air emissions at the dental clinic

Elemental and/or particulate mercury emissions to the air from dental clinics may occur during handling of amalgams or placement and removal of fillings, or they may occur as releases from the wastewater system at the clinic.

4.4.1 Air emissions during dental work

Dental personnel may be exposed to the following sources of mercury vapors: “accidental mercury spills; malfunctioning amalgamators, leaky amalgam capsules or malfunctioning bulk mercury dispensers; trituration, placement and condensation of amalgam; polishing or removal of amalgam; vaporization of mercury from contaminated instruments; and open storage of amalgam scrap or used capsules” (JADA 2003).

To take one example, a Lumex monitoring device was used to record the mercury concentration in the air of a dental office while an amalgam filling was removed. Figure 3 presents the data recorded – first outside the office, and then inside the office before, during and after amalgam removal. It should be noted that no amalgam fillings had been placed in this office during the preceding 20 years – only removed, as necessary. Upon reviewing the data, the dentist was concerned, first, at the relatively high ambient mercury level in the office;[18] and second, at the noticeable spike during the procedure, despite the use of a high-vacuum scrubber. The dentist

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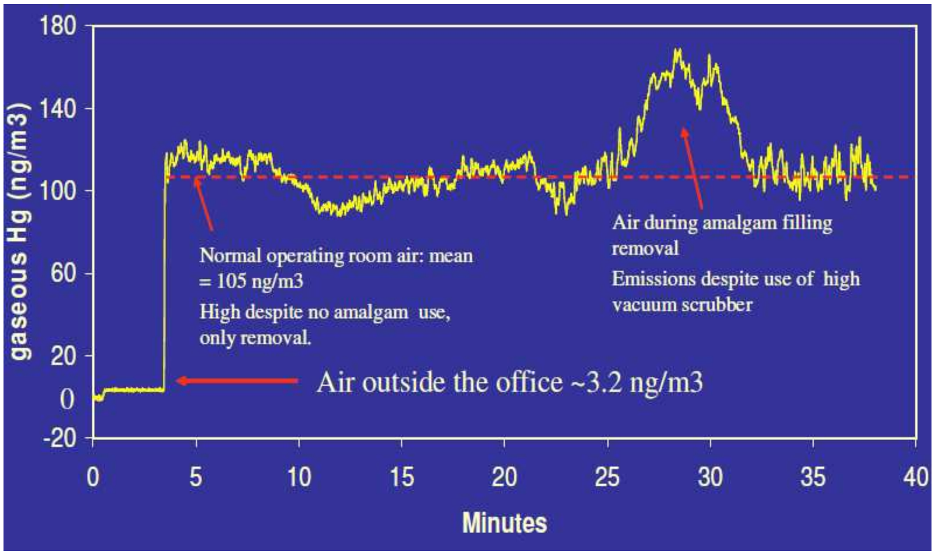
[18] The World Health Organisation (WHO) prescribes an air quality guideline of 200 ng/m^3 for long-term inhalation exposure to elemental mercury vapour (WHO 2007, citing IPCS 2003).

subsequently installed ventilation equipment designed to reduce the level of mercury in the office air (Telmer 2009).

Figure 3 – Mercury concentration in the air of a mercury-free dental office



Normal operating room air: mean = 105 ng/m3

High despite no amalgam use, only removal.

Air during amalgam filling removal

Emissions despite use of high vacuum scrubber

Air outside the office ~3.2 ng/m3

Source: Telmer 2009.

4.4.2 Air emissions from the dental clinic wastewater system

As already mentioned, dental clinic procedures generate mercury wastes, slurry and fine particulate and dissolved matter especially from drilling out mercury amalgam filling materials. Some of these wastes are discharged into the municipal wastewater system via the clinic vacuum pump or a similar system. This system may also discharge large volumes of air, including mercury vapor, either into the atmosphere outside the dental clinic or into the wastewater system, depending on the type of equipment used (Rubin and Yu 1996).

4.5 Biomedical waste treatment

A survey in 2000 found that 25-30% of dentists disposed of some of their dental amalgam waste as infectious waste due to the potential presence of pathogens (KCDNR 2000). Typically infectious waste is disposed of by biomedical waste treatment methods such as “autoclaving” (sterilization) and landfill, which may also result in some mercury vapor releases, discharge of effluents to the wastewater system, etc. (HCWH 2002).

4.6 Recycling

Recycling of dental amalgam wastes, mostly of mercury waste collected in chairside traps, is increasing. Amalgam separators are another potentially significant source of mercury waste that may be easily recycled, although as recently as 2007 less than 5% of the nation’s dentists used them (Bender 2007). Recycling is a logical way to deal with large amounts of mercury waste with a high mercury content, and the high-temperature retorting process employed by recyclers also deals with any concerns about pathogens in the amalgam wastes.

The recycling process also generates some air emissions of mercury, but these are generally low if the recycling facility meets the required regulations. There may also be reason for concern about the fate of mercury recovered from recycling, as it may end up being sold for use in products or processes that are associated with more significant and/or diffuse mercury releases.

4.7 Mercury storage and final disposal

Until fairly recently, most dentists had stocks of mercury in their clinics that they had used in the past to mix dental amalgams by hand. Given the relatively few state collection programs conducted, it may be assumed that there remain substantial quantities of mercury in storage in dental clinics. These stocks of mercury are at risk of accidents, improper disposal or other releases due to neglect.

4.8 Burial

Amalgam fillings continue to release mercury after a person's death. Most cadavers still end up in a cemetery, from where the mercury will eventually enter the soil and/or groundwater.

4.9 Cremation

Alternatively, cremation is an increasingly common practice in the U.S. and other parts of the world as burial space has become more scarce and expensive, especially in urban areas. Cremation is typically carried out at a high temperature that vaporizes virtually all of the mercury in dental amalgams and sends much of it into the atmosphere with flue gases. Often crematoria are located within cities and close to residential areas – even schools – and flue gas stacks tend to be relatively low (UNEP 2003). It has proven difficult to balance the amount of mercury present in the dental amalgams of cadavers with precise measurements of mercury emissions in crematorium flue gases. Depending on the crematorium design, it appears that some mercury may adhere for a time to internal parts of the flue gas system. Various studies have estimated mercury emissions per cremation at anywhere from 1.0 to 5.6 grams per cremation (US EPA 2005). Yet the abatement of mercury emissions from crematoria is still rare in the U.S. (Cain *et al.* 2007) and far from the norm in the EU as well.[19]

5 Air emissions from dental mercury

It should be noted that this section of the report focuses largely on the quantities of mercury wastes and releases from dental uses of mercury, while Section 4 above dealt more specifically with the types of mercury wastes and releases generated.

5.1 Municipal wastewater and sewage sludge

Based on the analysis presented in Bender (2007) and the methodology of Cain *et al.* (2007), the quantity of dental mercury entering the municipal wastewater system in 2005, including 1.0-1.5 tons of dental mercury via human wastes, was estimated at over 9 tons, of which just over 90% may be retained in wastewater treatment sewage sludge under normal operating conditions. For purposes of this analysis, the total dental mercury retained by wastewater treatment plants was therefore estimated at about 8.5 tons per year, with something over 0.5 tons remaining in the effluent.

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[19] The Cremation Society of Great Britain provides rather comprehensive statistics on cremations in the EU-27 (CSGB 2004), amounting to nearly one-third of all EU deaths, and based on previous assumptions, releasing about 4.5 tonnes of mercury annually. Since that date the rate of cremation has increased significantly. There are two simultaneous trends contributing to this: a rise in the average number of fillings per person cremated (due to increasing numbers of original teeth), and a rise in the number of cremations. It is estimated that the amount of mercury from cremations will increase in the UK by two-thirds between 2000 and 2020, accounting for between 11% and 35% of all mercury emissions to the air in 2020 (EEB 2007).

5.1.1 Sewage sludge disposal

According to Cain *et al.* (2007), nationwide about 20% of sewage sludge is incinerated on average, some 60% is spread on agricultural and other land, about 15% is landfilled, and the rest is disposed of in other ways.[20] Each of these disposal pathways leads to some air emissions, the most important of which are sludge incineration and volatilization of mercury from land applications.

Based on the methodology of Cain *et al.* (2007) and information from NESCAUM (2005), mercury emissions to the atmosphere from sewage sludge incineration were estimated at 1.5 – 2.0 tons in 2005. Bender (2007) added another 0.8 tons per year released to the atmosphere from the application of sewage sludge to land, assuming about 50% of the mercury contribution in sewage sludge is due to dental mercury.

5.1.2 Dental clinic wastewater system

Bender (2007) included an extensive discussion of dental clinic mercury removal systems and releases, and concluded that mercury releases to the air from the wastewater system were over 2 tons in 2005 (Rubin and Yu 1996). However, the methodology used by Cain *et al.* (2007) suggested total air releases directly from dental clinics of just under one ton.

5.1.3 Dental mercury in municipal solid waste

A 2000 study in King County, Washington (U.S.A.), found that more than three-quarters of dental offices did not recycle or sequester mercury-bearing waste captured in chairside traps and vacuum pump filters. Rather, they put the mercury waste in the waste bin, included it with medical waste, stored it onsite for eventual disposal or flushed it down the drain (Savina 2003). Based on the Cain *et al.* (2007) methodology, 9.5-10 tons of dental mercury likely ended up in the municipal waste stream in 2005, of which about 20% was assumed to be incinerated, with most of the remainder going to landfill.

5.2 Cremation

According to the Cremation Association of America, there are about 1,900 crematoria in the U.S. Nationally, about 35% of Americans are now cremated, a figure that is anticipated to rise to 43% by 2025 as in Figure 4.

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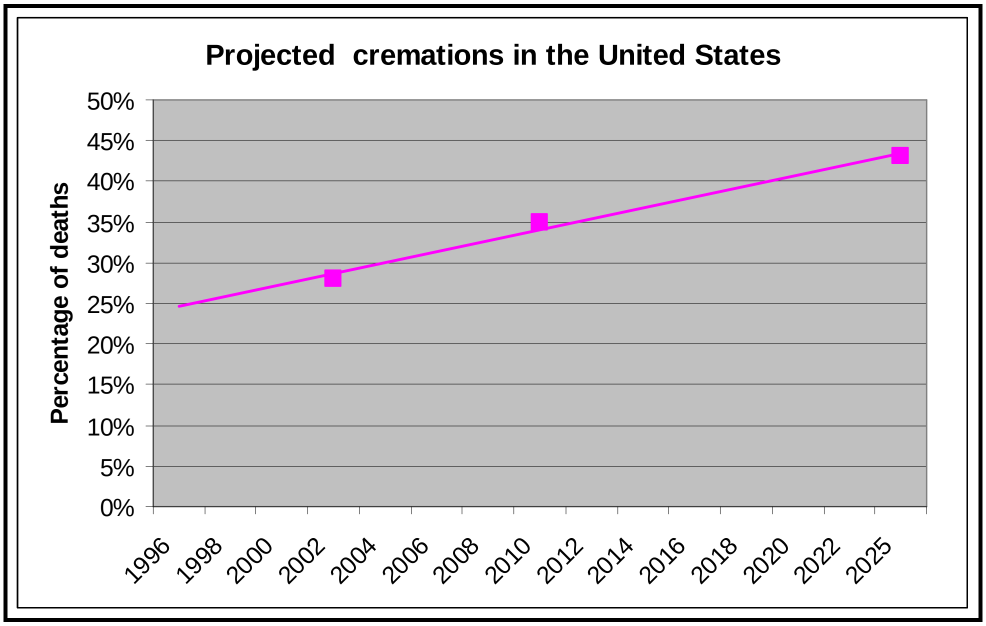
[20] The mercury content in sewage sludge, while quite variable, averages in the range of 1-3 mgHg/kg dry weight (AMSA 2002b).

Figure 4 – Projected cremations in the U.S. (1996-2025)



Source: Reindl (2007)

Based on a literature review including ground deposition studies in New Zealand and Norway (Reindl 2007), there is evidence to suggest that up to 90% of the mercury entering crematoria becomes emissions to the atmosphere, with some of the balance retained, at least temporarily, in combustion equipment and the stack. Cain *et al.* (2007) estimated that about 3.3 tons of mercury were emitted by crematoria in 2005.

5.3 Summary of dental mercury atmospheric emissions

Table 5 below summarizes the discussion above and gives estimated air emissions associated with dental mercury for 2005. Since the air emissions in Table 5 were based on a similar quantity of dental clinic mercury waste (31 tons) as we have calculated for 2009 (32 tons), it is reasonable to conclude that the 2009 air emissions are within the same range indicated in this table, i.e., some 7 to 9 tons.

Table 5 Atmospheric emissions of mercury (tons) from dental amalgam use in 2005

Pathway	Mercury emissions (low estimate)	Mercury emissions (high estimate)	Mercury emissions (average)
Human cremation	3.0	3.5	3.3
Dental clinics	0.9	1.3	1.1
Dental mercury sewage sludge incineration	1.5	2.0	1.7
Dental mercury sludge spread on land and landfilled	0.8	1.2	1.0
Dental mercury MSW incineration and landfill	0.2	0.5	0.4
Dental mercury infectious and hazardous waste	0.5	0.7	0.6
Human respiration	0.2	0.2	0.2
Total	**7.1**	**9.4**	**8.3**

Source: Bender (2007).

6 Dental mercury mass balance

It is necessary to now include other amalgam related releases to generate a complete picture of the mass balance flows of dental mercury through the economy and into the environment.

6.1 Dental mercury pathways

While the potential hazards of dental waste are increasingly recognized, their proper management still lags behind. A 2007 peer-reviewed article advised colleagues that “practitioners should not flush contaminated wastewater down sinks, rinse chair-side traps or vacuum filters in sinks, nor place material containing dental amalgam in general garbage or waste to be incinerated” (JCDA 2007).

An investigation of the various pathways followed by mercury from dental amalgam to different environmental media (air, water, soil and groundwater – unless the mercury has been effectively removed from circulation or returned to commerce) demonstrates that the interlinkages are complex. The waste fractions that follow a given pathway depend on such factors as the split of municipal solid waste between incineration and landfill, the size of the amalgam particles in the waste stream, the rate of decomposition of the amalgam in contact with other materials and at different pH levels, the landfill leachate treatment method, the types of flue gas control devices on an incinerator, the disposition of municipal wastewater treatment sludges and incinerator slags and residues to agricultural and/or other soils, the chemical composition of those soils, the runoff from those soils, etc.

Nevertheless, drawing on the detailed Cain (2007) and EEB (2007) analyses of the disposal pathways for dental mercury, a reasonably comprehensive model of dental mercury flows emerges as shown in Figure 5, which indicates 7 tons of mercury going to municipal solid waste, 9 tons to municipal wastewater, 3 tons to biomedical waste, 6 tons to hazardous waste disposal and other forms of sequestration, and 7 tons to recycling in 2009.

6.2 Dental mercury disposal/media matrix

Further based on Cain (2007) and EEB (2007), the "disposal/media matrix" presented in Table 6 has been developed, showing the rough percentages of dental mercury released to each of the major environmental media (atmosphere, surface water, etc.) via each of the main pathways mentioned above.

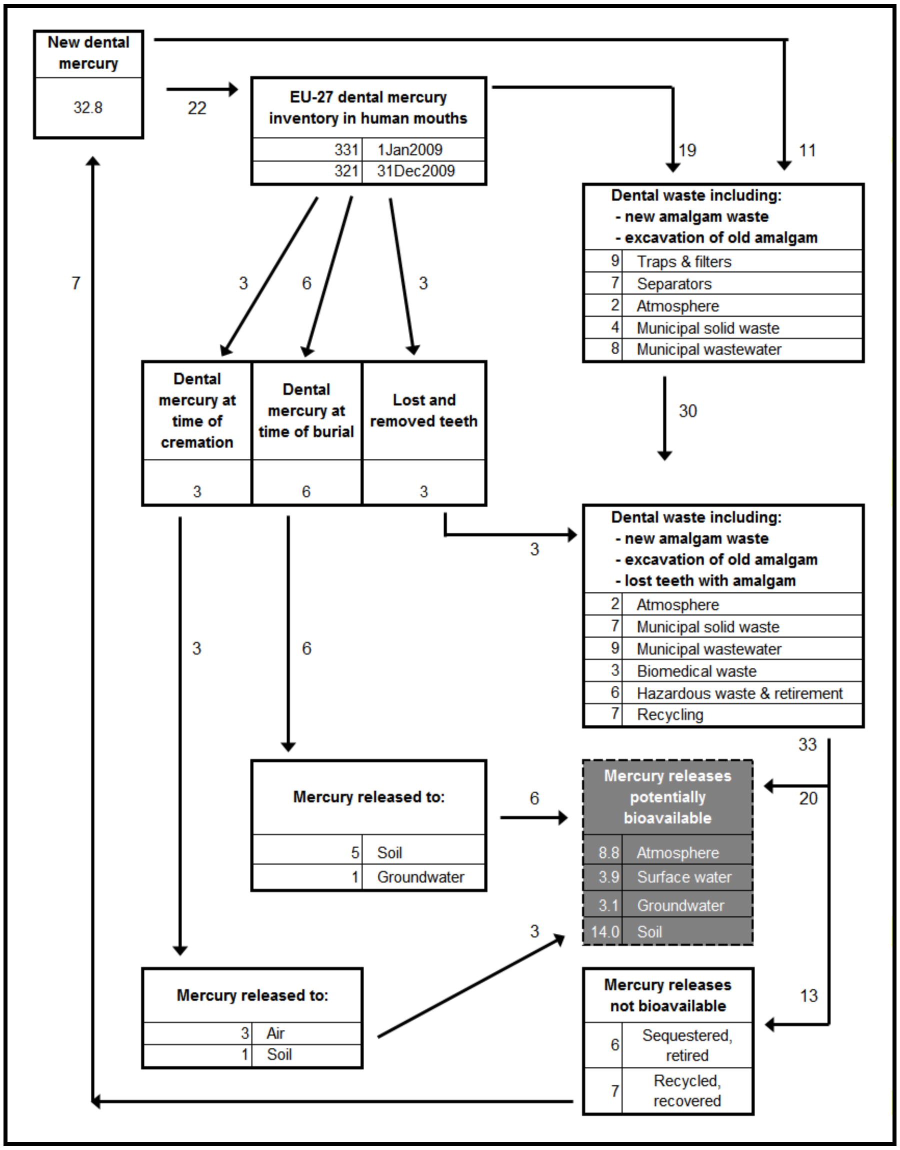
Table 6 Rough disposal/media matrix for mercury in dental amalgam

	Clinic wastewater to air	Municipal solid waste	Municipal wastewater system	Biomedical waste	Hazardous waste & retirement	Recycling	Burial	Cremation
Atmosphere	100%	10%	30%	30%	2%	2%	0%	80%
Surface water	0%	20%	25%	10%	0%	0%	0%	0%
Groundwater	0%	10%	10%	10%	0%	0%	20%	0%
Soil	0%	60%	35%	30%	0%	2%	80%	20%
Recycled/retired (not bioavailable)	0%	0%	0%	20%	98%	96%	0%	0%

6.3 Dental mercury pathways quantified

Integrating the main dental mercury flows with the disposal/media matrix in Table 6 permits the elaboration of the overall mass balance of dental mercury flows, which is merely a way of balancing and linking dental mercury sources with eventual destinations in the environment. This is presented in Figure 5.

Figure 5 – 2009 U.S. mass balance for dental mercury (tons)



Note: The format presented here was developed by EEB (2007).

While these numbers are obviously associated with varying degrees of uncertainty, nevertheless, as mentioned above, they may be considered a reasonable approximation of the relevant mercury flows, and therefore a sufficient basis for certain observations and conclusions. Figure 5 shows some 33 tons (rounded) of mercury releases (including amalgam in lost and removed teeth) from ongoing dental practices, plus another 9 tons of mercury in the teeth of deceased persons – for a total of some 42 tons entering the waste stream in 2009, of which:

- approximately 13 tons are removed from circulation and not released to the environment (of which an estimated 7 tons are recycled and returned to commerce); and
- approximately 30 tons end up in various environmental media, chiefly the soil (14 tons) and atmosphere (9 tons), but also important amounts to surface waters (4 tons) and groundwater (3 tons). At a speed that depends on the environmental medium and other variables, virtually all of this mercury may be expected to eventually circulate in the

biosphere, while part of it methylates, enters the food chain and potentially affects human health and wildlife.

For this analysis, the purpose of approximating these mercury flows is to help determine how much it would cost to prevent dental mercury releases, as discussed in Section 8; or alternatively, to determine the benefits to the environment and society of phasing out amalgam, as discussed in Section 9.

7 Commercial cost of fillings

In the following discussion we will differentiate between the "commercial cost" of a filling (i.e., the dental practitioner's charge to the patient for placing a filling) and the "full cost" of a filling (i.e., the commercial cost of a filling plus "external" costs which vary depending on the scenario chosen).

While there are a number of alternatives to amalgam – including the glass ionomers that are used in Atraumatic Restorative Treatment, or "ART" (a low-cost and accessible restorative and preventive technique especially adapted to the needs of poorer populations that may be served by technicians who require a lower level of training than the traditional dental professional) – this analysis will focus on composites, the most common alternative in use in the United States.

There are some key differences to be aware of between amalgam and composite fillings:

- the placement of an amalgam filling requires a (typically rubber) dam, instruments for placing the filling and carving away the excess amalgam, a triturator, a base cement, an amalgam "capsule" at least as large as the filling in order to ensure that enough amalgam material is immediately available for the procedure, and burs for trimming the excess amalgam and finishing/polishing the filling;
- the placement of a composite filling requires a rubber dam, instruments for placement of the filling, an etching agent to facilitate adhesion, a bonding agent (with limited shelf-life), a light[21] curing unit, the composite material (with limited shelf-life), burs for trimming the excess composite, and finishing/polishing systems (e.g. silicon carbide sandpaper).

Therefore, while there are a number of variables at play, the cost of specialized materials and equipment required to place a "typical" composite filling already adds some $5-10 to the filling cost as compared with amalgam. At the same time, and virtually impossible to value precisely, more of the natural tooth is preserved with composite as the dental practitioner needs only to remove the decayed part of the tooth before placing the filling. Thus the natural part of the tooth remaining is larger, stronger and will last longer (Fleming 2010).

Another variable that complicates the analysis is that often a composite will be used to replace a previous amalgam restoration. But the hole originally drilled to receive an amalgam filling is distinguished by a special "cup" shape designed to help retain the amalgam, and is typically considerably larger than the tooth material that would have been removed to receive a composite filling, rendering the replacement of an amalgam by a composite more difficult and time-consuming than it would have been if composite had been used in the first instance.

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[21] Typically, nowadays, intense visible light within a fairly narrow wavelength.

7.1 Commercial cost of dental amalgam

The distribution of amalgam fillings of different sizes among baby teeth and permanent teeth (virtually all rear or "posterior" teeth) is shown in Table 7 below. It may be assumed that the distribution in 2009 is more or less the same as in 2005-6. The commercial fee (a weighted average for 20 U.S. cities) for each type of filling is derived in the table in Appendix I based on an American Dental Association (ADA) survey, U.S. Bureau of Labor Statistics monthly survey of dental prices in the U.S., etc., as referenced in Appendix I.

Table 7 Distribution of amalgam fillings (posterior teeth)* and related private practice fees

Amalgam restoration size	Amalgam restoration type	Private practice restorations 2005-6	Percentage distribution 2005-6 (and 2009)	20-city average filling fee 2009	Contribution to "equivalent" filling fee 2009
1-surface	Baby tooth	1,023,601	1.96%	$102.03	$2.00
1-surface	Permanent tooth	15,730,330	30.14%	$132.30	$39.88
2-surface	Baby tooth	1,659,559	3.18%	$116.27	$3.70
2-surface	Permanent tooth	21,333,109	40.87%	$144.77	$59.17
3+surface	Baby tooth	141,120	0.27%	$137.65	$0.37
3+surface	Permanent tooth	12,304,451	23.58%	$166.15	$39.17
Total		**52,192,170**	**100.0%**		**$144.29**

* In the past, amalgam was used to restore "anterior" or front teeth as well, and it continues to be used sometimes to restore certain surfaces, especially on the "eye" or canine teeth. However, the use of amalgam on front teeth is now so limited as to permit us to ignore the practice for purposes of this analysis.

By allocating the appropriate part of the fee charged for each type and size of amalgam filling to the last column of Table 7, one can derive the private practice fee charged for an "equivalent" amalgam filling in the U.S. in 2009, which was $144.29.

It may be reasonably assumed that this fee covers all of the relevant costs to the dental practitioner (materials, direct labor, indirect labor, facilities, waste collection and disposal, insurance and other overhead) of placing a typical amalgam filling, as well as a margin of profit.

7.2 Commercial cost of composites

In a similar manner, the distribution of composite fillings of different sizes between front teeth and rear teeth[22] is shown in Table 8 below. As above, it may be reasonably assumed that the distribution in 2009 is more or less the same as in 2005-6. The commercial fee (a weighted average for 20 U.S. cities) for each type of filling is derived in the table in Appendix I based on an American Dental Association (ADA) survey, U.S. Bureau of Labor Statistics monthly survey of dental prices in the U.S., etc., as referenced in Appendix I.

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[22] For historical reasons composite fillings have been differentiated between front and rear teeth rather than between baby and permanent teeth, as in the case of amalgam.

Table 8 Distribution of composite fillings and related private practice fees

Composite restoration size	Composite restoration type	Private practice restorations 2005-6	Percentage distribution 2005-6 (and 2009)	20-city average composite filling fee 2009	"Equivalent" composite filling fee 2009
1-surface	Front tooth	19,432,890	15.84%	$125.18	$19.83
1-surface	Rear tooth	33,623,950	27.41%	$126.96	$34.80
2-surface	Front tooth	15,115,060	12.32%	$175.05	$21.57
2-surface	Rear tooth	29,196,240	23.80%	$199.99	$47.60
3+surface	Front tooth	11,619,760	9.47%	$214.24	$20.29
3+surface	Rear tooth	13,679,050	11.15%	$294.39	$32.83
Subtotal	Front teeth	46,167,710	37.64%		$61.70
Subtotal	Rear teeth	76,499,240	62.36%		$115.23
Total	**All teeth**	**122,666,950**	**100.0%**		**$176.92**

By allocating the relevant part of the fee charged for each type and size of composite filling to the last column of Table 8, one can derive the private practice fee charged for an "equivalent" composite filling in the U.S. in 2009, which was $176.92, which is nearly 23% greater than the cost derived above for an "equivalent" amalgam filling.

As in the case of amalgam, it may be reasonably assumed that this fee covers all of the relevant costs to the dental practitioner (materials, direct labor, indirect labor, facilities, waste collection and disposal, insurance and other overhead) of placing a typical composite filling, including a margin of profit.

7.3 Comparison of commercial costs of fillings

A direct comparison of the commercial cost of amalgam vs. composite fillings is complicated for the following reason: A front-tooth filling is rarely placed with amalgam any longer, despite the belief of many dentists that the durability of amalgam is superior to that of composite. Apart from the fact that more of the healthy tooth is typically retained when a composite filling is placed instead of amalgam, the use of composite for fillings in front teeth is for reasons of both aesthetics and cost, since the procedure is generally faster and the commercial cost is typically lower when composite is used for a front tooth filling. Therefore, it makes little sense to compare the commercial cost of composite vs. amalgam for front teeth.

Looking at the cost comparison with regard only to rear teeth, Table 9 confirms one's expectation that the cost differential for rear teeth is greater than that calculated above for front and rear teeth combined. The cost of an "equivalent" composite filling in a rear tooth is 28% greater than the cost derived in Table 7 for an "equivalent" amalgam filling.

Table 9 Distribution of composite fillings for rear teeth and related private practice fees

Composite restoration size	**Composite restoration type**	**Private practice restorations 2005-6**	**Percentage distribution 2005-6 (and 2009)**	**20-city average composite filling fee 2009**	**Rear tooth "equivalent" composite filling fee 2009**
1-surface	Front tooth	ignore	ignore	ignore	ignore
1-surface	Rear tooth	33,623,950	43.95%	$126.96	$55.80
2-surface	Front tooth	ignore	ignore	ignore	ignore
2-surface	Rear tooth	29,196,240	38.17%	$199.99	$76.33
3+surface	Front tooth	ignore	ignore	ignore	ignore
3+surface	Rear tooth	13,679,050	17.88%	$294.39	$52.64
Subtotal	Front teeth	ignore	ignore		ignore
Total	**Rear teeth**	**76,499,240**	**100.00%**		**$184.77**

It is useful to take a closer look at the composition of this cost differential of roughly $40 between a typical amalgam and typical composite filling. Some clinicians claim that it takes twice as long to insert an average composite filling, and readily admit there is more profit in amalgam.[23] Others with more experience claim they can place a typical posterior tooth filling using composite nearly as fast as if they were to use amalgam. For the purpose of this analysis, and based on input from several dentists, one may assume that it takes the average dentist 25-50% longer to place a typical posterior tooth filling using composite rather than amalgam. A more detailed discussion of the fees charged for fillings by private practices may be found in Section 9.3.2.

Therefore, if we restrict our comparison of the average basic commercial billing cost of amalgam vs. composite fillings only to rear teeth, we confirm the general observation that "amalgam is cheaper than composite" by some $40 per "equivalent" filling, but this number does not help us to appreciate the various external costs (i.e., to society and the environment) of either amalgam or composite fillings.

It is also necessary to dismiss the common misconception that composites have a shorter service life than amalgam in rear teeth, which would otherwise add to the "equivalent" cost of composites due to more frequent repair and/or replacement. While the longevity of a filling depends on many factors, not least of which is the skill of the dental professional who placed it, already more than ten years ago a consensus had developed among product manufacturers and dental materials experts that composite and amalgam have comparable service lives in excess of 10 years when restorations are evaluated using standardized laboratory parameters of clinical success (ADA 1998). Among others, a more recent research paper has further confirmed "better survival of composite restorations compared with amalgam, a difference especially apparent after a longer observation period" (Opdam *et al.* 2010).

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[23] "Most dentists perceive [composites] to be far more complicated and technique-sensitive than amalgam fillings. Although a composite restoration takes twice as long as an amalgam, compensation is barely higher" (Ruiz 2010).

8 Cost of keeping dental mercury out of the environment

This analysis has identified two key approaches (or “scenarios”) for calculating the external cost of using amalgam – recalling that the “external cost” is the sum of the diverse costs (paid neither by dental practitioners nor their patients) to the environment and to society at large related to the use of mercury in dentistry.

i. The first approach, which is more conservative than the second, is to estimate the additional cost (i.e., beyond measures already being taken) required to keep dental mercury out of the environment, or at least to minimize the amount that reaches the environment. Since there is an international consensus that the global pool of mercury circulating in the biosphere needs to be greatly reduced, it is logical to calculate the cost of ensuring that more mercury does not enter the environment from dental uses.
ii. The second approach quantifies the benefits for people and the environment that would result from a phase-out of mercury use in dentistry. In most cases these benefits are simply the same as “avoided costs.”

The first of these two approaches is addressed below, while the second will be further elaborated in the next chapter.

8.1 Key pathways

The various pathways of dental mercury into the environment have been shown previously in Section 4. Figure 5 demonstrated that about 29 tons of dental mercury become potentially bioavailable each year, while another 13 tons are sequestered or retired. In order to avoid 90% of the 29 tons of mercury from entering the environment, end-of-pipe solutions to capture this mercury have been identified below, along with the associated costs. While there is limited source material from which to derive the costs for some of these end-of-pipe solutions, the breakdown of the analysis into a number of subcategories implies that the uncertainty in any given subcategory will not have an overwhelming effect on the total cost estimate.

It is important to note that even when a specific end-of-pipe technique is used to capture Hg, there is still a need to dispose of the resulting Hg waste – and a further cost as well. In addition, of course, there is a cost associated with the sequestration of the 13 tons of mercury identified above.

8.2 Operating chair-side traps to capture the larger mercury waste particles

We can take for granted that the majority of dental chairs are fitted with chair-side traps, so this cost may be assumed to be included already in the commercial cost of a filling. The various pathways followed by the mercury waste collected in these traps are discussed in further detail below, along with related prevention costs.

8.3 Operating separators to capture mercury in the clinic wastewater stream

The cost of separators has been assessed in detail in Bender (2008) at up to $5,000 per kg mercury removed from the clinic wastewater. Others have assessed much higher costs, exceeding $33,000 per kg mercury removed (Jackson *et al.* 2000, as cited by Hylander and Goodsite 2006), or $90,000-280,000 per kg Hg removed (OEWG2-5 Add1). Based on the diverse costs cited here, a mid-range of $30,000-60,000 per kg Hg removed appears justified. As in the case of chair-side traps, the dental clinics that use separators already include this cost in the fee charged for placing a filling.

It is reported that US EPA is in the process of developing effluent guidelines that will oblige more dental clinics to install separators. Nevertheless, whether one looks at the economic cost of installing more separators, or the cost of alternative methods of removing mercury from the environment, both approaches highlight costs of using dental amalgam that are presently borne by society.

8.4 Treatment or safe disposal of hazardous mercury waste

If the mercury content of waste is low and the volume high, it is not realistic to consider putting it in a hazardous waste landfill site or other sequestration due to the amount of storage space required. In this case the only solution is thermal treatment which is expensive for large volumes of materials.

ECHA (2010) gives the cost of secure landfilling of one metric ton of hazardous waste in Europe at about EUR 250 (i.e., about $340). However, in the U.S. landfilling of waste with more than 260ppm mercury content is not permitted, leaving the only option as thermal treatment.

Hazardous waste disposal companies in the U.S. charge an estimated $250-400/ton of Hg waste, for example, to mix the waste with cement and dispose of it safely. Assuming this waste averages 10% mercury, the on-site cost (i.e., excluding the various and significant management and handling costs) to dispose of one kg of Hg would be only $3-4.

Alternatively, thermal treatment of amalgam waste containing 30% or more of mercury could easily exceed $50/kg Hg removed, and rise to $400/kg Hg removed under a full-service recycling contract (MPP 2007), as described in “Recycling,” section 8.17 below.

8.5 Landfill of municipal waste

The mercury concentration in municipal solid waste (MSW) in New Jersey in 2001 was estimated to be in the range of 1.5-2.5ppm (NJ MTF 2002), although it may be assumed the content is now significantly lower since certain products such as batteries now contribute much less mercury to the waste. Even if it contains an estimated 0.5-1ppm Hg, the only removal option for this analysis is to incinerate it and scrub the flue gases ($20,000-40,000 per kg Hg as in section 8.7).

8.6 Dental clinic air emissions of Hg from the chair and from the wastewater

The removal of mercury from the air of a dental clinic would require a ventilation system fitted with activated carbon filters. The investment cost would not necessarily be high, but the amount of mercury that would be captured in this manner is relatively small. Assuming thermal recycling of filters containing 1% mercury, the cost/kg Hg captured could be estimated in the range of $1,000-1,500/kg Hg, as developed in section 8.17.

8.7 Removing mercury from the flue gas of municipal waste incinerators

We may assume that all large incinerators are already fitted with effective Hg emission controls. US EPA (1997), as cited by Hylander and Goodsite (2006), estimated the cost of activated carbon injection into the flue gas of a municipal waste incinerator at $465-1,900 per kg of mercury removed, although the percentage of mercury removed using that technology alone would be relatively low. Hylander and Goodsite (2006) have also given the cost of combined technologies applied to a municipal waste incinerator – suggesting a high level of mercury removal – at $40,000 per kg of mercury removed.

Another source cites investment and operating costs required for removal of 90-99% of the Hg from waste incineration (and cremation) processes ranging from $4.13 (two-stage scrubber+wet electrostatic precipitator – optimized) to $12.86 (virgin activated carbon injection (SIC)+venturi scrubber with lime milk+caustic soda+fabric filter – optimized) (dollars of 2008) per tonne of waste treated (OEWG 2008). If we assume that typical municipal solid waste (MSW) contains 0.5ppm Hg,[24] then the cost would be in the range of $10,000 to $20,000 (in dollars of 2008) per kg Hg removed.

In comparison, for a coal-fired power plant (CFPP), the U.S. Environmental Protection Agency (EPA) estimated that it would cost between $67,700 and $70,000 per pound (or between $149,300 and $154,000 per kg) to achieve 90% mercury reduction using sorbent injection (US EPA 2005b). This result is not too far from the cost of $234,000 per kg of mercury removed, estimated for the UN ECE Heavy Metals Protocol and cost of additional measures (Visschedijk et al. 2006). Meanwhile, according to Sloss (2008), there have been technological developments in recent years – as yet unsubstantiated on a broad commercial scale – that may significantly lower the cost of achieving a 90% mercury capture rate.

As discussed in the "Paragraph 29" study (UNEP 2010), a DOE economic analysis released in 2007 indicates that the cost of 90 per cent mercury emission control (from coal-fired power plants) by means of activated carbon injection ranged from about $30,000 to less than $10,000 per pound (equal to $22,000 to $66,000 per kg) of mercury removed for DOE field testing sites (Feeley, 2008). However, adding absorbents like activated carbon can affect the quality of the fly ash (and gypsum) and seriously reduce the value of those byproducts. Mercury control costs are therefore also affected by a potential loss of revenue for plants that sell their fly ash for reuse. A recent report from the Northeast States for Coordinated Air Use Management (NESCAUM) has indicated that an increase of 170-300 per cent in the mercury removal costs may be observed if such loss of fly ash revenue is taken into account (US DOE 2006 and NESCAUM 2010).

Drawing on the diverse assumptions and costs cited above, there is reason to estimate a mid-range cost of $20,000-40,000 per kg Hg removed from major combustion systems.

8.8 Removing mercury from incinerator ash of municipal waste incinerators

Assuming the use of thermal treatment to remove the mercury from large volumes of incinerator ash (average 50ppm Hg), the treatment cost would come to $160,000-240,000/kg Hg removed, as derived in "Recycling," Section 8.17 below.

8.9 Removing mercury from wastewater sludge to meet agricultural soil limits

In order to meet agricultural soil limits for land disposal, we assume thermal treatment of large volumes of wastewater/sewage sludge averaging 100ppm Hg content. As derived in "Recycling," Section 8.17 below, the treatment cost would come to $80,000-120,000/kg Hg removed.

8.10 Removing mercury from the flue gas of sewage sludge incinerators

The cost of mercury removal from the flue gas of sewage sludge incinerators may be assumed to be roughly similar to the cost of mercury removal from municipal incinerator flue gases, or $20,000-40,000/kg Hg removal as derived in section 8.7.

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[24] The mercury concentration in municipal solid waste (MSW) in New Jersey in 2001 was estimated to be in the range of 1.5-2.5ppm (NJ MTF 2002). It is conservatively assumed to be significantly lower now.

8.11 Removing mercury from the flue gas of recycling systems

Mercury recycling operations typically remove mercury from the exhaust system with activated carbon filters. Assuming thermal recycling of filters containing 1% mercury, the cost/kg Hg captured is estimated in the range of $1,000-1,500/kg Hg, as developed in section 8.17.

8.12 Removing mercury from the exhaust gas of biomedical waste treatment systems

As above, mercury is removed from the exhaust gas of biomedical waste treatment systems with activated carbon filters. Assuming thermal recycling of activated carbon filters containing 1% mercury, the cost/kg Hg captured is estimated in the range of $1,000-1,500/kg Hg, as developed in section 8.17.

8.13 Removing mercury from the process water of biomedical waste treatment systems

Although this is initially a chemical process, we assume the cost of the final treatment process is similar to the cost of dealing with wastewater sludge averaging 50ppm Hg content. As derived in “Recycling” section 8.17 below, the treatment cost would come to $160,000-240,000/kg Hg removed.

8.14 Secure landfill or other safe disposal of biomedical waste

Under current circumstances much biomedical waste is sent to landfill after autoclaving, but still contains significant quantities of mercury. Following the guidance of section 8.4 with regard to the treatment and/or safe disposal of hazardous mercury waste, and considering that the content of this waste may be on the order of 500ppm, the only viable option would be thermal treatment at $16,000-24,000/kg Hg removed, as derived in “Recycling” section 8.17 below.

8.15 Removing mercury from the flue gas of crematoria

Flue gas cleaning at crematoria has been estimated in Hylander and Goodsite (2006) at $170,000-340,000/kg Hg removed, based on installations in Sweden in 2004. About the same time, it was estimated at $29,000/kg Hg removed in the UK (BBC News 2005, as cited by Hylander and Goodsite 2006).

The cost of removing Hg from the flue gas of municipal waste incinerators has been estimated in Section 8.7 at $20,000-40,000 per kg Hg removed. Due to the customized systems required for crematoria, and the far smaller scale, the cost of removing mercury from crematoria flue gases is here estimated at $30,000-50,000 per kg Hg.

For comparison, if amalgam fillings are intentionally removed and replaced by composite, the cost amounts to about $250,000/kg Hg removed from the mouth, to which one must then add the cost of disposing of the resulting Hg waste.

8.16 Long-term storage or sequestration of elemental mercury

DNSC (2004) calculated the cost of long-term above-ground storage of elemental mercury at about $300/tonne Hg/year. This cost was also found to be reasonable by the EC (2006). The present value of this disposal option over the long term (40 years) amounts to some $6,000-10,000/tonne Hg, or about $6-10/kg Hg.

8.17 Recycling (thermal treatment cost)

A typical cost for thermal treatment or retorting of mercury waste by recyclers in 2002 was $2-3/kg of waste treated (Maxson 2004). In 2009 that cost is estimated at $8-12/kg of waste treated. If the waste has 20% Hg content, the equivalent treatment cost would be $40-60/kg Hg removed. If the waste has 5% Hg content, the equivalent recovery cost would be $160-240/kg Hg removed. In the case of recycling of amalgam waste captured in chair-side traps, Hylander and Goodsite (2006) cited a 1999 estimate (from Minnesota) of $240/kg mercury recovered, based on a typical full-service contract with a recycling company, which is estimated at about $400/kg mercury recovered in 2009. On the basis of $8-12/kg of waste treated, thermal treatment of low-level waste (such as 50ppm Hg content) would cost $160,000-240,000/kg Hg removed.

8.18 Cemetery releases to the soil

Landfill controls can be implemented to limit mercury releases and will also benefit management of many other hazardous wastes. As an example, based on the thermal treatment of 80,000 tonnes of soil at Lipari Landfill site in New Jersey for $430,000 in capital cost and $5,019,292 in operation and maintenance costs, the unit cost for this process was $67/tonne of soil (OEWG2-5 Add1). Assuming the soil contained an average of 100ppm Hg, this is equivalent to $670/kg Hg removed.

Comparing the thermal treatment carried out at the Lipari Landfill with another typical site clean-up, EKA was a Swedish chlor-alkali firm that closed in 1928. The total costs to decontaminate the area where the industry was located were estimated at $28 million in 2008. About 90% of the estimated 16 tonnes of Hg will eventually be removed at an equivalent cost of $1,944/kg Hg removed.

In another example, site cleanup/restoration costs in Örserum Bay and Lake Thuringen (Sweden) were between €8,726 and €21,8159 ($10,000-$25,000) per kg of mercury removed in 2004 (Hylander and Goodsite 2006).

Based on the above, a cost range for soil remediation may be estimated at $2,000-10,000 per kg mercury removed.

8.19 Management, manipulation and handling costs

Most of the above costs are estimates of the specific technical treatment costs involved in removing mercury from various waste streams. However, as demonstrated in section 8.4, amalgam waste that may be mixed with cement and disposed of for $3-4/kg of mercury on site is actually far more expensive when a dental clinic deals with the full extent of the problem, including maintenance of mercury removal equipment at the clinic, removal of mercury waste from the separator, transport and handling of the waste and finally, proper recycling of the waste. A contract with an accredited service firm could come to the equivalent of $400 per kg of mercury recycled (MPP 2007).

A review of the various treatment techniques discussed above reveals the impossibility, within the scope of this report, of identifying similar costs for the other techniques. Nevertheless, while the above example of a full mercury waste management and handling cost that is 100 times the specific treatment cost is admittedly an extreme case, overall a conservative estimate of the relevant waste management, manipulation and handling costs would appear to be at least equivalent to the treatment costs, and likely considerably greater. This estimate has therefore been retained in the cost analysis.

8.20 Summary costs of avoiding dental mercury releases

Table 10 below summarizes the main pathways and quantities of actual (2009) dental mercury releases as described in Section 6, it indicates the end-of-pipe control costs necessary to prevent the release of 90% of that mercury to the environment and it calculates the rough cost of that prevention for the main dental mercury pathways in 2009.

When the total prevention cost of $2.1-3.4 billion is allocated over the roughly 51 million amalgams placed in 2009, the result is that the cost of keeping an additional 90% of typical dental mercury releases out of the environment amounts to an estimated $41-67 for each amalgam placed.

In comparison to coal combustion emissions of mercury in the U.S., which exceed 50 tons (Schmeltz *et al.* 2011), atmospheric emissions attributable to amalgam use in the U.S., while significant, are only about 15% of those attributable to coal. Therefore, it should be understood that phasing out amalgam will have only a limited net effect on the overall societal and environmental risks associated with mercury exposure. This is not an argument against controlling amalgams. Rather it is a realization that the net risk of mercury to society and the environment comes from multiple sources and multiple pathways, and the responsible policy response is to reduce all sources to the extent practicable. Since it is both feasible (alternatives are available) and cost-effective (as demonstrated here) to phase out dental amalgams, this measure should therefore be recognized as one of the key strategic priorities as we move forward.

Table 10 Cost of preventing an additional 90% of dental mercury releases from entering the environment (2009)

Key pathways of dental mercury to the environment	Mercury (tons)	End-of-pipe or other preventive mechanism	Approx. cost range ($US/kg Hg removed)		Approximate cost ($US)	
			Low	High	Low	High
Municipal solid waste incinerator (large) emissions to the atmosphere	0.2	Assume flue gas controls are already present on all large incinerators	n.a.	n.a.	n.a.	n.a.
Municipal solid waste incinerator (smaller) emissions	0.1	flue gas controls	20,000	40,000	2,000,000	4,000,000
Municipal solid waste incinerator ash & residues to treatment (50ppm Hg)	1.0	thermal treatment to remove elemental Hg from ash/residue	160,000	240,000	160,000,000	240,000,000
Municipal solid waste (low Hg) previously landfilled	5.6	incineration of waste with flue gas controls	20,000	40,000	112,000,000	224,000,000
Municipal wastewater sludge incinerator emissions	1.8	flue gas controls	20,000	40,000	36,000,000	72,000,000
Municipal wastewater sludge (low Hg) previously landfilled	1.5	incineration of sludge with flue gas controls	20,000	40,000	30,000,000	60,000,000
Municipal wastewater sludge to agricultural and other land dispersal (100ppm)	5.5	thermal treatment to remove elemental Hg before land dispersal	80,000	120,000	440,000,000	660,000,000
Biomedical waste process emissions to the atmosphere	1.0	capture mercury in exhaust gases with activated carbon filters	1,000	1,500	1,000,000	1,500,000
Biomedical waste process water treatment	0.3	chemical treatment of process wastewater	160,000	240,000	48,000,000	72,000,000
Biomedical waste to treatment and disposal (500ppm Hg)	1.3	thermal treatment to remove elemental Hg	16,000	24,000	20,800,000	31,200,000
Cemetery releases to the soil	6.2	thermal treatment of soil to remove elemental Hg	2,000	10,000	12,400,000	62,000,000
Cremation emissions to the atmosphere	3.3	flue gas controls (specialized)	30,000	50,000	99,000,000	165,000,000
Dental clinic occupational emissions to the atmosphere	0.5	ventilation and capture mercury in exhaust gases with activated carbon filter	1,000	1,500	500,000	750,000
Dental clinic wastewater emissions to the atmosphere	0.9	capture mercury in exhaust gases with activated carbon filters	1,000	1,500	900,000	1,350,000
Human exhalation to the atmosphere	0.2	none feasible	n.a.	n.a.	n.a.	n.a.
Hazardous waste to landfill or safe disposal	6.1	secure landfill or safe disposal	3	35	18,300	213,500
Recycling amalgam waste (service contract)	6.0	thermal treatment to remove elemental Hg	200	400	1,200,000	2,400,000
Recycling amalgam waste (50ppm Hg)	1.2	thermal treatment to remove elemental Hg	160,000	240,000	192,000,000	288,000,000
Emissions to the atmosphere during recycling	0.1	flue gas controls (specialized)	30,000	50,000	3,000,000	5,000,000
Total environmental releases	42.8					
Safe storage/disposal of elemental mercury and mercury waste generated in the above processes, including:						
- filter cake from flue gas controls	12.4	secure landfill or safe disposal	3	35	37,200	434,000
- recovered elemental mercury	23.9	long-term above-ground safe storage	6	10	143,400	239,000
Total waste treatment cost (multiplied by 90%)					1,043,099,010	1,701,077,850
Indicative waste management, manipulation and handling costs					1,043,099,010	1,701,077,850
Total waste management and treatment costs					**2,086,198,020**	**3,402,155,700**
Total waste management and treatment costs per filling (allocated over 51 million amalgam fillings)					**$40.91**	**$66.71**

9 Benefits of a dental amalgam phase-out

As the previous chapter has quantified the costs necessary to keep dental mercury out of the environment, this chapter quantifies the benefits to people and the environment in the U.S. that would accrue from a phase-out of dental amalgam use. In most cases these benefits are simply the same as "avoided costs."

The benefits of reduced Hg releases include a spectrum of human health, environmental and socioeconomic benefits. The scope of this analysis does not consider any direct health risk to a person from his or her own amalgam fillings (Mutter 2011). Nevertheless, there is ample evidence of human health effects due to environmental mercury exposures, and since some of those exposures are the result of dental mercury in the environment, they will be considered here.

For example, it has been previously described how dental mercury can end up in the atmosphere via cremation and other processes, and how atmospheric deposition can bring it back to earth where it may be transformed into methylmercury. Human exposures to methylmercury through fish consumption (as well as other pathways) can cause a range of health effects including neurological effects, reductions in IQ (Intelligence Quotient), etc. Other effects on human health may include other types of neurological effects, some types of cardiovascular disease, etc. The effects of mercury exposures may be significantly higher for populations that are especially reliant on fish in the diet, such as Native Americans and Asian Americans.

Environmental effects of mercury releases mostly comprise adverse effects on wildlife, including multiple behavioral changes such as mating behavior, feeding habits, caring for offspring, numbers of offspring, energy and activity levels, etc. – not to mention a range of physiological changes that are often not apparent until exposures are relatively high.

Socioeconomic benefits of reduced Hg releases would result, for example, from a reduction in fish consumption advisories, which would re-stimulate the recreational and commercial fishing industries. Moreover, at least according to economic theory, a shift from amalgam fillings to composites could also be expected to create jobs, as described below.

9.1 Human health effects

9.1.1 Health effects of mercury emissions to the atmosphere circa 2005

It has been noted previously that micro-organisms and natural processes generate the most common organic mercury compound, methylmercury, from other forms of mercury. Thus, while methylmercury is not intentionally created or used in dentistry, the US EPA and diverse researchers have studied the pathways from elemental mercury emissions to diffusion in the atmosphere, deposition on soils and subsequent runoff, deposition on (salt and fresh) water bodies, etc. Wet environments are particularly conducive to the uptake and conversion of mercury to methylmercury by micro-organisms and natural processes, some of which is then accumulated in the food chain – especially via predatory fish (Harris *et al.* 2007) – and eventually returns to humans and wildlife in their diets (GAO 2005). The quantities of mercury and methylmercury that follow this route are significant, and the health implications and related costs are considerable, as shown below.

Using this methodology, among others, there have been a number of efforts in the U.S. to model and quantify the health benefits – and sometimes the environmental benefits – of reducing atmospheric mercury emissions and/or human exposures, including:

> EPRI. 2003. A Framework for Assessing the Cost-Effectiveness of Electric Power Sector Mercury Control Policies, Technical Report 1005224, Electric Policy Research Institute, Palo Alto, CA, May 2003.
>
> Gayer T and RW Hahn. 2005. "Designing environmental policy: Lessons from the regulation of mercury." Regulatory Analysis 05-01, AEI-Brookings Joint Center for Regulatory Studies. http://www.aei-brookings.org/admin/authorpdfs/page.php?id=1126
>
> Hagen DA, JW Vincent and PG Welle. 1999. Economic Benefits of Reducing Mercury Deposition in Minnesota. Minnesota Pollution Control Agency. http://www.pca.state.mn.us/publications/reports/mercury-economicbenefits.pdf
>
> Jakus PM, M McGuinness and A Krupnick. 2002. "The Benefits and Costs of Fish Consumption Advisories for Mercury in the Chesapeake Bay." Resources for the Future Discussion Paper 02-55, October. http://www.rff.org/Documents/RFF-DP-02-55.pdf
>
> Lutter R, E Mader and N Knuffman. 2001. "Regulating mercury: What do we know about benefits and costs." Regulatory Analysis 01-03, AEI-Brookings Joint Center for Regulatory Studies. http://aei-brookings.org/admin/authorpdfs/page.php?id=143
>
> Palmer K, D Burtraw and JS Shih. 2005. "Reducing emissions from the electricity sector: the costs and benefits nationwide and in the Empire State." Resources for the Future Discussion Paper 05-23. http://www.rff.org/documents/RFF-DP-05-23.pdf
>
> Rae D and L Graham. 2004. "Benefits of reducing mercury in saltwater ecosystems." Report for Office of Wetlands, Oceans, and Watersheds, US EPA. http://www.cleanairnow.org/pdfs/officewatermerc.pdf
>
> Rice G and JK Hammitt. 2005. "Economic valuation of human health benefits of controlling mercury emissions from U.S. coal-fired power plants." Report for NESCAUM, Northeast States for Coordinated Air Use Management. http://bronze.nescaum.org/airtopics/mercury/rpt050315mercuryhealth.pdf
>
> Trasande L, PJ Landrigan and C Schechter. 2005. Public health and economic consequences of methyl mercury toxicity to the developing brain. Environmental Health Perspectives 113:590-596.
>
> US EPA. March 2005. Regulatory Impact Analysis of the Clean Air Mercury Rule. EPA-452/R-05-003. 566 pp. http://www.epa.gov/ttn/atw/utility/ria_final.pdf
>
> US EPA. October 2005. Technical Support Document. Revision of December 2000 Regulatory Finding on the Emissions of Hazardous Air Pollutants from Electric Utility Steam Generating Units. http://www.epa.gov/ttn/atw/utility/TSD-112-final.pdf

These studies represent a range of scenarios for reduction of mercury emissions and exposures – most of them motivated by the intensive debate surrounding the costs and benefits of reducing mercury emissions from coal combustion. It could be argued that the mix of mercury species – elemental mercury Hg^0, reactive gaseous mercury Hg^{++} and particulate Hg – emitted at the end of various dental mercury pathways may be somewhat different from the mix of species emitted by coal-fired power plants (typically about 80% Hg^0), but for the purposes of this analysis, the effects of any such difference are not significant.

The mercury-exposure-related health endpoints addressed by these studies include, variously, decreases in intelligence quotient (IQ) or increases in general neurological deficiency, increases in acute myocardial infarction (AMI) or all-cause mortality (ACM), etc. The benefits are calculated, depending on the study, on the basis of a range of economic methodologies such as lost earnings, "willingness to pay," cost of illness, value of a statistical life, etc. The uncertainties associated with different benefits vary considerably due to the fact that each research team was obliged to decide how best to deal with several critical variables:

1. what assumptions to make regarding the relationship between mercury emissions and mercury deposition to water bodies – both freshwater and marine;
2. what assumptions to make concerning the relationship between mercury deposition to water bodies and levels of methylmercury in fish;
3. what assumptions to make concerning the relationship between fish methylmercury levels and human methylmercury exposure via diet; and
4. what assumptions to make concerning the relationship between human methylmercury exposure and human health effects.

Due to methodological differences among these studies, any comparison must be made with caution. However, a simple but useful metric that may be drawn from these studies is a quantified health benefit per unit mass of mercury emissions eliminated. On this basis (and where a range was presented, we have taken the "most likely" benefits as identified by the researchers), the annual health benefits (converted to 2009 dollars)[25] calculated by these studies ranged from a low of about $7 (the parental willingness to pay for IQ increases through chelation therapy) per gram of atmospheric mercury emissions eliminated, to a high of about $260 (costs associated with decreased IQ as well as increases in non-fatal AMI, hypertension and ACM) per gram of atmospheric mercury emissions eliminated.

In an effort to narrow the benefit range for the purposes of this analysis, it was logical to disregard the more extreme high and low values, to focus on the methodologies with lower levels of uncertainty, to consider researcher reputation and independence, to recognize particular methodological rigor and, again in the interest of reducing uncertainties, to generally favor more conservative assumptions. These criteria led to a focus, in particular, on three of the research efforts listed above – the peer-reviewed paper by Trasande *et al.*, the study by Rice and Hammitt and the October 2005 report published by the US EPA.

Trasande *et al.* (2005) limited their analysis to the neuro-developmental impacts of methylmercury exposure[26] – specifically loss of intelligence – in the U.S. The authors chose not to include mortality benefits, but assumed that a small percentage of mercury deposition to the ocean is probably implicated in human health effects. The Cost-of-Illness (COI) impact was calculated, assuming that a reduced mental capacity is directly related to diminished economic productivity that persists over the lifetime of the individual exposed. Based on these conservative assumptions, the authors concluded that approximately $1.3 billion (the most likely value in the range of $0.1–6.5 billion, in dollars of 2000) each year in diminished productivity is attributable to the (49 tons of) mercury emissions from American power plants (Trasande *et al.* 2005). One can readily calculate – for this single health effect – annual benefits of about $37 (2009 dollars) per gram of mercury emissions eliminated.[27]

Rice and Hammitt (2005) analyzed comprehensively the health benefits of reducing mercury emissions to air from coal-fired power plants. Reductions in mercury emissions were assumed to

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[25] 2004 dollars have been converted to 2009 dollars by increasing the 2004 value by the consumer price index (CPI) inflation rate of 13.5% during that period. 2004 euro have first been converted to 2004 dollars, which were then inflated to 2009 dollars. Appendix III shows the inflation and exchange rates used.

[26] This health effect is related to a level of exposure for which there is clear evidence of human neurotoxicity based on several peer-reviewed epidemiological studies (e.g., in the Faro Islands and New Zealand).

[27] Since only a small percentage of US mercury emissions are assumed to enter the food chain and cause health effects in the US population, this should be considered a highly conservative estimate. In contrast, an estimate of the global benefits of US mercury reductions would have to assume that an additional percentage of those emissions enters the food chain of populations outside the US.

lead to lower methylmercury concentrations in fish, and thus reduced human exposure to methylmercury. The modeling analysis was based on the EPA Clear Skies Initiative, and accounted for potential changes in both cognitive abilities (IQ) and cardiovascular effects. Overall, the health benefits of reducing mercury emissions were calculated to be between about $7 and $230/kg mercury. The lower range of benefits related to the IQ effects for exposures above the reference dose, while the higher range of benefits included cardiovascular effects and premature mortality in all consumers of fish. A reasonably high level of certainty was claimed for health benefits in the range of $25-30 per gram of mercury emissions reduced.

The authors of the October 2005 US EPA study, like Trasande *et al.*, limited their analysis to the COI measurement of reduced U.S. neuro-developmental capacity due to methylmercury exposure, and likewise did not include mortality benefits. However, contrary to Trasande *et al.*, these authors ignored the effects of mercury deposition to seawater (despite the preponderance of marine species in the typical American diet), focusing instead on the recreational and subsistence freshwater fish pathway of mercury exposure, under the assumption that the freshwater pathway “leads to the greatest individual exposure due to utility-attributable mercury emissions.” The US EPA analysis concluded that the implementation of the Clean Air Interstate Rule (CAIR), which was expected to eliminate well under 10 U.S. tons of annual mercury emissions, could confer some $168 million (dollars of 2004) per year in U.S. health benefits (US EPA 2005c). This would imply – for this single health effect – annual benefits of about $27 (2009 dollars) per gram of mercury emissions eliminated.[28]

This level of benefits is not directly comparable to, but still consistent with an earlier analysis prepared by the U.S. Environmental Protection Agency with specific regard to basic mercury emission controls for chlor-alkali production facilities. In this calculation, the EPA determined that more stringent mercury controls are “cost-effective and warranted” if the incremental annual cost is up to $9,000 (in 2001-2 dollars) per additional pound of mercury eliminated (US EPA 2002). This is equivalent to an annual benefit of just under $27 (2009 dollars) per gram of atmospheric mercury emissions eliminated.

These calculations also reflect the results of an earlier and well regarded analysis by Staring and Vennemo, based on a wide range of other studies, which estimated the health cost of atmospheric mercury emissions at about $17 (1996 dollars) per gram (Staring and Vennemo 1997), which would be equivalent to over $35 (2009 dollars) of health benefits per gram of mercury emissions eliminated, and significantly more if one considers that the $17 figure calculated by Staring and Vennemo represented a weighting of health costs in both richer and poorer countries.

The above calculations ignore other “indirect” human health effects such as those due to mercury exposure by dental practitioners, but we may assume those are small by comparison.

We note once again that the assumptions behind the studies referenced above are uniformly conservative. For comparison, Rae and Graham (2004, see above) determined that even based on reasonable assumptions about the cost of other human health effects from mercury exposure such as non-fatal heart attacks, mortality benefits and child hypertension, the comprehensive human health benefits could be seven times greater than in the case where only the loss of IQ points were considered. In light of these and other findings cited above, if one were to take account only of the range of health effects for which there was a reasonable degree of certainty in

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[28] See footnote 27.

2005, one could readily justify a conservative estimate of $30-45 of health benefits per gram of atmospheric mercury emissions eliminated.

9.1.2 Health effects – developments since 2005

During the relatively few years since the 2004-5 studies discussed above were published, mercury has been shown to be both more harmful, and harmful at much lower doses than we were able to prove in 2005.

In one case, research in the Seychelles reported that neither maternal fish intake nor methylmercury exposure appeared to be linked to developmental cognition in children when each effect was considered separately. However, when maternal fish intake and methylmercury exposure were included in the analysis at the same time, the results confirmed expectations that the fish part of the diet (especially Omega-3 fatty acids) had beneficial effects while the methylmercury content conferred negative effects (Strain *et al.* 2008). Likewise in the Faroe Islands it was shown that the toxicity of methylmercury was greater than previously thought since the deleterious effects on human health had been lessened somewhat by the beneficial effects of fish intake during pregnancy (Budtz-Jørgensen *et al.* 2007).

In another case, whereas cardiovascular effects have long been suspected, an expert group recently found the "body of evidence exploring the link between methylmercury and acute myocardial infarction (MI) to be sufficiently strong to support its inclusion in future benefits analyses, based both on direct epidemiological evidence of a methylmercury-MI link and on methylmercury's association with intermediary impacts that contribute to MI risk" (Roman *et al.* 2011).

These and other studies of health effects associated with the consumption of contaminated fish demonstrate that the health effects cited in support of previous calculations were underestimated since they did not consider simultaneously the beneficial effects of fish intake. The extent of the underestimate is difficult to quantify as it depends on the type and quantity of fish consumed. However, the Seychelles research provides a hint in that the negative health effects of methylmercury exposure from a diet high in fish were rendered invisible by the beneficial effects of fish consumption, implying that the two effects, while opposite, appeared to be roughly equal in magnitude. This observation supports an estimate of methylmercury toxicity 100% greater than that assumed in the studies cited in Section 9.1.1 above (Budtz-Jørgensen *et al.* 2007).

In 1999, the US Environmental Protection Agency (EPA) established a Reference Level for methylmercury in blood of 5.8 µg/l, and a Reference Dose for dietary methylmercury intake of 0.1 µg/kg body weight/day. These guidelines represent the current official US definition of acceptable exposure to methylmercury. In fact, however, the level of exposure at which no adverse effects occur (if one exists) has not been determined. More recent research (Oken *et al.* 2008 and Lederman *et al.* 2008, as cited by Groth 2010) strongly suggests that not only are the effects of methylmercury exposure apparently greater when the confounding beneficial effects of fish consumption are taken into account; but also the adverse effects of methylmercury occur at doses around one-tenth the level considered harmful when Trasande *et al.* (2005) did their analysis, and thus affect far more individuals than we thought then.

Elsewhere, the Center for Health and the Global Environment of Harvard Medical School published an in-depth study of the real costs of coal combustion in the U.S. This study evaluated the cost of health impacts (including some that have been better confirmed since 2005) and lost productivity due to coal related mercury emissions at $5.5 billion per year (CHGE 2011). This is equivalent to well over $100 of impact on human health per gram of mercury emissions to the atmosphere.

A "mercury avoided" approach

A recent European Union analysis carried out by the European Chemicals Agency (ECHA 2010) assessed a number of other studies and found generally "rather high" benefits associated with reducing mercury emissions. These typically ranged from about €5,000 to €20,000 (approx. $7,000-27,000) per kg mercury emitted, but some values were much higher (e.g. over $300,000) where less certain health effects such as cardiovascular effects were included. Moreover, these values related only to emissions to air.

In order to respond to the needs of its analysis, ECHA (2010) aimed to determine how much money should reasonably be spent to avoid the health risks associated with putting additional mercury (in products) on the market. Based on its research, a benchmark of €10,000 was determined to reflect the cost of a "well established" health risk related to one kg of mercury "placed on the market." On the contrary, a benchmark of €100,000 was determined to reflect the upper limit of any health effects of one kg of mercury "placed on the market." The range between these two benchmarks was then divided into two sections. If one kg of mercury could be avoided for an investment of less than €20,000, the justification for such an investment would have been "fairly well" established. If one kg of mercury could be avoided for between €20,000 and €100,000, the justification for such an investment would have been "possibly" established. This methodology is summarized in Table 11; it may be inferred from the ECHA text that the benchmarks have been selected with particular conservatism in order to avoid any doubt about the level of cost-effectiveness claimed.

Table 11 Health risk due to mercury "put on the market" in products

Health risk based on atmospheric emissions	**Range of investment required (per kg of Hg "put on the market") to avoid the health risk**
"Well established"	Under €10,000
"Fairly well established"	€10,000- €20,000
"Possibly established"	€20,000-€100,000
"Not established"	Over €100,000

Source: ECHA 2010

As discussed previously, some 8.8 tons (over 20%) of the 42.8 tons of mercury released in 2009 from dental "product" uses were emitted to the atmosphere. If we assume that the same percentage of mercury "placed on the market" for use in mercury products is likewise eventually emitted to the atmosphere; and if we consider that an investment of €10,000 (roughly $13,900 at the average 2009 exchange rate) per kg mercury placed on the market, of which only some 20% becomes atmospheric Hg emissions, would avoid a "well established" health risk, then we would be obliged to invest up to $13,900/20% = $69,500 to avoid one kg (or nearly $70 to avoid one gram) of atmospheric emissions associated with a "well established" health risk. While this result is based on an entirely different methodology from that used to calculate health effects, nevertheless it provides further support for the general validity of the previous calculations and estimates of health benefits resulting from the reduction of atmospheric mercury emissions.

Based on the above discussion and the present level of medical understanding, we conclude that a readily justifiable range of human health benefits accruing from reduced mercury emissions to the atmosphere would be $50-150 per gram of mercury emissions avoided, and the most likely value probably exceeds $100 per gram of mercury emissions avoided.

9.1.3 Health effects of mercury releases to water and soil

While industrial releases of mercury to the water may generally be considered to cause local or regional pollution, it has been demonstrated previously that releases of dental mercury to the water, on the contrary, are quite diffuse. The exposure pathways of diffuse releases of dental mercury directly to surface waters are not dissimilar to those of mercury deposition on water from the atmosphere. However, one is compelled to assume that more of the mercury released directly to surface waters is likely to become bioavailable as compared to atmospheric mercury emissions, implying more substantial health effects per gram of mercury released. Recalling the figure of 3.9 tons of mercury releases to surface water, as compared to the 8.8 tons of emissions to the atmosphere that are implicated in the health effects above (via deposition to water bodies and uptake from there into the food chain), we assume that the health effects per gram of diffuse releases of dental mercury to water are 50% greater than those related to one gram of mercury emitted to the atmosphere. We conclude that a justifiable range of health effects due to mercury releases to surface water would be $75-225 per gram of mercury released, with the most likely value around $150 per gram of mercury released.

With regard to mercury releases to the soil, they may be assumed to be somewhat less bioavailable than mercury releases to the water except in the case of runoff, which has already been accounted for in the previous estimate of mercury releases to water. Therefore, the conservative decision is taken in this case to ignore any human health effects of mercury releases to the soil.

9.2 Environmental effects

The environmental impacts and associated costs of mercury and methylmercury exposures have received far less research attention than have the human health impacts. Nevertheless, there is broad consensus that the effects of mercury releases on the integrity of the ecosystem are substantial. Various species – especially eagles, loons, kingfishers, ospreys, ibises, river otters, mink and others that rely on fish for a large part of their diet – have been observed to suffer adverse health and/or behavioral effects. Observed disorders such as effects on the muscles and nervous system, reduced or altered mating habits, ability to reproduce, raise offspring, catch food and avoid predators have been demonstrated to affect individual animal viability and overall population stability. Even songbirds and bats have been recently added to the growing list of species where significant effects have been observed. Moreover, these indications are suspected to be the "tip of the iceberg" with regard to environmental effects because such effects are more readily observable than other impacts such as changes in the microbiological activity in soil, etc. (Borg 1969; Hoffman *et al.* 2005; Heinz *et al.* 2009; Edmonds *et al.* 2010; Frederick and Jayasena 2010; Sleeman *et al.* 2010; Evers *et al.* 2011; Hallinger *et al.* 2011; Jackson *et al.* 2011; Jedlicka *et al.* 2011; Lane *et al.* 2011; Evers *et al.* 2012; Nam *et al.* 2012; etc.)

In 2005, a study sponsored by the European Commission (DHI 2005) assessed the impacts on human health and the environment of proposed REACH[29] legislation. The study concluded that the annual environmental benefits of reducing chemical emissions in the European Union likely approximate the direct health benefits. While the DHI study did not address the case of mercury in isolation from other chemical emissions, and while one cannot categorically assume the DHI findings are directly transferable to the case of mercury, it nevertheless provides a basic marker for

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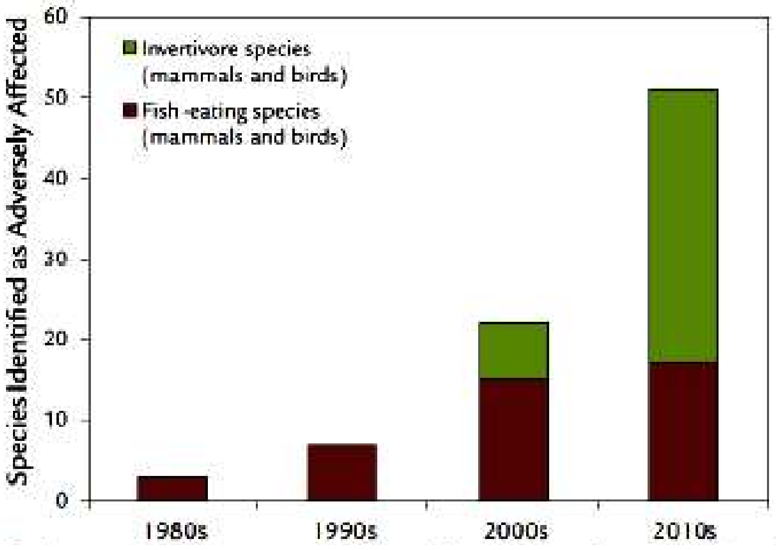
[29] REACH (Registration, Evaluation and Authorisation of CHemicals) is the acronym for a draft EU law on chemicals.

the hypothesis that the environmental benefits due to reducing mercury emissions may be considered to be in the same general range as the health benefits.

Just as more extensive health effects are being documented now than five years ago, so also are more extensive environmental effects. According to a recent publication of the Biodiversity Research Institute:

> *In recent years, researchers have identified an increasing trend of species at risk to the availability of mercury in the environment, particularly within invertivores, such as songbirds and bats. This rising trend demonstrates that the more we look, the more we find; the more we find, the more we understand about the impacts of mercury in the food web. Unfortunately, the impacts are much greater than were realized only a few years ago.* (Evers *et al.* 2012)

Figure 6 – Species determined to be at risk to mercury in the environment



Source: Evers *et al.* 2012

Based on the above research and trends, we conclude that the environmental benefits of mercury emissions reduced or avoided may be considered to be in the same general range as the health benefits.

9.3 Socioeconomic impacts

9.3.1 Commercial and recreational benefits

Along with health benefits, the economic benefits of removing fish consumption advisories along part of the Chesapeake Bay were assessed by Jakus *et al.* (2002). The authors based their calculations on changes in the value of commercial and recreational services. For commercial fishing areas, the economic impact of advisories was based on changes in supply and demand for mercury-contaminated commercial species. The reduced consumption of striped bass, for example, was converted to lost market value accruing to both consumers and fishermen. A similar approach (using the "travel cost method") was used to measure the impact of advisories on recreational angling, observing that they reduced the number of recreational trips and/or changed the species targeted.

The combined commercial and recreational economic benefits of lifting the fish consumption advisories were calculated by Jakus *et al.* at $9.1 million (2004 dollars). For comparison, the same study calculated the health benefits at $15.4 million (2004 dollars). However, the inclusion of a relatively broad range of health effects – IQ, acute myocardial infarction and all-cause mortality – may be considered to reflect the upper range of health benefits as discussed in Sections 9.1.1, 0 and 9.1.2 above. Therefore it is conservatively estimated that the commercial and recreational economic benefits of reduced mercury releases are roughly similar to the health benefits, but only for those populations and those regions where there is significant commercial and recreational activity around fishing. This is estimated to include some 10-15% of the U.S. population.

Other commercial benefits are also evident. The business of developing and marketing mercury-free filling materials is high-tech, innovative, and spread among many more companies than the handful that market amalgam. Any move that further encourages mercury-free materials will also encourage investment, R&D, marketing and related commercial activities – not to mention increased exports – well beyond any that might take place among the staid amalgam producers. The overall benefits in this case, including increased competition and a steadily decreasing price for the product, are difficult to calculate with any precision, but they are clearly significant.

In addition, it is evident that a steady move away from amalgam will also imply gradually reduced hazardous waste disposal costs for dental clinics as the quantity of mercury waste generated declines. Nevertheless, hazardous waste will be a concern for as long as patients continue to carry amalgam in their teeth. Again, this benefit is not calculated here but is noted as an anticipated reduction in the cost of doing business.

Finally, costs (today paid by all users) may be saved by public sewage treatment facilities if more of the sewage sludge has a low enough mercury concentration to be applied as fertilizer in agriculture, and therefore does not need special treatment or disposal as it often does today due to excess mercury contamination. This assessment has not, however, investigated to what extent mercury in sewage sludge is a limiting factor for its use in agricultural applications, and what the cost of that limitation may be.

9.3.2 Employment benefits

Upon examination of average comparative dental fees across the U.S. for typical 2-surface amalgam and composite fillings in rear teeth, there are only three potential explanations (directly related to the fillings) for the price difference: 1) different cost of filling materials and specialized equipment, 2) different profit margins applied to amalgam vs. composite fillings and 3) different amount of time required to place amalgam vs. composite.

The extra cost of composite filling material is $3-5 per filling. As mentioned in Section 7, the overall cost of specialized materials and equipment required to place a “typical” composite filling is no more than $5-10 more than similar costs associated with amalgam.

With regard to profit margin, there is no intrinsic reason for a dental practitioner to assess a higher profit margin for composite fillings. The profit margin would typically be an integral part of the standard hourly fee.

This leaves the amount of time required for a dental practitioner to place a filling as the only significant justification for higher composite related fees. The average 2-surface amalgam filling is placed in a rear tooth by the average dental practitioner in about 20 minutes. An equivalent composite, by contrast, presently requires 25-30 minutes of the average dental practitioner’s time, although the actual range is greater depending on the training and experience of the practitioner, the nature of the filling, etc.[30] (It may also be noted that the average composite filling time would be less but for the fact that often the hole being filled was originally drilled for an amalgam filling, which typically requires the removal of substantially more healthy tooth, and which creates a larger and differently configured hole in the tooth than would have been drilled if the original filling material were composite.)

A typical work-year of a private dental practitioner is 194 billable days, or about 87,300 minutes assuming 7.5 hours per day. If we assume that $500,000 annual revenue is generated by the average dentist, this comes to about $5.73/minute. Therefore 5-10 extra minutes required to place a composite filling would be valued at $29-57 which, together with the $5-10 of specialized materials and equipment costs, entirely explains the roughly $40 additional fee charged for a typical composite filling.

It is important to note that the need for additional time in order to deliver essentially the same service as previously – in this case to place a composite filling rather than amalgam – implies either more time required of dental practitioners already working, or the creation of new employment opportunities for dental practitioners who are not yet working or who are not fully employed. Either way, in economic terms this is the equivalent of job creation. Therefore, whatever part of the $40 difference in average composite vs. amalgam filling fees is not allocable to specialized materials and equipment should be considered an employment benefit, i.e., $30-35 per filling placed.

9.4 Additional benefits for children

Public health authorities (and amalgam manufacturers) have warned against the use of amalgam in children's teeth for a number of years in light of the particular susceptibility of the developing brain to toxic exposure, as discussed previously. Furthermore, WHO has confirmed that mercury-free restorative materials of adequate quality are available for use in children (WHO 2010). Nevertheless, as noted previously, 15% of amalgams continue to be placed in the teeth of children under the age of 10.

Since such a large number of dental practitioners would not ignore the health warnings of manufacturers and public health authorities without good reason, the only explanation must be that amalgams are perceived to be less expensive for patients and insurance companies. It is useful, therefore, to focus briefly on the real cost of amalgam use in children, especially as this particular case requires consideration of economic factors that would not necessarily apply to adults.

First, any concern about the longevity of a restoration is irrelevant when it comes to young children. Since primary teeth will eventually be replaced by permanent teeth, the maximum time a restoration needs to remain in a primary tooth is about 6 years" (Frencken *et al.* 2006).

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[30] It is important to note that composite does not intrinsically take more time to place – insufficient training and/or experience is a significant factor. As WHO has noted, dentists have more trouble using any material with which they have less training or experience (WHO 2010). Similarly, if they find a material more difficult to handle, they will not only be slower at placing the filling, but unsurprisingly they will also show a preference for other material(s) with which they are more familiar. Many dental programs provide only minimal clinical training in posterior composite placement, which would help explain why many dentists are slower with composite (Lynch *et al.* 2011). A 2011 study concluded, "...over the past two decades, studies have been conducted in North and South America, Europe and Asia examining the teaching of resin-based materials for restoring posterior teeth. The findings of each study were similar, and concluded that the emphasis on teaching posterior resin composite placement had increased, but most dental graduates had minimal clinical experience with their placement" (Liew *et al.* 2011).

Furthermore, amalgam failure rates are higher in children than in adults, and higher than for any other major alternative. According to a 2005 study published in the *American Journal of Dentistry*, "the failure of amalgam restorations occurs more frequently in primary teeth, especially in small children, due to moisture contamination of the cavities during condensation" (Hickel *et al.* 2005).

Second, mercury-free alternative materials may be considered to be more child-friendly than amalgam, as they do not typically require the same extent of preparatory drilling. This fact is likely to result in less resistance to dental visits, fewer delayed dental treatments, and hence, more frequent but simpler and less expensive treatments during childhood.[31]

Third, the special risk of exposing children to mercury from amalgam is widely acknowledged, and the costs, both short- and long-term, associated with even minor neurological damage are high. Hence the cost of incurring this particular health risk should be taken into account. Joining a number of European countries (Italy, Spain, Austria, Sweden, Norway, among others) and Australia, the U.S. and Canada have issued formal warnings:

- In its amalgam regulation, the U.S. Food and Drug Administration ("FDA") makes its point as follows. "The developing neurological systems in fetuses and young children may be more sensitive to the neurotoxic effects of mercury vapor" (FDA 2009). Subsequently, the FDA's advisory panel on dental amalgam in December 2010 expressly warned against the use of amalgam in "vulnerable populations."
- Health Canada also advised its dentists to stop using amalgam in pregnant women, in order to avoid it being passed along to the fetus, as long ago as 1996 (Health Canada 1996).

The various points above confirm that the elimination of amalgam use in children in favor of non-mercury alternatives would confer even greater benefits (per amalgam filling eliminated) than in the adult population.

9.5 Summary costs/benefits of phasing out the use of amalgam

Combining the various assessments above, Table 12 presents a summary of the range of benefits that would be accrued in 2009 if composite fillings were placed instead of amalgam. The total benefits of $3.1-6.5 billion, when allocated over the roughly 51 million amalgams placed in 2009, amount to some $60-128 for each amalgam avoided, or $72-152 per gram of mercury release avoided.

It is interesting to compare the benefits shown in Table 12 with Hagen *et al.* (1999), who used a methodology known as "contingent valuation" to calculate overall benefits to human health as well as benefits to recreational anglers and wildlife as a result of mercury reduction policies in Minnesota. In the Hagen study, people were asked how much they would be willing to pay for policies that would reduce environmental mercury levels. The authors observed that the responses captured, at least for a significant number of respondents, perceived benefits for future generations as well as broader ecosystem services, i.e., well beyond benefits linked directly to individual mercury exposure. The study found that a statewide reduction in emissions of 50% was associated with wide-ranging perceived benefits (i.e., health benefits, recreational fishing benefits

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[31] At one extreme we could cite those dentists who have become familiar with atraumatic restorative treatment (ART), which does not involve drilling equipment, who have found children to be far more willing patients (Frencken 2009).

and wildlife benefits) of \$152[32] per gram of mercury emissions avoided. While noting that Minnesota is a state in which a considerable part of the economy is associated with outdoor recreation, Hagen's result is quite comparable to the range of \$72-152 per gram of mercury avoided as presented in Table 12, while keeping in mind that the latter does not quantify a number of benefits that appear to have been included in the Minnesota study.

One important observation more or less hidden in the recent research results of increased risk to cognitive development in exposed populations is that such effects are likely to occur in a much larger fraction of the population than previously thought. In effect, it may be argued that reducing mercury exposure for the population as a whole – even by a few percent – can have a disproportionately large benefit "at the margin." Specifically, the report states that the greatest risk from methylmercury exposure is borne by a small fraction of the public, i.e., those with the greatest exposure and/or particular sensitivity. In that narrow range of the dose-response curve, the slope (which represents the unit increase in health effect per unit increase in dose, or exposure) is quite steep, and even a small reduction in exposure may have a comparatively large risk-reduction impact. Thus, it should be stressed that even relatively "small" reductions in exposure, such as those associated with the elimination of dental mercury releases to the environment, may still have quite significant beneficial effects. People farther down the dose-response curve may reap considerably lower benefits from the same reduction in mercury exposure. This is a strong reason for pursuing all feasible exposure-reduction strategies.

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[32] After conversion to 2009 dollars.

Table 12 Annual benefits of phasing out dental amalgam

			Benefit per kg Hg release eliminated			Total benefit due to dental Hg releases eliminated		
Benefit description	**Quantity of mercury (kg)**	**Assumptions regarding benefit**	**lower range**	**upper range**	**best estimate**	**lower range**	**upper range**	**best estimate**
Health benefit of eliminating 8.8 tons of mercury emissions to the atmosphere	8800	Range based primarily on studies of CFPP emissions	$50,000	$150,000	$100,000	$440,000,000	$1,320,000,000	$880,000,000
Health benefit of eliminating 3.9 tons of mercury releases to the water	3900	150% of the benefits due to reducing atmospheric emissions	$75,000	$225,000	$150,000	$292,500,000	$877,500,000	$585,000,000
Health benefit of eliminating 14 tons of mercury releases to the soil	14000	Not widely bioavailable other than runoff already included above	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Environmental benefit	12700	Assumed similar to total health benefits	n.q.	n.q.	n.q.	$732,500,000	$2,197,500,000	$1,465,000,000
Economic benefit of lifting fish consumption advisories	12700	Lower range is estimated at 10% of total health benefits; upper range at 15%	n.q.	n.q.	n.q.	$73,250,000	$329,625,000	$201,437,500
Economic benefit to the dental supply industry and customers	n.q.	Investment, innovation, R&D, competitive pricing of Hg-free materials	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Economic benefit for dental clinics due to reduced hazardous waste disposal	n.q.	Steadily decreasing quantities of mercury waste generated by clinics	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Economic benefit for wastewater treatment plants as Hg in wastewater declines	n.q.	Steadily decreasing quantities of mercury released to wastewater	n.q.	n.q.	n.q.	n.q.	n.q.	n.q.
Total non-employment benefits in 2009						**$1,538,250,000**	**$4,724,625,000**	**$3,131,437,500**
Non-employment benefits per filling		Divide by 51 million fillings in 2009				$30.16	$92.64	$61.40
Employment benefit per filling						$30.00	$35.00	$32.50
Total benefits per amalgam filling eliminated						**$60.16**	**$127.64**	**$93.90**
Total benefits in 2009		Multiply by 51 million fillings in 2009				$3,068,250,000	$6,509,625,000	$4,788,937,500
Total benefits per g of dental Hg releases eliminated		**Divide by 42.8 tons of releases in 2009**				**$71.69**	**$152.09**	**$111.89**
Note: n.q. = not quantified								

10 Potential hazards of mercury-free filling materials

One occasionally hears that the filling materials used in place of amalgam may have their own risks. In general, EU health authorities and dental associations have concluded that the use of non-metallic restoration materials is safe for patients (including pregnant woman and children), as well as for dental health professionals.

Some resin-based filling materials contain bisphenol A (BPA), a known endocrine disruptor. Researchers have concluded that BPA exposure from composite resins is considerably lower than tolerable daily intake values specified by Health Canada, the USEPA and the EU Scientific Committee for Food, and do not present a significant risk for adverse health effects (Richardson *et al.* 1999; SCENIHR 2008; Van Landuyt *et al.* 2011). Moreover, composite resins without BPA are widely available and, according to the American Dental Association, BPA is an increasingly rare ingredient in alternative filling materials (ADA 2010).

One key advantage of mercury-free restoration techniques is that they leave more intact natural tooth tissue as compared with dental amalgam restoration. While the use of dental amalgam tends to weaken the tooth structure (due to the removal of substantial healthy tooth tissue), alternative materials tend to prolong the life of the tooth beyond what may be expected from amalgam. WHO recently confirmed that preserving the tooth structure and improving the survival of the tooth is imperative (WHO 2010).

Due to the concerns sometimes expressed that there may yet be minimal unknown risks associated with the use of mercury-free filling materials, for the purpose of this analysis it is assumed that any such risks are more than offset by the significant benefits of retaining more of the natural tooth structure.

11 Conclusions

In order to obtain a useful perspective on the “external” costs to society that are not included in the fees a dental patient pays the practitioner, we have examined 1) the costs of keeping dental mercury releases from being released into the environment, and 2) when dental mercury is no longer released into the environment, the various benefits accrued to human health and society. As shown in Table 13, whichever analytical approach one chooses, even when using conservative assumptions, and even allowing for the uncertainties inherent in much of the cost data, it is clear that the real cost of using amalgam far outweighs the cost of using mercury-free composite, not to mention an even cheaper alternative such as ART.

Table 13 Average dental clinic fee vs. the real cost of an average ("equivalent") amalgam filling

	Rear tooth "equivalent" composite filling	**Rear tooth "equivalent" amalgam filling**
Average private clinic fee	$185	$144
Methodology 1 – "External" costs of preventing toxic dental materials from being released into the environment*	$0 – minimal**	$41-67
Total real cost (Methodology 1)	**~$185**	**$185-211**
Methodology 2 – Benefits to health and society of phasing out dental amalgam	$0 – minimal**	$60-128
Total real cost (Methodology 2)	**~$185**	**$204-272**

* In the case of mercury, this is the cost of preventing 90% of dental mercury from entering the environment.
** See discussion in Section 1.

The inescapable conclusion is that continued reliance on amalgam as a main option for dental care is one that will only be more costly to the economy and the environment than the mercury-free options. As confirmed by a recent report for the European Commission, "the fact that Hg-free dental restorations are more expensive than dental amalgam restorations can be seen as a market failure in the sense that negative externalities associated with the use of dental amalgam (management of dental waste and effluents) are not factored in the actual price of dental amalgam restorations" (BIO 2012).

Moreover, completely apart from the economic arguments, i.e., for primarily environmental reasons, the World Health Organisation has recently come out in support of a "phase-down" of the use of amalgam (WHO 2010).

Nevertheless, the challenges to doing so are well spelled out in a recent UNEP report on renewable energies, with which there are a number of parallels. The report notes that the shift to renewables "has not been realized due to many barriers. An important task is to identify the means to eliminate the economic, regulatory and institutional barriers … that undermine its competitiveness…." (UNEP 2012).

This analysis has demonstrated that the figures periodically reported by industry to the Interstate Mercury Education and Reduction Clearinghouse (IMERC) for dental mercury sales in the U.S. seriously underrepresent the actual situation. This report calculates dental mercury consumption for 2009 at over 32 tons, while the equivalent IMERC figures suggest less than 20 tons. Since the former calculation is based on extensive ADA survey results, there is strong reason to believe that IMERC does not receive reports from all companies selling dental mercury in the U.S. This is an important conclusion because any calculations of environmental and other effects must be based on a clear understanding of the extent of mercury use in dental applications. Likewise any targets for reducing amalgam use need to be based on a solid understanding of the actual situation.

This is in no way a criticism of the IMERC approach, but rather an argument for the IMERC reporting requirement to be extended to all manufacturers of amalgam selling their products anywhere in the U.S., and for the requirement to be rigorously enforced. This effort is not only necessary to establish a solid "baseline" for the use of dental mercury, but the least one might expect in terms of regulating commercial transactions involving a toxic substance.

In closing, it is important to recall that public health authorities (and amalgam manufacturers) have warned against the use of amalgam in children's teeth for a number of years in light of the particular susceptibility of the developing brain to toxic exposure. Furthermore, WHO has confirmed that mercury-free restorative materials of adequate quality are available for use in children (WHO 2010). Nevertheless, 15% of amalgams are placed in the teeth of children under the age of 10. While not the main focus of this analysis, this is a situation that can no longer be ignored. It represents an entirely unnecessary risk to children's health, and immediate action should be taken to eliminate the risk.

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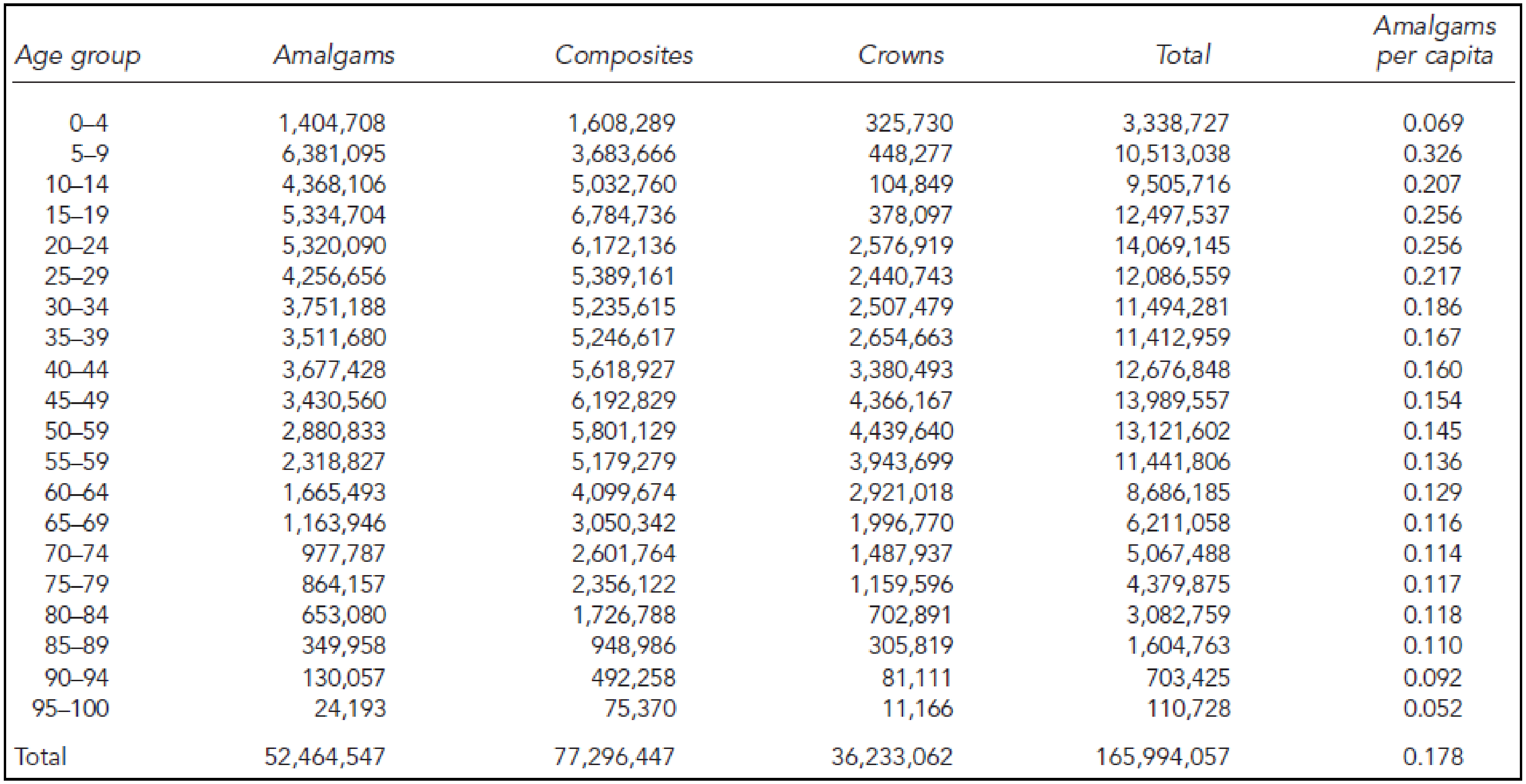
Appendix I U.S. 20-city private practice dental filling costs (2009)

City, State	2009 population (U.S. Census Bureau)	1-surface amalgam (baby)	1-surface amalgam (permanent)	2-surface amalgam (baby)	2-surface amalgam (permanent)	3-surface amalgam (baby)	3-surface amalgam (permanent)	1-surface composite (front)	1-surface composite (rear)	2-surface composite (front)	2-surface composite (rear)	3-surface composite (front)	3-surface composite (rear)
Mobile, Alabama	193205	$88.95	$115.32	$101.36	$126.19	$119.98	$144.81	$109.12	$110.67	$152.56	$174.29	$186.70	$256.53
Yuma, Arizona	91105	$93.65	$121.44	$106.73	$132.88	$126.34	$152.49	$114.90	$116.53	$160.66	$183.54	$196.62	$270.16
Sacramento, Calif.	466676	$123.14	$159.71	$140.35	$174.77	$166.17	$200.59	$151.11	$153.26	$211.35	$241.47	$258.68	$355.50
Pueblo, Colorado	104877	$85.27	$110.55	$97.17	$120.97	$115.02	$138.81	$104.61	$106.09	$146.25	$167.07	$178.97	$245.89
Pensacola, Florida	53752	$90.17	$116.91	$102.75	$127.93	$121.63	$146.80	$110.62	$112.19	$154.67	$176.69	$189.28	$260.07
Gary, Indiana	95707	$87.25	$113.12	$99.43	$123.78	$117.69	$142.04	$107.03	$108.56	$149.65	$170.96	$183.13	$251.62
Minneapolis, Minn.	385378	$96.01	$124.49	$109.41	$136.22	$129.52	$156.33	$117.79	$119.47	$164.71	$188.17	$201.57	$276.98
Cedar Rapids, Iowa	127764	$93.65	$121.44	$106.73	$132.88	$126.34	$152.49	$114.90	$116.53	$160.66	$183.54	$196.62	$270.16
Trenton, New Jersey	83242	$118.71	$153.97	$135.30	$168.48	$160.19	$193.37	$145.67	$147.74	$203.74	$232.77	$249.36	$342.69
Hattiesburg, Miss.	53582	$87.53	$113.49	$99.75	$124.18	$118.07	$142.50	$107.38	$108.91	$150.13	$171.51	$183.73	$252.44
Goldsboro, N. Carolina	38335	$94.60	$122.66	$107.80	$134.22	$127.61	$154.03	$116.06	$117.71	$162.28	$185.39	$198.60	$272.89
Houston, Texas	2257926	$88.10	$114.22	$100.39	$124.98	$118.83	$143.42	$108.08	$109.61	$151.11	$172.62	$184.92	$254.07
Philadelphia, Penn.	1547297	$118.71	$153.97	$135.30	$168.48	$160.19	$193.37	$145.67	$147.74	$203.74	$232.77	$249.36	$342.69
Provo, Utah	119775	$98.36	$127.55	$112.10	$139.57	$132.70	$160.17	$120.68	$122.40	$168.76	$192.79	$206.53	$283.79
Cleveland, Ohio	431369	$98.84	$128.16	$112.64	$140.24	$133.34	$160.94	$121.26	$122.99	$169.57	$193.72	$207.52	$285.15
Madison, Wisconsin	235419	$106.18	$137.70	$121.01	$150.68	$143.26	$172.93	$130.29	$132.14	$182.20	$208.16	$222.99	$306.42
Topeka, Kansas	124331	$94.22	$122.17	$107.37	$133.68	$127.10	$153.41	$115.59	$117.24	$161.63	$184.65	$197.81	$271.79
Fargo, North Dakota	95556	$93.56	$121.32	$106.62	$132.74	$126.21	$152.34	$114.78	$116.42	$160.50	$183.36	$196.42	$269.89
Baltimore, Maryland	637418	$114.85	$148.95	$130.90	$162.99	$154.97	$187.07	$140.93	$142.93	$197.10	$225.18	$241.23	$331.51
Burlington, Vermont	38647	$111.83	$145.04	$127.46	$158.71	$150.90	$182.15	$137.23	$139.18	$191.92	$219.26	$234.89	$322.78
Total population	7181361												
20-city weighted aver.		**$102.03**	**$132.30**	**$116.27**	**$144.77**	**$137.65**	**$166.15**	**$125.18**	**$126.96**	**$175.05**	**$199.99**	**$214.24**	**$294.39**

Source: http://www.bracesinfo.com/dentalcosts/methodology.htm, based on the relevant American Dental Association (ADA) survey, U.S. Bureau of Labor Statistics monthly survey of private practice dental treatment costs in the U.S., etc.

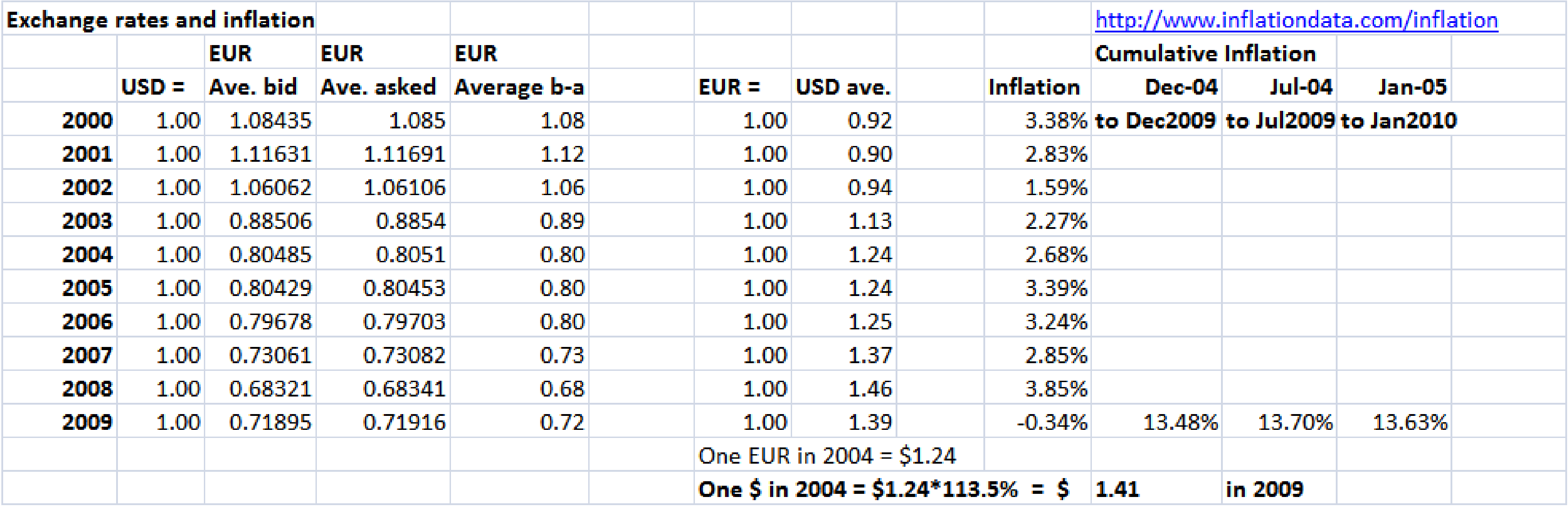
Appendix II **Number of restorations by type of restoration and per capita number of amalgams placed in the U.S. population (2005)**



Age group	Amalgams	Composites	Crowns	Total	Amalgams per capita
0–4	1,404,708	1,608,289	325,730	3,338,727	0.069
5–9	6,381,095	3,683,666	448,277	10,513,038	0.326
10–14	4,368,106	5,032,760	104,849	9,505,716	0.207
15–19	5,334,704	6,784,736	378,097	12,497,537	0.256
20–24	5,320,090	6,172,136	2,576,919	14,069,145	0.256
25–29	4,256,656	5,389,161	2,440,743	12,086,559	0.217
30–34	3,751,188	5,235,615	2,507,479	11,494,281	0.186
35–39	3,511,680	5,246,617	2,654,663	11,412,959	0.167
40–44	3,677,428	5,618,927	3,380,493	12,676,848	0.160
45–49	3,430,560	6,192,829	4,366,167	13,989,557	0.154
50–59	2,880,833	5,801,129	4,439,640	13,121,602	0.145
55–59	2,318,827	5,179,279	3,943,699	11,441,806	0.136
60–64	1,665,493	4,099,674	2,921,018	8,686,185	0.129
65–69	1,163,946	3,050,342	1,996,770	6,211,058	0.116
70–74	977,787	2,601,764	1,487,937	5,067,488	0.114
75–79	864,157	2,356,122	1,159,596	4,379,875	0.117
80–84	653,080	1,726,788	702,891	3,082,759	0.118
85–89	349,958	948,986	305,819	1,604,763	0.110
90–94	130,057	492,258	81,111	703,425	0.092
95–100	24,193	75,370	11,166	110,728	0.052
Total	52,464,547	77,296,447	36,233,062	165,994,057	0.178

Source: Based on dental insurance claims data as provided by Delta Dental of Michigan, Ohio, and Indiana, and analyzed and presented by Beazoglu *et al.* (2007).

Appendix III Exchange rates and inflation 2000-2010



Exchange rates and inflation										http://www.inflationdata.com/inflation			
		EUR	**EUR**	**EUR**						**Cumulative Inflation**			
	USD =	**Ave. bid**	**Ave. asked**	**Average b-a**		**EUR =**	**USD ave.**		**Inflation**	**Dec-04**	**Jul-04**	**Jan-05**	
2000	1.00	1.08435	1.085	1.08		1.00	0.92		3.38%	**to Dec2009**	**to Jul2009**	**to Jan2010**	
2001	1.00	1.11631	1.11691	1.12		1.00	0.90		2.83%				
2002	1.00	1.06062	1.06106	1.06		1.00	0.94		1.59%				
2003	1.00	0.88506	0.8854	0.89		1.00	1.13		2.27%				
2004	1.00	0.80485	0.8051	0.80		1.00	1.24		2.68%				
2005	1.00	0.80429	0.80453	0.80		1.00	1.24		3.39%				
2006	1.00	0.79678	0.79703	0.80		1.00	1.25		3.24%				
2007	1.00	0.73061	0.73082	0.73		1.00	1.37		2.85%				
2008	1.00	0.68321	0.68341	0.68		1.00	1.46		3.85%				
2009	1.00	0.71895	0.71916	0.72		1.00	1.39		-0.34%	13.48%	13.70%	13.63%	
						One EUR in 2004 = $1.24							
						One $ in 2004 = $1.24*113.5% = $				**1.41**	**in 2009**		