CLIMATE AND POLLUTION AGENCY

Mercury

Review of Norwegian experiences with the phase-out of dental amalgam use

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Preface

Vista Analysis has been asked by the Norwegian Climate and Pollution Agency (Klif) to review the experiences from the phase-out of the use of dental amalgam as tooth filling material in Norway, and make an assessment of the costs to the society from the actions taken to limit the release of mercury. The purpose is to show how Norway has carried out this policy.

The final report is written by John M. Skjelvik, and Eirik Schou Grytli has contributed to the interviews with dentists and other data collection. Karin Ibenholt has been the internal quality controller. Potential errors and misunderstandings are Vista Analysis's responsibility.

Oslo, 10. mai 2012.

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Content

Executive Summary

Mercury is among the most hazardous substances. Dental amalgam is the largest use area of mercury-added products worldwide and a significant source of mercury release to the environment in Norway. Norway has a national goal of eliminating use and release of mercury by 2020.

Background

New filling materials were introduced in Norway in the 1970s, and were gradually preferred for aesthetic reasons. Focus on dental amalgam as an environmental problem emerged during the 1980s as part of a broader policy to limit emissions of mercury. In 1991 the health authorities issued guidelines recommending dentists to reduce the use of dental amalgam, and new guidelines from 2003 required that other materials than dental amalgam should be considered as the first choice in tooth fillings. Preventive use of fluoride has also contributed to improved dental health and reduced use of dental amalgam.

A requirement to have an approved dental amalgam separator installed in all dental clinics was introduced in 1994. Requirements to control the mercury air emissions from crematoria with more than 200 cremations per year were implemented in 2007.

Norway introduced a general ban on the use of mercury in products from 2008. Limited exemptions for dental amalgam use were applied until the end of 2010.

Main conclusions from the review

From this review of the experiences from the phase-out of the use of amalgam as tooth filling material in Norway the following conclusions are presented:

Use and release of mercury are substantially reduced

The estimated use of mercury in tooth fillings has been considerably reduced over the years. Early sources indicate that the use of mercury in new tooth fillings was as high as 2 000 kg in 1985. In 1995 the use of mercury in new tooth fillings was 840 kg, and was then gradually reduced close to zero in 2008 when the general use was banned (Klif 2010a, 2010c).

The mercury release to water from dental amalgam use was significantly reduced from 1995 to 2008. This is partly a result of the requirement to install amalgam separators in dental clinics from 1994.

Amalgam fillings have long durability. The quantity of amalgam in the population represents approximately 10 tons of mercury in Norway today (the total Norwegian population is close to 5 million people). People over fifty years have considerable amounts of amalgam fillings. As people pass away or the fillings are replaced with other materials, the quantity of mercury in the population will decline. It is expected that mercury release from existing fillings will continue for up to at least 30 years.

Experiences with the alternatives to dental amalgam are generally positive

The interviews performed among dentists for this report, as well as earlier assessments by others show that dental personnel and patients generally are satisfied with the alternatives to dental amalgam. The most common material used now is resin-based composites, but various glass ionomers and ceramic-based materials are also used to some extent. The necessary technical equipment and basic skills to use the alternative materials have been established over long time.

The main advantages with the alternatives from the dental personnel's point of view are that the materials have good adhesive properties, implying that one needs to remove less amounts of the sound tooth substance compared to when using amalgam. Therefore, it sometimes takes less time to use the alternative materials in small fillings. However, larger fillings are somewhat more time-consuming to apply and can take 15-45 minutes longer time, depending on the dentist's skill and the complexity of the filling. For the economic assessment presented in this report, 15-30 minutes is used in the calculations. An important advantage for dental personnel's health is that amalgam is not used in the working environment.

A disadvantage is that the alternative materials can be challenging to use, especially in larger fillings. Another disadvantage is that bacteria are more easily formed on the surface of the filling, thus requiring more follow up from both the patient and the dentist. Because of this and less "chewing-strength" the composite fillings do not yet last as long as the amalgam fillings (some say half the lifetime of amalgam fillings), but the longevity is increasing and approaching the longevity of amalgam fillings.

When introduced, the alternative materials were reported to cause some allergic reactions in the mouth of patients and in the hands of the dental personnel. However, the number of reported adverse impacts from the use of resin-based fillings has not increased to the same degree as the increase in the use of these materials.

Abatement "end-of-pipe" costs lower than dental amalgam phase-out costs

The interviews for this report shows that the marginal costs of measures aiming at reducing the emissions from dental clinics and crematoria are generally substantially lower than the marginal costs related to phasing out the use of amalgam in tooth fillings. Abatement costs for a dental amalgam separator are calculated to NOK 8,000 – 12,400 (€ 1,000 – 1,550)/kg mercury, and emission reductions from crematoria are estimated to cost around NOK 29,200 – 122,000 (€ 3,650 – 15,250)/kg mercury. In comparison, costs of phasing out the use of amalgam in new fillings are calculated to some NOK 67,000 – 533,000 (€ 8,375 – 66,625)/kg mercury or some NOK 67 – 533 (€ 8.5 – 67)/filling and are not including costs related to more frequent replacements of fillings. In Norway the costs are mostly borne by the adult consumers.

The substitution of dental amalgam started as a result of public awareness and guidelines from the health authorities before the general ban on mercury in products was introduced by the environmental authorities. Thus, it is difficult to assess the total costs of the ban itself. However, policy actions have been important in the substitution process.

Most of the costs related to the phase-out of dental amalgam are related to increased time spent at dental clinics when using the alternatives, and to more frequent change of fillings. Also, composite fillings are improving and will likely last longer in the future and thus reduce the need for filling changes and the total costs associated with it.

Dental amalgam phase-out should be seen in a broader perspective

Assessing the various interventions purely from an abatement cost comparison could easily lead to the conclusion that dental amalgam separation/collection and abatement of emissions from crematoria should be required, and that the choice of filling materials should be left to the dentist and patient.

However, since the overall, long term goal is to eliminate the use and release of mercury to the environment, the use of mercury has to be addressed. Therefore, the use of dental amalgam should be phased out, and at the same time the actions towards the release of mercury from existing tooth fillings have to be implemented. In the future, when there is no mercury left in tooth fillings, the need for dental amalgam separation/collection and abatement of emissions from crematoria will cease.

Sammendrag

Kvikksølv er blant de farligste helse- og miljøskadelige stoffene. Dentalt amalgam er på verdensbasis den største produktgruppen som inneholder kvikksølv og er en betydelig kilde til utslipp av kvikksølv. Norge har et nasjonalt mål om å eliminere bruk og utslipp av kvikksølv innen 2020.

Bakgrunn

Nye fyllingsmaterialer ble introdusert på 1970-tallet, og er etter hvert blitt foretrukket av estetiske årsaker. Fokuset på dentalt amalgam som et miljøproblem vokste gjennom 1980-tallet som del av en mer omfattende politikk for å begrense utslippene av kvikksølv. Helsemyndighetene utga i 1991 retningslinjer som anbefalte tannlegene å redusere bruken av dentalt amalgam, og nye retningslinjer i 2003 slo fast at andre materialer enn dentalt amalgam skulle være førstevalget i tannfyllinger. Bruken av dentalt amalgam har også gått gradvis ned på grunn av bruk av fluor som har ført til bedre tannhelse.

Et krav om å installere godkjent amalgamavskiller i alle tannklinikker ble innført i 1994. Krav om å kontrollere utslippene av kvikksølv til luft fra krematorier med flere enn 200 kremasjoner per år ble innført i 2007.

Norge introduserte et generelt forbud mot bruk av kvikksølv i produkter fra 2008. Et begrenset unntak for dentalt amalgam gjaldt til utgangen av 2010.

Hovedkonklusjoner

Fra gjennomgangen av erfaringene med utfasingen av amalgam som tannfyllingsmateriale i Norge kan det trekkes følgende hovedkonklusjoner:

Bruk og utslipp av kvikksølv er betydelig redusert

Den anslåtte bruken av kvikksølv i tannfyllinger er betydelig redusert over årene. Tidlige kilder antyder at bruken av kvikksølv i nye tannfyllinger var så høy som 2 000 kg i 1985. I 1995 var bruken av kvikksølv i nye tannfyllinger 840 kg, og den ble så gradvis redusert til tilnærmet null i 2008 da den generelle bruken ble forbudt (Klif, 2010a, 2010c).

Utslippene av kvikksølv til vann fra dentalt amalgam ble betydelig redusert fra 1995 til 2008. Dette er delvis et resultat av påbudet om godkjent amalgamavskiller i tannklinikkene fra 1994.

Amalgamfyllinger har lang levetid. Mengden amalgam i eksisterende tannfyllinger i Norge i dag representerer ca. 10 tonn kvikksølv (den totale befolkningen er på nesten 5 millioner). Personer over femti år har store mengder amalgamfyllinger i tennene. Etter hvert som folk dør eller fyllingene erstattes med andre materialer vil denne mengden reduseres. Det må imidlertid forventes at kvikksølv fortsatt vil slippes ut fra eksisterende fyllinger i minst 30 år framover.

Erfaringene med alternativene til dental amalgam er generelt positive

Det mest brukte materialet i bruk i dag er plastbaserte kompositter, men ulike glassionomer og keramikkbaserte materialer brukes også i noen grad. En intervjurunde blant tannleger for denne studien viser at både tannhelsepersonell og pasienter generelt er fornøyde med de alternative materialene Det nødvendige tekniske utstyret og grunnferdighetene blant personellet for å håndtere de nye materialene er blitt utviklet over lang tid.

Hovedfordelene med alternativene til dental amalgam sett fra tannhelsepersonellets side er at materialene har gode festeegenskaper, noe som betyr at en kan nøye seg med å fjerne mindre av den friske tannen enn om en bruker dentalt amalgam. Derfor tar det noen ganger mindre tid å bruke de alternative materialene i små fyllinger. Større fyllinger er imidlertid noe mer tidkrevende å legge og kan ta mellom 15-45 minutter mer tid avhengig av tannlegens dyktighet og fyllingens kompleksitet. I denne kostnadsberegningen er 15-30 minutter vært brukt. En viktig helsefordel i arbeidsmiljøet er at amalgam ikke lengre brukes.

En ulempe er at de alternative materialene kan være krevende å bruke, spesielt for store fyllinger. En annen ulempe er at bakterier lettere dannes på overflaten av en fylling, noe som krever noe mer grundig oppfølging av pasienten og tannlegen. På grunn av dette og mindre «tyggestyrke» varer komposittfyllingene ennå ikke så lenge som amalgamfyllingene (noen påstår at de varer halvparten så lenge som amalgamfyllinger), men de fleste tannleger hevder at levetiden øker og nærmer seg levetiden for amalgamfyllinger.

I de første årene de nye materialene var i bruk ble det rapportert noen allergiske reaksjoner i munnen på pasienter og i hendene til tannhelsepersonellet. Men antallet rapporterte bivirkninger fra bruk av de nye materialene har ikke økt i like stor grad som den økte bruken av disse materialene.

Rensekostnadene lavere enn kostnadene ved å fase ut bruken av dental amalgam

Undersøkelsen i denne studien viser at de marginale kostnadene ved tiltakene som tar sikte på å redusere kvikksølvutslippene fra tannklinikker og krematorier generelt er mye lavere enn de marginale kostnadene knyttet til å fase ut bruken av amalgam i tannfyllinger. Tiltakskostnadene for en amalgamavskiller er beregnet til rundt NOK 8.000 – 12.400 (€ 1.000 – 1.550)/kg kvikksølv, og utslippsreduksjoner fra krematorier er anslått å koste rundt NOK 29.200 – 122.000 (€ 3.650 – 15.250)/kg kvikksølv. Kostnadene ved å fase ut bruken av amalgam i nye fyllinger er til sammenlikning beregnet til NOK 67.000 – 533.000 (€ 8.375 – 66.625)/kg kvikksølv eller ca. NOK 67 – 533 (€ 8,5 – 67)/fylling, ikke inkludert kostnadene ved hyppigere skifte av fyllinger. I Norge belastes kostnadene i all hovedsak de voksne konsumentene.

Substitusjon av dentalt amalgam startet som et resultat av offentlig oppmerksomhet og retningslinjene fra helsemyndighetene før miljømyndighetene innførte det generelle forbudet mot kvikksølv i produkter. Det er derfor vanskelig å vurdere de totale kostnadene ved forbudet. Men tiltakene har vært viktige i substitusjonsprosessen.

Det meste av kostnadene ved utfasingen av dentalt amalgam er relatert til høyere tidsbruk hos tannklinikkene når de bruker de alternative materialene, samt til kostnadene ved hyppigere skifter av fyllinger. Komposittene må også forventes å få lengre levetid i fremtiden og dermed redusere behovet for skifte av fyllinger og kostnadene knyttet til dette.

Utfasing av dentalt amalgam må sees i et bredere perspektiv

Vurdering av tiltakene kun ut fra en sammenlikning av tiltakskostnadene kan lett lede til en konklusjon om at separering/innsamling av dentalt amalgam og rensing av utslippene fra krematoriene burde gjennomføres, og at valget av materialer i fyllinger kan overlates til tannlegene og pasientene.

Ettersom det overordnede, langsiktige målet er å eliminere bruk og utslipp av kvikksølv til omgivelsene, må bruken av kvikksølv også adresseres. Derfor bør bruken av dentalt amalgam fases ut, samtidig som tiltakene rettet mot utslippene fra eksisterende tannfyllinger gjennomføres. Når det i framtiden ikke er noe kvikksølv igjen i tannfyllingene vil det ikke lenger være behov for amalgamavskillere og tiltak mot utslipp fra krematoriene.

1 Introduction

1.1 Mercury

Mercury is one of the most toxic pollutants and is a global threat to human health and the environment (UNEP, 2008). Dietary intake of and contact with various mercury compounds may cause permanent brain damage, particularly in the fetus. Mercury exposure may also increase heart rate and blood pressure, and thus cause cardiovascular disease. Inorganic mercury can cause kidney damage. Exposure to mercury can also lead to contact allergy and cause acute poisoning. Mercury is not degradable, and accumulates in food chains.

There are several different chemical forms of mercury: elemental mercury, organic and inorganic mercury. The health and environmental problems associated with mercury are mainly a result of bacterial conversion of inorganic mercury under anaerobic conditions in aquatic systems to the highly toxic organic compound methyl mercury. Methyl mercury accumulates in the food chain and is found in fish, where it is stored largely in the muscle tissue. Dietary intake of fish and other seafood is an important source for human exposure to mercury.

Methyl mercury is mainly absorbed through the digestive tract. Mercury vapor is mainly absorbed by the lungs. The body processes these forms of mercury differently and has different levels of tolerance for mercury vapor and methyl mercury. Methyl mercury is more toxic than mercury vapor.

Mercury is transported over long distances with ocean currents and in the atmosphere. Pollution thus spreads to areas far from emission sources, especially to the highly vulnerable Arctic environment. Deposition of atmospheric, long range mercury in Norway was in 2008 calculated to approximately 2,200 kg. This was 2.5 times the national emissions to air, water and soil that year, or about 3 times the national emissions to air (Norwegian Pollution Control Authority (Klif[1], 2010b).

Despite the fact that many countries have taken steps to reduce mercury pollution, more action is still needed to reduce global pollution. The UNEP's[2] Mercury Programme was established in 2003 on the basis of the conclusions from a global risk assessment of mercury. International negotiations on a legally binding instrument on mercury started in 2010 and the goal is to complete the negotiations by 2013.

1.2 Dental amalgam is one of the largest sources of mercury pollution

The use of mercury in tooth filling materials has been some of the largest use areas of mercury-containing products. Mercury is used to bind the alloy particles together into a strong, durable, and solid filling. Mercury's unique properties (it is the only metal that is a liquid at room temperature and that bonds well with powdered metal alloys) have made it an important component of dental amalgam that contributes to its longevity.

[1] Former Norwegian Pollution Control Authority (SFT)
[2] United Nations Environment Programme

1.3 Norway has phased out the use of dental amalgam

Other dental filling materials were introduced in Norway in the 1970s. In 1991 the health authorities issued guidelines in order to reduce the use of dental amalgam, and new guidelines from 2003 required that other materials than amalgam should be considered as the first choice in tooth fillings. The use of amalgam in tooth filling was prohibited from 1 January 2008 as part of a general ban of the use of mercury in products. Requirement to install dental amalgam separators in the waste water stream from dental clinics entered into force in 1994, and limits for mercury emissions to air from crematoria were implemented in 2007. Together all these actions have substantially reduced the importance of dental amalgam as a source for mercury emissions to air, water and soil in Norway.

1.4 This report reviews the actions taken

This report presents the results of a review of the experiences with the phase-out of dental amalgam use in Norway, and estimates the costs to society of the various actions taken. The benefits from the actions in the form of reduced releases of mercury to the environment are described. The review has focused on the advantages and disadvantages for dental treatment personnel and patients from using tooth fillings with alternative materials to amalgam.

Costs for the dental clinics and the patients and costs of installing dental amalgam separators and mercury air emissions abatement measures in crematoria are estimated and compared to previous cost assessments and international data. Since many of these actions were taken several years ago it has been hard to find good Norwegian cost data for some of the actions. The results are presented in the form of costs per unit (dental clinic, filling, cremation) and per kilogram (kg) mercury emissions removed. Some few estimates of total costs to the Norwegian society from the actions are also presented.

Data have been gathered from dental clinics, material and equipment suppliers, crematoria, local and central authorities etc. Another important data sources has been various reports from Klif and UNEP on Norwegian and international evaluations, cost assessments and other documents, see the reference list.

Through the UN negotiations Norway is actively pursuing a legally binding global agreement on the reduction of the use and release of mercury. A ban on the use of products containing mercury is one of the areas Norway will focus on in particular. Thus, the results from this review show the experiences from actions taken in Norway and the related costs. Therefore, the report also present estimated costs for some selected countries calculated by using purchasing power parity (PPP) exchange rates.

2 Dental amalgam

In this section we give a brief overview of the use of dental amalgam and its substitutes.

2.1 What is dental amalgam?

Dental amalgam is a dental filling material used to fill cavities caused by tooth decay. It has been used for more than 150 years in hundreds of millions of patients worldwide (FDA, 2009). Dental amalgam is a mixture of metals, consisting of liquid mercury and a powdered alloy composed of silver, tin, and copper. Approximately 50 percent of dental amalgam is elemental mercury by weight. Amalgam fillings are also known as "silver fillings" because of their silver-like appearance.

When placing dental amalgam, the dentist first drills the tooth to remove the decay and then shapes the tooth cavity for placement of the filling. Then a softened dental amalgam putty is placed in the prepared cavity, where it hardens into a solid filling. Two types of dental amalgam were used in Norway; 1) copper amalgam where the amalgam tablets were softened by heating and triturated before placed in the cavity, and 2) dental amalgam where mercury was mixed with alloy powder in closed devises or through the use of multi-use capsules with pre-dosed amounts of mercury. In recent years mostly single time use, disposable capsules were used. The copper amalgam was not used in Norway after 1994.

2.2 Alternatives to dental amalgam

Other materials can also be used to fill cavities caused by dental decay. Like dental amalgam, these direct filling materials are used to restore the biting surface of a tooth that has been damaged by decay (FDA, 2009). The primary alternatives to dental amalgam are as follows:

- Composite resin fillings
- Glass ionomer fillings

Composites consisting of plastic materials were introduced already in the 1970s. Initially, they were only used in teeth without chewing pressure. But their technical and chemical properties gradually improved to be used in molars. The use of these materials increased for aesthetic reasons and because of the risks associated with the use of dental amalgam.

Today compomers, giomers, and dental porcelain inlays, gold inlays and full crowns are also viable alternatives to dental amalgam. Below some of the properties of these materials are elaborated.

- *Composite resin fillings* are the most common alternatives to dental amalgam. They are sometimes called "tooth-colored" or "white" fillings because of their color. Composite resin fillings are made of a type of plastic (an acrylic resin) reinforced with powdered glass. The color (shade) of composite resins can be customized to closely match surrounding teeth. They easily blend in with surrounding teeth and require minimal removal of healthy tooth structure for placement compared with dental amalgam. Composites require a bonding system for micromechanical adhesion to the tooth structure. But they may be less durable than dental amalgam and may need to be replaced more frequently. They also tend to cost more than some other types of dental filling materials, notably amalgam.

- Glass ionomer cement fillings are based on the reaction of silicate glass powder and polyalkenoic acid. These tooth-coloured materials were introduced in 1972 for use as restorative materials for small cavities. Glass ionomer cements have the ability to bond chemically to dental hard tissues and to release fluoride for a relatively long period. Their chief disadvantage is that they are limited to use in small restorations due to low resistance to fracture.
- *Resin-modified glass ionomers* combine the traditional glass ionomer with a resin material. Such materials undergo both an acid-base ionomer reaction supplemented by a second resin polymerization initiated (usually) by a light-curing process. These materials are more fracture resistant than glass ionomers and combined with the ability of chemical bond to tooth substance, they are used for small restorations, especially in pediatric dentistry, in addition to the same indications as glass ionomers.
- *Compomers* have a composition similar to that of a dental composite modified with glass ionomer, making it a polyacid-modified composite. Compomers still require a bonding system to bond to tooth tissue and are less force resistant than composites. It is used for small restorations in pediatric dentistry and serves as an alternative to resin-modified glass ionomers in such cases.
- *Giomer* is a subgroup of composite resins using fluoride containing fillers. They are infrequently in use.
- *Dental porcelain and gold alloys* is used for inlays and onlays and requires manufacture in a laboratory, so called indirect technique. Despite excellent properties for dental restoration gold alloys and dental porcelain is less frequently used because of its costs and time-consuming procedure.

The experiences with the use of the various filling materials in Norway are discussed in section 4.

3 The use and release of mercury from tooth fillings in Norway

In this section we present an overview of the development of the regulations of the use of amalgam in tooth fillings in Norway, and the various measures taken to reduce the release of mercury from tooth fillings to the environment.

3.1 Dental amalgam was first addressed as a health problem

3.1.1 A long history of dental amalgam use

In Norway, dental amalgam has been used as a restorative material in dentistry for more than a century, and has helped to eliminate class distinctions with regard to the dental health of the population (Norwegian Board of Health, 1999). Most Norwegians today aged 50 years and older have many and extensive amalgam fillings in their teeth, for which reason they are often referred to as the "fillings generation". However, despite many cavities they were enabled to retain their teeth. This was largely due to the availability of such a cheap and durable restorative material as dental amalgam.

3.1.2 Dental health improved

Since the 1970s dental health in general and of children and youth in particular has improved, largely as a result of preventive use of fluoride. A survey showed that in 1985 50 percent of all five-year olds had caries-free teeth; in 1997 this figure had risen to 70 percent. The corresponding figures for 18-year-olds for the same years were 1 percent and 13 percent, respectively (Norwegian Board of Health, 1999).

3.1.3 Potential health impacts from dental amalgam use

It is recognized that amalgam fillings release mercury which is absorbed by the human organism. Furthermore, it has been broadly agreed that mercury from amalgam fillings constitutes a considerable part of the general population's mercury exposure (Norwegian Directorate of Health, 2003). The amount of mercury vapor released from amalgam fillings increase with increased chewing, tooth brushing etc. Humans with high concentrations of mercury in the blood and/or urine because of intensive use of chewing gum are reported (Norwegian Directorate of Health, 2003).

It is documented in Norwegian and international studies that mercury from amalgam fillings could be traced in various parts of the human body, see for instance the Norwegian Directorate of Health (2003). The amounts of mercury in the brain of deceased people are correlated with the number of amalgam fillings. Mercury passes placenta, and the mercury concentrations in fetuses are correlated with the number of amalgam fillings of the mother. People with amalgam fillings have more mercury in their body liquids than persons without such fillings.

The Norwegian Directorate of Health (2003) state that:

"*The available evidence is inadequate to establish that exposure to mercury in amalgam fillings leads to health effects other than allergic reactions. However, risk analysis indicates that there is some possibility for adverse health effects caused by mercury from amalgam fillings in a small minority of the population.*"

In Life Science Research Office (LSRO, 2004) the results of a comprehensive review of scientific studies of these issues are presented. The report concludes that there is little evidence to support a causal relationship between mercury fillings and human health problems. The authors note, however, that many research gaps existed, which, if addressed, may settle the dental amalgam controversy once and for all.

However, risk assessments indicate that potential health impacts from mercury in dental amalgam could not be excluded (The Norwegian Directorate of Health[3], 2003). Some of the most common symptoms associated with amalgam exposure are joint and muscular pain, lethargy, debility, dizziness, headache, stomach and intestinal ailments, visual disorders and loss of short-term memory. It is very difficult to ascertain the extent of the problem because:

- there is no accepted way of making a diagnosis;
- many of those who ascribe their health problems to amalgam fillings may be suffering from other illnesses with similar symptoms of a general nature, and
- some patients may be allergic to one or more of the components used in dental restorative materials without being aware of it.

3.1.4 Increased public focus on the negative sides of dental amalgam use

During the 1980s and 1990s a debate on the use of dental amalgam as a restorative material in dentistry became especially intense in the media. The Norwegian Dental Patients Association (Forbundet Tenner og Helse) was a driving force in this debate. The association represents people who believe that their health has been impaired as a result of dental treatment. In Sweden a similar debate even more intense than in Norway emerged.

The media often featured interviews with people claiming that their health problems were caused by amalgam fillings, and who have regained their health after replacing their amalgam fillings with a different material. Some scientific studies also reported that patients have been restored to health after having had their amalgam fillings replaced. However, these studies were heavily disputed.

3.1.5 Occupational health problems from mercury in copper amalgam

The heating of mercury without a vent pipe and personal protection equipment, and blending the metal powder alloy by hand, resulted in inhalation of mercury vapor by the dental treatment personnel. They have for years complained about long term health damages similar to those claiming damages from mercury fillings, and requested compensation for their sufferings.

The Norwegian Knowledge Centre for the Health Services (Kunnskapssenteret) was asked by the authorities to look into this issue by reviewing scientific studies. In their report (Kunnskapssenteret, 2011) they conclude that dental treatment personnel in Norway were exposed to mercury to variable degrees in the 1960s, 1970s and 1980s. The highest exposure is found in the 1960s. Mercury concentrations found in urine and in other body tissues were generally higher in dental treatment personnel than in unexposed control groups, both in Nordic and international studies. Dental surgery assistants in general had higher concentrations of mercury in urine than dentists.

[3] The Norwegian Directorate of Health is the former Directorate of Health and Social Affairs

As a result of this process mercury is now accepted in Norway as the source of an occupational health problem for dental treatment personnel who worked with the material. Also, the question of compensating those who suffer from this is about to be solved on an individual basis.

3.2 Regulatory actions

3.2.1 Actions taken by the health authorities

Guidelines for dental filling therapy introduced in 1991

As a result of the debate on mercury risks, the Norwegian Directorate of Health in 1991 introduced guidelines with the purpose of reducing the use of dental amalgam, based on the precautionary principle (Norwegian Directorate of Health, 1991). Although no connection between dental amalgam and health problems were scientifically proven, it seemed probable that for a small segment of the population exposure to mercury may lead to adverse health effects. Nor could responses to other dental restorative materials be excluded (Norwegian Board of Health, 1999).

The Norwegian Directorate of Health recommended in the guidelines that extensive dental amalgam therapy should be avoided for pregnant women for reasons of general prevention. The guidelines also stated: *"As a contribution to reducing the environmental impact of mercury, the Directorate recommends that the use of dental amalgam be reduced successively"*. It was also underlined that dental treatment personnel who handle dental materials run a greater risk of developing allergies.

New guidelines in 2003 requires justification of any dental amalgam use

The new, updated "*National Clinical Guideline for the Use of Dental Filling Materials*", was published by the Norwegian Directorate of Health in 2003. They specify that dental amalgam should usually not be the first choice for any indication of filling therapy, and especially not as a filling material when treating pregnant women, children and young people up to the age of 18 years under the auspices of the Public Dental Health Service. Generally, the use of dental amalgam should be limited as far as possible out of consideration for the environment and potential damage to health. Restraint should be exercised in using dental amalgam on persons with specific health problems, e.g. persons suffering from allergies or renal (kidney) ailments. The use of dental amalgam should be justified in the patient records and the patient should give his or her consent.

The guidelines also include precaution for the dental treatment personnel:

"Every effort should be made to reduce the exposure of patients and dental health care personnel to chemical substances during dental treatment, both when placing and removing dental fillings. Water cooling and suction shall be used when removing old dental fillings. Contact with materials before they are hardened should be avoided."

The Norwegian Dental Biomaterials Adverse Reaction Unit established in 1993

Another action was the establishment of the Dental Biomaterials Adverse Reaction Unit (Bivirkningsgruppen) at the University of Bergen, which commenced its activities in 1993 and is funded by the Norwegian government. In 1999 the Dental Biomaterials Adverse Reaction Unit was organized within Uni Research AS, a research company owned by the University of Bergen. It was the first such body in the world. The unit is active in three main areas, covering both dental amalgam and other materials:

- registration of adverse reaction reports
- research and information activities
- clinical examination of referred patients

The work of the unit has been and is closely followed abroad, which shows that Norway was breaking new ground with this unit. In 1996 Sweden opened an adverse-effects register along the same lines as Norway.

The Nordic Institute of Dental Materials (NIOM) is the Nordic Cooperative Body for dental biomaterials. The Institute's activities in research, materials testing, standardization and research-based consulting are directed towards dental health services and health authorities in the Nordic countries. The Institute is owned jointly by UniRand (a wholly owned subsidiary of the University of Oslo) and the Norwegian Ministry of Health and Care Services. Activities are financed by the Nordic Council of Ministers, the Nordic ministries for health services, materials testing and consulting services.

3.2.2 Actions taken by the environmental authorities

Steps to limit mercury discharges to the environment from dental treatment were taken by the environmental authorities as part of a broader policy to limit emissions of mercury to air, water and soil, and the long run goal to phase-out the use of mercury in various products. An important part of this was to establish "The substitution principle", which states that the users of hazardous substances are expected to replace these with alternatives that entail less risk, and as a general rule to discontinue use of the most dangerous substances if less hazardous alternatives are available.

Mandatory dental amalgam separators introduced in 1994

A requirement to have an approved dental amalgam separator installed in all dental clinics was introduced in 1994 as set out in the Norwegian Pollution Regulations, section 15A-6. Older separators must be type-approved, while a minimum efficiency of 95 percent was required for those installed after 2006. This led to significant reductions in mercury discharges into municipal sewers.

There will be some discharge of mercury even after purification, regular emptying and inspection of the dental amalgam separators that are necessary to achieve a 95 percent degree of purification. All waste and sludge containing dental amalgam must be delivered to certified collectors of hazardous waste.

Regulations of mercury emissions from crematoria from 2007

The discharge of mercury into the air from the largest crematoria has been regulated since 2007. The regulation, which is set out in the Norwegian Pollution Regulations section 10, was introduced in 2002, and applies to crematoria established after 1 January 2003. For crematoria that existed before 1 January 2003, purification requirements apply from 1 January 2007. The largest crematoria (more than 200 cremations per year) must fulfil limits for mercury concentration in the flue gas. No specific requirements apply to the smallest crematoria, as their mercury emissions are small (Klif, 2010a).

In 2008 the mercury emissions to air from crematoria was 58 kg. The number of cremations per annum varies between 14,000 and 15,000, constituting 35 percent of the total number of deaths per year (Klif, 2010a). Without regulations the mercury emissions from crematoria were expected to increase significantly towards 2020, and then gradually decline with the decline in the number of amalgam fillings in the deceased.

General ban on mercury in products from 2008

On 1 January 2008, Norway introduced a general ban, with few and mainly time-limited exemptions, on the production, import, export and placing on the market of mercury in new products (including dental amalgam), which is set out in the Norwegian Product Regulations, section 2-3. This decision was based on an overall evaluation of the risks to people and the environment posed by sources of mercury pollution in Norway, and the long-term goal to phase-out emissions and use of mercury.

Prior to the ban an impact assessment was made, see SFT (2006). It referred to the large reduction in dental amalgam use, and also referred to a survey indicating that the dentists preferred the alternatives to dental amalgam (Norwegian Directorate of Health, 2003). According to the assessment, aesthetic dental treatment has gradually become a concept that excludes the use of dental amalgam. Possible adverse effects, patients' increased interest in filling materials and patients' preferences had probably also accelerated the development away from dental amalgam.

The Norwegian Directorate of Health considered that a ban would not lead to any treatment-related consequences for the most common dental treatment performed, as dental amalgam was little used.

The comments from the consultations of the proposed ban led to a 3-year-exemption on the use of dental amalgam for two patient groups. One exemption was for patients that needed dental treatment under general anaesthesia. General anesthesia in itself poses a certain risk and the time spent for a patient should be as limited as possible. Dental amalgam was considered to take less time to use than other restorative materials. It was also difficult to keep the filling area sufficiently dry when treating a patient who is under general anaesthesia, which is necessary when using composites. The second exemption was for patients that are allergic to components in mercury-free fillings.

From 1 January 2011 these exemptions expired and the ban on the use of dental amalgam now is total. However, it is possible to apply for an exemption from the Norwegian Climate and Pollution Agency (Klif) for the use of dental amalgam for a single patient. Very few applications for such use have been received by Klif.

In Sweden, since 1 June 2009 dental amalgam could only be used in special medical circumstances rather similar to those in Norway before end 2010. In June 2010 only three of a total of 68 hospital dental clinics that could still use dental amalgam had actually done so (Kemi, 2010).

Although the use of dental amalgam is now banned in Norway, it will take many years before all existing amalgam fillings are removed. This makes it important to have good waste collection and emission control systems to prevent release of mercury to the environment.

3.3 Use and release of mercury substantially reduced

Mercury use in products and emissions of mercury has been substantially reduced over the years. The most important action in Norway in the 1980s was to limit mercury emissions from industry. Norway's national target is to continue this development with the goal of eliminating use and release of mercury by 2020 (Klif, 2010a). According to the national action plan from 2005, the limitation on use of mercury in products, and especially dental amalgam, was considered an important measure.

From 1995 to 2008, releases of mercury from incineration plants, crematoria and combustion of landfill gas dropped by 33 percent according to data from The Climate and Pollution Control Agency (Klif). Furthermore, discharges to water via municipal sewers and sludge from dental clinics was reduced from 490 kg mercury in 1995 to 15 kg mercury in 2008 (Klif, 2010c).

Table 3.1 Use of dental amalgam. Kg Mercury.

	1995	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Use	840	275	263	230	139	137	96	80	43	0

Source: Klif

Table 3.1 shows that the use of mercury in tooth fillings gradually has been reduced since 1995. Some sources indicate that the use of mercury in tooth fillings was as high as 2,000 kg in 1985 (Scandpower, 1994), showing a large reduction of dental amalgam use before 1995. Amalgam fillings are durable and the quantity of amalgam in the population represents approximately 10 tons of mercury in Norway today. It is estimated that 1.5 million Norwegians of a total of 5 million citizens (i.e. 30 percent) have amalgam fillings (Norwegian Board of Health, 1999). As people pass away or the fillings are replaced with other materials, the quantity of mercury in the population will fall. Nevertheless, it should be expected that some mercury will be released to the environment for up to 30 years after phase out of the use of dental amalgam.

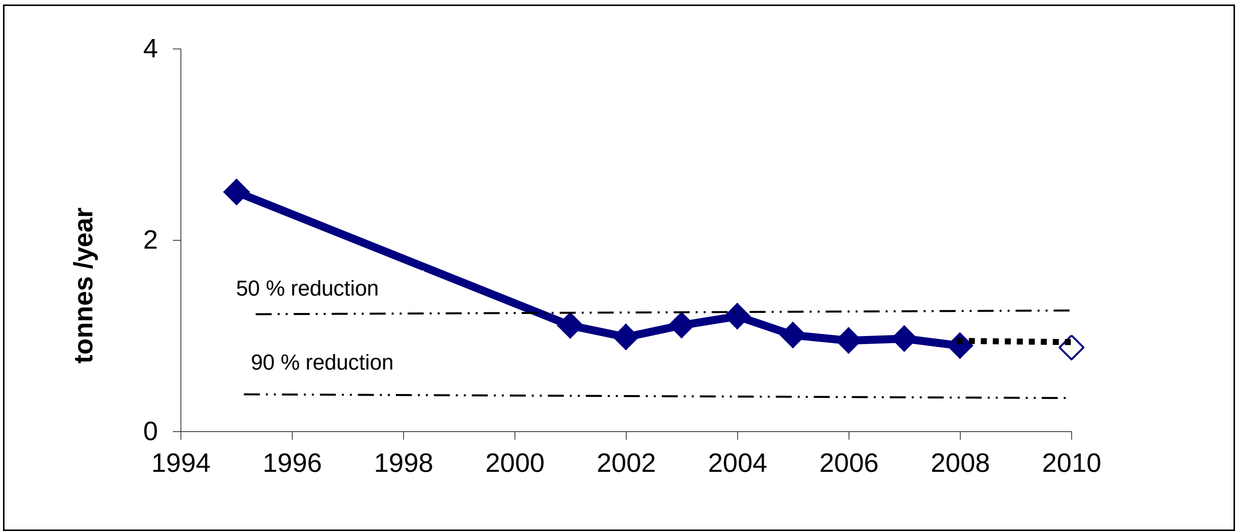
Table 3.2 Use of mercury in products in 1995 and 2009. Kg Mercury.

	1995	**2009**
Dental amalgam	840	0
Batteries	215	5
Light sources	130	118
Thermometers	90	0
Measuring devices	55	0
Laboratory chemicals	40	37
Mercury switches and relays	5	0
Mineral fertiliser	3	2
Flat screens	0	4
Total	*1378*	*166*

Source: Klif (2011)

Table 3.2 shows that the largest use of mercury in products in 1995 was in dental amalgam, comprising 73 percent of mercury consumption in products that year. Consumption of dental amalgam was reduced by approximately 95 percent during the period 1995 – 2007, i.e. the year before the general ban went into force. Table 3.2 also reveals that total consumption of mercury in products is reduced by approximately 88 percent from 1995 to 2009. Consumption of mercury in all products except flat screens has been reduced in this period.

Figure 3.1 Norwegian releases of mercury (excluding those from contaminated sites, sediments and shipwrecks) in the period 1995–2008, and projected releases in the period 2008–10



Source: Klif (2010a)

Figure 3.1 shows that even if the release of mercury has been substantially reduced in Norway, there is still some way to go to eliminate these emissions by 2020 as the official goal says.

4 Main experiences with the alternatives to dental amalgam

In this section we present results of various assessments of the experiences with alternative materials to dental amalgam, including telephone interviews for this report among selected operating dentists and county dentists (fylkestannleger) in Norway.

4.1 Some scepticism in the early days

Interviews among dentists, physicians and the general public on their views of the restorative materials used in dentistry were performed in 1998 (Norwegian Board of Health, 1999). More doubt regarding possible harmful effects of dental amalgam existed in the general public than among doctors and dentists. The interview showed that dentists favoured dental amalgam or gold if they needed to replace a large filling in a molar, whereas physicians and people in general preferred composite fillings.

A survey conducted by the Norwegian Directorate for Health in 2002 revealed that dentists at that time preferred to use composites as a filling material. This survey showed that the proportion of amalgam fillings used for children and young people was reduced by around 90 percent since 1995 (Norwegian Directorate of Health, 2003).

4.2 Recent observations show few negative impacts of the alternatives

The resin-based materials mostly used to replace dental amalgam in Norway contain small ceramic particles in order to achieve sufficient strength for the fillings to withstand the pressure from chewing. These composites are delivered uncured and thus need a polymerization reaction to harden. The composite materials that contain acrylate monomers may leak unreacted components in days/weeks after the dental filling has been polymerized. In addition to allergic reactions, laboratory studies have shown that these monomers have a potential for biological effects (Samuelsen 2011). It is, however, not yet documented that the monomer exposure in such concentrations as found after polymerization is high enough to cause health effects.

The use the new materials seemed to cause some allergic reactions in the mouth of patients and in the hands of dental treatment personnel. Both the patients and dental treatment personnel should thus avoid skin contact with the material before it is hardened.

Particular attention has been paid to harmful substances like bisphenol A and/or bisphenol A-derivatives which may leak from the materials. These substances are endocrine disruptors and it has been shown that they have an effect resembling that of oestrogen. At present there is little knowledge of whether exposure to low doses of bisphenol A can result in adverse health-related effects.

However, the quantities of monomers from resin-based materials emitted are small and the risks for toxic reactions are considered negligible. Studies from Norway show that, these substances are traceable in the saliva only 10 minutes after the filling is made, and after 7 days no substances are detected.

The Adverse Reaction Unit of Dental Biomaterials has closely followed the transition from the use of dental amalgam to the increased use of resin-based tooth filling materials. In Bivirkningsbladet (2010) they present a summary of the experiences so far. The number of reports about potential adverse effects from the use of resin-based tooth filling materials have increased somewhat in recent years up till 2010, while the share of reports related to impacts from dental amalgam use has declined somewhat. Since the use of dental amalgam was prohibited from 2008 this development is as expected. However, the number of reported adverse impacts from the use of resin-based fillings has not increased to the same degree as the increase in the use of these materials. It is claimed that this could be a random variation in the reporting, and that it is too early to draw any conclusions.

In addition to chemicals that start the polymerization process in the composites, a special light is also used to get a quick hardening when the material is put into the tooth. This light may cause harm to the eyes if they are not properly protected (Bivirkningsbladet, 2010).

The first weeks after a composite filling is laid it is not unusual to feel pain and "icing" when chewing or drinking cold drinks. This usually vanishes after a short time. The sealing systems that are used today will probably reduce these effects, since they give a better sealing of the rims (Bivirkningsbladet, 2010).

4.3 The alternative materials are considered good alternatives to dental amalgam, but in some cases more challenging to use

The general impression from the interview performed for this report is that dentists are satisfied with the alternative materials. The most common material used now is resin-based composites, but various glass ionomers and ceramic-based materials are also used to some extent. These materials have been used for years, long before the ban on dental amalgam use entered into force. Thus, the necessary technical equipment and basic skills among the personnel have been established for long.

The main advantage from the dental treatment personnel's point of view is that they have good adhesive properties, implying that the dentist needs to remove less amounts of the fresh tooth compared to when using dental amalgam. This can offset some of the extra time needed for hardening of these materials especially for small fillings, and some dentists even claim that they use less time than when using amalgam. Larger fillings are some more time-consuming than when using amalgam. The dentists in the review for this study claim that they use 15-45 minutes more, depending on the dentist experience and the complexity of the filling. For the economic assessment presented in this report, 15-30 minutes is used in the calculations. Patients seem to like the alternative materials because of their tooth-like appearance.

The disadvantages are that the alternative materials could be challenging to use, especially for larger fillings. They need a completely dry environment to seal properly. Another disadvantage is that bacteria are more easily formed on the surface of the filling, thus requiring some more follow up from both the patient and the dentist. Because of this and less "chewing-strength" the composite fillings do not last as long as the amalgam fillings (some say half the time of amalgam fillings), but the longevity is increasing and approaching the longevity of amalgam fillings. Since the alternative filling materials are sensitive to the techniques used, the skills and experiences of the dental treatment personnel are important to get a good result. Especially the sealing, i.e. the intensity of the light used for sealing and the wave length of the light are important in order to achieve a good filling.

4.4 Swedish assessment generally positive to a ban

Sweden introduced a general ban on the use of mercury in products from 1 June 2009. However, dental amalgam may be supplied to the Swedish market for patients in special need for it until 31 December 2011, and may be used for this purpose until 30 June 2012. A total ban applies to the use of dental amalgam on children and adolescents (Kemi, 2010).

An assessment of the impacts of a ban performed in 2004 by the Swedish Chemicals Agency concludes that for the general tooth treatment a ban on the use of dental amalgam would not have any negative impacts, see Kemi (2004). The analysis showed that there are other materials on the market that can replace dental amalgam, and that these materials were already used in 95-98 percent of all new tooth fillings. However, they also pointed to the possibility of increased risks for caries for patients with improper mouth hygiene.

Kemi (2004) also points to the fact that there are clinics treating patients under general anaesthesia that never use dental amalgam. Instead they use various composites, and this take no longer time than when using dental amalgam. Dental amalgam corrodes and can thus expand and break the tooth. The risks for such consequences and the need for new, comprehensive treatment would be reduced when a dental amalgam ban is introduced.

In the middle of the 1990s the number of skin damages and allergies among dental treatment personnel in Sweden increased because of the increased use of acrylate-based composites and binding materials that were used to seal the gap between the filling and the tooth. However, the reported damages of these kinds in dental clinics were reduced from 38 in 1997 (the year with the highest number) to 5 in 2000. In 2001 the number was 11. In Kemi (2004) it is therefore concluded that a ban on dental amalgam should not increase these damages, since the personnel learned to handle the materials and the producers changed the packaging to reduce the risk.

5 Costs and benefits from phase-out

In this section we assess the costs in Norway for the various involved actors and the society of phasing out the use of dental amalgam and collecting the mercury waste from dental clinics and cleaning emissions to air from crematoria.

5.1 All costs and benefits should ideally be included

5.1.1 Benefits are measured through mercury emission reductions

Since the focus of this review is on mercury emissions to the environment from dental amalgam use, no other benefits are quantified. However, there could be several other impacts related to the actions taken to reduce mercury emissions:

- positive or negative impacts on patients' health
- differences in pain, allergic reactions etc. between the materials
- benefits for the dental clinics' working environment
- aesthetic benefits
- benefits from reductions in emissions of other pollutants

Some of these impacts could be substantial, and are to the extent possible described for the various actions when relevant.

5.1.2 Cost components that should be included

For the various actions required to phase-out dental amalgam use, handling waste and controlling emissions, the following costs should ideally be assessed:

- *Costs of collecting and handling the waste*. These comprise investment costs for installing dental amalgam separators and operating costs for collection and treatment of the dental amalgam waste containing mercury. We conventionally assume 50 percent mercury content in the dental amalgam. Removed drain pipes etc. from dental clinics may contain substantial amounts of mercury, and the costs of removing and treating this should be included.
- *Costs for the dental clinics* of using other filling material than dental amalgam. These costs are related to:
    - differences in purchasing costs between dental amalgam and the alternative filling materials
    - potential investments in new equipment
    - differences between the materials treatment time in the dental clinics
    - other potential impacts and costs (e.g. training)
- *Costs for the patients* in the form of:
    - higher prices for fillings with other materials
    - different lifetimes of dental amalgam and other fillings (potentially more frequent change of fillings with the alternatives)

- *Costs for the crematoria.* These are:
    - investment costs for the equipment to clean mercury emissions to the air
    - operating costs for the cleaning equipment
    - potential reductions in general operating costs
    - potential increased costs because of early closing of old crematoria
- *Costs for the authorities.* Costs of imposing and enforcing the regulations should also be included in an overall cost assessment

Some of these costs could not be related to the ban on the uses of dental amalgam. For instance, since alternatives to dental amalgam were introduced long before restrictions were introduced on dental amalgam use, the dentists had invested in equipment and skills for the use of the alternative materials. We have tried to correct for this, but also to present what the total costs could be when there are little or no experience with the alternative filling materials.

Some crucial parts of the cost data are *historic* costs, notably for the installation of dental amalgam separators, but also for the use of amalgam fillings in dental clinics compared to the use of alternative materials. Since these data are not observable today, we had to find people who remember these costs and/or have access to historic data. This and other information has also to the extent possible been compared to previous Norwegian and international studies and cost investigations.

5.1.3 Assumptions

The following exchange rates are used:

1 € = 8 NOK

1 USD = NOK 5.85

1 GBP = 9 NOK

1 SEK = 0.85 NOK

1 DKK = 1.04 NOK

All prices are adjusted to the price level of 1 January 2011, using the Norwegian consumer price index. Furthermore, when calculating annual costs for the investments we are using a real discount rate of 4 percent p.a. as recommended by the Norwegian Ministry of Finance for these kinds of investment. 10 years economic lifetimes for investments in dental clinics and 20 years for abatement investments in crematoria are applied.

Some of the costs may be financed through public budgets. For instance, in Norway the authorities pay for dental treatment for all persons until the age of 18, for the mentally disabled and the elderly in institutions. The authorities also pay for their own costs connected to enforcement of the regulations. The financing of these costs would have to be done through raising public taxes, which can lead to an efficiency loss (deadweight loss or marginal cost of public funds), because they create a wedge between private and social costs[4].

The efficiency loss of using general taxes to finance a policy/project will probably differ between countries. For most Nordic countries the efficiency loss is estimated to be around 20 percent of the costs, and this figure is used in calculations of costs and benefits. This means that all costs that are financed through public budgets by general taxes will be subject to a 20 percent surcharge.

One of the purposes with this review is to show other countries what the costs of reducing mercury emissions from dental amalgam use could be. Since the costs of dental treatment in most countries are paid directly by the patients, little or none of the costs are financed through public budgets. Thus, the cost of public funds is not relevant for them, and we have therefore not included this cost in the cost figures even if it should have been when considered from a strict Norwegian point of view. But also in Norway most of the costs for dental treatment are paid directly by the patients.

5.2 Costs of waste collection and handling

5.2.1 Cost assessment before dental amalgam collection was made mandatory

In 1992 Klif (then called the Norwegian Pollution Control Authority (SFT)) in an internal memo made a brief assessment of the costs of introducing mandatory mercury removal from dental clinics. This assessment was made two years *before* the collection and treatment of mercury-containing waste from dental clinics were required. It was estimated that installment of a mercury separator unit would cost some NOK 8,700 (€ 1,090) per treatment chair (unit) or some NOK 1,075 (€ 135)/year. The separators were assumed to have a 10 years life time. Maintenance and collection of the waste would cost some NOK 1,450 (€ 180) per chair per year. Administering of the requirement by the environmental authorities would cost NOK 500,000 (€ 62,500) per year or some NOK 145 (€ 18)/chair. All amounts are recalculated in 2011 price value by us.

This gives total annual costs of almost NOK 2,670 (€ 335) per unit per year. It was assumed that the separators would remove around 1 ton of mercury per year from Norwegian dental clinics, i.e. 0.333 kg/unit. This implies specific costs of around **NOK 8,020 (€1,000)/kg** mercury removed.

5.2.2 Nordic assessment showed high waste handling costs

In ECON (1997) treatment costs for various mercury-containing waste in the Nordic countries were estimated. For dental amalgam *only the costs of collecting and treating* the waste were assessed, assuming that all Nordic dental clinics would have installed dental amalgam separators as this was required in all the countries by mid-1998. Therefore, the cost data from this study are not comparable with the costs calculated

[4] A simple example of this efficiency loss is if person A is willing to perform a service for person B for NOK 100 and B is willing to pay NOK 110 for this service, then both will benefit from this transaction. But if A has a marginal tax equal to 50 percent he will only get NOK 55 of the NOK 110 person B is willing to pay, and thus the transaction will not take place and the potential gain of NOK 10 will not be realized.

above, which consider all costs related to investments and operation of the equipment. The costs estimated in Econ (1997) are presented in table 5.1,

Table 5.1 Current collection and treatment costs for dental waste in Nordic countries. NOK (€)/kg mercury removed, 2011 price level.

Denmark	Finland	Iceland	Norway	Sweden
32-528 (4–66)	158-212 (€20–27)	120 (€15)	1,478-2,244 (€185-281)	116-233 (€15-29)

Source: ECON (1997)

The table shows that the cost estimates vary widely between as well as within most countries. Norway had by far the highest calculated costs among the countries. The reasons for this seem to be different amounts (the smaller amounts collected the costlier), the conditions of the waste and the waste treatment chosen. Some of the countries at that time (including Norway) exported the waste for final treatment, which increased the costs.

For Norway the waste handling costs were calculated at an average of some **NOK 1,860 (€ 235)/kg** mercury removed per year. This is somewhat lower than the cost estimated by Klif in 1992 before installation of dental amalgam separators was required in Norway (maintenance and collection costs of NOK 4,355 (€ 545)/kg mercury).

5.2.3 Removal costs of mercury from drainage pipes could be rather high

SFT (2004) presents the results of a pilot project from 2003 on how to remove mercury deposits from drainage pipes etc. in dental clinics. Five clinics were chosen for the pilot. Removed mercury amounts varied between 6 and 160 gram per treatment chair. The total amount of mercury removed was 682 gram.

Total costs for the operation was NOK 114,000 (€ 14,250), i.e. around NOK 23,000 (€ 2,875) per clinic with two treatment chairs. Cost per kg mercury removed was some NOK 167,000 (€ 20,895). The cost for similar activities in Sweden was around **NOK 136,000 (€ 17,000)/kg** mercury. The rather high costs in the Norwegian pilot was probably caused by high transportation costs (a Swedish firm did the job), pre-inspection of the clinics etc. The Swedish cost level is probably more realistic if this activity is to be carried out on a large-scale. Anyway, these costs are very high compared to the costs of removing the mercury before it enters the drainage pipes.

5.2.4 Current Norwegian costs for waste handling are in line with some international studies

A requirement to install amalgam separators on existing dental treatment chairs (units) was implemented in Norway in 1994. The price of such a separator today is estimated to be NOK 16,000 (€ 2,000) plus installation expenses. Assuming 2 hours are needed for installation at an average cost of NOK 360/hour (average wage costs in Norway) gives total costs of some NOK 16,700 (€ 2,090) or NOK 2,060 (€ 260) per year.

From around 1997 on, all new units have an in-built centrifuge for separation of dental amalgam, and the price of this is included in the total unit price. It is not possible to estimate the price of the centrifuge. Larger clinics often have installed central wet centrifuges, serving several units.

The filters in the units are usually changed once a year. Prices are dependent on filter type, but total costs are around NOK 1,100 (€ 140) for the separator, NOK 600 (€ 75) for treatment and some NOK 360 (€ 45) for labour expenses (assuming one hour of labour needed). This implies annual collection and treatment costs of around NOK 2,060 (€ 260) per unit. This is also supposed to include maintenance of the mercury collection unit. For larger clinics annual costs for removing the central unit containing the dental amalgam are some NOK 9,360 (€ 1,170), assuming one hour of work is needed for this. If there are 5 units or more per clinic, the costs are lower than the ones calculated for single units.

The total annual costs for dental amalgam collection investment, waste collection and treatment would then be NOK 4,120 (€ 515) per treatment unit or some **NOK 12,370 (€ 1,545)/kg** mercury removed, assuming that the separator still collects around 0.333 kg mercury/year from each dental unit. This amount is based on the emissions of mercury from dental clinics before amalgam collectors were installed, and would likely be somewhat high, given that the mercury release now only comes from the removal of old fillings.

This calculated cost is more than 50 percent higher than the calculated costs in 1992, which is mainly due to the doubling of investment costs for dental amalgam separators. One reason for this could be that installing separate dental amalgam separators on existing units is no longer common, since most old treatment units have been replaced and new ones have this equipment in-built. Thus, there are reasons to believe that the last calculation overestimate the real, current costs of collecting dental amalgam from dentist treatment chairs.

This is confirmed by ADA (2008), who assumes that the costs in US of purchasing and installing a dental amalgam separator is around NOK 7,000 (€ 875), which is more in line with the estimate from 1992. Dental amalgam collection is not mandatory in the US. On the other hand, ADA (2008) estimates annual capital and operating costs at some NOK 4,450 (€ 555)/unit, which is very similar to the estimate calculated here (NOK 4,120 (€ 515)). We do not know the discount rate used or the lifetime for their calculation.

In a price example from Denmark, Cowi (2008) shows that the annual cost per clinic are around NOK 3,275 (€ 410) for a full installation of a dental amalgam separator and service package. This price does not comprise in-situ evaluation of filter efficiency and accreditation of the services, which would add some NOK 800 (€ 100). Thus, they indicate that a price level of NOK 3200 – 4000 (€400-500) per clinic per year seems realistic. This is at the same level as the calculations in this report.

In 1992 Klif anticipated about one man-year for administration of the dental amalgam collection regulation. According to the information gathered for this report this seems far too high today, and thus we do not include any such costs. Assuming the same costs as in 1992 would have added some NOK 145 (€ 18)/treatment unit per year to the costs.

5.2.5 Summary of waste handling costs

Table 5.2 presents the waste handling costs as calculated in 1992 and current costs.

Table 5.2 Estimated costs of installing and operating a dental amalgam separator in dental clinics. NOK (€), 2011 prices.

	1992 calculation	**Current calculation**
Annual cost/unit	2,670 (€335)	4,120 (€515)
Cost per kg mercury removed	8,020 (€1,000)	12,370 (€1,545)

Source: Vista Analysis

We assume that the 1992 calculations in a better way reflect the historic costs in Norway from installing and operating (including waste treatment) a dental amalgam separator than the calculated current costs of installing such a separator. Since a separator has been embedded in new dental treatment units for many years the extra costs from this are probably low, but unknown to us. Current costs could reflect a situation when a dental amalgam separator has to be installed in an old dental unit, which could be the case in many countries without such equipment.

The calculated costs are far lower than the calculated costs of removing mercury from drainage pipes in dental clinics (NOK 136,000 (€ 17,000)/kg mercury removed).

Total investment costs for Norway, assuming some 3,000 dental units needed to be equipped with a dental amalgam separator, would be between NOK 26 million (€ 3.3 million) and NOK 48 (€ 6 million). Total annual costs would be between NOK 8 million (€ 1 million) and NOK 12.4 million (€ 1.55 million).

5.3 Current extra costs for dentists from dental amalgam ban are declining

Because alternatives to dental amalgam were introduced in Norway in the early 1980s and gradually took a larger share of the market before the ban on mercury in products was introduced, it is hard to assess what the real costs of a ban on dental amalgam use have been and what they might be if the phasing out would have to be done over a shorter period with little or no pre-experience with the alternative materials. However, in addition to assessing the costs of the Norwegian ban we have also tried to include some or most of the costs that would likely occur if one was to phase-out the use of dental amalgam without much experience with alternative materials.

The following costs are relevant when considering a ban:

- *Different material purchase costs*: according to the price list of one material supplier the cost of dental amalgam for a two-surface filling (two- and three-surface fillings are most common, covering two and three surfaces of the tooth, respectively) is around NOK 13 (€ 1.5). The comparable price for composite material is some NOK 65 (€ 8) per filling, consisting of NOK 40 (€ 5) for the composite material itself and approximately NOK 25 (€ 3) for "glue". Thus the material purchase cost difference is NOK 52 (€ 6.5)/filling.
- *Different treatment time*: this seems to vary widely among dentists. For small fillings (i.e. one-surface) the time used seems to be about the same for dental

amalgam and composites, and some dentists even claim that they use less time. For larger, more complicated fillings some dentists claim that they need 15-45 minutes extra. We assume that 15 minutes more spent on all fillings on average could be a modest estimate. Using the average hourly rates for dentists offered by the public dental services in Akershus and Troms counties (which are a central and rural country, respectively) gives increased labour costs of some NOK 340 (€ 43).

- *Investments in new equipment*: dentists need to invest in a curing lamp to be able to cure the composite fillings properly. However, almost all dentists in Norway have invested in this a long time ago to be able to use composite fillings. The investment costs are today some NOK 15,000 (€ 1,875). This gives cost per filling of some NOK 2.5 (€ 0.3) assuming an average of 3 fillings/day produced by the dentist.
- *Training*[5]: most dentists received a one-day training on the use of the new filling materials during the 1990s and into the 2000s. There are still trainings in the use of new materials coming into the market, but younger, newly educated dentists are well trained in the use of these materials from the university. We assume 8 hours spent on training for a dentist which, using the same hourly rate as for the treatment time (NOK 1,358 (€ 170)), gives a cost of NOK 12 (€ 1.5)/filling.

To calculate the mercury avoided we need the amounts of mercury in each filling. According to Reindl (2008) a one-surface filling (restorations) typically has 0.37 g of mercury, calculated from one dental amalgam unit with 0.55 g mercury, minus 0.14 g waste during the filling process, minus 0.04 g in trimmings. A two-surface filling starts with two dental amalgam units, and the amount of mercury in the final filling is implied to be 0.74 g. Total amounts of avoided mercury will be the average of one and two dental amalgam units, i.e. 0.825 g mercury. Since two-surface fillings are more common than one-surface fillings, at least when using dental amalgam, this may underestimate the avoided mercury amounts somewhat. Therefore, we assume avoided emissions of 1 g mercury per filling.

Some control could be necessary to follow up on the prohibition of the use and import of dental amalgam. But since dentists long time before the ban was introduced voluntarily switched to using alternative filling materials the import of dental amalgam were already low when the ban was introduced. Some follow-up of the prohibition could anyway be necessary, but there is reason to assume that the administrative costs are low (SFT, 2006). Thus, we have not included any administrative costs in the cost calculations.

[5] This is relevant for countries that have not yet started to use the alternative fillings.

Table 5.3 Total extra costs per filling for dentists substituting dental amalgam for composites. NOK and €/filling and kg mercury emissions avoided.

	NOK (€)
Increased material purchase costs/filling	52 (€6.5)
Increased treatment time/filling	340 (€43)
Investments in new equipment/filling	2.5 (€0.3)
Training/filling	12 (€1.5)
Total cost increase/filling[6]	406 (€51.3)
Total costs/kg mercury avoided	406,000 (€50,750)

Source: Vista Analysis

Table 5.3 shows that increased treatment time is the cost component that matters, accounting for almost 85 percent of the total cost increase per filling. If for instance the extra time spent on composite material fillings compared to amalgam fillings is increased from 15 to 30 minutes, the costs increase to NOK 745 (€ 93)/filling and NOK 745,000 (€ 93,125)/kg mercury avoided. If there is no extra time used in dental clinics with composite materials than with dental amalgam, the extra costs are reduced to some NOK 67 (€ 8)/filling and NOK 67,000 (€ 8,375)/kg mercury avoided. But in countries mostly using dental amalgam the extra time needed for dentists when switching to alternative materials may be around the higher of these estimates. But the extra time used will likely go down in these countries when existing dentists get more experienced with the alternative materials and new dentists who are trained from school in using the materials gradually enter the workforce.

5.4 Treatment costs for dental patients have increased over time

Before the ban on dental amalgam use was introduced it was considered that the costs of a ban would be low, since the use of dental amalgam already was strongly reduced (SFT, 2006). This was based on the assumption that a ban would not result in an increase in the replacement of amalgam fillings.

A brief assessment was performed using the rates from the Norwegian Ministry of Health and Care Services for public subsidies for dental treatment, to calculate an estimate of the price difference for the patient between the different dental filling materials (SFT, 2006). For preparation and filling, the price difference between dental amalgam and composites was NOK 80 (€ 10) for one-surface and NOK 235 (€ 29) for two-surface filling. If it is necessary to use gold as an alternative filling material to amalgam, the price difference would be much higher.

The cost of the material for a filling, regardless of the material, represented approximately 5-10 percent of the total treatment costs according to SFT (2006). They

[6] Potential reduced waste treatment cost from reduced mercury use is not included here.

claim that nearly 75 percent of the costs are salary costs, which is a little lower than what we found in our calculations presented in table 5.3 (85 percent). The purchase costs for composite material, among others, were higher than for dental amalgam and the increased demand for alternative filling materials had then not led to a lower purchase price from suppliers.

Data gathered for this review found that for a three-surface filling the price difference between dental amalgam and composite fillings charged the patients has been in the range of NOK 385 (€ 48) – 575 (€ 72) per filling (average NOK 480(€ 60)), which is a price increase of between 33 and 50 percent compared to the price of an amalgam filling. This is somewhat higher than the price differences from SFT (2006). This is as expected since a three-surface filling is more complicated and costly.

The calculated total extra cost of NOK 406 (€ 51)/filling on average for *all* fillings for dentists using composites instead of amalgam may seem a little high compared to the price increase for *large* fillings (NOK 480(€ 60) on average). But price variations across the country and competition among dentists could possibly explain why the calculated cost increase has not fully been reflected in the increased market price.

Data from Sweden presented in Kemi (2004) reveal price differences ranging from 14 to 70 percent between amalgam and composite fillings. During the period 1998 till 2004 prices for amalgam fillings in Sweden increased more than prices for fillings using other materials. Based on this, the assessment was that costs would not be negatively affected by a ban on dental amalgam use. It should be noted however, that in Sweden only restoration work with alternative filling materials to amalgam is subsidized. Subsidies vary between local counties.

Some price estimates from two Belgian dental clinics presented in Cowi (2008) show that prices charged from patients vary from being similar for amalgam and composite fillings to some 40 and 50 percent higher for composite fillings. Price differences were generally highest for two- and three-surface fillings. For the clinic where the price charged for amalgam and composite fillings was the same, it was however mentioned that the clinic typically added a surcharge when extra time was required to place a filling.

According to Cowi (2008) the higher prices for composite fillings are mainly due to the fact that today's composite fillings must be prepared in a sequence of thinner applications with intermediate curing of the polymer resin. Future technology improvements may possibly reduce the labour intensity of composite fillings. In states with generally lower labour cost levels than Western European countries, the price differences between preparation of amalgam and composite fillings may be lower than in the cited examples.

Cowi (2008) presents a hypothetical mean price increase when shifting from amalgam to composite fillings based on Danish data from 2004 of NOK 312 (€ 39) mainly due to extra work time needed for the filling. Considering the scarce data it appears reasonable according to Cowi (2008) to assume a large range of NOK 91 (€ 11) to NOK 638 (€ 80) extra price per average filling, with an average extra price of NOK 365 (€ 46). The calculated estimate in this review for a cost increase for a three-surface filling and the data from SFT (2006) for one and two surface fillings are rater close to this calculated mean price increase, which is a good indication of the accuracy given that wage costs are rather similar in Denmark and Norway. Thus, we apply the average of these Norwegian estimates to get an average cost increase of **NOK 300 (€ 38) per filling and some NOK 300,000 (€ 37,500) per kg mercury** removed.

Another potential cost for patients could be more frequent replacement of fillings, since composite fillings do not seem to last as long as amalgam fillings. Even though the duration of the alternative materials is increasing, they still will have shorter lifetime than amalgam fillings for many years. In cases when an alternative filling is replacing an amalgam filling it will last shorter than when treating new caries with an alternative filling. We assume that people who otherwise would have chosen amalgam fillings in general will have to replace their fillings at least once during their lifetime compared to if they had used amalgam fillings. Taking the average prices for one-, two- and three-surface fillings (which may underestimate these costs since two- and three-surface fillings are most common) from the county dentists' price lists in Akershus and Troms counties gives extra costs of some **NOK 825 (€ 103)/filling**.

5.4.1 Summary of costs of phasing out dental amalgam use

Table 5.4 summarizes the costs calculated.

Table 5.4 Costs of phasing out the use of dental amalgam in new fillings. NOK (€).

	Low (no extra time)	Medium (+15 min)	High (+ 30 min)
Total extra costs/filling	NOK 67 (€ 8.5)	NOK 300 (€ 38)	NOK 533 (€ 67)
Total costs/kg mercury	NOK 67,000 (€ 8,375)	NOK 300,000 (€ 37,500)	NOK 533,000 (€ 66,625)

Source: Vista Analysis

The costs vary according to the extra time spent on composite fillings in dental clinics compared to amalgam fillings. The low alternative represents a situation where there is no extra time, the medium alternative is when approximately 15 minutes extra time is spent, and the high alternative is when the extra time is half an hour. However, the costs presented may underestimate the total costs of phasing out dental amalgam since they do not include more frequent replacement of fillings because of shorter lifetime of composite fillings compared to amalgam fillings. This could give extra costs of some NOK 825 (€ 103)/filling.

Due to lack of data about the number of fillings it is impossible to estimate total costs for Norway from the phasing out of dental amalgam use. Besides, most of the substitution of dental amalgam took place before the mercury ban was introduced.

5.5 Crematoria abatement costs

5.5.1 Mercury emissions are assumed to be some 5 g/cremation

The mercury content in the cremated bodies and thus the emissions to air from the crematoria before any abatement actions is a key variable to assess the impacts of abatement measures. In Norway 5 g/cremation is used as an estimate for the mercury content in the deceased (SSB, 2001).

This emission factor could be somewhat high compared to a factor of 3 g/cremation used in UK (Defra, 2003). They refer to some test cremations, where the emissions varied widely but the average emission was as low as 0.9 g/cremation. However, the study also shows that the emission factor has been steadily increasing over the years, and is likely to increase further.

According to Defra (2003) the population could be divided into roughly the following three cohorts:

- The very old with no teeth
- Those with heavily restored teeth
- The fluoride generation

Defra (2003) refers to a study from the Netherlands predicting a doubling of mercury emissions from crematoria from 1995 to 2020. The reason for this is the decreasing number of older people with no teeth and increasing number people with large fillings. The study also reports a decline in the number of fillings in young people, but makes no prediction about when this will affect mercury emissions from crematoria.

Using the data referred above and information on the number of deaths in different age groups, Hogland (1994) calculated that mercury emissions from crematoria in Sweden (before abatement) will increase from 177 kilograms a year in 1985 to 602 kg/year in 2020, following by a decrease to 570 in 2025.

A similar development could be expected in Norway and other countries that have experienced the same development in dental treatment and dental amalgam use. However, it is not clear to what extent the increased use of other filling materials than dental amalgam might influence this development, since many of the ”middle generation” will have their numerous amalgam fillings replaced with other materials. This underlines the importance of mercury abatement requirements for crematoria since mercury emissions will likely be a problem for many years to come.

5.5.2 The regulations have speeded up the restructuring of the crematoria

Regulation of mercury and other emissions to air from crematoria came into effect in 2007 in Norway. The regulation separates the crematories in two categories; category I with more than 200 cremations/year, and category II with less than 200 cremations/year.

Both categories face limits for concentrations in the flue gas of total dust and carbon monoxide (CO), but only category I crematoria have limits regarding mercury concentration and must install mercury filters or similar to comply with this requirement. In many cases some extension or reconstruction of the buildings will be necessary for installing flue gas cleaning.

Also, category I crematoria should each year ensure that control monitoring of the emissions is carried out by an independent monitoring institution, and report emission data etc. to the pollution authorities. For category II crematoria similar requirements apply every second year.

In 2002 there were 35 crematoria in Norway in operation according to Kirkegårdsforeningen (2010). Several of these have been closed down and replaced by new, larger crematoria, and by the end of 2010 there were 24 crematoria in operation (Kirkegårdsforeningen, 2011). All building investments, both in new or existing buildings vary between the crematoria. Not all crematoria have completed their investments by November 2011.

The emission regulations speeded up the change in the crematoria structure, and some crematoria were closed before their technical and/or economic lifetime, see for instance Gann & Rødahl Lie (2009). This imposes an implicit cost to the society. On the other hand, the new crematoria also create benefits in reduced operating costs, mostly reduced labour costs (Gann & Rødahl Lie, 2009). These costs and benefits are not considered here. We only focus on those crematoria that have or are in the process of installing cleaning devises to comply with the mercury regulations. Furthermore, we do not take into account the impacts these devises might have on emissions on other pollutants, notably that mercury filters also remove dioxins.

5.5.3 Mercury abatement filter costs are relatively low

To fulfill the emission limits for CO, total dust and mercury, the crematoria often needs to make the following investments:

- CO emission limits may require a new cremator (oven),
- The total dust emission limits may require flue gas cooling and cleaning
- The mercury emission limits require a filter system in addition to the flue gas cooling, using active coal.

Total investment cost for all the above equipment today is around NOK 6 million (€ 0.75 million), and would likely be a necessary investment for a new crematorium. Of this around 50 percent are for the cremator (oven), and the flue gas cooling and dust cleaning constitutes some 35 percent of the investment (NOK 2.1 million (€ 0.25 million)). Then the investment costs for the mercury filter constitutes some 15 percent of the investment, or NOK 0.9 million (€ 0.1 million).

The latter is the marginal investment for Norwegian crematoria to comply with the mercury regulations, and thus the cost relevant to consider when mercury abatement costs are calculated for Norway.

The cleaning efficiency for mercury is 96-99 percent according to the supplier of the equipment. We use an average of 97.5 percent efficiency, implying that some 4.875 gram mercury per cremation is removed by the filters.

Thus, the investment costs for the flue gas cleaning would be more or less the same for most Norwegian cremators in question, who mostly have between 200 and some 1,100 cremations per year.

Operating costs for a mercury filter mainly consists of the purchase of coal and the costs of depositing the used coal as hazardous waste. Coal purchase and deposit costs seem to be around NOK 12 (€ 1.5)/cremation. Also some small amounts of energy (electricity) are needed to operate the filter system. Service and maintenance costs are considered to be low. We estimate that these operating costs all together are NOK 15 (€ 2)/cremation.

The annual monitoring and certification costs for mercury cleaning operation are around NOK 40,000 (€ 5,000)/crematorium. These costs covers hiring the certified monitoring company, reporting to the environmental authorities, inspection etc.

Table 5.5 Mercury abatement costs for crematoria. NOK and €.

	NOK (€)
Investment costs	900,000 (€ 112,500)
Annual monitoring costs	40,000 (€ 5,000)
Total annualized fixed costs	106,240 (€ 12,655)
Average fixed costs per cremation	127 (€ 15)
Operating costs per cremation	15 (€ 2)
Total costs per cremation	142 (€ 18)
Total abatement costs per kilo mercury	**29,170 (€ 3,485)**

Source: Vista Analysis

Extending the lifetime to 30 years reduces the specific costs for mercury filter only to some NOK 25,700 (€ 3,210)/kg mercury. Likewise, reducing the discount rate to 3 percent only reduces the costs to some NOK 27,800 (€ 3,470)/kg mercury. This shows that the choice of discount rate and lifetime only have marginal impacts on the cost calculations.

5.5.4 Abatement costs could be higher when no other regulations are in place

As mentioned the calculated abatement costs are relevant for Norway and other countries where crematoria have to comply with mercury regulations in addition to regulations on dust and CO. In a country where there are no other regulations on air emissions, the costs of all the other equipment and eventually a new cremator and building restructuring would have to be included as well. In this case approximately NOK 3 million (€ 0.38 million) has to be invested in total flue gas abatement equipment. For new crematoria this constitutes total abatement investment costs.

When rebuilding an existing crematorium to give room for the cleaning devices, some additional NOK 3 million (€ 0.38 million) in building works seem to have been an average investment, making the total investment equal to approximately NOK 6 million (€ 0.75 million).

5.5.5 Danish cost estimates are rather similar to the above findings

Costs for installation and maintenance of mercury and dust retention filter for crematoria are presented in Cowi (2008) based on Danish examples. The examples include the installation of bag filters with carbon injection, which according to Cowi (2008) is deemed the most relevant technology, and adaption/extension of buildings to house installations. Typical costs for filter installation were reported to be around NOK 3.6 million (€0.45 million) per filter serving one cremator, plus on average NOK 0.82 million (€0.1 million) per installation for needed building adjustments/extensions (range NOK 0.22 – 2 million (€ 0.03 - 0.25 million)). Maintenance costs were estimated at roughly NOK 14 - 22 (€ 1.75 – 2.75) per cremation performed, including consumed carbon and fees for disposal of used carbon as hazardous waste. This gives a cost per kg mercury removed of some **NOK 69,200 (€ 8,650)**, which is at the same level as the estimate in this review for flue gas cleaning including mercury filter when no building adjustments are necessary.

The bag filters also act as dust retention which is required in some countries. For crematoria which already have suitable bag filters installed and have room for extra equipment, the addition of a carbon dispenser would involve only limited extra installation costs; around NOK 109,000 (€ 13,600), plus the same maintenance costs as mentioned above (Cowi, 2008). This is much cheaper than the estimated costs in our study, which amounts to NOK 900,000 (€ 112,500).

5.5.6 Data from UK show rather similar abatement costs as in Norway

Several studies from the UK have identified abatement costs for the removal of mercury from crematoria.

Defra (2003) discusses the advantages and disadvantages of various end-of-pipe options for removing mercury from the flue gas. They recommend a dry sorbent/filter system or equivalent as the best available technique for removing mercury from crematoria flue gas, after the gas has been conditioned (i.e. cooled, captured and collected) together with a draught fan and stack. It is claimed that it is possible to have one gas treatment plant for two cremators (ovens), but for cremators with more than 978 cremations per year one gas cleaning system per cremator seems necessary.

Defra (2003) presents investment costs for existing crematoria at NOK 2 million (€ 0.25 million) for one flue gas cleaning plant (comparable to the NOK 3 million (€ 0.375 million) for flue gas cleaning in Norway), commissioning costs at NOK 113,500 (€ 14,190) and civil/building costs at NOK 850,000 (€ 106,250) per single flue gas cleaning plant. The latter varies widely between plants, but all plants will have to do some changes in existing buildings to enable the installation of the flue gas cleaning unit. In addition Defra (2003) assumes an increase in operating costs due to the flue gas cleaning of some NOK 100 (€ 13) per cremation and some average periodic monitoring costs of NOK 8,500 (€ 1,065)/year. Assuming a removal of 4.85 g mercury/cremation gives total costs per cremation of some NOK 370 (€ 46) and total abatement costs of around **NOK 76,290 (€ 9,535)** per kg mercury removed.

Bristol City (2010) estimate far higher costs to install flue gas cleaning devises in their two old cremators. An investment cost of NOK 5.2 million (€ 0.65 million) for the flue gas cleaning devise alone for each of the crematoria is estimated, in addition costs of

NOK 4.5 million (€ 0.56 million) to extend the building in one of the cremators is assumed. This total investment of NOK 14.9 million (€ 1.85 million) is compared with an option to install three new cremators with mercury cleaning equipment in one of the existing crematoria to replace the existing ones at an estimated cost of NOK 15 million (€ 1.88 million). Using the same assumptions as above give cost of some NOK 470 (€ 59) per cremation (3,000 cremations/year) and total abatement costs of some **NOK 97,140 (€ 12,145)** per kg mercury removed.

North Lincolnshire Council (2005) estimate costs in the region of NOK 5.9 million (€ 0.75 million) for the installation of a flue gas filter system, including NOK 1 million (€ 0.13 million) for civil works necessary to house the equipment. In addition increased operating costs of some NOK 125 (€ 15.5) per cremation are estimated. This gives total costs of some NOK 430 (€ 54)/cremation, (1,450 cremations/year) or **NOK 88,700 (€ 11,090)** in total abatement costs, which is also higher than in Defra (2003).

These abatement costs could be compared to the costs calculated from Norwegian data where investments in total flue gas cleaning devises and building work are included, which should be between **NOK 67,480 (€ 8,435)** and **NOK 122,000 (€ 15,250)** per kg mercury removed. It can be seen that all the abatement costs from UK are within this range.

5.5.7 Summary of total abatement costs for crematoria

Based on Norwegian data mercury abatement costs are presented in table 5.6.

Table 5.6 Mercury abatement costs for crematoria based on Norwegian data. NOK and €.

	Only mercury filter	**Filter plus flue gas cleaning & cooling**	**Filter plus flue gas cleaning & cooling + building work**
Total costs/cremation	142 (€ 18)	327 (€ 41)	592 (€ 74)
Total costs/kg mercury emissions reduced	29,170 (€ 3,645)	67,480 (€ 8,435)	122,000 (€ 15,250)

Source: Vista Analysis

The total investment costs for Norway to fulfill the mercury emissions regulations for crematoria could be estimated to some NOK 15 million, taking into account investments in mercury filters only.

The abatement costs in other countries would depend on what kind of air emission regulations that are already in place, and what kind of building changes that would be necessary to have enough space for the flue gas cleaning and cooling. The latter would vary widely among sites, but the investment costs in abatement equipment should be rather similar across countries.

5.6 Socioeconomic impacts in Norway

So far only the costs to society of the various abatement actions have been assessed. However, it is also of interest to assess who bear the costs and get the benefits from the emission reductions. It can always be argued that the consumers either directly through prices they face or indirectly as taxpayers pay for interventions to reduce pollution. But various groups of consumers could be disproportionately affected by the costs and the benefits.

The benefits from reduced mercury emissions generally affect all people in Norway and to some extent also neighboring countries since these emissions are transboundary. Especially children and fetuses will benefit from reduced mercury exposure from the environment. Furthermore, dental clinic workers who have been exposed to dental amalgam in their work environment also benefit.

In Norway the following categories of people have their dental treatment costs covered by the public budgets:

- Children and young people up till 18 years
- Mentally disabled in and outside institution
- Groups of seniors, long time ill and physically disabled people in institution and under home care

The county municipalities are responsible for the public dental treatment. On a voluntary basis they can offer wholly or partly subsidized dental care to 19 or 20 year olds, and other groups that they decide to prioritize, and this varies somewhat between counties. The treatment is either carried out by the counties' own dental treatment personnel or by private dental clinics that have an agreement with the county municipality.

Other groups than those mentioned have to pay for the dental treatment in full.

Patients who used to have amalgam as a filling material have experienced increased costs when they get alternative filling materials instead. Although the dental health of the majority of the population is good there are great individual differences. Poor dental health often affects weak groups in society who neglect treatment on account of the high costs. For some major restoration work, the alternative to relatively inexpensive amalgam fillings is expensive treatment in the form of crowns.

6 Conclusions

In this section we present some conclusions based on the data and discussions presented in section 4 and 5.

6.1 The experiences with the alternative materials are generally positive

The interview performed among dentists for this report, as well as earlier assessments by others show that dental personnel and patients generally are satisfied with the alternative materials. The most common material used now is resin-based composites, but various glass ionomers and ceramic-based materials are also used to some extent. Most dentists gradually started to use these materials. Thus, the necessary technical equipment and basic skills among the personnel have been established over long time.

The main advantages with the alternative materials are that the materials have good adhesive properties, implying that removing of less amounts of the sound tooth substance is necessary compared to when using amalgam. Therefore, it sometimes takes less time to use the alternative materials in small fillings. Larger fillings are somewhat more time-consuming than when using amalgam, from 15-45 minutes more is claimed, depending on the dentist's skill and the complexity of the filling. For this economic assessment we have used 15-30 minutes in the calculations.

A disadvantage is that the alternative materials can be challenging to use, especially for larger fillings. Another disadvantage is that bacteria are more easily formed on the surface of the filling, thus requiring somewhat more follow up both from the patient and the dentist. Because of this and less "chewing-strength" the composite fillings do not yet last as long as the amalgam fillings (some say half the lifetime of amalgam fillings), but most dentists claim that the longevity is increasing and approaching the longevity of amalgam fillings. A few respondents claim that at least the small fillings already last as long as amalgam fillings. An important advantage for dental personnel's health is that amalgam in not used in the working environment. However, monomers from resin based materials may pose an occupational risk.

6.2 Total abatement costs for mercury from dental amalgam use

Estimated abatement costs for the various interventions performed for this study are summarized in table 6.1. Total costs for a dental amalgam separator in table 6.1 are the assumed historic costs of installing and operating the devise (Low alternative) and the calculated current costs (High alternative), and the Medium alternative is simply an average of these. The three alternatives for the costs of phasing out dental amalgam use are based on the assumptions of no extra time used by dentists when applying alternative materials (Low), 15 minutes more time (Medium) and 30 minutes more time (High). The abatement costs for emission reductions from crematoria are developed from a situation when only a mercury filter is needed (Low), a filter plus flue gas cleaning & cooling is installed (Medium) and when in addition building work is needed (High).

Table 6.1 Total abatement costs for mercury from dental amalgam use. NOK and €/kg mercury emissions reduced.

	Low cost	Medium cost	High cost
Dental amalgam separator	8,010 (€ 1,000)	10,190 (€ 1,275)	12,370 (€ 1,545)
Phasing out use of dental amalgam in new fillings	67,000 (€ 8,375)	300,000 (€ 37,500)	533,000 (€ 66,625)
Emission reductions from crematoria	29,170 (€ 3,645)	67,480 (€ 8,435)	122,000 (€ 15,250)

Source: Vista Analysis

Table 6.1 shows that the abatement “end-of-pipe” measures aiming at reducing emissions from dental clinics and crematoria are generally much lower than the abatement costs related to phasing out the use of amalgam in tooth fillings. Furthermore, the presented costs underestimate the total costs of phasing out dental amalgam since they do not include more frequent replacement of fillings because of shorter lifetime of composite fillings compared to amalgam fillings.

However, the costs of phasing out dental amalgam are zero for those who voluntarily have switched from this material to resin-based composites for various reasons before the ban on mercury-containing products was introduced. Thus, one should be very careful when comparing the cost figures in table 6.1.

Over time, costs for phasing out use of dental amalgam will likely converge towards the low alternative in table 6.1 as new dentists who are trained from school in using composites gradually enter the work force. Also, composite fillings will likely last longer in the future. so that these costs also will go down. Furthermore, in the long run amalgam separators and mercury emission cleaning in crematoria will no longer be necessary when all dental amalgam is phased out.

The abatement cost estimates are at the same level as those calculated in Cowi (2008). Cowi estimated the abatement costs of dental amalgam separators to be in the range of €1,400-1,800 per kg mercury release reduction, the costs of phasing out the use of dental amalgam to be in the range of €11,000-78,000 per kg mercury use reduction and the costs of emission reductions from crematoria at €17,000 per kg mercury release reduction. It can be seen that the estimated range in table 6.1 for the cost of dental amalgam separators are somewhat lower than Cowi’s, while the dental amalgam phase-out cost are very similar to (but a little lower than) Cowi’s. The high cost alternative for crematoria in table 6.1 is about the same as Cowi’s, which is likely due to the fact that we in this alternative have included full air emission abatement investments and some building work.

6.3 Dental amalgam phase-out should be seen in a broader perspective

Assessing the various interventions purely from an abatement cost comparison could easily lead to the conclusion that dental amalgam separation/collection and abatement of emissions from crematoria should be required, and that the choice of filling materials should be left to the dentist and patient.

Since the overall, long term goal globally is to eliminate the use and release of mercury to the environment, the use of mercury has to be addressed. Therefore, the use of dental amalgam should be phased out, and at the same time the actions towards the release of mercury from existing tooth fillings have to be implemented. When there in the future is no mercury left in tooth fillings there will be no need for dental amalgam separation/collection and abatement of emissions from crematoria anymore.

6.4 Comparisons across countries using Purchasing Power Parities (PPP)

Purchasing Power Parities (PPPs) are currency conversion rates that both convert to a common currency and equalize the purchasing power of different currencies. In other words, they eliminate the differences in price levels between countries in the process of conversion. Because market exchange rates are based on short-term factors and are subject to substantial distortions from speculative movements and government interventions, comparisons based on exchange rates, even when averaged over a period of time such as a year, may yield unreliable and misleading results. By establishing purchasing power equivalence, where usually one dollar enables purchase of the same quantity of goods and services in all countries, PPP conversions allow cross-country comparisons of economic aggregates on the basis of physical levels of output, free of price and exchange rate distortions.

In their simplest form PPP show the ratio of prices in national currencies of the same precisely-defined product in different countries (WB, 2011). For example, if the price of one kilo of oranges of a specified quality is 45 rupees in country A and 3 dollars in country B, the PPP for such oranges between the two countries, when B is the base country, is the ratio 45 to 3 or 15 rupees to the dollar. In other words, for every dollar spent on oranges of the specified quality in country B, 15 rupees would have to be spent in country A to obtain the same quantity and quality of oranges.

We have used PPP conversion factors from the United Nations Statistical Division (UN, 2011) from 2009 for some selected countries to illustrate what the abatement costs would be in their local currencies. The results are presented in table 6.2. For all countries except Canada this led to lower costs than when using official exchange rates, implying that the local price levels are lower than reflected in the exchange rates.

Table 6.2 Mercury abatement costs in some selected countries based on purchasing power parities. Local currencies/kg mercury emissions avoided.

Brazil (Real, BRL)	Low	Medium	High
Amalgam collector	1 430	1 819	2 208
Phasing out amalgam use	14 385	64 962	115 320
Emission reductions from crematoria	5 207	12 045	21 777

Canada (Dollar, CAD)	Low	Medium	High
Amalgam collector	1 095	1 393	1 692
Phasing out amalgam use	11 020	49 766	88 344
Emission reductions from crematoria	3 989	9 227	16 683

Chile (Peso, CLP)	Low	Medium	High
Amalgam collector	311 035	395 687	480 338
Phasing out amalgam use	3 129 382	14 132 117	25 087 090
Emission reductions from crematoria	1 132 697	2 620 309	4 737 370

China (Renminbi, CNY)	Low	Medium	High
Amalgam collector	3 478	4 425	5 372
Phasing out amalgam use	34 995	158 037	280 544
Emission reductions from crematoria	12 667	29 302	52 977

India (Rupee, INR)	Low	Medium	High
Amalgam collector	16 053	20 423	24 792
Phasing out amalgam use	161 516	729 400	1 294 818
Emission reductions from crematoria	58 462	135 242	244 509

Peru (Sol, PEN)	Low	Medium	High
Amalgam collector	1 421	1 808	2 195
Phasing out amalgam use	14 301	64 582	114 645
Emission reductions from crematoria	5 176	11 975	21 649

Source: Vista Analysis

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<tr><td colspan="4">Forfattere
John Magne Skjelvik og Eirik Schou Grytli, Vista Analysis AS</td></tr>
<tr><td colspan="4">Tittel - norsk og engelsk
Erfaringer i Norge med utfasing av bruk av amalgam
Review of Norwegian experiences with the phase-out of dental amalgam use
Rapporten er på engelsk.</td></tr>
<tr><td colspan="4">Sammendrag – summary
En oversikt over norske erfaringene med utfasingen i bruken av dentalt amalgam som tannfyllingsmateriale i Norge og en vurdering av de samfunnsøkonomiske kostnadene ved tiltakene for å redusere utslippene av kvikksølv som følge av bruk av dentalt amalgam. Hensikten er å vise hvordan Norge har gjennomført tiltakene og hva dette kan ha kostet.
A review of the experiences from the phase-out of the use of dental amalgam as tooth filling material in Norway, and an assessment of the socio-economic costs from the actions taken to limit the release of mercury caused by the use of dental amalgam. The purpose is to show how Norway has carried out this policy.</td></tr>
<tr><td>4 emneord
Amalgam, kvikksølv, utfasing, sosio-økonomiske kostnader</td><td colspan="3">4 subject words
Amalgam, mercury, phase-out, socio-economic costs</td></tr>
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Climate and Pollution Agency

The Climate and Pollution Agency reports to the Ministry of the Environment and has 325 employees, based mainly in Oslo. We implement government policy on pollution. We act as advisors, guardians and stewards for the environment. Our most important fields of work include climate change, chemicals, marine and freshwater environment, waste management, air quality and noise. Our vision is a future without pollution.
We are working to

- reduce greenhouse gas emissions
- reduce the spread of hazardous substances harmful to health and the environment
- achieve integrated and ecosystem-based management of the marine and freshwater environment
- increase waste recovery and reduce emissions from waste
- reduce the harmful effects of air pollution and noise

TA-2946/2012