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Heavy Metals in Vehicles

Final Report

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1 Introduction

Starting from September 1999, Ökopol has been performing a study on heavy metals in vehicles which was commissioned by DG Environment of the European Commission.

The objectives of this study include

- the generation of a reliable information basis, concerning the presence and quantity (including market trends) of heavy metal containing parts and components in vehicle categories M1 and N1;
- the analysis whether technical alternatives to the use of heavy metals (lead, mercury, cadmium and hexavalent chromium) in vehicles exist;
- the examination of the technical, environmental and economic implications of these alternatives;
- the examination of technical options for separation of heavy metal containing parts before shredding, description of technical recycling options, and the analysis of their economic implications.

Based on some preliminary research in the Internet and in recent literature, we established contacts with numerous automobile manufacturers and suppliers of parts and components who are relevant in the context of heavy metal applications in vehicle categories M1 and N1.

Concerning the specific applications of heavy metals to be examined in detail, the original list of Annex 2 of the Draft Directive on End-of-life Vehicles in its version of 21 June 1999 [97/0194(COD)] formed the basis of our work.

With evolving discussions, a number of modifications and additional applications of heavy metals came into focus with the recommendations (of 09 Nov.1999) of the EP rapporteur and the derogations adopted by the Environmental Committee (13 January 2000) to be proposed for the second Parliament reading.

The structure of this report is oriented towards the structure of Annex II of the draft ELV directive:

2 Results

2.1 Lead as an alloy

2.1.1 Steel containing lead

Field of application and product description

Lead is added to steel to achieve an approved machinability. The dissipitated lead leads to a situation where chips break off easier and shavings stay shorter. In addition an improved surface quality can be achieved.

There is a wide range of applications in automobiles, e.g. crankshafts, connection rods, fitting turn-offs, high pressure fuel injector parts.

The machinability of steel is of great importance not at least because around 50% of the value of a machined automobile component is due to machining costs.

Alternatives: strength - weakness profile (technical)

In the last two or three decades steel containing other elements (sometimes in addition to lead) for an improved machinability has been developed (sulphur, phosphorus, selenium, calcium, tellurium or bismuth), but did not substitute lead in real production in a wider range.

In view of the production process a phase out of leaded steel in this area would be technically possible. The main barriers are the necessary changes of the production processes (machines, tools, speed). Increasing energy consumption may result if the substituting element does not achieve the same reduction in machining efforts as lead. While in most cases this is technically already possible, the higher costs remain as a problem.

One car manufacturer mentioned that there may be a significant potential for future substitutions of lead by calcium. (Pb and Ca are not used in combination. Rather the Pb is eliminated completely where possible). Overall costs (material and production) for those lead-free parts may rise by an estimated 10 to 20 %.

Another alternative could be the replacement of lead by tin. As an example the leaded steel type "12L14" with 0.3 weight per cent lead can be substituted by "12T14" with 0.06 weight percent tin. Presently a relatively small quantity of this steel is produced (~ 1,400 t). The cost for products made by free cutting steel with tin will be in the same range as from steel with lead[1].

[1] pers. com. University of Pittsburgh A. J. DeArdo 1/2000

Replacing lead by bismuth is technically possible in a wide range of applications, and a similarly improved machinability can thus be achieved. While the car industry claims that there is no sufficient market supply of bismuth and prices may rise rapidly, the Bismuth Institute believes that there will be sufficient resources.

Amount

According to EN 10087, steel for machinery purposes usually contains between 0.15 and 0.35 weight percent lead.

In discussions with car producers a lead content of 0.3% was mentioned as an acceptable compromise between the goal of lead reduction and the goal of easily workable steel. In cases where higher Pb concentrations would be needed, one company uses calcium instead in its production.

Environmental relevance

Concerning heavy metals in the steel recycling process see chapter 3 p. 44.

The relevance of tin as a potential impurity of recycled steel is expected to be small because steel with a requirement for extremely low tramp element concentrations (e.g. for deep drawing sheets) is not produced in the electric arc furnace (EAF) but from ore via the blast furnace route, where mainly higher scrap qualities are used in the oxygen furnaces.

Other potential substitution elements are expected to have very little influence on steel quality.

Conclusions

Technically a substitution of lead in steel for machinery purposes is possible either by realising changes in the production processes, or by using other "alloying" elements.

Economically the material costs for potential substituting elements are less important than possible changes in machinability.

If an improved machinability cannot be achieved by substituting elements to the same extent as it is reached by lead, some environmental burdens can increase (higher power consumption, shorter lifetimes of tools).

In the very broad application field of leaded steel it was not possible to examine every application in depth. A case specific examination would be necessary.

Concerning the maximum lead concentration of 0.3 % or 0.35 %, car manufacturers stated that normally 0.3 % are sufficient. The main reason for making amendments concerning the concentration of lead may be that in the European standards for steel 0.35 % are mentioned.

2.1.2 Zinc coatings

Field of application and product description

Zinc coatings are mainly used for corrosion protection of steel. In the galvanizing process steel reacts with the zinc to form an alloy. Additionally a metallic zinc coating is deposited on the surface when the steel is, for example, taken out of a hot dip galvanizing bath.

Lead is used in the production process for an improved viscosity and drainage of excess zinc when the parts are withdrawn from the bath. With poor drainage, zinc can accumulate in corners and angles on the workpiece and bridge over small holes and channels. By addition of lead the appearance of the surface, the coating micro structure, coating formability and the drip formation are influenced as well.

Lead has a protective function for the zinc containing kettle in the process in those cases where the kettle walls are made of steel (which is mostly the case).

It has no function during the use of the coated steel.

Alternatives: strength - weakness profile (technical)

In the field of strip coating, around 90% of the production in Germany have already been changed to a lead-free process. This development is not easily transferable to batch processes. The protective function of lead during the process can become superfluous by using an internal clad to resist zinc attack. This is technically feasible, but this type of kettle is significantly more expensive. Lead may also become unnecessary if some emerging techniques are introduced, involving however a redesign of the process.

From a technical point of view, alternatives such as Bismuth have an almost identical influence on the physical properties of zinc (both wet or dry batch galvanizing). Bismuth containing Zinc is already used in mass production[2]. The dross and ash production and the zinc consumption may be influenced by the substitution of lead by bismuth, but experts are still divided on the subject as is reflected in recent literature.

2 For example Bi containing alloys carry the trademark name “Galvaflow”.

Costs of Bismuth are higher than of lead. But due to the relatively small amount of Bismuth in the final product, there will be no significant rise of the final product's costs as long as the price of Bismuth does not rise extremely.

Amounts

No data are available about the quantity of lead contained in zinc coatings of an average passenger car. A typical zinc bath composition of a batch process contains 1 % lead. Given the fact that lead-free strip coating is already applied in many cases, the overall amount will be far below one gram of lead per car.

The new formulation in the draft ELV Directive ("Steel (including galvanised steel) containing up to 0.35 % lead by weight") is not precise enough because the 0.35 % might be understood to refer to the whole steel parts, rather than just to the zinc layer.

Environmental relevance

The zinc coating will not be removed from the steel in the shredding process to a large extent. So the main part of the leaded zinc will run into the steel recycling process (see chapter 3 p. 44).

Conclusions

From a technical point of view, lead in zinc coatings can generally be replaced by other metals like bismuth or by changes in the production process. In the very broad application field it was not possible to examine every application in depth. A case specific examination may be necessary.

Concerning the final product of galvanised steel, the increase of costs by using alternatives such as bismuth will not be significant as long as the price of Bi does not rise extremely. Fundamental changes of the process techniques, like internally clad kettles or fully redesigned processes, will be more cost intensive.

Only in processes where state of the art dust abatement systems are installed it can be expected that lead emissions from ELV recycling will not be affected by zinc coatings containing lead.

In the ELV recycling chain, only a low percentage of lead contained in zinc coatings will be recovered in pure form. In the present situation the recovery rate of alternative alloys will be even lower.

2.1.2 Aluminium

Field of application and product description

Aluminium is increasingly used in vehicles as part of the overall efforts to reduce weight and thus reduce fuel consumption. The most important application of aluminium in vehicles is the engine, but there are numerous other potential application fields, including, e.g. the car body, the rear axis and the wheels.

In aluminium alloys commonly used, lead is basically an impurity element. In secondary aluminium, a certain amount of lead can be contained involuntarily[3] as a tolerated impurity, because it is not possible to separate the lead completely from the aluminium in the remelting process.

In the majority of standardised casting alloys, the lead content typically lies around 0,1%. For a few aluminium casting alloys, the European standards (EN 1706, EN 1676) allow higher lead contents of up to 0,35%. Neither in casting alloys, nor in the majority of wrought alloys there is a need for using lead as an alloying element in order to reach specific properties of the metal alloy.

For some minor applications, however, aluminium alloys are formulated with a lead addition of up to 1% for improved machinability. The European Aluminium Association has estimated the market share of these products at circa 0,3% of all aluminium used in automotive applications, with a decreasing trend in time.[4]

Lead concentrations higher than 1% (and up to 4%) which have recently been raised for being important in automobile manufacturing appear to be fairly exceptional. Such alloys potentially do occur in some niche applications at individual car manufacturers who probably could switch to substitute materials if necessary.

Concerning specific applications of aluminium alloys which have been mentioned during the discussions on Annex 2 of the Draft ELV Directive and the derogations proposed by Parliament, the status quo is characterised as follows:

3 originating e.g. from ELV scrap due to lead balance weights on aluminium wheel rims.

4 European Aluminium Association, letter to DG Environment 6 Nov 1998.

- Light metal wheels are made of aluminium and/or magnesium alloys with a lead content far below 0,4% and normally do not contain lead which has been deliberately added to the alloy.[5]
- Even if there may have been exceptions many years ago, no manufacturer could be identified who uses window levers containing up to 4% lead in today's assembly of cars.
- With respect to machined aluminium parts which are made of alloys containing more than 0,4% lead, a variety of small applications, including small engine parts and levers used in gears, were mentioned by industry to us.

Alternatives: strength - weakness profile (technical)

As already stated, in the majority of applications no lead is added to aluminium alloys in order to achieve specific properties. The aluminium industry has an interest to keep the lead impurities in the secondary aluminium cycle as low as possible. Aluminium scrap containing elevated lead concentrations is therefore either not accepted at all by secondary smelters, or only at a reduced price because further addition of clean scrap is necessary.

In those cases in which lead is deliberately added to the aluminium alloy in order to increase the workability of the material, bismuth could be a potential alternative.[6]

Amounts

Typically, the quantity of aluminium used in a modern car lies in a range between 40 kg (for a middle class car) and 100 kg (for an upper class car), with the majority being secondary cast aluminium.

In an example car which contains 40 kg of aluminium cast alloys containing 0,4% lead, the resulting quantity of lead in this cast aluminium would be 160 grams. More realistically, with an average lead concentration of 0,1% in cast alloys, approximately 40 grams of lead will be contained in the aluminium parts of a middle class car.

Only few parts contain higher lead concentrations of up to 1 per cent because they need to be machined. No quantitative information about the overall lead contribution from these applications could be obtained, but their market share in automotive appli-

5 This was confirmed by numerous experts both from the aluminium industry and from the car manufacturing industry.

6 According to the Bismuth Institute, lead in free-cutting aluminiums is slowly but increasingly substituted by bismuth in Switzerland and the U.S. (Y. Palmieri, pers. comm. 10-01-2000).

cations is estimated to be well below 1%. Depending on the precise material quantity and the lead contained in these alloys, machined aluminium will contribute between one and five grams of lead in a middle class car.

Environmental relevance

Upon shredding, lead contained in aluminium will mostly end up in the non-ferrous heavy fraction. After sorting, the aluminium alloys will enter into aluminium recycling. As the separation process is not precise enough to eliminate lead completely from the aluminium fraction, the lead will mostly remain in the aluminium cycle.

The aluminium industry has a strong interest that no enrichment of lead in secondary aluminium takes place. From the industry's practical experience, a maximum content of 0,4% lead in aluminium scrap provides a sufficient safety margin to ensure that the tolerable lead contents in aluminium alloys from secondary smelting are not exceeded.

Conclusions

There are sound reasons to allow a certain concentration of lead (0,4% at maximum) in secondary aluminium in order not to interfere with the established recycling structures. No necessity could be identified to tolerate higher lead concentrations of up to 4% in wheel rims or window levers.

From a quantitative point of view, aluminium alloys for machinery purposes (e.g. for engine parts) are of minor importance because they make up for less than one per cent of all aluminium used in vehicles. A maximum lead content of 1% should be sufficient to achieve the required machinability. On a medium-term perspective, alternative alloys are expected to be available which will allow full substitution of lead used as an alloying element.

2.1.3 Copper alloy containing up to 4% lead by weight

Copper alloys with a lead content of up to 4 % are used in European cars for example in bearing shells and bushes (see following section 2.1.4). Besides these there is a big variety of other applications like e.g. nozzles, connection parts, fixtures or locks made from brass or other alloyed copper. A case specific examination would be necessary for these applications.

2.1.4 Lead/Bronze bearing shells and bushes

Field of application and product description

Bearing shells and bushes are used in cars in a wide range of applications e.g. bearing of crankshafts, hinges and in shock absorbers. Lead has the function of a lubricant especially during the start of the operation (e.g. start up of the motor). Additionally there must be a soft surface for making it possible that small foreign particles can be included in the material.

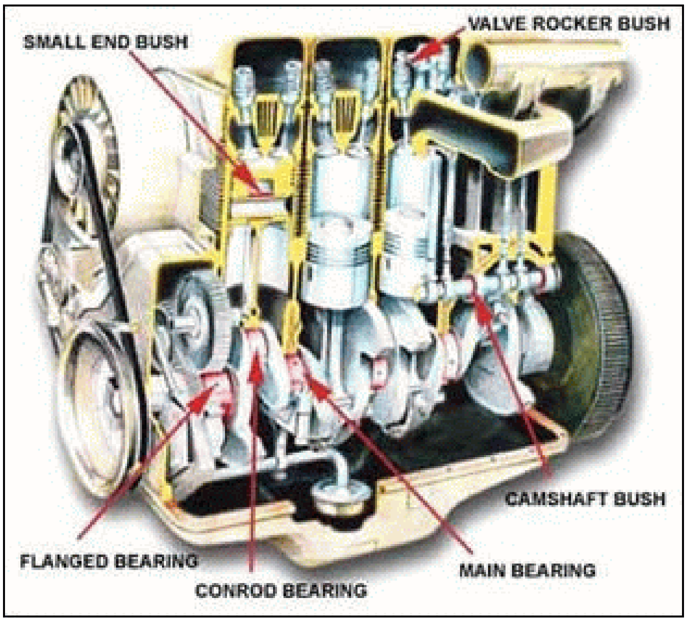

Figure 1: Bearings and bushes in a motor

Alternatives: strength - weakness profile (technical)

A broad variety of different lead free solutions is already applied in mass production, or is at least under discussion presently. Examples are the main bearing shells of crankshafts as well as most hinges in cars presently made of lead free materials. Where lead is substituted by other alloying elements, tin is the most appropriate alternative.

On the other hand there are still some applications where the emergency lubricating properties of lead cannot be substituted yet. Such applications are e.g. antifrictional parts of connection rods and sometimes shock absorbers. Graphite will be in some application fields a possible material for improved antifrictional characteristics e.g. in high strength metal matrix composite material.

Amount

No data are available that would allow a reliable estimate of the amount of lead from bearing shells in an average car.

Environmental relevance

During the use of a car, part of the material of the bearing shells will be worn out and removed. Upon recycling, depending on the way of treatment of the ELV, the lead from bearing shells will end up in the steel, aluminium, or copper smelting processes.

Concerning the steel recycling chain see chapter 3 p. 44.

In the secondary aluminium process lead must be considered as a disturbing element (see chapter on "Aluminium" p 8).

The recovery of lead in the copper process is possible only in those cases where appropriate techniques are used.

Conclusions

The applicability of lead free solutions for bearing shells and similar antifrictional parts can only be proven in some application fields. When substitution of lead by other alloying elements is considered, the main criteria are functional requirements during the use of the product (emergency lubrication) rather than costs.

2.1.5 Lead/Bronze pistons

In spite of intense discussions with suppliers, car manufacturers and the German Association of Car Manufacturers (VDA), no case of using lead / bronze pistons in today's cars could be identified.

2.2 Lead and lead compounds

2.2.1 Batteries

Field of application and product description

Today's car starter batteries are lead / sulfuric acid batteries with a relatively long lifetime of around 3 to 5 years.

Amounts

Batteries are the main application field of lead in a car. With an average weight of 15 kg per car it makes up more than 90 % or even > 95 % of the total lead amount in a car.

Alternatives: strength - weakness profile (technical)

No practicable alternatives for a mass production level are known for lead starter batteries.

Environmental relevance

In some European countries and according to the draft ELV Directive the dismantling of lead batteries from ELV is mandatory. Shredding companies have a strong interest not to pollute the shredder products and residues by those large amounts of lead. Profits from selling of lead derived from batteries are in the range of 100 to 250 Euro. A recycling system for lead / acid batteries is established in some countries since several years, sometimes connected with a deposit system. Recycling or neutralisation of the acid is not supported by market forces.

Conclusions

No practicable alternatives for lead starter batteries are known that would be available at a mass production level.

2.2.2 Fuel tanks

Field of application and product description

Automobile fuel tanks can be made using terne metal, which is steel sheet that has been coated with a lead-tin alloy in hot dip process.

Alternatives: Strength - weakness profile (technical)

Presently there are some lead free alternatives available and widely used by car producers:

- galvannealed[7] steel sheets with an additional organic coating
- galvanized steel with a nickel flash plating
- tin-zinc alloy coated steel sheet
- aluminium plated steel
- zinc nickel alloy with a chromium oxide film
- zinc plate coated with epoxy resin
- plastics

Some companies changed to lead-free steel tanks already several years ago. Other companies only use plastic tanks or a mixture of plastic and steel tanks.

[7] Galvanized steel with a following thermal treatment.

Plastic tanks have the advantage that they can be fitted even in complicated shapes. On the other hand, fuel permeability can lead to problems especially on the North American market due to the introduction of stricter permeability standards.

The costs of non-leaded steel tanks are in the same range or lower than for leaded tanks. In Europe, zinc coatings are easily applicable. In other countries, a higher water content of fuel or the use of ethanol gasoline (attracts water from air) may cause problems because the zinc coating will be consumed upon contact with water. Requiring non-leaded steel tanks may cause problems when cars are imported to Europe from countries like e.g. Brazil. Organic coatings may sometimes not be satisfying as an alternative because of their solubility in gasoline and because of increased mechanical wear.

Amounts

No data are available concerning the amount of lead used in lead coated tanks.

Environmental relevance

Leaded steel tanks will usually not be dismantled. The lead content runs back to the steel works (see chapter 3 p. 44.)

Organic coatings will be burned off in the steel process. Plastic tanks will end up in the shredder light fraction.

Conclusions

Presently there are several car producers who do not use lead coated tanks. There are sufficient alternatives available which are also economically feasible.

2.2.3 Vibration dampers

Field of application and product description

Vibration dampers made of lead can be used in various applications, including the balancing devices on the axle from gearbox to wheel and the steering column. It is generally understood that wheel balancing devices are not covered by this term.

Principally, such vibration dampers are not favoured by the manufacturers themselves, because they contribute significantly to the overall weight of a car and thus are in conflict with the targets of weight reduction and fuel saving. Manufacturers therefore try to improve their mathematical vibration modelling during the conceptual phase of a new model in order to avoid the necessity to use vibration dampers.

Nevertheless, in the development of a new model they may become necessary at a rather late stage, e.g. when certain noise problems cannot be solved otherwise, or when a test driver of a prototype reports about unstable behaviour at high velocity.

Alternatives: strength - weakness profile (technical)

Vibration dampers made of lead are a fairly easy solution to vibration problems, but at the same time they are in conflict with the aim of weight reduction.

In some new models, lead used for balancing devices on the axle from the gearbox has been successfully substituted by cast iron. Presently, this substitution is not possible in all existing models for space reasons. Furthermore, cast iron does not absorb vibrations as effectively as lead and can give rise to secondary vibration problems.

In some cases substitution of vibration dampers is possible:

- In some cases, use of the airbag module for vibration compensation has turned out to be a successful construction alternative for the use of mounted vibration dampers in the steering column.
- With a system called "Integrated Starter Alternator Damper (ISAD)"[8] in some cases the mass damper in the drive train can be substituted.

Amount

The quantity of lead used in vibration dampers can be significant. Typical weights are 100 - 300 grams, but heavier weights up to 4,7 kilograms in new car models (where the increased use of plastics led to serious noise problems) have been reported.

Environmental relevance

Although massive lead will have a tendency to accumulate in the non-ferrous heavy fraction after shredding, even car manufacturers admit that vibration dampers may contribute significantly to the lead contamination of the shredder light fraction.

Therefore, it is proposed by some manufacturers to remove these massive lead parts during dismantling of end-of-life vehicles. It is claimed that dismantlers themselves should have an interest to collect the lead because of its market value.

[8] While usually cars use two separate electrical machines – one for starting up and one for power supply -, the ISAD system provides one unit that replaces the automotive vehicle's starter, generator and flywheel. Working as generator, ISAD controls the electric energy supply. Drive train vibration – and thus vibration in the vehicle as well – are reduced electromagnetically.

However, this argument neglects the problems related to the dismantling of vibration dampers containing lead: While the material value of a lead weight would be sufficiently high to compensate for circa 10-15 seconds of working time at the dismantlers', in many cases the balancing devices used as vibration dampers are not at all easily accessible. Moreover, normally the dismantler has no information about the presence of vibration dampers in an old car, and the position where they are located.

Conclusions

Substitution of lead has been successfully practised in standard models and should be possible for new models of all manufacturers within two or three years' time. Certain problems may exist for special vehicles (e.g. open sports cars where the car body gives less rigidity), but also for other cars where plastics are increasingly used as construction materials.

Because of the large quantities of lead contained in them, vibration dampers appear to be a high priority for future efforts to minimise the presence of toxic heavy metals in vehicles. As long as they are still in use, dismantling of lead-containing vibration dampers is very important to avoid lead contamination of the shredder light fraction.

Under present circumstances, however, it cannot be expected that vibration dampers will be dismantled because of insufficient information to dismantlers, and because market forces stand against dismantling.

Consequently,

- vibration dampers made of lead should be avoided wherever possible;
- "design for recycling" must be improved for lead which cannot be avoided;
- it should be mandatory for manufacturers to offer information to car dismantlers about the presence and location of vibration dampers containing lead;
- incentives and / or controls are needed to ensure that dismantling is actually done.

2.2.4 Vulcanising agent for high pressure or fuel hoses

Field of application and product description

Lead as a vulcanising agent is used for high pressure and fuel hoses with high security demands (e.g. in power steering, fuel tubes etc.).

These hoses provide the required flexibility and meet safety requirements. Therefore, although they are more expensive, they are preferred to e.g. steel tubes.

Alternatives: strength - weakness profile (technical)

Irrespective of costs, no technical alternatives could be identified for this application field.

Amount

The lead content in the material is lower than 0.1 % by weight. The total quantity of lead in this application in an average car has not been reported.

Environmental relevance

High pressure hoses are leaving the shredder process via the shredder light fraction (SLF) or shredder heavy fraction (SHF) and are subsequently deposited on landfills or incinerated. For a detailed discussion of the environmental relevance of lead in shredder light fraction the reader is referred to section 2.2.6, page 21.

Conclusions

Irrespective of costs, no technical alternatives for substitution of lead as a vulcanising agent for high pressure and fuel hoses could be identified during this study.

The environmental relevance is considered to be relatively small due to the rather small amounts of lead in this application.

2.2.5 Lead as stabiliser in protective paints

Field of application and product description

The first of several layers of protective paints on the car body is the electrodeposited coating (E-coat) whose main function is to protect the metal against corrosion. In a cathodic bath, laquer particles are deposited on the metal surface by application of an electrical field. After removal of excess paint material, the laquer is fixed by heating, yielding a laquer thickness of circa 18 µm.

Alternatives: strength - weakness profile (technical)

Until some years ago, lead in E-coat was considered necessary to give car bodies the required corrosion protection. More recently, laquer suppliers such as PPG or BASF have developed new, water-based cataphoretic laquers in which the use of lead is obsolete. One further advantage of the new method is that pre-treatment of the metal surface is possible without using toxic heavy metals.

Beginning in the 1990ies, several European and Asian car manufacturers have taken the initiative to change their production methods, increasingly using lead-free cataphoretics while the lead-containing protective paints are gradually being phased out. According to manufacturers, the main impetus for this change was to reduce hazardous waste problems, both in waste-water discharge and filter disposal. An additional advantage is given by the fact that the new formulations have much lower contents of volatile organic compounds (VOC).

Today, these new paints safely meet the high quality requirements of the car manufacturing industry. The costs are competitive with the old lead-based paints (the slightly higher price of the paint is compensated by the greater yield) provided that either the paint shop is newly constructed, or the conversion is carried out simultaneously with some other retrofitting or repair measures. Consequently, most car manufacturers are now applying lead-free protective paints in full scale production in at least some of their paint shops.

Some car manufacturers identified problems when applying lead-free cataphoretic paints in situations where different metals are combined with each other. These problems are expected to be overcome within the next two years.

The conversion of existing paint shops in which lead-containing protectives are still applied is possible but rather expensive. If it is accepted that the conversion is economically feasible only in combination with some other retrofitting or repair measures, the complete phase-out of lead-containing E-coats should be possible within a couple of years.

A similar period may be required for necessary changes along the supply chain until all suppliers will have phased out the use of lead-containing protective paints completely.

Amount

The thickness of the E-coat layer is approximately18 µm. No total amount of lead per average car is reported.

Environmental relevance

Upon shredding of the car body, some of the lead-containing E-coat may remain in the steel fraction (for further fate in steel plants see chapter 3 p. 44) while the majority will end up in the shredder light fraction.

For a detailed discussion of the environmental relevance of lead in shredder light fraction the reader is referred to section 2.2.6, page 21.

Conclusions

The conversion of existing paint shops in which lead-containing protectives are still applied should be possible within a couple of years. A similar period may be required for necessary changes along the supply chain until all suppliers will fully meet the specifications requiring the use of lead-free protective paints.

2.2.6 Lead as stabilizer in plastics

Field of application and product description

All relevant applications of lead used as stabilizer in plastics refer to the use of polyvinyl chloride (PVC) in car manufacturing.[9]

The relevant fields of application of PVC in cars are underseal, cables and wires, and upholstery of the car's seats. Other existing uses include the covering of dashboards, panelling of the doors and doorhandles, or coating of hat racks. Smaller quantities are found in ledges, floorings, and sealings of seams.

Depending on the specific requirements, PVC can be equipped with additives to obtain special mechanical or inherent properties. While the use of other additives such as plasticizers, flame retardants or biocides depends on the specific purposes, the addition of stabilizers is always required for two reasons: firstly, they guarantee heat resistance during manufacturing, and secondly they elevate the resistance of products against external impacts like visible light, UV-rays and heat.

Since the consumption of cadmium-based stabilizers has strongly decreased in recent years,[10] the most important stabilizers are based on lead today. According to [UBA,

[9] Since other plastics are inherently more stable against external impacts such as UV radiation or heat, they do not need to be stabilized by lead additives or their substitutes.

[10] The restriction on use of cadmium stabilizers after council directive 91/338/EEC (interior, exterior, underbody of vehicles for road transport and insulation for electrical wiring) has led to a replacement of cadmium-based systems mainly by lead stabilizers.

1999][11] approximately 60-75 % of all stabilizers used for PVC-products in Europe contain lead. Lead concentrations in PVC range between 0,5-3 weight-% (ibid).

At the technical level, possible alternatives for lead stabilizers are calcium/zinc stabilizers, barium/zinc stabilizers and organotin compounds (mono- or diorgano-compounds).

It is estimated that between 6 and 15% of all PVC on the market is stabilized with organotins. Tin concentrations lie around 0,4 weight-% or lower [UBA, 1999].

More recently, alternatives which are free of heavy metals are being developed on the basis of magnesium-aluminium carbonate ("Hydrotalcite").

Related to the main application fields the status quo is as follows:

- Car underseal made of PVC is already free of lead stabilizers today (as is confirmed by suppliers of underseal as well as by car manufacturers).
- Presently, 90% of all cable and wire coatings used in the automotive industry are made of PVC (alternative coating materials are fluoroplastics, polypropylene or polyamides). In this application, lead compounds are frequently used as stabilizers.
- Upholstery for car seats made of PVC has lost its importance in cars for private use and is now mainly used in cars like taxis where easy cleaning of the seats is important. In these remaining cases, lead stabilizers are commonly used.
- For other applications like dashboards, door panelling, sealing of seams etc., PVC-free alternative materials are readily available and well introduced on the market. These materials which can be used instead of PVC include polypropylene (PP), polyurethanes (PUR) and various other polymers and co-polymers. Their additional costs range from 0 - 200 per cent, depending on the specific application.

Alternatives: Strength - weakness profile (technical and economic)

Cables and wires in cars must be heat-resistant to temperatures between 90 and 140 °C. With lead stabilizers, it can be easily guaranteed that these requirements are met. Where heat resistance up to 100 °C is required (e.g. in many consumer products), the use of Ca/Zn-soaps instead of lead stabilizers is standard practice today.

If exposure to higher temperatures may occur, substitution of lead by Ca/Zn-systems is technically feasible if special Ca/Zn-compounds are applied. One potential solution is Ca/Zn with epoxydized soyabean oil as co-stabilizer. Such compounds are more sensi-

[11] "Handlungsfelder und Kriterien für eine vorsorgende nachhaltige Stoffpolitik am Beispiel PVC". Umweltbundesamt, Berlin 1999.

tive than Pb-systems and therefore require a more precise dosage and processing. Some processing parameters need to be adjusted because the floating properties of Ca/Zn differ from those of Pb-systems. The additional costs of Ca/Zn-based stabilizers for cables and wires are estimated to be 50-200 per cent of the cable price (which, in a complex installation, maybe equivalent to a relative cost increase of 10-20% [UBA, 1999]). Lead-free harnesses for cables stabilized by a Ca/Zn-system were introduced on the market in Toyota cars in 1997/98.[12]

Also, non-halogenated insulation materials for automotive wires based on polyolefines which are free of lead or other heavy metals are commercially available. The costs of these cables are said to be 35-50% higher than for PVC-coated cables.

Recently, German car manufacturers have embarked on a joint initiative to phase out lead from application in cables and wires.

With butyltin or octyltin, heat resistance up to 140 °C can be achieved at low dosages. For car seat upholstery made of PVC, application of organotins is a possible alternative to lead-based compounds. Mainly butyl- and octyltin compounds are used in Germany, while methyltin compounds are less common in Western Europe.

Dashboards can also be stabilized with Ba/Zn-stabilizers; requirements of heat resistance up to 130 °C due to solar radiation are fulfilled.

Amounts

In Europe, about 170.000 metric tonnes of PVC annually are consumed by the car industry for use in the manufacturing of cars. In Germany, 95.000 t PVC were used only for cables in the year of 1990. Thereof cables for vehicles had a share of 8.550 t (9 per cent).[13]

Environmental relevance

Since lead is bound to the PVC-matrix, emissions during product use are negligible. More important are emissions in cases of accidental fire [UBA, 1999] and during disposal.

Because the market forces stand against this, it is unlikely that cables, dashboards or other PVC-containing parts will be removed at the car dismantler's. After shredding, approximately half of the cables are found in the shredder heavy fraction (SHF) and the

12 [Metal Bulletin, 7 July 1997].

13 With a lead concentration of 0,5-3 %, this would mean that a mass flow of between 40 and 250 metric tonnes of lead is contained just in the cables of one years' German car manufacture.

other half in the shredder light fraction (SLF). After partitioning of the SHF, separated cables can be handed over to cable recyclers. Sorted PVC will partly be recycled or otherwise disposed of.

With respect to the remainder, the major part of SLF is presently being landfilled in Europe. Specialised waste incinerators are not selected as a disposal route because of their high costs of incineration. Co-incineration of SLF in the cement industry has been tested in some Member States.

In the future, co-incineration of SLF (or its high-caloric fractions) in large industrial installations is expected to gain increasing importance. However, the presently high concentrations of heavy metals and also halogens in SLF cause serious problems for the relevant industrial sectors because they interfere with their input quality requirements related to process control, product quality, and also environmental and workers' health aspects [Ökopol, 1997].[14] The Lower Saxony expert commission on wastes from end-of-life vehicles recommended to reduce the use of disturbing elements like heavy metals and halogens in plastics (and in particular cable coatings) in order to facilitate energy recovery of the high-caloric fraction of SLF.[15]

While in a modern incineration plant, lead would mostly be collected in incinerator ashes, fly ash and neutralisation residues, the situation for co-incineration is more complex: due to dilution effects, in spite of the revised Directive on the Incineration of Wastes [98/0289 (COD)] it must be assumed that the atmospheric lead emissions from co-incineration or other recycling of SLF are more significant. In any case, upon incineration or co-incineration of lead-stabilized plastics, the lead will either end up in the product or in the solid residues of the process.

In case of landfill, especially under acidic conditions, leaching of lead is possible.

Among the possible alternatives to lead stabilizers, Ca/Zn-based systems are preferable because of their non-toxicity to humans and ecosystems [UBA, 1999].[16] Systems based on Ba/Zn are less preferable because of the moderate toxicity of barium to humans. Use of organotin compounds cannot be recommended as long as no reliable evidence about their behaviour in the environment is available.

14 "Limitierende Inputparameter bei der Entsorgung von Shredderleichtfraktion in Zement- und Stahlwerken und deren methodische Ableitung". - Ökopol, 1998, commissioned by the German Federal State of Lower Saxony.

15 3. Regierungskommission der Niedersächsischen Landesregierung zur Vermeidung und Verwertung von Abfällen, Arbeitskreis 16 "Kfz-Recycling", Final Report, Hannover 1998.

16 As far as they are technically available, Mg/Al-carbonates would rank similar to Ca/Zn-systems.

Table 1: Environmental profiles of various PVC stabilizer systems

Criteria \ Variants		Pb	Ca/Zn	Ba/Zn	Organotins	Mg-Al carbonates
emissions during winning		lead emissions due to separation and extraction from the ores	Cd accompanies zinc ores Cd emissions during winning	Cd accompanies zinc ores Cd emissions during winning		
toxicity		Pb toxic to humans and ecosystems	non-toxic to humans and ecosystems	Barium is moderately toxic to humans	not well examined (but some concerns raised)	not well examined but unlikely
emissions during product use		bound to matrix	bound to matrix	bound to matrix	bound to matrix, but emissions from new products (especially soft PVC)	
disposal	recycling	dispersion of lead into recycling products			sulfur containing organotins hamper recycling (formation of insoluble sulfides with Cd, Pb, Zn)	
	process output via SLF / SHF without recycling	emissions of lead from thermal processes potential emissions from landfill			tinoxide emissions from thermal processes emission from landfill not well examined	

Conclusions

PVC is the only plastic material in which lead is commonly used as a stabilizer.

To phase out the lead contained in PVC, two principal strategies are possible: either, the PVC is substituted by some other plastic material, or PVC is maintained as a material but another stabilizer is used.

The quantitatively most relevant PVC application in cars, the underseal, is already lead-free today.

For all other applications, a change to Ca/Zn-stabilizers is technically feasible and clearly preferable from an environmental point of view. Lead-free cable harnesses are already introduced on the market, and a joint initiative of car manufacturers to change to lead-free cable insulations is presently under way.

Instead of changing the stabilizer systems, it is also possible and often even cheaper to change to lead-free plastics other than PVC which are available for all PVC applications in vehicles.

2.2.7 Soldering

Field of application and product description

Soldering in the automotive includes a number of issues from soldering of printed circuit boards (PCB) to brazing of components like petrol tanks.

Technical progress leads to an increasing use of electronic devices in automobiles, some of them under extreme conditions such as strong vibrations and high temperatures (e.g. when applied directly on the engine block) which require solders with higher melting point.

Brazing of components:

Brazing is used as a connection method for car components like fuel nozzle and metal tanks.

Printed circuit boards

The most important soldering methods for printed circuit boards are:

Through-Hole-Mount (THM)	The components are inserted in prefabricated holes on the printed circuit boards. The high reliability of this method makes it important for automotive electronics.
Surface-Mount-Technology (SMT)	Components are fixed on the boards with an adhesive or mounted on the solder paste. Lower product costs when soldering large volumes make this technique important for consumer electronics.

Soldering can be divided into wave soldering, where after preheating of the components solder is applied with a wave machine, and reflow soldering where the joints are performed in a furnace (convection, infrared). The latter is more common for SMT.

Alternatives: Strength - weakness profile (technical)

The proposed European WEEE-Directive which mentions a phase-out of lead before 2004 and objectives of major Japanese electronic manufactures to eliminate lead within the next years, gave research a new impulse. Large companies like Motorola, Philips, Siemens, Matsushita, Fujitsu (elimination of lead from products planned for 2002) and Nortel are already investigating the feasibility of lead free soldering technologies.

There is no universal solution for replacing leaded solders that would fit for every application in cars. As some substitutes may contain up to four or five different elements, the list of potential alternatives is very long. However, substitute alloys which are suitable for the mainstream electronics assembly industry must fulfill some key requirements, including:

- low metal price,
- availability of the metal,
- no toxic or ecotoxic properties,
- suitable melting point,
- other physical properties,
- solderability.

Some alloys which are not appropriate for the mass market might still remain important to fill niche markets. Several car manufacturers are presently searching for lead-free solders or are already testing alternatives.

Three different aspects of soldering must be considered:

- the solder itself
- fluxes and
- the surface of parts

Solder Tin is the base metal used for lead-free alloys and is commonly accompanied with silver, copper, zinc, antimony, indium or bismuth.

All lead-free alternatives are more expensive than the standard tin-lead alloy (63Sn37Pb). For bar or wire soldering the metal price (60 % of the product price) is much more relevant than for solder pastes (5-8 % of the product price, production costs of mixing and filling have the main share). Only a small number of lead-free alloys are patented. Costs for patented alloys will be higher than for those which are not patented.

Generally costs cannot be fixed at metal prices because the density of the metals determines the mass used. In an exemplary comparison of product costs, printed circuit boards soldered with SnAg are only 0.1 % more expensive than those soldered with standard SnPb.

Aspects like the applied technique and the demands on the soldered product influence the selection of the solder. Nevertheless, some general remarks on special metals are possible.

The worldwide availability of indium is rare, so a significant share of indium raises the costs of the alloy. Alloys with indium can only be used for soldering in special application fields and are disregarded in further considerations.

Alloys with zinc are problematic because zinc is subject to rapid oxidation.

Fluxes

In soldering processes fluxes are used to clean the joining surfaces chemically. Depending on the conditions of the soldering process the flux has to meet different requirements. Fluxes for lead-free processes have been developed and are available for all techniques.

Surface

Lead-free protective coatings to prevent corrosion or contamination of the boards are already in use. Metallic or organic coatings in different variations are available on the market.

Components are provided with a plated or dipped solderable coating usually a thin lead-tin layer. The lack of components with lead-free coatings could be limiting the implementation of lead free processes. The further use of components with lead containing coatings is possible but the occurrence of low melting phases is to be considered especially if Bi-containing solders are used. Lead-free coatings of components are for example tin, nickel/palladium, nickel/gold or gold which are already used in the electronic industry. Problems are therefore not attributed to the coating but to technical difficulties as components must resist 20 - 30 K higher soldering temperatures. Especially mechanical components might lose their functioning.

Amounts

The total lead amount in printed circuit boards in Japanese middle class cars is roughly estimated at 50 g. With Through-Hole-Mount (THM) technology, the lead amount per joint is about 4 mg, with Surface-Mount-Technology (SMT) about 0,2 mg[17].

Brazing alloys contain around 70 % lead. For brazing of steel tanks the amount per car is 30 to 60 g.

Environmental relevance

Lead from printed circuit board soldering will leave the shredder process mainly via the shredder light fraction (SLF). The main share of brazing will rerun to the steel recycling chain (see chapter 3 p. 44) or will be carried out of the shredder with the shredder heavy fraction (SHF) with a low probability of being recovered.

Bismuth is a by-product of the refining process of lead, therefore emissions of the ecotoxic and toxic lead must be taken into account. Direct mining of bismuth is possible but will cause increasing costs.

Antimony and indium are considered to be toxic and ecotoxic. As only small amounts of antimony are used in the alloys, impacts might not be that serious. Nevertheless, less harmful alternatives (e. g. SnAg, SnAgCu) are to be preferred.

In a life-cycle approach the environmental burdens of soldering with lead-free solders were compared to those caused by 63Sn37Pb. Results showed that lead causes the highest impact. From the tested alloys, 99,3Sn0,7Cu and 96,5Sn3,5Ag were the environmentally least harmful alloys.

Lead-free alternatives will require higher process temperatures. This means that emissions relevant to climate, as well as energy costs, will increase. A summarizing study has not been worked out yet. Therefore, it is difficult to quantify the environmental impact.

Conclusions

Presently extensive investigations to find lead-free alternatives are carried out by several car manufacturers and suppliers, and replacement of lead is already possible in several application fields. But it has to be considered that there is no universal solution that would be suitable for all cases. Unlike consumer electronics like TV or hifi systems, safety requirements in cars, in combination with temperature and mechanical stress and corrosive conditions, make replacement more problematic.

[17] KEMI: Some uses of lead and their possible substitutes. Hedemalm, P., KEMI Reports 3/94

Lead free soldering in the automotive industry can only be implemented stepwise. Experiences from applications with moderate safety demands and ongoing research will lead to transfer of lead-free soldering technology from automotive parts with less adverse conditions (e.g. interior) to those with more demanding requirements.

A total ban of lead containing soldering cannot yet be recommended in the present situation.

3.2.9 Wheel balancing weights

Field of application and product description

Wheel balancing weights are applied to wheel rims to compensate unbalances and guarantee therewith true running of the tyres.

Usually these weights are made of lead. They are available on the market in all weight classes and for all rim types. To prevent corrosion of aluminium or magnesium rims, weights are provided with a coating. Weights for steel rims, which make up the main market share, do not need to be coated in order to ensure corrosion protection. Nevertheless, often even weights for steel rims are supplied with a polymer or zinc coating to avoid pick up of lead during handling.

Strength-weakness profile (technical)

Tin, steel and plastics are the main substitutes for lead in balance weights. Wheel balances made of tin or steel are already on the market. Tin weights are presently not applied by car manufacturers, not even in new models. However, Japanese manufacturers announced a phase-out of lead wheel weights by the year of 2000 (Nissan) respectively 2002 (TOYOTA) by changing from lead weights to steel weights for cars. Nissan is already applying steel weights up to 30 grams.

As tin and steel are specifically lighter than lead, the volumes of those weights will increase. According to tests carried out by a manufacturer this must not necessarily cause a loss of balance performance.

Similar to lead-weights, also tin-weights must be coated when attached to aluminium or magnesium rims in order to prevent a direct contact with the alloy. Steel weights must be coated for all types of rims to protect the weights themselves from rusting.

Table 2: Comparison of characteristics of metal for wheel balancing devices			
Variants / criteria	Pb	Sn	Fe
Melting point durability at high temperatures close to the breaks	330 °C alloys containing 6 wt. % antimony have a melting point of app. 252 °C	232 °C alloys containing 6 wt. % antimony have a melting point of app. 247 °C	1.500 °C
specific weight volume must fit restricted space at the rims	11,3 kg/dm³ high specific weight makes manufacturing of weights with a minimal volume possible	7,3 kg/dm³ feasible for standard sizes if space is restricted other alternatives must be considered[18]	7,9 kg/dm³ feasible for standard sizes if space is restricted other alternatives must be considered
ductility adjusting weights to rim radius	easily achieved	easily achieved[19]	very restricted ductility might make broader product series necessary
corrosion	coated products for aluminium and magnesium rims	coated products for aluminium and magnesium rims	no corrosion prevention for the rims necessary but coating for rust prevention of the weight itself
costs/vehicle[20]	0,042 Euro	0,48 Euro	< 0,042 Euro

Amounts

Weights are offered between 5 and 400 g. JAMA gives lead amounts of 240 g per vehicle resulting from wheel weights. For new models a calculation of 100 g per car might be more realistic. The annual demand for the production of wheel weights is estimated between 40.000 and 70.000 t.

[18] Tungsten-alloys with a high specific weight for heavy weights in combination with restricted space.

[19] According to suppliers, ductility is as good as for lead-weights. Nevertheless ductility depends on the alloy used.

[20] Estimation based on prices for pure metals. Costs for processing not considered.

Environmental relevance

In the following, the recycling and disposal is assessed along two pathways:

- either the wheel weights are dismantled, followed by recycling
- or wheel weights are not dismantled, but disposed of without recycling.

In Europe the dismantling of wheel balances before passing the car to the shredder is not mandatory[21]. Although the weights can be easily removed from the rims as they are only attached with a clip or polymer adhesives, it is questionable whether dismantling is actually done because profits of 0,015 Euro per car (this gives dismantlers only a time of 6 seconds to remove wheel weights if they want to work economically) make dismantling not worthwhile.

To avoid lead emissions during product use, manufacturers proposed to coat all wheel weights, including those for steel rims. Since numerous weights fall off during use, this will not be sufficient to fully avoid lead emissions to the environment. Coatings which have been damaged either mechanically or due to environmental impacts will not sufficiently prevent lead from entering the environment.

Alternatives made of tin or steel are attached in the same manner to the rims as lead weights and therefore require similar efforts to be removed. Steel weights do not need to be separated from steel rims before recycling. As tin achieves higher prices than lead the recycling rate of such weights may even increase.[22]

If balance weights (or the complete wheel rims, respectively) are not removed, lead and tin will enter the shredder heavy fraction or may become part of ferrous scrap (see chapter 3 p. 44).

When entering thermal processes, lead or tin alloys containing antimony may form toxic antimony oxides (antimony trioxide is considered to be carcinogenic).

Conclusion

Wheel balancing devices made of steel are approved on a mass production level for weights up to 30 g. For bigger weights, major changes in balancing technique would be necessary which are not yet approved on a mass production level and which will have to be implemented also in service stations and garages.

[21] In the "European Parliament legislative resolution on the common position adopted by the Council with a view to the adoption of a European Parliament and Council Directive on end-of-life vehicles (8095/1/1999 - C5 - 0180/1999 - 1997/0194 (COD))" Amendment 31 says that the removal of tyres is only mandatory if they are not segregated in the shredder process. In those cases removal of wheel balancing devices will become more unlikely.

[22] e.g. Pewter (SnSbCu) scrap yields around 2500 Euro/t.

Tin weights are about 1,5 - 3 times more expensive than lead weights whereas prices for steel weights are in the same range as for lead weights.

2.2.9 Electrical or electronic components which contain lead in a glass or ceramic matrix

2.2.9.1 Spark plugs

Field of application and product description

Lead is used in the glace around the ceramic insulator at the top of the spark plug (see figure 2).

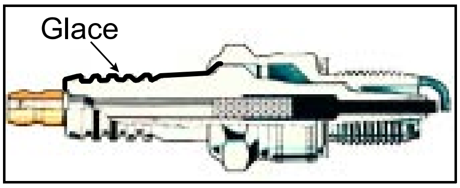

Figure 2: lead-containing glace on a spark plug

The main functions of the glace are to achieve a sufficient mechanical strength, which is needed in this part of the plug mainly during the fitting, and to achieve a sealing of the plug.

10% of the produced spark plugs are sold for supplying new cars, the remaining 90% for the spare parts and garage market.

Alternatives: Strength-weakness profile (technical)

No lead-free alternatives are known at the moment on a production scale level. No supplier could be found which is producing a lead free glace which is used on a mass production level. Presently research is under way, one possible alternative being the substitution of lead by bismuth.

Amounts

The glace contains around 50 weight percent lead in form of a lead - silicate glass. The overall amount in one spark plug is around 0.15 g.

At Bosch Bamberg (one of the largest production sites in Europe) 220 million spark plugs are produced every year.

Environmental relevance

The spark plugs will usually not be removed at the dismantling site. Because of its high specific gravity of 3.7 the plug will remain in the heavy fraction from shredding.

Conclusions

At the moment, no alternatives are known for a production scale level. Nevertheless it is remarkable, that in the light of the oncoming ELV-Directive one of the biggest European producers took up again his research for a lead-free glace at the beginning of 1999 which he had stopped 5 years ago.

2.2.9.2 Electronic components

Field of application and product description

In the last two decades more and more electronic devices are used in cars for security devices (e.g. air bag, ABS) and for motor management. One example of lead containing sensors are knock sensors. They utilise the characteristics of piezoelectric ceramics which contain lead oxide to detect engine knocking. Another emerging application are actuators for fuel injection systems.

In several of these electronic applications lead is used in a special kind of glace serving for stability, insulation or electronic purposes. The material is applied in form of thick film compositions which are then heated up to temperatures between 450 and 900˚C.

Furthermore, lead is contained in other electronic parts of equipment such as navigation systems, car radios, car phones etc.

Alternatives: Strength-weakness profile (technical)

Only little information is available about this very dynamic field where the argument of "trade secret" plays an important role. Therefore, a general assessment or proposal concerning the whole field can hardly be given.

In the field of thick film compositions, one big manufacturer found that substitution of lead by bismuth will often be possible in cases where the layer has no electrical function. One producer estimates that it will be possible to reduce lead in thick film compositions by 50 % within the next three or five years.

An other producer mentioned that for airbag and rotation rate sensors development of alternatives is under way.

Amounts

An overall estimate on the lead quantities contained in electronic devices of an average car is not possible. For some applications, the following statements can be made:

- Knock sensors can contain around 3 g lead per sensor. Presently three to four million sensors annually are sold EU-wide just by one producer.
- Actuators for fuel injection systems produced by one company contain 5 to 6 g lead.
- As mentioned above, electronic components with thick film compositions are used in a variety of electronic applications. The overall amount of lead is roughly estimated in a range between 0.1 g and 1 g per car depending on their number.

Concerning the present situation the following estimates were submitted by two different suppliers:

Table 3: Quantities of lead in electrical and electronic components (estimated by two suppliers)

Supplier A	Application	number per car	lead content in the ceramic (in g)	lead amount per car (in g)
knock sensor	motor control system	1	2	2
shock sensor	airbag	3	0,2	0,6
	airbag (shock sensor)	1	0,1	0,1
ultra sound sender / receiver	Back Sonar	4 - 8	0,03	0,1 – 0,24
	airbag	4 - 6	0,03	0,1 – 0,18
	warning device	2 - 4	0,03	0,06 – 0,1
resonator	general	5 - 15	0,007	0,04 – 0,1
			total	3 – 3,3

Supplier B

Application	lead content in the ceramic (in g)	Number per car with ... cylinders		
		4	6	8
Airbag	0,1	2	2	2
Rotation rate sensor	0,05	1	1	1
Nock sensor	3,8	1	2	2
Piezo actor	11,5	4	6	8
total amount	~ 15 g	~ 50 g	~ 77 g	~100 g

Environmental relevance

Depending on how the shredder process is carried out, lead from electronic devices will enter either the shredder light fraction, or the shredder heavy fraction or the specific metal fraction and will thus end up in incineration, landfills, or in specific metallurgical processes (for aluminium process see chapter 2.1.2 p. 8, for steel process see chapter 3 p. 44). Leachability of lead from ceramics and glass matrices is very low but still possible under the specific acidic conditions in landfills. In thermal processes (e.g. cement kilns) lead will mostly end up in the product, but some part may be mobilized and emitted.

Conclusions

Although substitution of lead in certain electronic components is possible, no overall recommendation can be given. Besides technical reasons (mainly electrical properties of lead in certain applications) the lack of information plays an important role here.

2.2.10 Pistons

Field of application and product description

Lead has been used for many years for solid lubrication. For this purpose, a very thin coating has been applied on the surface (e.g. 0.5 µm). The coating of pistons has an increasing importance because of the strengthening of the motor power.

Alternatives: Strength - weakness profile (technical)

Alternatives for the use of lead are tin or graphite or a combination of both (described by a producer as "a combination of braces and belt").

Since some years the relevant European piston producers do not produce lead coated pistons for the relevant car types anymore. Figure 3 shows as an example the companies provided with the lead-free pistons from MAHLE which is one of the biggest piston producers.

ABC	Bolenz & Schäfer	Crossley	GEC Diesels	Kirloskar	MWM	Solo
Abt	Borsig	Cummins	Gilera	Knorr-Bremse	NAVISTAR	SSCM
AESA	Bosch	Daewoo	GM	Kockums	ÖAF-Gräf & Stift	Stab. Mecc. VM
Agria	Brian Hart	DAF	Grenaa	Kohler	Opel	Steyr-Daimler-
Alfa Romeo/	Brons	Detroit Diesei	Gutbrod	König, Berlin	Perkins	Puch AG
Autodelta	Cagiva Motor	Dolmar	Hatz	Krupp MaK	Peugeot-Citroën-	Stihl
Alpina (BMW)	Casal	Düsterloh	Hauhinco	Lamborghini	Talbot	Stork-Wärtsilä
Alsthom	Caterpillar	EMAB	Holden	Lancia V.S.	Peugeot-Renault-	Südd.
AMG	Cegielski	(Husqvarna,	Holder	Lanz	Volvo	Bremsen AG
Atlas Copco	Chevrolet	Jonsereds,	Idem	Liebherr	Porsche	Sulzer AG
AUDI	Chiron	Jo-Bu, Partner)	Ikarus	Linde	Raba	Vauxhall
Austin Rover	Chrysler	Empresa	Ilmor	Lister Petter	Renault	Motors Ltd.
Group	Cockerill	Nacional Bazan	Irmer _Elze	Lotus	RVI	Volvo
Barreras	Colt Industries	ENASA	Irmscher	M.A.N	Saab Scania	Volvo-BM
Baudouin	Cooper Energy	Farymann	Iveco	MBESA	SACM	Volvo-Penta
Becker	Copeland	Ferrari	J. I. CASE	Mercedes-Benz	Saurer	VW
Bergens MV	Cosworth	Fiat	Jenbacher	Mercury	Schlüter	Wabco
BMW	Creusot-Loire	Fichtel & Sachs	Werke	Minarelli	SEAT	Wärtsilä
		Fincantieri	John Deere	Mirrlees	SEMT Pielstick	Zakspeed
		Flottmann	Kaeble	Blackstone	Siemens	
		Ford	KHD	MTU	SKL	

Figure 3: Vehicle and motor manufacturer which use Mahle pistons

The first lead replacement activities were started in the USA years ago, followed by substitution activities in Europe. More recently, also Asian producers are changing to lead-free pistons at least for their cars destined for the European market.

Discussions with car producers confirmed that no car producer is known who is using leaded pistons for the relevant car types any longer.

From a material point of view, lead pistons are cheaper. But in an overall view, the additional costs related to occupational protection during production make graphite coated pistons cheaper than lead coated ones.

Amounts

The coating has a thickness of approximately 0.5 µm at the moment of production but will be gradually worn off with aging of the engine.

Environmental relevance

Apart from the lead which is lost during the lifetime of the motor, the remaining lead will usually go to secondary aluminium smelters (see chapter Aluminium p 8).

Conclusions

Discussions with piston suppliers and car producers exhibited that lead-free alternatives are presently dominating the market.

2.3 Corrosion preventive coating containing hexavalent chromium

Field of application and product description

Zinc chromate and chromium chromate are used in car manufaturing as anti-corrosion pigments with active corrosion-preventive properties. Their application as priming coat serves the two-fold purpose of passivating the metal surface and as a fixation ground before additional layers of paint are applied.

Protective coatings based on hexavalent chromium are very effective because of their "self-healing" properties after small injuries of the surface layer.

In present car manufacture, corrosion-preventive coatings containing hexavalent chromium are applied on small connecting elements like screws and clips which must be disconnectable even after several years of use, but also on other aluminium, zinc and magnesium parts. Also, it cannot be excluded that certain parts are chromated for merely decorative purposes today (e.g. to yield a blue, black or yellow surface colour). This, however, would not fall under the exemption list of Annex 2.

Alternatives: strength - weakness profile (technical)

Depending on the specific application, alternative priming coats have been developed on the basis of basic zinc phosphate-hydrate, zinc-aluminium phosphate-hydrate, zinc dust, barium metaborate [TRGS 602][23], trivalent chromium, cobalt or nickel and others.

According to the German TRGS 602, no alternative fixation ground with passivating properties is available for surface treatment of aluminium alloys.

At least one European manufacturer states that he has changed to screws which are completely free of hexavalent chromium (passivation is effected by chromium-III) but cannot guarantee yet for all of his suppliers.

Similarly, other European car manufacturers have officially banned the use of hexavalent chromium from their production (on their internal list of "unwanted" substances) but have difficulties to find out whether this rule is complied with in every application.[24] Also, there are cases where substitution is technically feasible but the optical appearance of the alternative material will not be accepted by the designer.

[23] German Technical Rules for Hazardous Substances: Technische Regeln für Gefahrstoffe TRGS 602 - Einsatzstoffe und Verwendungsbeschränkungen - Zinkchromate und Strontiumchromat als Pigmente für Korrosionsschutz-Beschichtungsstoffe (Stand: Mai 1988).

[24] In car manufacture, immediately there is a very strong internal pressure on the production responsibles as soon as any corrosion problems occur, which can lead to a situation in which the old and effective method is reintroduced as a last resort.

The costs of alternative treatment methods are said to be between 10 and 20 per cent higher than for chromium-VI coatings (with screws and clips being a fairly low-cost item in car manufacture). Two-layer systems (e.g. Fe-Ni coatings) may be more expensive due to higher processing effort.

Amounts

According to one European car manufacturer, calculations based on typical use patterns (number of screws and clips in a model car) lead to an estimated 4 grams of hexavalent chromium in a new car.

Due to other sources, the worst case estimate of a European manufacturer yielded 7,4 grams of Cr-VI per car. Of these, only 0,7 grams are contained in screws and clips, while 6,7 grams where located in other zinc, aluminium and magnesium parts.

Chromated surface layers can have a thickness between 0,1 and 1,25 µm and a Cr-VI content of 1 - 36 $\mu g/cm^2$. Modern galvanizing companies apply lower quantities of less than 0,3 $\mu g/cm^2$ Cr-VI since this was introduced as a standard by Volvo in 1992.

Environmental relevance

The main concerns about chromium-VI are related to occupational safety and health issues, and to production waste and discharge waters. For these reasons, its use has already been significantly reduced by car manufacturers in recent years.[25]

Zinc chromate and chromium chromate are cancerogenic substances which upon inhalation cause cancer to the bronchial tract. Skin contact may cause sensitization towards allergical reactions. Human exposure can occur mainly during production, in repair shops during grinding, and in recycling processes.

Car manufacturers claim that over a car's lifetime part of the Cr-VI will be chemically transformed into Cr-III, so that an end-of-life vehicle would contain less chromium-VI than a new car, but no quantitative information about this is available.

After shredding, the part of the chromium-VI which remains in the metal fractions will enter metallurgical processes in which Cr-VI will be transformed into chromium-III.

Hardly any data are available about the content of hexavalent chromium in shredder light fraction (SLF). Leaching of Cr-VI from SLF has not been observed yet.

[25] Some years ago, hexavalent chromium was still deliberately applied on the surface of brakes, thus leading to direct losses to the environment.

Conclusions

It is possible to produce cars without chromium-VI in most applications already, with some remaining problems concerning the supply chain. Corrosion-free screws which are required to be disconnectable even after many years may be particularly difficult to substitute.

Because of the technical importance and the variety of application fields, a general ban of zinc and chromium chromates may not be appropriate. Rather, the applicability of alternative materials or processes should be examined on a case-by-case basis, and substitution should be done wherever possible.

2.4 Mercury

2.4.1 Gas discharge devices for headlamps

Field of application and product description

Some bulbs for headlights contain mercury. They are sold under trade names like "XENARC" (Osram) or "XENON" (Philips). These are gas discharge bulbs filled with a mixture of sodium, scandium and mercury as an illuminant, and very small amounts of thorium oxide and sometimes of thallium (0.2 µg/bulb). To reach the necessary voltage, additional devices are necessary (see figure 4).

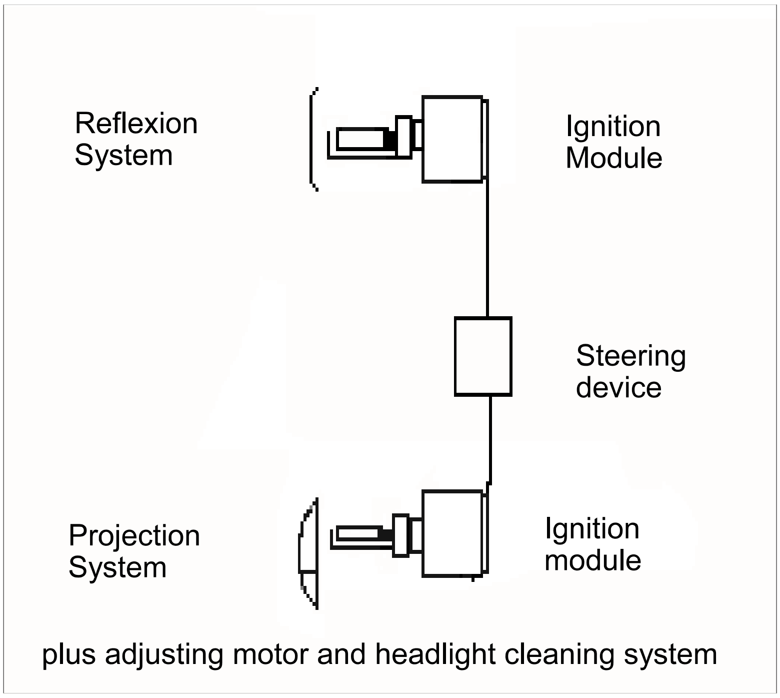

Figure 4: Gas discharge headlight system (example)

Mercury containing light systems have a very strong light intensity, a bluer light and a long life span. One disadvantage (during the use of those bulbs) is the subjective glare effect for oncoming drivers.

Besides the technical facts further arguments must be taken into consideration for understanding the use of those very expensive lamps (around 200,- Euro per lamp). One such argument is the subjective impression of an improved visibility of the driver. Furthermore the car industry and their suppliers claim that the blue/ white colour of the lights stands for high prestige.

Alternatives: Strength - weakness profile (technical)

The following table shows a comparison of halogen bulbs and mercury containing gas discharge headlights as they are produced by Osram.

Table 3: Comparison of characteristics of halogen and gas discharge lamps.

	Halogen						Dis-charge
	H1*	H4*	H7	H8	H9	H11	Xenarc
light intensity lumen (low beam/ high beam)	1550	1500/ 1650	1500	800	2100	1350	3200
energy consumption (W) (low/high)	55	60/55	63	35	65	55	42
lumen/energy consumption	28	25/30	24	23	32	25	76
life time (h)	500	450/ 800	530	800	500	2000	3000
colour temperature (kelvin)	3200	3200	3300	3200	3400	3200	>3700

* Some new developed H1 and H4 bulbs (H1 and H4 SUPER) are 30% brighter than conventional systems.

Halogen lamps offered by Osram under the trade name "Cool Blue" generate a bluer light (3700 K) because of an absorption layer coating. By using this kind of bulbs the subjective aspects of Hg-discharge bulbs can be fulfilled (appearance of the light), but because of the absorption layer they need to produce a greater light intensity. This is achieved by high output bulbs which consume more energy and have a shorter lifetime.

Discharge lamps must be adjusted very precisely by small electrical motors. The steering device has a weight of around 400 g (presently decreasing). The ignition module needs additional electrical power (for a 35 W bulb, 42 W are needed). A headlight cleaning system is required for gas discharge headlights in order to reduce the additional glare caused by the scatter effect of dirt.

Amounts

One gas discharge headlamp contains 0.5 - 0.55 mg Mercury. On a worldwide scale, around 3.5 million mercury containing headlights per year are used in the production of new cars (≙ 1.75 kg mercury per year).

As a general trend, the use of this type of headlights is expected to increase because they are now also available for middle class cars.

On the other hand, their use will be limited by their high price and by the necessity of a very precise adjustment which can almost only be done in professional car repair shops.

Environmental relevance

From an environmental point of view, the lower energy consumption and longer lifetime of gas discharge bulbs are their main advantages when compared to halogen bulbs.

One producer of bulbs for headlights is presently performing a Life Cycle Assessment which has not yet been published and/or validated. In a first discussion of preliminary results of this LCA, it was pointed out that the lower energy consumption of mercury containing bulbs potentially leads to reduced atmospheric mercury emissions from fuel production.[26]

The dismantling of headlight bulbs is rather time-consuming, and the high disposal costs for dismantled mercury containing bulbs classified as hazardous waste form a significant barrier towards separate disposal. Thus, even if there is an obligation to dismantle lamps containing mercury, efficient control will be difficult.

If mercury containing bulbs are not dismantled, mercury will be emitted from the shredder.

Conclusions

During use, mercury containing gas discharge bulbs have clear advantages over halogen bulbs in terms of light intensity, whiter light and lower power consumption. Halogen bulbs cannot combine all these aspects but can exhibit only single ones.

During ELV disposal, mercury containing bulbs are rather time-consuming to dismantle and very expensive to dispose of. High dismantling quota can therefore only be expected when the dismantling and/or disposal will be subsidized.[27]

Balancing up the environmental hazard of mercury containing bulbs (plus their necessary periphery) versus the environmental benefit of reduced energy consumption will only be possible on the basis of validated LCA data.

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[26] Philips Automotive Lighting, pers. comm.

[27] But even then the export of cars e.g. into Eastern European countries ouside the EU will remain as a problem.

2.4.2 Other discharge lamps

Field of application and product description

Besides their application in headlights, fluorescent lamps are used for background illumination of displays in automobiles (e.g. in navigation systems). One main reason for using those types of lamps is the space restriction.

In rare cases, mercury containing lamps are also used for lighting inside the car (e.g. in the loading compartment).

Alternatives: Strength - weakness profile (technical)

In recent years, new bulbs have been developed based on the principle of a dielectric barrier discharge using Xenon excimers as the UV emitting species. The discharge is driven by a pulsed mode resulting in a significantly improved efficiency for the generation of UV radiation. Presently, this technique is not yet used on a mass production level.

For lighting inside the passenger room or loading compartment, conventional lamps are widely used. Unlike mercury containing headlights for which, in an overall assessment, the lower energy consumption and improved safety may lead to positive results, the much shorter overall usage time of interior lighting cannot be expected to lead to the same results.

Amounts

In background lighting for navigation systems, around 1.2 mg Hg per system are used. 200.000 navigation systems annually are sold by one German company alone, with a rising trend.

No quantitative data are available concerning the use of other mercury containing lamps inside the car. Discussions with car manufacturers, suppliers and manufacturer associations bore out that they are very seldomly used.

Environmental relevance

The environmental relevance during recycling and disposal will be similar as for discharge headlights. As long as those bulbs are not dismantled, mercury emissions will occur during the shredder process.

Conclusions

While there are no mass production approved alternatives for background illumination yet, mercury containing bulbs for lighting of the passenger room or loading compartment are replaceable.

2.5 Batteries containing cadmium

Principally, alternatives for cadmium containing batteries exist for all their potential applications in vehicles. These alternatives include NiMH cells and Lithium cells which are well introduced on the market for many small applications since years.

It has been more difficult to develop cadmium-free cells with a high energy density which can be used as traction batteries for electrical vehicles, but it appears that this problem has now been solved.[28]

For instance, in their Environmental Report 1999 the Mitsubishi Motor Corporation (MMC) declare that they have developed a lithium-ion battery that uses cheap and plentiful manganese for the positive electrode instead of the formerly used cobalt which was considered to be prohibitively expensive. According to MMC, mass production of high-performance batteries at low cost is now possible.

Because of the high environmental relevance of cadmium, substitution of cadmium containing batteries in vehicles should be aimed at with high priority.

[28] e.g. "Lithium-Akkus bald mit größerer Kapazität - Verwendung vom Hörgerät bis zum Elektroauto", DIE WELT, 26.06.1997.

3 Heavy metals in the steel recycling process

In this chapter, a brief outline of the effects of heavy metals in the steel recycling process will be given in order to avoid frequent repetition concerning environmental aspects in the subchapters on individual heavy metal applications.

In Europe, the main share of scrap is recycled in Electric Arc Furnaces (EAF). Steel containing lead, tin or other heavy metals will run back into the steel recycling cycle mixed up with other scrap which is free of those elements.

At a temperature above 2500˚C (up to 3500˚C may be reached) lead and zinc will be evaporated and removed via the off gas. The major part of the lead and zinc will condense in the gas cleaning system and will subsequently be removed, provided that there is a state of the art dust abatement system.

Recovering solely lead from EAF dust is not profitable but it can be economic if zinc is recovered simultaneously. The latter can be carried out without additional costs (except for transportation) as long as the zinc content is above ~ 16 % by weight. This will only be achieved if additional steps are taken in the steel plant for rising up the concentration. Experience shows that those steps will only be undertaken if there are no cheaper possibilities for disposing of the dust. Recovery of pure lead via the steel recycling route will be done - if at all - only for a small portion of the total amount of lead originally used.

The recovery of pure Bi (which is also evaporated from the steel bath) from EAF dust is unlikely in the present configuration of the steel recycling chain. If EAF dust contains both zinc and bismuth, zinc recovery will only be possible after an additional refinery step which will increase the costs of treatment.

Tin will not be evaporated or slagged in the EAF process but will remain in the steel bath and thus must be seen as impurity. It is mainly problematic in a view of stabilizing the steel cycle and reducing the need of "clean" primary metal for dilution.

4 Summary of results

As can be seen in the following table, for many applications of heavy metals in vehicles there are alternatives available at least from the perspective of technical feasibility. Many alternatives have even reached the state of large-scale industrial application in routine production.

Thus it appears that alternatives to most heavy metal applications have been principally developed and are often used even in regular production. However, the situation is more complex when the details are looked into, e.g.:

- In many cases some new car models are produced without the use of heavy metals in specific applications (including some of those listed in Annex 2 of the Common Position), but manufacturers claim to need an interim phase-out period for older models which will be further produced (e.g until the year of 2005).
- Interim periods are said to be needed by car producers not only because of the car model cycles, but also because the immediate reconstruction of complex production equipment may not be appropriate for both economic and environmental reasons (e.g. conversion of paint shops is so expensive and resource consuming that it should preferably not be done as an isolated action, but rather in combination with other retrofitting measures).
- Some applications of a certain type (e.g. vulcanizing agents for hoses in general) are now obsolete, while others are more difficult to substitute (high pressure hoses).
- Other critical points mentioned by the vehicle producers are
  - the need to use heavy metals in certain occasions in order to correct unexpected problems ("emergency solutions" for e.g. corrosion problems)
  - the difficulty to fully control the use of heavy metals in the supply chain
  - geographical variations (e.g. type of fuel available on specific markets), leading to problems in import and export of cars.

Table 4: Summary of results

material or application field	**phase-out of heavy metal**	costs ≤10% = slight ≤ 20% = medium	remarks
lead in steel for machinery purposes	**technically possible**	slight increase	case specific examination necessary
lead in zinc coatings	**technically possible**	slight increase	case specific examination may be necessary. Change of wording in Annex II recommended because the mentioned 0.35% refer to the whole steel part and not only to the zinc coating
lead in aluminium	**technically possible for concentrations above 0.4 % / 1 %**	neutral to slight increase	Secondary aluminium may contain lead as an impurity. Change of wording in Annex II recommended (no need for wheel rims or window levers with up to 4% lead).
lead in copper			case specific examination necessary
lead/bronze bearing shells, bushes	**not generally possible**	slight increase	
lead in batteries	**not possible**		
lead in fuel tanks	**possible**	no increase	
vibration dampers made of lead	**mostly possible (but not always)**	no increase	strong need for • improved "design for recycling" • info to dismantlers • incentives and/or controls in order to ensure dismantling and thus avoid light shredder waste contamination
lead in high pressure hoses, fuel hoses	**not possible**		
lead in protective paints	**technically possible + partly under way**	cost neutral in new or retrofitted paint shops	
lead in stabiliser in plastics	**possible**	neutral to medium increase (depending on specific application)	
lead in solder on printed circuit boards	**single case solutions not yet generally applicable**		R & D under way

Table 4: Summary of results

material or application field	phase-out of heavy metal	costs ≤10% = slight ≤ 20% = medium	remarks
lead in brazings	**technically possible**	medium increase	R & D under way
wheel balancing weights made of lead	**approved for small weights; for bigger weights possible only after constructive changes of wheel balancing technique**	no increase	
lead in glace of spark plugs	**presently not possible**		R & D under way in order to replace lead e.g. by bismuth
lead in other electronic or electrical components	**presently not possible**		little information available only
lead on pistons	no longer used in recent European cars		
lead in corrosion preventive coatings	**mostly possible**	slight to medium increase	100% phase-out of hexavalent chromium not yet appropriate
mercury in bulbs for headlights	**technically possible but with disadvantages**		LCA required to assess conflicting targets in terms of energy consumption and overall mercury balance. - Need for • improved "design for recycling" • info to dismantlers • incentives and/or controls in order to ensure dismantling and thus avoid SLF contamination
mercury in background lighting devices	**not yet possible** R & D under way		change of wording in Annex II recommended in a way that only bulbs for headlights and background lighting devices are included
mercury in other lighting devices containing mercury	**possible**	no increase	
batteries containing cadmium	**technically possible**		

5 Conclusions

Although it appears that the vehicle manufacturers and their suppliers have already taken a number of steps to reduce the use of heavy metals in car construction, it appears that a legal framework such as Article 4(2) of the ELV Directive will be needed in the future in order to significantly reduce the contamination of the waste streams arising from end-of-life vehicles, and in particular the shredder light fraction (SLF).

It can be observed that the recent legislative developments have already exerted a strong stimulus for manufacturers and suppliers to develop products which are free of heavy metals. Some examples are

- spark plugs
- steel containing lead
- soldering in electrical and electronic devices
- wheel balancing weights.

On the other hand, it appears that the manufacturers will need some more time to fully implement the phase-out as formulated in the ELV directive, meaning that some exceptions from the general phase-out decision appear to be justified (see Section 4, Table 4 for details).

The difficulty is how to accommodate the justified requests for interim periods and qualified exceptions without undermining the general goal to phase out lead, cadmium, mercury and hexavalent chromium, and how to prevent a roll-back of the generally positive trend which can presently be observed.

Possible instruments would be the definition of quantitative reduction targets related to time-scales, in combination with a systematic monitoring of the progress achieved in terms of reduced heavy metal consumption in new car models. Parallel to this, it should be monitored whether the measures taken by manufacturers are sufficient to bring about a trend towards reduced heavy metal contamination of the steel scrap and the heavy and the light fractions after shredding of ELV.

<u>Identification and labelling of heavy metals to be separated at the dismantler's</u>

In many cases, labelling of heavy metal containing applications on the respective part or component itself will not be effective to ensure stripping of heavy metal containing components according to Article 6(3)(a) of the Draft ELV Directive, unless dismantlers will have an easy access to information explaining which heavy metal containing parts are to be expected in an ELV of a specific car model.

One possible way to forward this information for those applications of heavy metals which shall be labelled or made identifiable in accordance with Article 4(2)(b)(iv) will be within the official ownership and registration documents of the car.

Furthermore, it should be made mandatory for manufacturers to offer information to dismantlers about the quantity and location of such applications via the computer-based International Dismantling Information System (IDIS) not only concerning future exceptions from the general phase-out decision, but also about heavy metals in existing car models.

Cost-efficiency of dismantling and necessary monitoring

Where parts and components made of lead, cadmium, mercury and hexavalent chromium cannot be avoided, it will be crucial to improve the "design for recycling" because otherwise no dismantler will undertake the effort to carefully remove those parts. Prominent examples in this context are lead vibration dampers and mercury containing gas discharge lamps.

Nevertheless, even if the dismantling effort can be reduced by means of an improved design for recycling, the separate disposal of some parts will cause significant extra costs for the dismantler (e.g. mercury containing bulbs and lighting elements), while in other cases the revenues from metal recycling will not always cover the additional time and effort needed for their extraction from the ELV (e.g. certain vibration dampers or wheel balancing weights).

Consequently, ways will have to be found to cover the dismantlers' additional efforts and costs for dismantling and separate disposal, preferably by internalization of these additional costs in the product price of new cars. At the same time, intensified controls of the dismantling quality will be needed to ensure that extraction of heavy metal containing parts and components is actually done before shredding.

Annex

Annex 1: Description of soldering alloys

alloy	melting range (°C)	costs (US$/kg)	application field	remarks
63Sn/37Pb	183	370	all fields	
90Pb/10Sn	302		die-attach	
96,5Sn/3,5Ag	221 (eutectic)	1210	- TV, audio-video, office equipment - industrial, telecom[29] - solder paste application[30]	- proofed properties - Ricoh (automotive application) -successfully tested by Motorola and Ford Motor Company
96,3Sn/3,2Ag/0,5Cu	217-218		- industrial, telecom - automotive, military - solder paste application[3]	-successfully tested by Marconi Communications (shares unknown)
95,5Sn/3,8Ag/0,7Cu	217 (-219)	1260	- industrial, telecom - automotive, military	-successfully tested by Marconi Communications (shares unknown)
95,5Sn/4,0Ag/0,5Cu	216-219	1300	- industrial, telecom - automotive/ military	-successfully tested by Marconi Communications (shares unknown)
96,7Sn/2Ag/0,8Cu/0,5Sb	216-222 217-220	920	- TV, audio-video, office equipment - automotive/ military	
96,2Sn/2,5Ag/0,8Cu/0,5Sb	213-218	ca. 9,20	- TV, audio-video, office equipment - automotive/ military	
99,3Sn/0,7Cu	227 (eutectic)	550	- TV, audio-video, office equipment - bar solder for wave soldering - wire solder for hand/robotic soldering	- Nortel (telephone) - successfully tested in the Brite-Euram project
91,7Sn/3,5Ag/4,8Bi	210 (eutectic)	ca. 12,10	- TV, audio-video, office equipment - automotive/ astronautics[31]	- Bi might form with lead low melting phases - Matsushita (mini-disk-player)

29 Lead free soldering, (1999) DTI

30 A Benchmark Process for the Lead Free Assembly of Mixed Technology Printed circuit board`s. (1997), Bastecki, C.

31 Reduced environmental Impacts by lead free electronic assemblies? (1999), Müller, J. et al., IPC Works `99, October 26-28, 1999, Minneapolis

Annex 2: Environmental characteristics of some metals

Criteria \ Variants		Pb	Sn	Fe
production	surface destruction	high in surface mining moderate in underground mining	moderate in underground mining dredging on the sea floor destroys benthic living space	high in surface mining
	material intensity	no data available	no data available	7 t/t primary 1,5 t/t secondary
	specific energy demand	primary 17,67 MJ/kg* primary 28,1 MJ/kg** secondary 1,12 MJ/kg* secondary 1,6 MJ/kg**	no data available	primary 16,21 MJ/kg* (pig iron) primary 23,2 MJ/kg** (steel hot rolled) secondary 5 MJ/kg secondary 2,59 MJ/kg*
environmental open use of the product		human- and ecotoxic, in case of Sb-alloy: Sb human- and ecotoxic	in case of Sb-alloy: Sb human- and ecotoxic	/
disposal	recycling	moderate probability	higher probability	highest probability
	steel production	emission from steel production, occasionally antimony as further problematic metal	disturbing element in steel cycle, occasionally antimony as further problematic metal	/
	shredder output via SLF / SHF without recycling	emission thermic process, emission from land fill occasionally antimony as further problematic metal	emission from land fill occasionally antimony as further problematic metal	/

* Ökoinventare von Energiesystemen, ETH-Zürich, 1996

**KEA-database, Umweltbundesamt, 1999