4.10 Exemption no. 8 "Solder in electronic circuit boards and other electric applications"

Electrical and electronic components and units have become indispensable for vehicles. The use of electrical and electronic devices and their long-term reliability play an important role for the safety, reliability, efficiency and the convenience of vehicles. Within the automotive industry there are very high demands to electronic components which are similar to the requirements of aeronautic and military equipment.

Lead solder alloys have been widely used in electrical and electronic applications due to their low melting points, the ductility of lead, and the prevention of whisker growth. These properties, the longstanding application, and decades of experiences with their use allow industry to process them with high yields and low failure rates and make them a well-known and hence reliably applicable interconnection material.

One main application of lead solders is on printed circuit boards (PCBs) to make interconnects between the contact areas of electrical/electronic components and the contact areas on the PCB surface.

A further application of lead solders on PCBs is their use as finishes on component terminations and on the conductive paths and contact areas of PCBs.

Another application of leaded solders besides their use on PCBs is their use on glasses to make electrical contacts. Since a stakeholder claimed to have found a substitute for this use of leaded solders, the 2006 stakeholder consultation requested comments on this particular application. Other stakeholders, mainly representing automotive industry suppliers, submitted comments stating that the substitute presented was not suitable to replace lead in solders for the application on glass. The sound review of these opposing views on the second lead application field will require a comprehensive assessment of test results and arguments provided.

Finally, besides electronic circuits and glasses, lead solders are applied in other electric applications as well. More detailed information is given in the next chapter.

For the review of exemption no. 8, "Lead in solders of electronic circuit boards and other electrical applications", the exemption has to be split in three parts:

1. Lead in solders in electronic circuit boards
2. Lead in solders used on glasses in other electric applications
3. Lead in solders for other electric applications

The three applications, although currently part of a single exemption, will be reviewed in two chapters in order to maintain a clear structure and overview:

- Lead in solders in electronic circuit boards and other electric applications except on glasses: sections 4.10.1-4.10.4;
- Lead in solders used on glasses for other electric applications: section 4.10.5-4.10.7.

4.10.1 Description of exemption "Lead in solders in electronic circuit boards and in other electric applications except on glasses"

Lead-containing solders in electronic circuits are used in manifold applications and functionalities in vehicles, and in combination with different materials. The automotive industry requests a continuation of the exempted use of lead in solders in electronic circuits and in other electric applications.

The solders in electronic circuit boards contain between 20% and 40% of lead, the rest being mainly tin. Their melting points range between 183°C to around 210°C. Such solders are used to attach electrical and electronic components to different substrates (carrier materials for the electronic circuits):

1. For the soldering of electrical and electronic components to printed circuit boards (PCB). Depending on the expected operating temperature in the application, different PCBs are used:
    a. (High performance) epoxy resin laminates reinforced with glass-fibre with glass transition temperatures between 180°C and 200°C. This is the classical substrate.
    b. IMS-Substrate ("Insulated-Metal-Substrate"): a PCB, in which an insulating dielectric under a structured copper laminate or a thin PCB is laminated on an Al- (aluminium) base plate. Due to its improved heat dissipation properties and the higher temperature resistance, this PCB is applied if power components are used which generate heat on the PCB itself, e.g. Power-MOS (high performance metal oxide semiconductors), IGBT (insulated-gatebipolar transistor) or LED (light emitting diodes).
2. In some applications, flexible substrates are applied, to which the components have to be soldered as well.
3. Applications for high operating temperatures and/or power components generating heat during operation require ceramic based substrates. Different versions are available:
    a. Ceramics based on Al_2O_3 with conductive paths printed with thickfilm pastes on the ceramic substrate and then sintered on the ceramic base material.
    b. LTCC (Low Temperature Cofired Ceramic) multilayer circuits made of Al_20_3, mostly used for complex logic circuits. The conductive paths are printed with thickfilm pastes and then sintered on the ceramic base material.
    c. DBC (Direct Bonded Copper) / AMB (Active Metal Brazing) ceramics made of Al_2O_3, AlN (aluminium nitride), Si_3N_4 (silicon carbide).

A further application of lead solders are finishes on the contact areas and pins of electrical and electronic components and the contact areas of PCBs. The contact areas and pins consist of copper (components and PCBs), nickel-iron or sometimes also other metals (components only). These surfaces are prone to corrosion and corroded surfaces are difficult to solder. The solders do not or insufficiently wet the surfaces resulting in defective solder joints. A tin-lead surface finish of a few micrometer thickness is therefore applied on these surfaces to protect them from corrosion and to increase the solderability of the components.

Besides the applications on electronic circuit boards and on glasses in other electric applications, there are other electric applications in which leaded solders are applied. Some examples are:

- in generators;
- in electrical motors;
- for wiring harnesses and connectors;
- for battery contacts;
- in special components in punch-grids (e.g. protection diodes, suppression capacitor,...);
- for coil contacts (e.g. signal-horn, actuators, valves, ...);
- and others.

High melting point (HMP) solders are a specific type of lead solders. HMP solders contain more than 40% of lead, mostly 85% by weight and more, the rest being tin. The melting points of such solders are at 280°C and higher. Additions of silver and other metals are possible. The HMP solders are used inside components mainly as well as in some high temperature applications. After the production of electronic components, these components have to pass soldering processes – mainly reflow and wave soldering processes – to interconnect them mechanically and electrically to the PCBs. These soldering processes operate at peak temperatures of up to 275°C. The high melting point of the HMP solders prevents the remelting of the solder joints inside the components during the soldering process that connects the components to the printed wiring boards.

Also, if a PCB has to undergo several soldering processes, HMP solders are sometimes used for the first soldering process to prevent the remelting of the solder joints applied in the first soldering process in the second soldering process.

A viable lead-free substitute for the HMP-solders with more than 85% of lead has not yet been available. For technical reasons, exemption no. 8 must cover this use of lead in the future as well.

Annually, around 18 million vehicles are newly registered in the EU. The stakeholders estimate the amount of lead in solders in electronic circuit boards in these vehicles with around 500 to 700 t per year. It is not clear, whether these figures include the lead in solders in other electrical applications as described above and in HMP solders.

4.10.2 Stakeholders' criteria for justification of exemption continuation

The electronic circuits in vehicles are exposed to harsh conditions with frequent temperature changes over a wide range of temperatures, vibration, humidity, and operating temperatures of up to 185°C. At the same time, the reliability requirements for electrical and electronic applications in vehicles are similar to the requirements of aeronautic and military equipment [23]. Figure 4 shows a comparison of the operation and reliability requirements across different sectors of the electronics industry.

Parameter	*Consumer*	*Industrial*	*Automotive*
temperature	0°C → 40°C	-10°C → 70°C	-40°C → 85/155°C
operation time	1-3 years	5-10 years	up to 15 years
humidity	low	environment	0% up to 100%
tolerated field failure rates	< 10%	<< 1%	target: zero failure
supply	none	up to 5 years	up to 30 years

Figure 4: Operating requirements of electrical and electronic devices in automotive applications compared to other applications (source: Robert Bosch GmbH [23])

The harsh operation conditions of electronic circuits in cars correspond to tough testing requirements for the qualification of materials, components and electronic circuits in automotive uses. Examples for such tests, some of which are used in combination, are:

- temperature cycling -45 to +150°C, 3'000 cycles;
- mechanical vibration tests up to 100 g at elevated temperatures;
- -40°C to +210°C, 100 cycles;
- -40°C to +175°C, 1'000 cycles;
- -40°C to +160°C, 1'000 cycles.

According to CLEPA, these high testing and operation demands require the use of lead in solder and electrical applications since lead-free substitutes in many cases have not yet achieved the same level of quality and reliability.

Meanwhile, lead-free soldering has become the standard interconnection technology in consumer electronics as well as in most of the industry electronics. CLEPA says that the experiences in lead-free soldering from these industry sectors cannot be simply transferred to automotive applications due to the harsh environmental conditions and the much higher reliability demands. Some applications are safety relevant and may cause accidents in case of failure. Especially applications with high and intensive thermal stress – high temperatures, fast and frequent temperature changes, particularly from very low to very high temperatures – combined with mechanical vibrations are a heavy challenge for the interconnects in electrical and electronics systems, which lead-containing solders can meet best.

CLEPA et al. [23] say that in some applications lead-free components like sensors or switches could be realised in lead-free soldering technology. The stakeholders claim that a broad and general solution for assemblies, modules and control units, however, is not yet available. Lead-free solder substitutes often tend to embrittle or to fatigue earlier which can cause drop outs up to total failures of an assembly.

Lead-free solder processes need around 25 to 30 Kelvin higher soldering temperatures, as most lead-free solders have higher melting points. The elevated soldering temperatures impose additional thermal stress on components on electronic circuit boards. Components therefore must be qualified for the elevated temperatures in lead-free soldering processes. Due to the implementation of lead-free soldering in electrical and electronic devices under the scope of the RoHS Directive, the component market offers components qualified for lead-free soldering. Nevertheless, not all of these components are appropriate for automotive applications. The higher soldering temperatures cause higher thermal stresses on the components, which may cause minor damages like micro-cracks or delamination of composite or interconnected materials.

As described above, components, units, and systems must also be qualified for the specific use in automotive applications. The respective tests are the most challenging ones of all tests done on electrical and electronic devices in the electronics industry. While pre-damaged components pass the less demanding qualification tests for consumer and even industry electronics, the pre-damages may result in component failures in the harsher automotive standard test programs and in the later use phase in vehicles.

According to the stakeholders, substitutes could be developed for most of the related components. But life time and reliability demands are in some cases still not on the level of components used for lead containing solder processes.

4.10.3 Critical review of data and information given by stakeholders

CLEPA et al. state "[…] that in some applications lead-free components like sensors or switches could be realised in lead-free solder technology." [23] This was confirmed in more detail by AB Mikroelektronik, Austria, a supplier to the automotive industry.

This supplier has produced the following lead-free devices that in parts have been regularly used in cars in broad application for up to 10 years already [27]:

1. electronics for water pumps (more than 1 million units);
2. sensors for oil (more than 27 million units);
3. sensors for light (more than 70'000);
4. LED-systems for signal and daylight lamps (start of sale in 2008).

The lead-free implementation and successful use of some devices like the hybrid oil sensors show that the avoidance of lead in solders was possible if intended, even though the use of lead-free solders might have been technically driven. The higher melting points allow higher operation temperatures.

The stakeholders explained that all developments are single point applications fitting in the system architecture of a single car type only. They are thus not transferable to other models, types or carmakers. This would explain that, although lead-free applications have been available on the market already for a longer time, not all manufacturers could simply use them. This argument is plausible, but does not answer the questions why other manufacturers had not started and implemented the substitution for products like the oil sensors above if such applications had already proved to be implementable in lead-free soldered versions around 10 years ago.

The above mentioned examples prove that the use of lead has been avoidable at least in some applications. During the stakeholder workshop on 10 October 2007, this fact was agreed upon. The manufacturers were asked to set up a product and application based list for which lead-free soldering or alternative interconnection technologies or designs are a viable option already. The existing exemption could then be limited to the other applications, where the use of lead remains unavoidable for the time being.

The stakeholders said that the vehicle manufacturers dictate the systems' technical tailoring. The systems' technical tailoring differs not only from one manufacture to the other, but in parts also from one car model to the other of the same manufacturer. Each vehicle manufacturer in detail follows his own sequence and strategy to implement the substitution of lead in solders. The stakeholders say that technical needs resulting from individual design of cars and electronic systems as e.g. installation space and available accessories require this individual proceeding.

The stakeholders state that generally, in a step-by-step approach, the reliability of a lead-free soldered solution has to be proven with new designs over several years ranging from laboratory tests to small series in-field uses. Introduction of lead-free soldering is decided with regard to

- security level (function content of ECU / signal use of sensor,…);
- environmental demand (placement in car design, system tailoring,…);

- maturity of ECU's complete process demands (design, components e.g. large ceramic capacitor, AL-Caps,…);
- maturity and process portfolio of supply chain (supplier, components,…).

The manufacturers started with product designs of low complexity, which therefore have been in the market for years already, but in different applications depending on the manufacturer and its individual lead-free implementation strategy. The stakeholders say that higher complexity and reliability products (based on product design, components with temperature sensitivity, and product safety needs) are just now being introduced within the past one or two years. Most automotive manufacturers and their electronic suppliers are currently transitioning several product types over to lead-free soldering, with plans to expand the applications as they are proven in the field. The suppliers and manufacturers limit the transition to new applications. Running products are not changed. The stakeholders explained their reasons for the limitation to new type products (see the section on "Limitation to new type approved vehicles").

Although lead-free implementations are already available, it is hence not possible, according to the manufacturers, to categorise them and put them on a list in order to limit or ban the use of lead in these applications, as they are different from manufacturer to manufacturer and in parts from car to car.

The stakeholders say furthermore that it is also impossible to categorise lead-free applications by location in the car. Inside the passenger cabin, the conditions are e.g. less demanding for the electronics as in under-hood applications close to the engine. The stakeholders say that the electronic systems differ strongly over the cars.

They gave the following examples:

- In small cars, the automatic transmission control often is integrated in the motronic ECU (electronic control unit). Larger cars mostly need a separate traction control unit (TCU). The TCU usually is attached directly to resp. inside the gearbox or remotely mounted in a separate electronics mounting space (E-Box) depending on supplier process availability and car design space.
- Yaw Rate Sensors are installed as separate sensor unit or integrated in Airbag, ESP (Electronic Stabilisation Program) or navigation control unit.
- Control of tire pressure sensors is designed in instrument cluster or navigation / multimedia display module.
- Cabin electronics is tailored by function (seat-, window-, door-control) or by area (front, middle, back).

It is not clear to the contractor, why the examples should prove that a categorization of lead-free applications via the location in the car in principle should be impossible. Why, for example, is the function or area tailoring of cabin electronics an argument against the ban of lead in cabin electronics with less harsh conditions compared to underhood-applications close to the engine? In both cases it would be inside the cabin. If it is outside the cabin, the ban of lead would not apply assuming that inside/outside the cabin is the differentiation criterion. There are remaining questions that may be possibly misunderstandings, which, however, due to the time constraints cannot be cleared.

The automotive industry suggests to leave the selection and sequence of lead-free introduction into specific applications to the vehicle makers and to just give targets in volume and time for the substitution of lead in solders.

The contractor depends on the information given by the stakeholders. Opposing stakeholder comments are not available to the stakeholders' above statements. Several questions remain open, as pointed out above. The stakeholders' proposal to give targets in volume and time for the substitution of lead in solders could be a viable approach in case it is possible to achieve checkable results for the substitution of lead in solders. For this purpose, ACEA presented a roadmap towards the application of lead-free solders in vehicles.

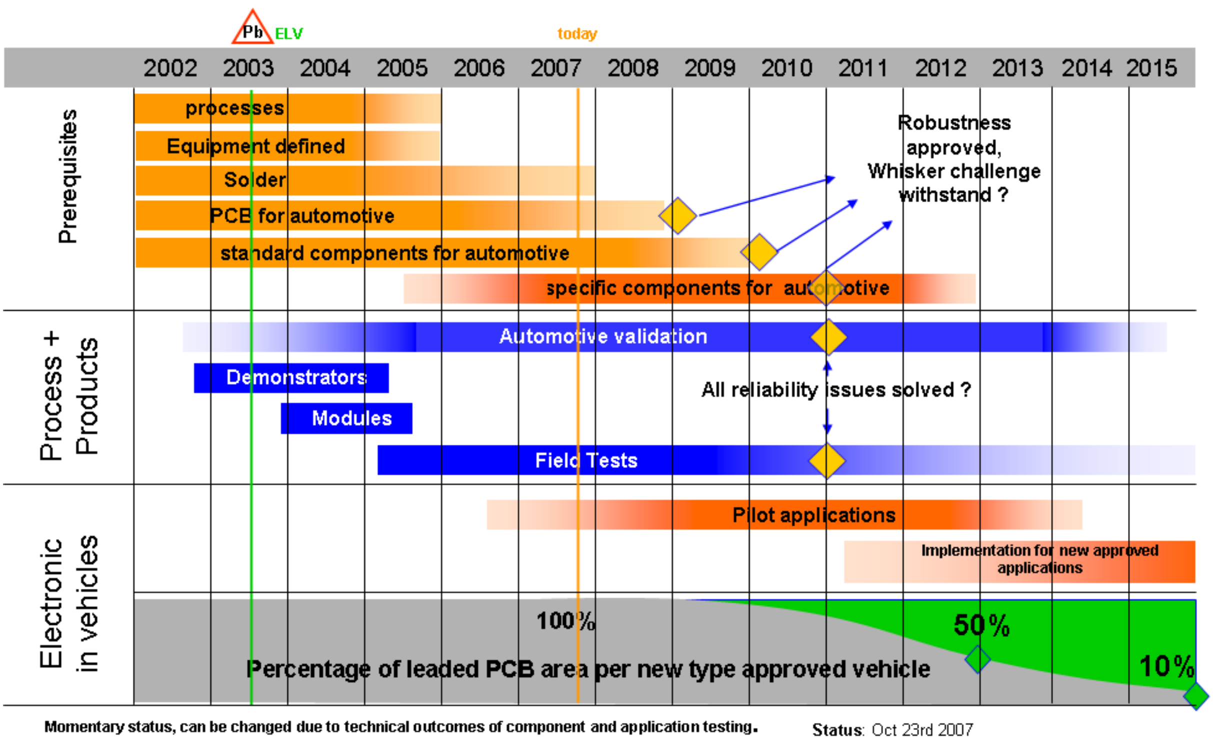

Figure 5: ACEA Roadmap towards implementation of lead-free soldering in vehicles

The stakeholders explain the steps in the roadmap as follows:

- Processes
  - Process- and test specifications defined and approved

- Equipment defined
  - Equipment for lead-free soldering processes with higher temperature and smaller process window defined and validated. Means not purchased in the plants.
- Solder
  - Standard material defined and qualified
- PCB for automotive
  - Base Material qualified for automotive application
- Standard components for automotive
  - Need to be qualified for automotive requirements
- Spec. components for automotive
  - Dedicated automotive components
  - Standard components redesigned for automotive (e.g. redesigned Elko, new mould compound for IC, …)
- Automotive validation
  - Extensive testing of reliability, quality, processability on application, system and vehicle level
- Demonstrators
  - Generic test boards in laboratory testing. Some components / processes not lead-free compliant
- Modules
  - Real applications in laboratory testing. Some components / processes not lead-free compliant
- Field Tests
  - First low volume applications in controlled vehicles in the field parallel to regular high volume leaded series production
Gain first field experience with different processes, components and applications
  - Check if all needed automotive components / applications could be qualified.
If not, special exceptions may be necessary permanently to be reviewed 2012
- Pilot applications
  - First real application designed for lead-free soldering in low to medium volumes in series production for some vehicle variants
- New type approved vehicles
  - High volume production application for application in complete model lines

- Percentage of leaded PCB area per new type approved vehicle
  - 10% may be necessary if exemptions needed due to reliability issues; to be reviewed 2010

The stakeholders put the 50% and the 10% lead area target as milestones which they propose to transfer into a rewording of exemption no. 8 (summary of wording proposal by the contractor):

Exemption 8(a)(1):

Lead in solder in electronic circuit boards for new type approved vehicles with a limitation of 50% of area or weight starting 1 January 2013 and 10% of area or weight starting 1 January 2016.

Exemption 8(a)(2):

Lead in solder with high melting point containing >85% lead (without expiry date).

The stakeholders say that the exemption should be reviewed in 2010 when sufficient reliability data and all necessary components with appropriate quality level should be available.

<u>Limitation to new type approved vehicles</u>

The exemption wording as proposed by the stakeholders would refer to new type approved vehicles only. The stakeholders state that the change of running systems towards lead-free solders and finishes often technically will not be possible and would exceed the personal and technical resources of the automotive industry as well as their suppliers. They say that for products in service for longer time, a significant amount of components are not available any more due to production termination of electronic component suppliers. Therefore, the automotive suppliers take high volumes of components on end of live stock to assure production for the required lifetime (last time buys).

Last time buy issues thus are a major technical reason that, according to the stakeholders, running systems cannot be changed to lead-free. Concerning the personnel constraints, the stakeholders say that a single supplier can have several thousand families of electronic control units (ECU) in his product portfolio. Shifting these ECUs lead-free takes around 1 person-year of labour per ECU family for redesign, testing, and component qualification. This would require several thousand person-years of labour creating an additional demand of several hundred highly qualified engineers, even assuming a transition period of several years. These engineers would have to be readily available so that they could start working right away. The stakeholders say that this situation is impossible to handle for suppliers and car manufacturers and conclude that a transition of running parts and systems to lead-free hence is not possible.

Opposing views are not available. The stakeholders' technical and personnel arguments against a change of running systems to lead-free soldering are, however, plausible.

Proposed area or weight limitation

The wording proposed by the stakeholders was not yet clear in several points:

- Considering 50% and 10% limits for area or for weight, what should be the 100% reference unit?
- The 50% and the 10% weight limit would refer to the lead, or to the lead solder?

The stakeholders commented on this in the commenting round of the draft final report.

The stakeholders say that the 100% reference should be the total area of PCB in the respective new type approved vehicle. For the weight limitation, the stakeholders want the weight of the used solder to be the 100% reference. They say that if the area of lead-free soldered PCB is increased to 50% this implies that 50% are without leaded solder [49].

They give an example:

"A car contains 30 ECUs [electronic control units] with a PCB [printed circuit board] area between 25 and 400 cm² with totally 3'500 cm². So there must be enough lead-free ECUs in the car to sum up to more than 1'750 cm².The selection of lead-free ECUs is to the car manufacturer."[49]

The above example refers to ECUs containing one or more printed circuit boards. The printed circuit boards in the ECU thus must be either completely lead-free or may be soldered with lead. Mixed boards with lead-free and lead-containing circuit boards, or ECUs with lead-soldered besides a lead-free soldered printed circuit board would not be allowed, as the example says "…there must be enough lead-free ECUs in the car to sum up to more than 1'750 cm²." The example does not refer to lead-free PCBs in the car, whose area has to sum up to more than 1'750 cm², but to lead-free ECUs in the car, whose PCB areas have to sum up to the minimum lead-free PCB area limit.

The high melting point solders with more than 85% by weight would, however, be allowed, as alternatives are currently not yet available. A ECU thus could contain lead in such high melting point solders, but still be considered as lead-free in the sense of the above example.

This seems to be a viable and checkable option to start the limitation of lead use in electronics circuit boards as intended in the ELV Directive. In case of controls, the manufacturer would have to point out the lead-free soldered ECUs, which could then be controlled completely or partially by spot-check for the absence of lead. A full proof of compliance would, however, always require a complete check of all PCBs in the ECUs, which the manufacturer declares as lead-free.

Some questions on details are still remaining:

1. How exactly is the area of electronic circuits assessed? Are the surfaces of component pins and the component sides (vertical) surfaces part of the PCB reference area?
2. Are there electronic circuits in cars that are not part of an ECU? If this is the case, the above limitation would not apply to them.
3. What about lead in solders, which are neither used in electronic circuits nor on glasses (see list of examples in chapter 4.10.1)? No specific information is available to the consultant on these applications, and the above area limitations of lead use as proposed by the stakeholders would not apply to this application of lead.

In their example, the stakeholders had skipped the weight limitation. It is hence not discussed further on, the more, as the area definition could be a viable approach, if the above details can be clarified.

The proposed wording is not yet unmistakably. Besides the issues raised in the above list, it does not reflect the fact that ECUs have to be completely lead-free (besides the high melting point solder) and that boards with lead-free and lead-containing solder or finish mixes are not allowed. Due to time constraints, these questions cannot be discussed to achieve a final result, the more as any substantial change of the exemption wording would require a detailed discussion with the stakeholders.

The stakeholders themselves propose that the exemption should be reviewed in 2010. Given the time constraints in the review process, the contractor proposes to add the stakeholders' 2010 review date as the expiry date to the exemption, but otherwise not to change the exemption for the applications for lead in solder of electronic circuit boards and in other electric applications besides glass. The area limitations discussed above are not intended to enter into force before 2010 or soon afterwards. The 2010 review should be used to clear the open questions, check the proposed time and application restrictions and to find a clear new wording for the exemption.

4.10.4 Final recommendation "Lead in solders in electronic circuit boards and in other electric applications except on glasses"

It is recommended to continue the exemption, but to review it in July 2010. The exact new wording of exemption 8 can be found in the final recommendation in chapter 4.10.8.

4.10.5 Description of exemption "Lead in solders used on glasses in other electric applications"

The US-based company Antaya has claimed to have appropriate lead-free indium-based substitute solders for the application of solders on glass and thus requests a removal of the exemption from Annex II. Other stakeholder comments opposing the continuation of the exemption are not available.

The goal of the evaluation is to analyse whether Antaya's application is a viable substitute and whether a continuation of this part of exemption 8 is still justified for the following applications of lead-containing solders on glasses:

1. Soldering of electrical connectors to printed heated products for supplying power to silver printed heat grids which serve as de-foggers or heated windscreens (front or more commonly rear)
2. Soldering of electrical connectors to printed circuits for antennas, which may be used for GPS, AM/FM, cell phone and remote starter devices.
   Silver is an excellent conductor when screened and fired into the surface of the glass and terminals can be soldered to the silver layer to make an electrical contact. Typical solder alloys used are a combination of tin, lead, bismuth, and silver with lead being the highest percentage element with at least 62%.
3. Contact between busbars and wires in wire heated products

According to Antaya, the average number of terminals per vehicle for the first and second application is three with an average quantity of 0.3 g of lead per terminal. The average quantity of lead per vehicle for this application thus is 0.9 g. Antaya assumes that 100 million vehicles are produced annually worldwide. The resulting total quantity of lead consumed for this particular application thus is around 90 t of lead.

The average quantity of indium replacing the lead is 0.15 grams per vehicle, which would amount to 15 t of indium for these applications. No data are available for the third application.

Besides the above application-specific characterization, the use of lead on glasses can also be differentiated into the following different technologies:

1. Soldering on thin or thick metallic layers directly on glass for electric or electronic applications (in the following denominated as technology 1).
   For soldering on printed silver layers, it must be further on distinguished between laminated and tempered glass products. Soldering on tempered glass is much more difficult than on laminated glasses, as tempered glass is much stronger than laminated glass.
2. Contact to metallic structures in laminated products for electric or electronic applications (in the following denominated as technology 2)

Both technologies are used for antennas as well as for heating applications.

4.10.6 Stakeholders’ criteria for justification of exemption continuation and exemption removal

In the stakeholder consultation, Antaya, a US-based company, claimed to have a lead-free substitute solder based on indium. Antaya requests to remove the exemption of lead in solders to be used for the above applications. Other stakeholders, such as the automotive suppliers St. Gobain and Pilkington, negate the viability of Antaya’s lead-free solders for their products and request the current exemption to be continued.

CLEPA provided an overview of specific requirements for solders in the different applications [22]:

The solder must [22]:

1. provide a durable electrical contact between the connector and the printed glass;
2. provide a mechanical bond capable of achieving a load of 25 kg when pulled at 90º to the glass (connector foot area 32 mm^2 x 2);
3. allow stresses from the soldering operation to relax to acceptable levels (to prevent failure of the electrical contact or fracture in the glass in service);
4. be low cost and readily available;
5. contain silver to enable good wetting and adhesion to the silver printed circuits;
6. not be eutectic to allow gradual solidifying on cooling;
7. withstand high humidity and show no degradation in electrical and mechanical performance when exposed to humid conditions;
8. show no degradation in electrical and mechanical performance when exposed to acids and alkalis, and also salt spray tests;
9. be safe to use in manufacturing environments;
10. provide good wetting and adhesion to copper, tin plated copper, nickel plated copper and silver plated copper (connector materials);
11. be able to withstand temperatures between -40ºC and +80ºC;
12. be capable of being re-worked.

CLEPA added general notes saying that the application is used for a metal connector (usually copper) soldered to a brittle multi-layer system consisting of float glass, coloured glass frit based ink and silver metal. According to CLEPA, tests and experience indicate that when lead is eliminated from solders, there is reduced adhesion of the connector to the printed glass. This can result in an inability to meet customer requirements with failure in service. Further on, CLEPA maintains that tests and experience indicate that the lead in solder is beneficial for relieving stresses in the glass after soldering. This reduces the risk of failure of the electrical contact or glass fracture in service.

Lead-free solders result in higher stresses, with the exception of indium containing solders. According to CLEPA, the mechanical adhesion is low in such indium containing solders. As the process uses no-clean flux systems, replacements need to be compatible with such fluxes, as otherwise cleaning might be required. The soldering processes utilised are direct local heating systems where the connectors and the solder are heated in position on the glass. CLEPA provided a list with possible alternative solders commenting on why they are not appropriate substitutes of lead-containing solders in the targeted applications. The CLEPA list can be seen in detail in Annex IVa (chapter 6.4.1).

St. Gobain, one of the stakeholders, had conducted tests on glasses using lead-free indium-containing solders. The tests prove that the used solder with 24% of indium content is not a viable substitute for the use of lead solders in the tested application. The test results are available in Annex IVb (chapter 6.4.2).

Antaya has submitted test results to prove that its indium containing solders are a viable substitute for lead-solders on glasses. The tests are available in Annex IVc (chapter 6.4.3).

4.10.7 Critical review of data and information given by stakeholders

Both stakeholder groups, Antaya as well as St. Gobain/Pilkington, have submitted several documents on test results and statements for or against the use of lead-free indium-containing solders on glasses.

St. Gobain/Pilkington insist that the applicability of the indium-based solders has to be proven on their glasses and according to the standard European testing and qualification conditions including the OEM-specifications of these tests.

Antaya agreed to do all necessary tests after a mutual agreement with St. Gobain/Pilkington on the tests to be done and on the testing setup. The contractor, after consultation with Antaya, hence did not check whether and how far the test results Antaya had already submitted would suffice the European test and qualification standards. For the Antaya test and application results of lead-free indium-containing solders please check Annex IVc (chapter 6.4.3).

Compared to lead, indium is a scarce element. The annual mining worldwide amounts to around 500 t of indium per year [51]. According to Antaya, the additional indium demand for the substitution of lead would be around 15 t per year or around 3% of the global annual mining. A comprehensive life cycle oriented consideration of impacts on resources and on possible toxicity effects in this application of indium are not available. Further investigations are beyond the contractor’s mandate.

4.10.7.1 Qualification Test Procedure

According to St. Gobain/Pilkington, the qualification test requirements are identical independently from the vehicle type (category M1 and N1 Directive 70/156/EEC, passenger vehicles for up to 8 passengers plus driver, trucks up to 3.5 t). They are also independent from the solder-on-glass applications and technologies listed in chapter 4.10.5.

St. Gobain/Pilkington say that for every new glazing all products (windscreen, side-lites, back-lite) have to pass all tests. If a specific technology has been proven for one product, it does not mean that the technology can be considered as suitable for all other products. St. Gobain/Pilkington state that if a lead-free solution is tested, one has to take into account the whole product range. The solderability depends on the pre-product to be soldered. Besides the differences between laminated and tempered products, there are other differences like the black and silver printing and the firing conditions.

The standard qualification procedure for the qualification process of solders comprises different environmental climatic tests. According to St. Gobain/Pilkington, the crucial tests are

- Salt spray test according to DIN EN ISO 9227 [38] with the following OEM specifications
  - VW, Audi: PV 2504 duration 720 h
  - Daimler Chrysler: DBL 5610 duration 720 h
  - BMW: QV 51015 duration 480 h
- Climatic temperature with humidity tests (40°C) according to DIN EN ISO 6270-2 [39] with the following OEM specifications:
  - VW, Audi: PV 2504 duration 240 h
  - Daimler Chrysler: DBL 5610 duration 240 h
  - BMW: QV 51015 duration 480 h
- Constant climatic humidity tests (50°C/100% rel. humidity, duration 336h) according to ECE-TRANS-WP29-GRSG-2007-28e [40] and ANSI Z26.1 1996 [41] (both tests prescribe similar parameters)
  - Temperature change: -40°C to +72°C
  - High temperature: 2 h at 100°C
  - Humidity: 2 weeks at 50°C, 95%rh

  The test has the following OEM specifications:
  - VW, Audi: TL 957 duration 300 h
- Temperature cycle test ISO 16750-4:2003G
  - Temperature change -40 to +90

The test has the following OEM specifications in temperature ranges:

– Audi / VW: PV 1200, from -40°C to +80°C
– BMW: BMW GS95003-4 from -40°C to +80 (90°C)
– Daimler Chrysler: DBL5610, from -40°C to +80°C
– Ford: WSS-M28P1-B1 to B5, from -40°C to +90°C
– PSA: B217130, from -40°C to +90°C

St. Gobain/Pilkington have proposed the above tests. Antaya has not yet officially agreed on this test program (status 10 January 2008).

4.10.7.2 Further proceeding

As pointed out before, Antaya has agreed to do all necessary tests to show that their lead-free indium-containing solder is a viable option for the described uses on glass in vehicles. St. Gobain/Pilkington and Antaya will have to agree on the test program. St. Gobain/ Pilkington have additionally proposed a total procedure towards the qualification of these solders in Europe. So far, there is no official agreement, neither on the test program nor on the total procedure (status 10 January 2008).

Antaya is currently checking whether the above listed tests actually are the crucial tests and whether all necessary test standards and test cycles are accessible to Antaya (status 10 January 2008). Once a mutual agreement on the tests and the procedure is achieved, the opponents will define the exact test setups, the testing samples and the results necessary to achieve the qualification of the lead-free indium-based solders, as well as how the test will be conducted in detail. They will then decide about an independent certified testing laboratory to conduct the tests.

It will take time until the test program and the total qualification procedure are agreed upon between St. Gobain/Pilkington and Antaya, and until results are available. The subcontractor has initiated the procedure to arrive at a proceeding mutually agreed between the stakeholders. The contractor's obligations in the context with the contract for the review of this part of exemption no. 8 thus are fully accomplished.

St. Gobain/Pilkington pointed out that they welcome the above efforts for a common testing program and consider them as a first step towards an internationally more harmonized testing program. If this can be achieved, it is a considerable added value coming out of this review process.

4.10.8 Final recommendation for all applications of lead covered by exemption no. 8

Exemption no. 8 covers three types of lead applications in solders, which had to be differentiated and were treated in different chapters in this report:

1. Lead in solders of electronic circuit boards (see chapter 4.10)

2. Lead in solders in other electric applications except the use on glasses (see chapter 4.10)
3. Lead in solders used on glasses in other electric applications (see chapter 4.10.5)

For the use of lead in solders of electronic circuit boards, the stakeholders had proposed a future restriction of lead use and the review in 2010. The implementation of the proposed limitations and timelines into an unmistakable and clear wording for a new exemption, however, was not yet possible. There are remaining open questions which could not be discussed with the stakeholders due to severe time constraints. It is therefore recommended to continue exemption no. 8 for the use of lead in solders of electronic circuit boards, but to review it in July 2010 according to the stakeholders' proposal.

No information was available on the use of lead in other electronic applications besides their use on glasses. Neither is it clear whether nor how they could be substituted, nor would the future limitations proposed by the stakeholders apply to this application of lead solders. Further information and additional discussions with the stakeholders would have been necessary, which the time constraints did not allow. The contractor hence proposes to continue exemption no. 8 for the use of lead in solders of other electric applications except the use on glasses, and to review this application covered by exemption no. 8 in July 2010 as well. This would allow a complete review of both these lead applications in 2010, and a rewording of the exemption taking into consideration the uses of lead solders in electronic circuits and in other electric applications except the use on glasses.

For the use of lead in solders used on glasses, there are opposing views of stakeholders concerning the viability of lead-free indium-containing solders. The stakeholder will have to achieve an agreement on the tests and the total procedure towards a qualification of these alloys for this application. The process towards an agreement as well as the entire qualification process will require time. Given the current status (10 January 2008) of the procedure between the stakeholders, an exact timeline is not foreseeable. The stakeholders' views range from a few weeks to a minimum of one year.

The exemption allowing the use of lead solders in this application should therefore be continued. It is recommended to add a review date to this use of lead. The consultant considers this to be necessary on one hand with respect to the efforts of the stakeholder who had proposed alternative lead-free alloys to be used in this application, and on the other hand to keep up the pressure on all stakeholders involved to agree on the steps proving the viability or non-viability of these solder alloys. As already pointed out, an exact timeline is difficult to assess for the contractor. The consultant suggests January 2009 as review date for the use of lead solders on glasses. At that time, all necessary results and agreements should be available for a proper review and to discontinue the exemption, if justified.

The consultant proposes to maintain the core of the wording of the current exemption no. 8, but to split it into two parts with respect to the different review dates:

8(a) Lead in solder in electronic circuit boards and other electric applications except on glasses; to be reviewed in July 2010.

8(b) Lead in solder in electric applications on glasses; to be reviewed in January 2009.

4.10.9 References exemption no. 8

[22] CLEPA document "Use of Lead Containing Solder in Automotive Glazing (April 2007).doc"

[23] CLEPA document "CLEPA_on_Entry_8.doc"; ACEA, CCFA, VDA, BMW, Volkswagen, General Motors and other stakeholders or associations have submitted identical documents;

[24] Ziegler, Stefan, St. Gobain: "Soldering on Automotive Glass Products – version 5-8 10 07.ppt", presentation at the ELV Stakeholder Workshop in Brussels, October 10, 2007.

[25] Stakeholder document "ND0620 lead-free solder supplied by Antaya MR DIAS20061215.pdf" submitted by St. Gobain

[26] Antaya document "workshop response Antaya.pdf"

[27] AB Mikroelektronik, Salzburg, Austria: e-mail communication Gregor Spilka - Otmar Deubzer, Fraunhofer IZM, 3 October 2007; www.ab-mikro.at

[28] E-Mail information exchange between Antaya (Steven Antaya) and PPG (Kenneth A. Beckim), forwarded to Otmar Deubzer on 1 November 2007 by William Booth, Antaya

[29] Antaya document "letter to Otmar Deubzer oct 2007 non confidential.pdf" submitted via e-mail to Otmar Deubzer

[30] Antaya stakeholder document "2249-M205.pdf"

[31] Antaya stakeholder document "2252-IN31.pdf"

[32] Antaya stakeholder document "2355-CIJP.PDF"

[33] Antaya stakeholder document "PPAP.pdf"

[34] Lohse, J.; Sander, K.; Wirts, M.; Heavy Metals in Vehicles II (Final Report), Ökopol - Institut für Ökologie und Politik GmbH Hamburg July 2001. Report compiled for the Directorate General Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities Contract No B4-3040/2000/ 300649/MAR/E.3

[35] Deubzer, O.; Explorative Study into the Sustainable Use and Substitution of Soldering Metals in Electronics; PhD thesis TU Delft, January 2007, ISBN 978-90-5155-031-3

[36] Geibig, J. R.; Socolof, M. L., University of Tennessee; Solders in Electronics – A Life Cycle Assessment; US Environmental Protection Agency (EPA), EPA 744-R-05-001, August 2005; download from http://www.epa.gov/dfe/pubs/solder/lca/lfs-lca-final.pdf, last access June 10, 2006

[37] Alvarado, C. Ascencio; Madsen, Jacob Nordahl, Pré Consultants B. V.: LCA comparison of alternative soldering techniques; December 2005; Deliverable 3D5 of the IMS-Project no. IMS-2001-00028, EFSOT (Next Generation Environment-Friendly Soldering Technology); in Europe funded by the European Commission under the contract number G1RD-CT-2002-00838; EU-coordinator: Otmar Deubzer, TU Berlin, Germany; www.efsot-europe.info, also see http://www.pre.nl/

[38] Test standard DIN EN ISO 9227 (Braun,Celler).pdf

[39] Test standard DIN EN ISO 6270-2 (Goerenz).pdf

[40] Test standard ECE-TRANS-WP29-GRSG-2007-28e.pdf

[41] Test standard ANSI Z26.1 1996.pdf

[42] Audi test “PV1200”, see document “PV1200.pdf”

[43] BMW test “GS95003-4”, see document “GS95003-4.pdf”

[44] Daimler Chrysler test “DBL5610”, see document “DBL5610.pdf”

[45] Ford test “WSS_M28P1_B1-B5”, see document “WSS_M28P1_B1-B5.pdf”

[46] PSA test “B21 7130”, see document “B21 7130.pdf”

[47] ACEA stakeholder document “Generic Development Process-20071025.ppt”

[48] ACEA, document downloadable from ACEA website http://acea.thisconnect.com/images/uploads/VEHICLE_REGISTRATIONS_2006.pdf; last access 3 December 2007

[49] Stakeholder document “Final_report_exemption_8_comments_automotive_industry_V2 (2).ppt”, received via e-mail from Mr. Harald Schenk, ACEA, 2 January 2008

[50] Stakeholder document “Antaya Certified Lead Free Test Results.pdf”, submitted via e-mail to Otmar Deubzer, 10 January 2008

[51] United States Geological Survey (USGS): Mineral Commodity Summary 2007.pdf