## 4.17 Exemption no. 8b

*"Lead in solder in electrical applications on glass"*

The recommendations given here have already been published in September 2009 (http://circa.europa.eu/Public/irc/env/elv_4/library?l=/reports/099016_finalpdf/_EN_1.0_&a=d). Following these recommendations on adaptation of exemption 8, the Commission has adopted the fourth revision of Annex II to Directive 2000/53/EC. The amended Annex II has been published in the EU's Official Journal (Commission Decision 2010/115/EU of 23 February 2010;
(http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32010D0115:EN:NOT).

The wording of the current wording of exemption 8 b is:

*Solder in electrical applications on glass in vehicles type approved before 31 December 2010 and spare parts for these vehicles.*

The exemption is due for review in 2009 and hence must be adapted to the scientific and technical progress.

### 4.17.2 Background

Exemption 8 b was evaluated during the last revision of Annex II of the ELV Directive in 2007/2008 (Öko-Institut 2008). A stakeholder, Antaya, in 2007 had applied for repealing the exemption as they claimed to have a viable solution to substitute the lead-containing solders for soldering on glass. Glass makers and vehicle manufacturers opposed Antaya's arguments and views.

During the review process, the available stakeholder comments did not give a base for a clear recommendation. The reviewers hence recommended continuing the exemption, but to review it in 2009. The Commission set an expiry date in December 2011 for new type approved vehicles with a review in 2009 (Joint stakeholder working group 2009).

During the last review, the stakeholders – Antaya, glass makers, vehicle manufacturers – wanted to agree on a test program to find out whether Antaya's indium-based lead-free solders can be a substitute to the degree to makes the use of lead in soldering on glass avoidable.

The stakeholders set up a joint working group in April 2008 for this purpose. The group was open to all vehicle manufacturers and glass makers. The glass makers, the vehicle manufacturers, and Antaya, designated Otmar Deubzer to moderate and to coordinate the discussions and the activities of the group. Otmar Deubzer on the one hand already knew the technical background and the stakeholders' arguments and positions, and on the other hand as employee of a scientific institute was seen to be in a neutral position.

After several meetings, phone conferences and discussions, the stakeholders agreed upon a test program and started conducting tests in March 2009. The results have become available in April and May 2009.

### 4.17.3 Description of exemption

The exemption was described in detail during the last adaptation of Annex II of the ELV Directive to the scientific and technical progress in 2007/2008 (Öko-Institut 2008). For details on the technical background refer to this report.

### 4.17.4 Justification for exemption

**Justification for the postponement of the expiry date in the current exemption 8 b by ACEA et al.**

ACEA et al. (2009) put forward that most lead free solders are known to be unsuitable for soldering electrical connectors to printed automotive glass products. The main reason for this is that lead is very good at equalising the thermal expansion differences between the metallic connectors used for these products and the base glass used for the product. These physical differences between the two components are very difficult to overcome. Use of lead free solders that do not have the desired properties results in glass cracks as shown in the example photograph below (ACEA et al. 2009).

Figure 43 Cracks in glass caused by soldered connectors as visible from the outside face of the product (ACEA et al. 2009)

ACEA et al. (2009) explain that indium is the only known element that could be considered as a possible replacement for lead in solders for this application. However, solders that contain Indium have much lower melting points than other solders. This can cause significant difficulties when operating temperatures are elevated and in meeting OEM specifications. Figure 44 shows the phase diagram for indium-tin (InSn) solder compositions.

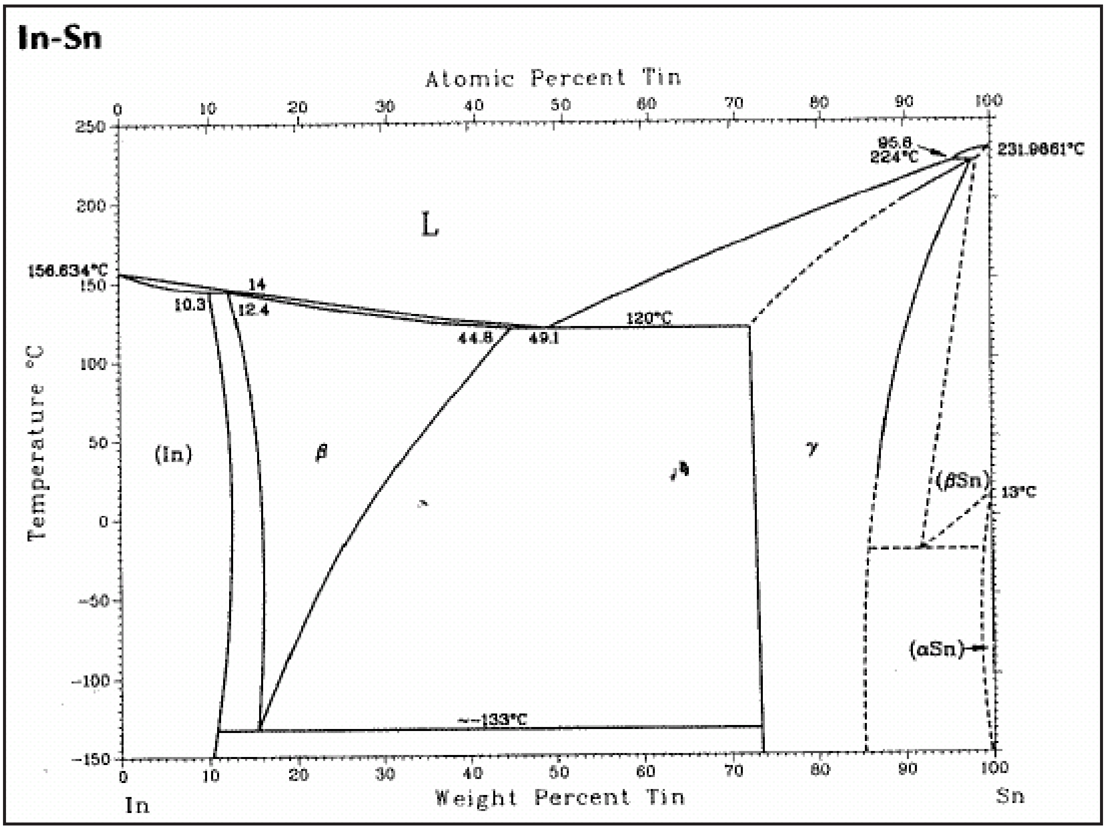


Figure 44 Indium-tin solder phase diagram (ACEA et al. 2009)

According to ACEA et al. (2009), the phase diagram shows that many solders with combinations of these two elements have a melting point of 120°C. With Vehicle Manufacturers having a requirement that the glass products should be capable of surviving elevated temperature (for example 110°C for one OEM and 120°C for another OEM) without any deterioration in performance, this low melting point is of great concern. ACEA et al. (2009) say that InSn solder compositions are not suitable for use on automotive glass products and it is necessary to add other elements to the solders to make them suitable. The addition of other elements to such solders affects the melting point further. As the composition and the melting point (solidus temperature and liquidus temperature) for the proposed solution from Antaya has not yet been confirmed, it is not possible to determine if that proposed solution will be capable of passing the high temperature requirements (product and process requirements) and will therefore be of concern for stability of the glazing product in service.

ACEA et al. (2009) say that some tests have been conducted on other indium containing solders and they maintain that it has been found that these do not pass the requirements of thermal cycle testing and humidity exposure tests with elevated temperatures and can therefore not be considered as replacements for lead containing solders (ACEA et al. 2009).

Further on, ACEA et al. (2009) say that lead free solders that are being used in other industries (e. g. electronics) are not suitable for soldering electrical connectors to glass products because of the aforementioned thermal expansion problems. These solders are generally high tin content and cause glass breakage if they are used on automotive glass products (ACEA et al. 2009).

Taking into consideration the lack of results from the Joint Stakeholder Working Group, the available data from testing of other Indium containing solders, the unknown suitability of the Antaya proposal and the timeline required by the Vehicle Manufacturers to implement any validated lead free solder, ACEA et al. (2009) conclude that the present timing in exemption 8b (31 December 2010) is not achievable .

ACEA et al. (2009) therefore propose to postpone the phase out date to 31 December 2014 with a review of technical progress starting in March 2011, after the first OEM field tests have been completed and results assessed.

**Justification for the maintenance of the current expiry date in exemption 8 b by Antaya**

Antaya claims that the current exemption 8b is not necessary as scientific evidence proves that the use of lead in this application is no longer unavoidable (Antaya 2009a). Antaya (2009a) hence wants exemption 8b to expire in 2011 following the current version of exemption 8b.

Antaya (2009a) explains that no evidence has been produced since the last review in January 2008 that would give reason to change the current exemption 8b in its wording and its expiry date. Antaya claims that in the previous year, the lead-free solder has been scrutinized, tested and evaluated by car companies, glass companies, independent testing laboratories and the widely recognized and independent worldwide authority on lead free solder, Dr. Jenny Hwang (Antaya 2009a). According to Antaya (2009a), the lead-free 65-indium alloy has passed every test to which it has been subjected. Furthermore, Antaya states to have worked with glass plants in the US, Mexico and Europe to validate the suitability of the lead free parts as replacements for the existing leaded parts. Antaya (2009a) claims that the lead-free material has been in use on over 700,000 vehicles dating back as far as 10 years with no reported failures.

Antaya (2009a) says to have developed a 65% indium based solder (65 alloy) in 1996 that proved to be more ductile and forgiving than its leaded equivalent, but more expensive. The solder was approved for use by Ford, Chrysler and the tier I supplier PPG Industries. According to Antaya (2009a), the alloy was originally developed for the Chrysler programs Dodge Caravan, Plymouth Voyager and Chrysler Town and Country. The lead free alloy was first adopted for use on the Ford Thunderbird. With the outstanding success of the “T-Bird” PPG recommended it be used on the GM U-Vans: Chevrolet Venture, Pontiac Montana and Oldsmobile Silhouette. According to Antaya (2009a), in more than 10 years, there has never been a warranty claim or complaint regarding the lead free alloy.

Antaya states that subsequently, Ford and General Motors had asked Antaya Technologies to develop a lead free solder alloy which would perform identically to the widely used leaded version on all automotive glass from fully annealed to fully tempered (Antaya 2009a).

In recent years, as a result of the ELV Directive banning heavy metals including lead, there has been renewed interest in the lead free material. Antaya has developed a series of much lower cost alloys which do not have the range of performance of the 65 alloy, but which pass many of the automotive industry tests (Antaya 2009a). Antaya says to have allowed Sekurit Saint Gobain (SSG) access to a 25% indium alloy which although less costly is only suitable to a limited range of conditions in accordance with certain specifications. SSG conducted tests, which Antaya maintains were wholly inappropriate for this less expensive material and extrapolated from this limited test that the material had failed (Antaya 2009a).

*Standards*

Antaya says that the Automotive industry uses a collection of testing standards to validate materials and parts for general use (Antaya 2009a). The widely recognized standards were submitted to the EC by leading glass manufacturers in January 2008 as part of the Third Adaptation of Annex II (Antaya 2009b). Antaya Technologies took these standards and commissioned an extensive test procedure to be conducted in accordance with these Standards. An independent laboratory used extensively by the global car companies was selected to conduct the tests and a well respected engineering firm was commissioned to oversee the work and to audit the results. According to Antaya (2009a), the material passed all the tests. Antaya says that the results can be reviewed in summary form in Section 2e) and 2 f-g (Antaya 2009g).

Antaya (2009a) further on states that on April 18th 2008, at VDA in Frankfurt, the following test scenario, which differs somewhat from the test protocol above, was jointly proposed by CLEPA, St Gobain, Guardian, AGC and Pilkington (Section 2b) (Antaya 2009i):

- **Temperature cycling tests** at defined humidity similar to ISO 16750-4:2003 G (-40°C to +90°C, 20 cycles)
- **Constant climatic humidity tests** (50°C/100% rel. humidity, duration 336h) according to ECE R43 and ANSI Z26.1 1996 or UNECE Global Technical Regulation
- **Climatic temperature with humidity tests** (40°C) according to DIN EN ISO 6270-2
- **High temperature storage** (100°C) according to UNECE Global Technical Regulation
- (Salt spray test according to DIN EN ISO 9227)

The salt spray test was discarded by the group for a variety of reasons (Antaya 2009a).

Antaya Technologies commissioned another study conforming to the test protocol above, once again passing all the tests under the scrutiny of an independent laboratory with third party oversight (Antaya 2009a). These results can be seen in Section 2f-g according to Antaya (Antaya 2009g).

According to Antaya , in July of 2008, Jerry Exner, Validation Engineer of General Motors raised a question about the study of Kirkendall voids in the lead free solder (Antaya 2009a). At General Motors' request, Antaya commissioned a special test procedure that included 500 hour 100°C aging procedure followed by a vibration test intended to simulate the effects of 10 years of potholes and closure shocks. Upon completion of analysis by General Motors, Mr. Exner wrote "It certainly allows us to conclude that there is no higher fatigue risk with the Indium solder than the leaded solder" (Antaya 2009a). The detailed results and commentary can be seen in Section 2f (Antaya 2009a and 2009g).

**Results of the joint test program**

The joint testing group had worked out a test program in order to assess the feasibility of Antaya's lead-free solder (Joint Testing Group 2009). The ageing procedures were conducted as laid down in the Joint Test Program in the section 2 "Laboratory Test Program". After the ageing, the soldered glass samples were tested (IR inspection, microcrack inspection, pull test) as described in section 4 "Acceptance criteria for laboratory tests" in the Joint Testing Program (Joint Testing Group 2009).

*Ageing and testing*

The ageing and testing was conducted following the Joint Testing Program (Joint Testing Group 2009).

Ageing procedures 1 and 4 and the subsequent testing were prepared and conducted in Wolfsburg at Volkswagen, ageing procedures 2 and 3 at BMW in Munich. The results were presented and discussed in detail among the stakeholders in a meeting open to all stakeholders in Frankfurt/Main, Germany, on 11 May 2009.

Table 20 shows the alloys and their melting points used in the joint test program, according to Antaya (Booth 2009b).

Table 20 Composition and melting points of solder alloys in the joint test program according to Antaya (Booth 2009b)

| Alloy | Liquidus Temperature in °C | Solidus Temperature in °C |
|---|---|---|
| 25Sn 62 Ag 10Bi 3 Ag | 224 | 160 |
| 30Sn 65In 0.5Cu 4.5 Ag | 127 | 109 |

Volkswagen had the composition of the lead-alloy analyzed used in the joint test program. The result in Figure 45 shows deviations from the nominal composition of the lead solder in Table 20.

| Element | Massen% | Atom% |
|---|---|---|
| Pb | 52.45 +/- 0.85 | 41.93 |
| Sn | 34.80 +/- 0.63 | 48.57 |
| Bi | 7.70 +/- 0.90 | 6.11 |
| Ag | 2.21 +/- 0.38 | 3.40 |
| Insgesamt | 97.17 | 100.00 |

| Spalte1 | Pb solder | Pb-free solder |
|---|---|---|
| Pb | 61% | - |
| Bi | 7.7% | - |
| Sn | 29% | 30% |
| Ag | 2% | 5% |
| In | - | 65% |

Figure 45 Analyses of solders used in the joint test program at Volkswagen (Rakus 2009) (left) and BMW (right) (Pinsker 2009c)

The lead content in the Volkswagen analysis is around 10% below the nominal composition, while the tin content is increased for around 10% compared to the nominal analysis.

The Volkswagen analysis of the lead alloy was presented to the stakeholders (Antaya, vehicle manufacturers, glass makers) at an open meeting in Frankfurt/Main on 14 May 2009. The stakeholders had agreed that the analyzed alloy was a usual lead alloy used for soldering on vehicle glass. The deviation from the nominal alloy composition was therefore not further discussed.

| Element | 1 (Wt %) | 2 (Wt %) | 3 (Wt %) |
|---|---|---|---|
| Sn | 24.76 | 24.38 | 25.01 |
| Pb | 62.12 | 62.25 | 61.65 |
| Cu | 0.30 | 0.22 | 0.18 |
| Bi | 9.95 | 9.54 | 10.16 |
| In | 0.001 | 0.002 | 0.001 |
| Ag | 2.77 | 3.48 | 2.90 |
| Sb | 0.08 | 0.11 | 0.08 |

| ELEMENT/ELEMENTO | % |
|---|---|
| (Al) ALUMINIUM/ALUMINUM/ALUMINIO | < 0.001 |
| (Sn) ETAIN/TIN/ESTANO | 24.9 |
| (Pb) PLOMB/LEAD/PLOMO | BALANCE |
| (Sb) ANTIMOINE/ANTIMONY/ANTIMONIO | 0.02 |
| (Cu) CUIVRE/COPPER/COBRE | 0.03 |
| (Ag) ARGENT/SILVER/PLATA | 2.9 |
| (As) ARSENIC/ARSENIC/ARSENICO | < 0.01 |
| (Bi) BISMUTH/BISMUTH/BISMUTO | 10.2 |
| (Fe) FER/IRON/HIERRO | < 0.01 |
| (Zn) ZINC/ZINC/ZINC | < 0.001 |

Figure 46 Analysis of lead solders as used in the joint test program by two different external labs contracted by Antaya (Booth 2009c; Booth 2009d)

The analyses results from documents (Booth 2009c) and (Booth 2009d) indicate good congruence with the nominal composition of the lead solder indicated by Antaya.

Volkswagen also had the lead-free alloy analyzed on possible lead content. No lead could be detected in the lead-free alloy (Rakus 2009).

### Pull test results

After the ageing procedures, pull testing of the connectors soldered to the glass samples was conducted according to the Joint Testing Program (Joint Testing Group 2009).

Figure 47 shows a summary of the pull test results from the joint test program.

| | | | Connector types: | T-bridge | | | | | | | | Crimp | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tested glass samples | | | | Ageings 1 - 4 LF no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 Pb no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 LF no. of connectors/no. failed/no. of glass | | | | Ageings 1 - 4 Pb no. of connectors/no. failed/no. of glass | | | |
| Supplier | OEM | Type | glass tpye | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| AGC | Audi | Q5 | tempered | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | | | | | | | | |
| | Lancia | Musa | tempered | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | 6 / 0 / 1 | 6 / 0 / 1 | | 6 / 0 / 1 | | | | | | | | |
| | Toyota | Aygo | tempered | 8 / 3 / 1 | 8 / 0 / 1 | | 8 / 5 / 1 | 8 / 0 / 1 | 8 / 0 / 1 | | 8 / 0 / 1 | | | | | | | | |
| | Citroën | C4 | tempered | | | 2 / 0 / 1 | | | | 2 / 0 / 1 | | | | | | | | | |
| | Citroën | Prototype | tempered | | | 2 / 0 / 1 | | | | 2 / 0 / 1 | | | | | | | | | |
| | Volkswagen | Passat | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| Guardian | Audi | A6 Avant | tempered | 8 / 0 / 1 | 8 / 0 / 1 | | 32 / 1 / 3 | 8 / 0 / 1 | 8 / 0 / 1 | | 33 / 0 / 3 | 3 / 1 / 1 | | | 3 / 1 / 1 | 3 / 3 / 1 | | | 3 / 2 / 1 |
| | Audi | A8 | laminated | 36 / 0 / 3 | 12 / 0 / 1 | | | 36 / 1 / 3 | 12 / 0 / 1 | | | | | | | | | | |
| | Porsche | Panamera | laminated | 24 / 8 / 2 | | | | 24 / 1 / 2 | | | | | | | | | | | |
| | Daimler | 5-Class | privacy | | | | | | | | | | | | 1 / 1 / 1 | | | | 1 / 0 / 1 |
| | BMW | X6 | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| | BMW | X5 | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| PPG | Daimler | 5-Class | tempered | | | 4 / 0 / 2 | | | | 4 / 0 / 2 | | | | | | | | | |
| | Daimler | 5-Class | laminated | 24 / 0 / 2 | | | 12 / 5 / 1 | 24 / 15 / 2 | | | 12 / 8 / 1 | | | | | | | | |
| Pilkington | BMW | 1-series | tempered | 20 / 0 / 5 | 6 / 0 / 1 | 4 / 0 / 2 | | 16 / 0 / 4 | 6 / 0 / 1 | 4 / 0 / 2 | | 5 / 4 / 5 | | | | 4 / 4 / 4 | | | |
| | BMW | XXX | | | | | 18 / 0 / 4 | | | | 18 / 0 / 4 | 4 / 0 / 4 | | | | 4 / 4 / 4 | | | |
| Saint-Gobain | BMW | 5-series | tempered | 63 / 0 / 5 | 28 / 0 / 2 | | 42 / 0 / 3 | 63 / 0 / 5 | 28 / 0 / 2 | | 42 / 0 / 3 | | | | | | | | |
| | Volkswagen | Golf | tempered | 30 / 0 / 5 | | | 17 / 0 / 3 | 30 / 0 / 5 | | | 18 / 0 / 3 | 5 / 5 / 5 | | | 1 / 1 / 1 | 5 / 3 / 5 | | | 1 / 1 / 1 |
| | Opel | Corsa | tempered | 6 / 0 / 1 | | | 6 / 1 / 1 | 6 / 0 / 1 | | | 6 / 0 / 1 | | | | | | | | |
| | Renault | Megane | tempered | 8 / 0 / 1 | | | 7 / 0 / 1 | 8 / 0 / 1 | | | 8 / 0 / 1 | | | | | | | | |

Figure 47 Summary of results from joint test program (Pinsker 2009a)

*LF: Lead-free solder*

*Pb: Lead solder*

Figure 47 shows that in tests 2 and 3 no failures occurred in pull testing, neither for the lead-free nor for the lead-containing solders. In tests 1 and 4, the result shows failures both with lead-free and lead-containing solders.

Table 21 shows the summary of the pull test results after ageing procedures 1 and 4 conducted at Volkswagen.

Table 21 Overall result of pull-off tests after ageing procedures 1 and 4 (Rakus 2009)

| | LF | Pb |
|---|---|---|
| Total | 381 | 380 |
| Pass | 358 | 362 |
| Failed | 23 | 18 |

Figure 48 shows the results of the pull-of test broken down to the ageing procedures 1 and 4.

| Ageing Proc. | Ageing Procedure 1 | | Ageing Procedure 4 | |
|---|---|---|---|---|
| Solder | Pb-free solder | Pb-solder | Pb-free solder | Pb-solder |
| No. of joints | 227 | 223 | 154 | 157 |
| Passed | 216 | 213 | 142 | 149 |
| Failed | 11 | 10 | 12 | 8 |
| % of failures | 5% | 4% | 8% | 5% |

Figure 48 Result of pull-off test for tests 1 and 4 (summary of slides 5 and 6 from (Rakus 2009) by Otmar Deubzer)

Figure 49 shows the results of the pull-of test for ageing procedures 1 and 4 broken broken down to the performance on laminated and tempered glass.

| Glass Type | Laminated glass | | Tempered glass | |
|---|---|---|---|---|
| Solder | Pb-free solder | Pb-solder | Pb-free solder | Pb-solder |
| No. of joints | 84 | 84 | 297 | 296 |
| Passed | 71 | 66 | 287 | 296 |
| Failed | 13 | 18 | 10 | 0 |
| % of failures | 15% | 21% | 3% | 0% |

Figure 49 Result of pull-off test for tests 1 and 4 by type of glass (summary slides 7 and 8 from (Rakus 2009) by Otmar Deubzer)

The pull testing results do not show significant performance differences between the lead-free and the lead solder joints (Pinsker 2009b; Rakus 2009). In the IR hot spot detection test as well as in the inspection for micro cracks, the lead-free solder joints did not show performances inferior to that of the lead solder joints (Pinsker 2009b; Rakus 2009).

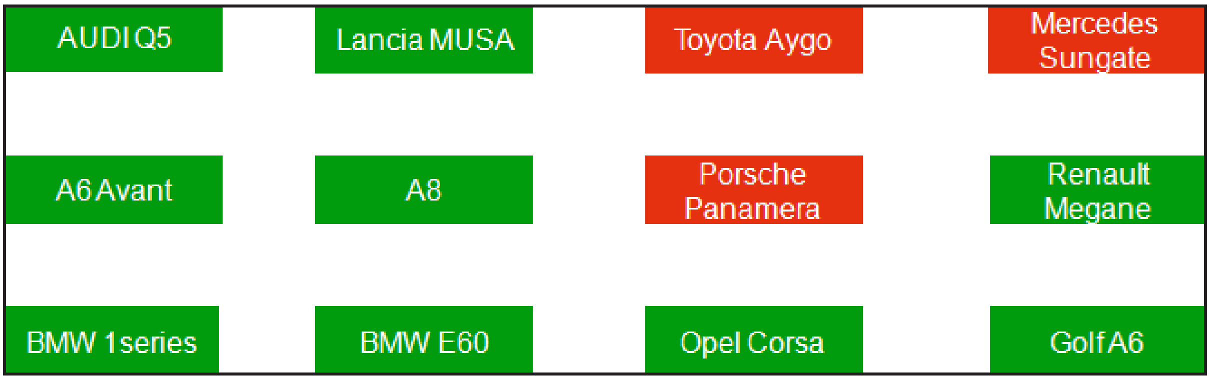


Figure 50 Failure accumulation of lead-free and lead soldered joints on specific samples (Rakus 2009)

On some glass samples, the observed failures after pull testing both of lead-free as well as of leaded solder joints was higher than on other glass. The reasons for the accumulated failure rates on the above glass could not be identified.

In the meeting in Frankfurt Main, it was discussed with the stakeholders whether this result might indicate that the tested lead-free solder alloy clearly would have failed on specific types of glass, which could technically be described and confined independently from glass maker and vehicle type. It was agreed that this was not possible.

### Microcracks

The glass samples soldered at Volkswagen in Wolfsburg were inspected for microcracks before pull testing according to the Joint Testing Program (Joint Testing Group 2009). Figure 51 shows the summary of microcrack countings detected in the glass samples after soldering and before pull testing (Antaya 2009c).

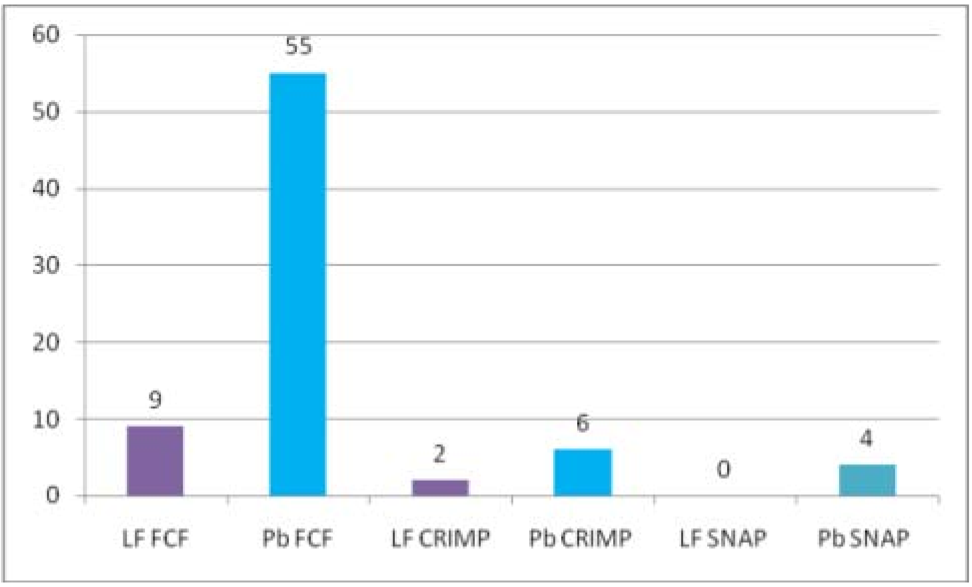


Figure 51 Microcracks in glass samples (Antaya 2009c); LF: lead-free soldered connections, Pb: lead soldered connections, FCF: classical T-bridge connectors

Figure 51 shows clearly higher counts of microcracks under the solder joints soldered with the lead-containing solder. A European glass maker (Marchant 2009) pointed out that the 32 of the 55 microcracks on Pb FCF had occurred on a single glass sample only. Such a high figure, according to this stakeholder, may indicate that something went completely wrong in the soldering of leaded connectors on this part. It would therefore not be adequate to fully include this glass with 32 failures into the statistical evaluation of the test (Marchant 2009).

The stakeholders agree on the fact that under the applied test conditions, the lead-free solders caused less microcracking than the lead solders. A further investigation of the backgrounds and possible reasons for the microcracks was therefore not conducted. Such an evaluation would have to include the lead-free solder micro cracks as well to maintain the balance in the evaluation of the results.

### Infrared inspection

All soldered joints were inspected by IR-camera during operation as laid down in the Joint Testing Program (Joint Testing Group 2009). If a hot spot was detected indicating a defect, the test was counted as “not passed” for the respective solder joint.

On the test samples at BMW, no hot spots were detected. On the test samples at Volkswagen, there was no unacceptable temperature distribution, and no difference in performance between lead and lead-free solder joints.

**Resistance test**

A resistance measurement as demanded by the Joint Test Program (2009) was not conducted. The infrared hotspot inspection did not indicate any impairment of the solder joints. The temperatures measured at the connector in the IR inspection as well as the measured current were in the expected range. In case of a resistivity increase, the temperature would have been increased, and the current would have been lower. The absence of such phenomena were interpreted in that way that the resistance of the solder joints was in the normal range.

**Summary of results from joint testing program**

To sum up, the lead-free indium-based alloy did not show performances inferior to the lead alloy, neither in pull testing after the ageing tests, nor in the IR inspection (Pinsker 2009b) (Rakus 2009). The lead-free solder joints caused less microcracks in the glass samples compared to the lead solders. Within the range of tested glass samples and connectors, there are no technically definable glass and connectors, where the lead-free solder joints would have failed to a degree that would prove that they are not appropriate for this kind of glass or connectors. In the joint test program, the lead-free solders could not be found to be not viable on any of the glass and connector technologies tested.

Antaya (2009f) had additional tests conducted at external laboratories. The tests were the same or identical tests like in the joint test program. The results underpin the findings from this joint testing program.

**Conclusions from the test results**

There were no significant performance differences of the lead-free and the lead solder in the joint test program (Pinsker 2009b; Rakus 2009). The glass makers and vehicle manufacturers stated that the results are promising, Antaya considers the results a full success for its lead-free solders.

This difference in the views on the test results become obvious in the stakeholders' stand points on the timing of the lead replacement, and in remaining concerns of the vehicle manufacturers and glass makers, in particular concerning the low melting point of the lead-free solders.

Antaya considers its lead-free alloy a drop-in solution, which can replace the lead-containing solders within short time (Booth 2009a). Antaya hence requests remaining with the current exemption 8a in its current wording and timing. The exemption for lead in solders on glass would then expire end of 2010 for new type approved vehicles.

The vehicle manufacturers and the glass makers plea for at least 4,5 years of total transition time from start of development on (Pinsker 2009b). This would result in an expiry of the exemption end of 2013.

The stakeholders positions are discussed in the following sections.

**Position of vehicle manufacturers and glass makers (Pinsker 2009b)**

The vehicle and glass manufacturers provided a roadmap for the further timeline towards the lead replacement in solders for soldering on glass.

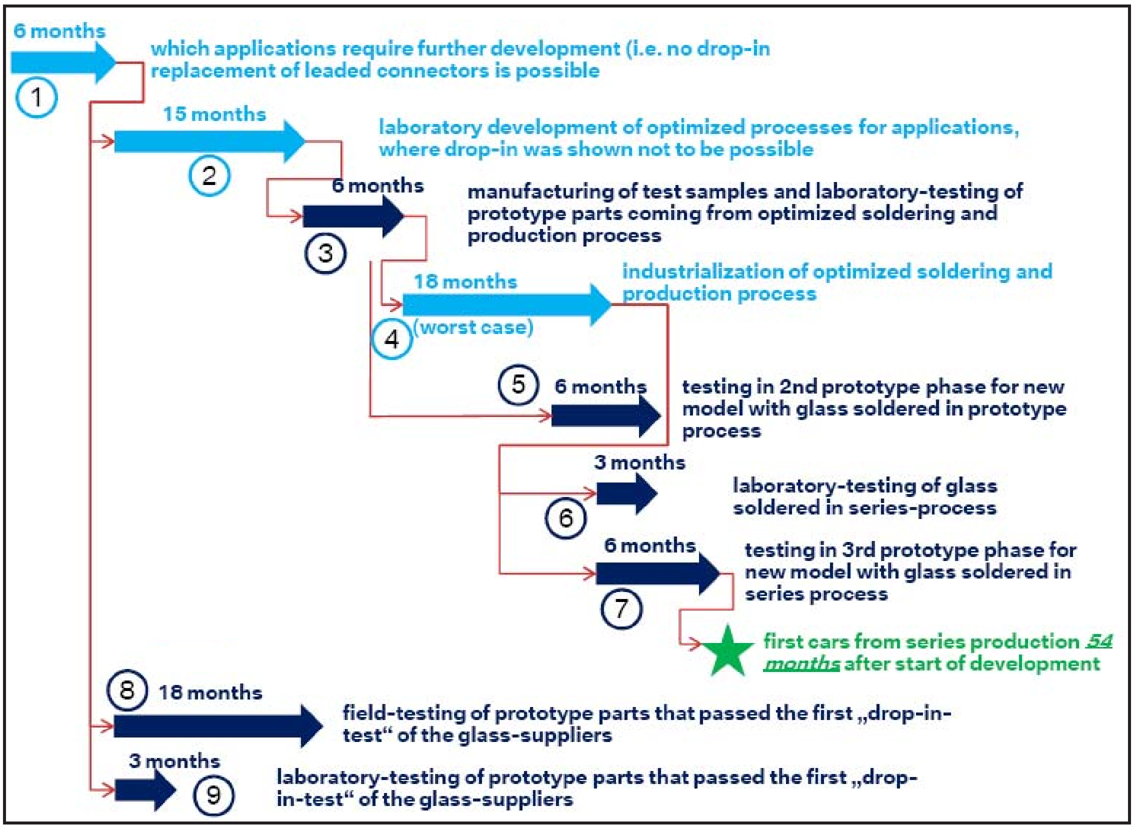


Figure 52 Proposed schedule for lead replacement in soldering on glass (Pinsker 2009b)

ACEA et al. describe the above roadmap in more detail (Pinsker 2009b):

1. Determination of applications requiring further development (Pinsker 2009b)
   a) Preparation of samples for all applications ⇨ 3 months [Samples must originate from "normal" production.
   b) Soldering ⇨ 1 month [roughly: 20 applications x 200 connectors = 4000 connectors].
   c) Since no adapted tooling for the series designs is available, all connectors must be processed by hand on a manual series production line.
   d) Tests and evaluation ⇨ 2 months.

   Total: 6 months.

2. A lab-development has to be started for all applications where no drop-in is feasible (Pinsker 2009b).
   a) Optimistically, the stakeholders assume for all such applications (only) two development cycles á lab-analysis of the failure-reasons, definition of process or product actions ⇨ 1–2 months.
   b) Execution of optimization ⇨ 2 months [if new tooling is required (e.g. new printing screens), time of delivery has to be taken into account].
   c) Preparation of samples incl. soldering ⇨ 1/2 month.
   d) Tests and evaluation ⇨ 2 months.

   Total: 6 months per cycle, ergo a good 12 months of development [Parallelization of the developments for different applications are limited by man-power. Hence, if the number of applications is big (>3), delays are unavoidable].

3. Presentation of prototypes for all applications at all OEMs, as all OEMs will want to apply their validation program (Pinsker 2009b)
   a) Preparation of prototypes on series or pilot lines ⇨ 3–6 months, depending on OEM demands.
   b) Validation program OEMs ⇨ 3 months.
   c) Field tests with prototypes ⇨ 15 months, but can be done in parallel to industrialization.
   d) After this validation introduction of the new technology into running development projects can start.

   Minimum lead-time until SOP (start of production) is 1 year, if no big engineering of production lines is required. Otherwise (e.g. new printing room), 1,5–2 years are realistic.

4. Industrialization (here the case of a required invest is discussed) (Pinsker 2009b)
   a) Invest preparation (dossier) and decision ⇨ 3 months.
   b) Engineering (compilation of list of requirements until PO) ⇨ 3–6 months.
   c) Time of delivery: 3–6 months.
   d) Waiting for shut-down ⇨ 0–6 months [larger modifications of the shop floor, e.g. an additional printing room or a modification of an automated soldering line, are only possible during summer or Christmas shut-down]
   e) Start-up and ramp-up ⇨ 3 months.

   Total: 1 to 1,5 years [The extent of the required actions is crucial, e.g. if no space on the shop floor is available to install a new printing machine + curing station (which unfortunately is quite often the case), it is necessary to change the complete line design. Then 1,5 year is quite challenging. If "only" a flux application apparatus has to be added to a line with amply shop floor space (and amply cycle time!!!), the engineering can be done in 6 months].

5. Testing in 2nd prototype phase of OEM (Pinsker 2009b)
   a) In the 2nd prototype phase cars are produced with toolings that are either series or close to series.
   b) The cars are used for thorough testing of the complete system. As for example chemicals used in the interior may interfere with the solder contacts, it is required that also the material used for the solder contacts is the same that will be used for series, thus the glass for these prototypes must have been produced under conditions close to series.
      - car buildup (prototypes!) ⇨ 1 month
      - laboratory testing (climate, shaker, ...) ⇨ 2 months.
      - summer- and winter testing ⇨ 2 months each, not including the time for waiting for correct weather conditions in the relevant countries.

   Total: around 9 months.

6. Laboratory-testing of glass soldered in series-process (Pinsker 2009b)
   a) As for the 2nd prototype phase no parts from series-process may be available, additional laboratory testing is necessary with series parts.

   Duration: 3 months including production of test specimen.

7. Testing in 3rd prototype phase for new model with glass produced and soldered in series process (Pinsker 2009b).
   a) As for the 2nd prototype phase no parts from series-process may be available, there is only the 3rd.
   b) prototype phase to test the parts coming from series tooling and series process.
      - car buildup (prototypes!) ⇨ 1 month.
      - laboratory testing (climate, shaker, ...) ⇨ 2 months
      - summer- and winter testing ⇨ 2 months each, not including the time for waiting for correct weather conditions in the relevant countries.

   Total: around 9 months.

8. Field-/laboratory testing of prototype parts that passed the first „drop-in-test“ of the glass-suppliers (Pinsker 2009b)
   a) In order to get first results and hints on what to focus on in the further development, first prototypes of glass with lead-free solder connectors are tested in

laboratory as well as in current series-cars under heavy driving conditions and special climates.

b) Main purpose of this test and the corresponding laboratory-test is to get a comparison between laboratory and real-life conditions: does the laboratory test really reflect real-life conditions?

These tests do not influence the total time needed for the development, they are done in parallel.

The stakeholders confine that in all cases of mentioned periods it was assumed that all work can be perfectly parallelized for all applications, products, plants, lines, customers, etc. (Pinsker 2009b). Since this technology concerns all customers and all plants and service centers, the limiting resource is man-power. The required know-how according to the stakeholders is very specific and cannot be studied at universities. All engineers are trained by the glass industry and there are only about 15–20 experts in all companies in total all over the world. Such experts hence are difficult to find, according to the stakeholders (Pinsker 2009b).

**Antaya position (Booth 2009a)**

*Lead-free solders as drop-in replacement*

Antaya defines “drop in” as meaning that the lead free part can be used as a substitute for the leaded part so long as the manufacturing process and its components may only be subjected to either usual and customary, or reasonable and inexpensive adjustments (Booth 2009a). For the purpose of clarification, a change to the glass itself such as making it thicker or changing its shape would not pass the “drop in” test. If a simple change to the part or process is made, then it would be considered within this definition of “drop in” (Booth 2009a).

Antaya explains that, when a new vehicle program comes online, the glass and its attachments (connectors) are designed to meet the requirements of the vehicle manufacturer. As part of the customary optimization of the glass and the leaded connectors, the following, almost certainly incomplete, list of adjustments can be made (Booth 2009a).

- Adjustments to glass (Booth 2009a):
  - % silver in the paste – (higher % means better adhesion);
  - thickness of the silver paste (double buss bar) – (thicker usually means better adhesion);
  - construction of screen which affects the profile of the silver paste, which in turn affects adhesion;
  - ceramic type – different ceramics have different performance characteristics;

  - ceramic thickness;
  - firing temperature.
- Adjustments to the part (connectors) (Booth 2009a):
  - flux type;
  - amount of flux;
  - application of flux (inside the solder or on the solder);
  - amount of solder on the part (connectors already contain solder deposit);
  - dimensions of solder pad (shape / size) – (bigger pad means better adhesion);
  - profile of solder.
- Soldering process (Booth 2009a):
  - silver abrasion method prior to soldering;
  - soldering temperature;
  - soldering time;
  - cool down time.
- Assembly plant (Booth 2009a):
  - installation method;
  - packaging in vehicle.

Antaya emphasizes that the above list of adjustments are not lead free adjustments. They are the customary variables that can be easily adjusted to improve performance (Booth 2009a). Antaya claims that it is inconceivable that the lead free part could require any adjustments beyond those detailed above in order to meet the standards as provided by the vehicle manufacturers. Antaya believes that 99% of adjustments will be part adjustments (i.e. adjustments that have to be done anyway). Antaya further maintains that since any possible adjustment is both customary and inexpensive, adjustments such as these should not be considered as grounds for further delays in the implementation of the ban on lead (Booth 2009a).

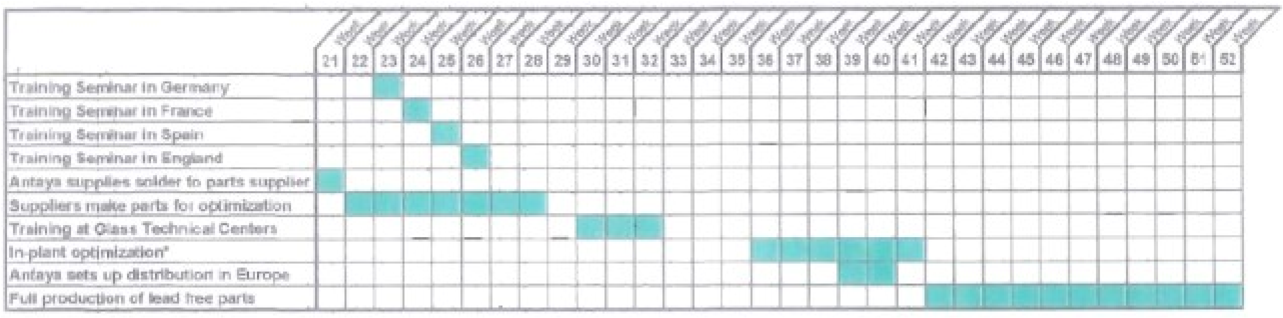


Figure 53 Antaya's schedule for transition to lead-free soldering on glass in vehicles (Antaya 2009e)

Antaya asks to consider what was learned from the joint test program (Booth 2009a). According to Antaya a representative range of glass types was tested, with 1,026 connectors across 5 global glass manufacturers, 9 OEMs and 14 vehicle programs. All of these programs were designed for a leaded part and Antaya had no previous experience with any of the glass. And yet, the lead free parts incurred fewer failures from pull tests and less than 1/6$^{th}$ the failures from cracking than the leaded parts (Booth 2009a). In short, Antaya states that it came to Volkswagen and BMW with a box of lead free parts and outperformed the leaded parts with absolutely no optimization or adjustments other than five minutes on the soldering device. None of the parts were designed for the glass on which they were tested and Antaya used demo soldering equipment which the Antaya representatives brought with them to Volkswagen and BMW (Booth 2009a).

*Research and development*

Two examples of research and development were mentioned at the meeting in Frankfurt on 11 May 2009:

- the possible use of online fluxing, and
- the potential need for double buss bars (at AGC).

Antaya believes that the term "research and development implies some kind of prolonged and extraordinary activity that has an unknown outcome and cost (Booth 2009a). Antaya states that double buss bars are widely used in many plants across Europe and around the world today. Double buss bars, according to Antaya, were in evidence on 25% of the vehicle manufacturers' glass tested in the joint test program. Antaya concludes that therefore double buss bars cannot be considered "research and development" (Booth 2009a).

Antaya continues that secondly, online fluxing, which is the use of flux core solder wire or ribbons at the part supplier (Antaya and its competitors), is not a requirement of the vehicle manufacturers (Booth 2009a). It is a convenience used by some glass plants in Europe. The alternative, post applied flux, is widely used by parts suppliers all over the world, including Europe, Asia, and the United States. Antaya currently supplies the alloy only in ingot, post-applied or pre-applied form. But firstly, Antaya claims to have been advised by a large multi national supplier of solder wire that they will supply Antaya's alloy in flux core solder wire worldwide and secondly, even if they are unable to do as they say, this nuance does not come close to the implied requirement that an exemption to Annex II should be sustained by a reasonably substantial issue (Booth 2009a).

*Field Tests*

Antaya challenges the vehicle manufacturers' position who had asked for field tests in addition to the "Joint Test Program" (Booth 2009a). Antaya cites the coordinator of the Joint

Test Program, Otmar Deubzer, as having said that it “was not up to [him] to tell the OEMs what field tests they might need”. Antaya argues that the accelerated aging protocol that was completed over the past two months was specifically designed to simulate the life cycle of the lead free alloy in its working environment. For the purpose of clarity, Antaya wishes to draw the attention to the document sent out on March 18 to the participants in the Joint Testing Group (Booth 2009a):

*Test 2.1 Temperature cycle test ISO 16750-4:2003*

This test ensures that the stress relaxation mechanism of the solder alloy is sufficient. About 20–30 cycles are required to simulate the ageing (e.g. work-hardening) of the alloy.

*Test 2.2 High temperature storage test according to UNECE Global*

This ageing procedure simulates the microstructural changes in the solder joint over the life-time of the car on an accelerated time scale to enable the testing of an aged sample.

*Test 2.3 Climatic temperature with humidity tests according to DIN EN ISO 6270-2 under load*

Condensation is a typical phenomenon in the cabin of a car. This procedure ensures that the product functionalities persist under condensation during the life-time of the car.

*Test 2.4 Constant climatic humidity tests ECE-TRANS-WP.29-GRSG-2007-28e*

Some alloys are vulnerable to this type of exposure. The alloy may become brittle or the adhesion at the interfaces might fail. The result is a cohesive or adhesive failure of the joint. This procedure ensures that the product functionalities persist during the life-time of the car.

Antaya claims that there are around 700 000 vehicles (and growing) on the road all over the world today using lead free on-glass connectors (Booth 2009a). Many of these vehicles have been on the road for more than 10 years. Antaya says that Tom Hagen, Senior Executive at General Motors responsible for Glass and Moldings personally went through all the warranty data on many of these vehicles looking for lead free issues, prior to approving the Antaya material for use on GM vehicles. There were no incidents reported on lead free connectors (Booth 2009a).

*Summary of the Antaya position (Booth 2009a)*

Antaya sums up that it has considerable experience with the lead free alloy and has never failed to “drop in” a replacement (Booth 2009a). According to Antaya, the alloy has been in use for ten years. The Joint Testing Group has been working collaboratively on this for 13 months and individually for several more years. Antaya claims that there is not one piece of evidence suggesting that the parts are not “drop in”. With only 5 minutes of optimization, the lead free parts in the group test outperformed the leaded parts, moderately in pull tests and significantly in cracking. Antaya states that there is no evidence that its solution is not a “drop in” (Booth 2009a).

### 4.17.5 Critical review of data and information

**Concerns on the melting point of the lead-free alloy**

The lead-free alloy, compared to the lead alloy, has a considerably lower melting point (Booth 2009b):

- liquidus temperature 127°C, compared to 224°C of the lead solder;
- solidus temperature 109°C, compared to 160°C of the lead solder.

*Liquidus temperature*

Maximum temperature at which crystals (unmolten metal or alloy) can co-exist with the melt. Above the liquidus temperature, the material is homogeneous, consisting of melt only.

*Solidus temperature*

Temperature at which an alloy begins to melt. Below the solidus temperature, the substance is completely solid, without molten phase.

Between the solidus and liquidus temperature (between 109°C and 127°C), solid phases (crystals) and the melt coexist.

ACEA et al. express concerns on possible adverse impacts of the low melting point of the lead-free alloy. High temperatures can be reached when a car is parked in direct sunlight (Pinsker 2009b).

*Antaya high temperature tests*

Antaya presented two tests to prove that the melting point is of no concern. The tests were conducted in external labs. The tests and their results are displayed in the Annex as test I and II.

In test I, test samples were stored at 105°C for 500 h. During the 500 h, weights of 500 g were hung from each of the connectors soldered to the carrier with the lead-free solder used in the joint testing program. According to the test report, no failures occurred, the connectors held the weights.

In test II (see Annex), test samples soldered with the lead-free alloy used in the joint testing program were stored at 100°C for 500 h and then subjected to mechanical shock and vibration tests. The samples passed the tests, according to the test results presented by Antaya.

The vehicle manufacturers and the glass makers were asked whether these test results might accommodate their concerns.

*Persisting concerns about adverse effects from the low melting point*

ACEA et al. explain that the maximum temperatures reached vary with installation location, the highest temperatures relevant for glazing applications are typically measured at the roof (Pinsker 2009b). The stakeholders put forward that on the surface of the IP-pad or on the inner surface of the rooflite, temperatures measured under real life conditions (ambient temperature 45°C, incident solar energy 1100 W/m² at mid-day sun, car parked for approx. 2 hours) are as high as 115 to 120°C (Pinsker 2009b). These temperatures may vary depending on parameters like

- incident solar energy (depends mainly on the climatic region where the car resides);
- color of the absorbing surface;
- installation angle;
- additional sources of energy like electrical power of the heater grids, which may create temperature differences as compared to the surface temperature at the connector of up to 50°C (see Figure 54 on page 172).

At these locations, measured temperatures exceed by far the value of 110°C where Antaya's solder alloy is known to fail, according to ACEA et al. (Pinsker 2009b). In very humid climate the maximum temperature reached on inner surfaces is usually lower (around 70 to 80°C), but the humid air often leads to fog on the inner surfaces of the car. Defogging of the rear window, which is crucial for the clear outside view of the driver and is thus a safety-relevant function, is usually done using the heater grid. Activation of the heater grid also heats up the connectors to up to 50°C above the surface temperature of the glazing, which may reach 70 °C to 80 °C under real-life conditions (Pinsker 2009b).

Hence, when the heater is activated in a humid environment for de-fogging of the rear window, the temperatures reached will be even higher than when exposed to direct sunlight without operation of the heater. Failure of the soldered joint in these high temperatures in the field will create a safety concern.

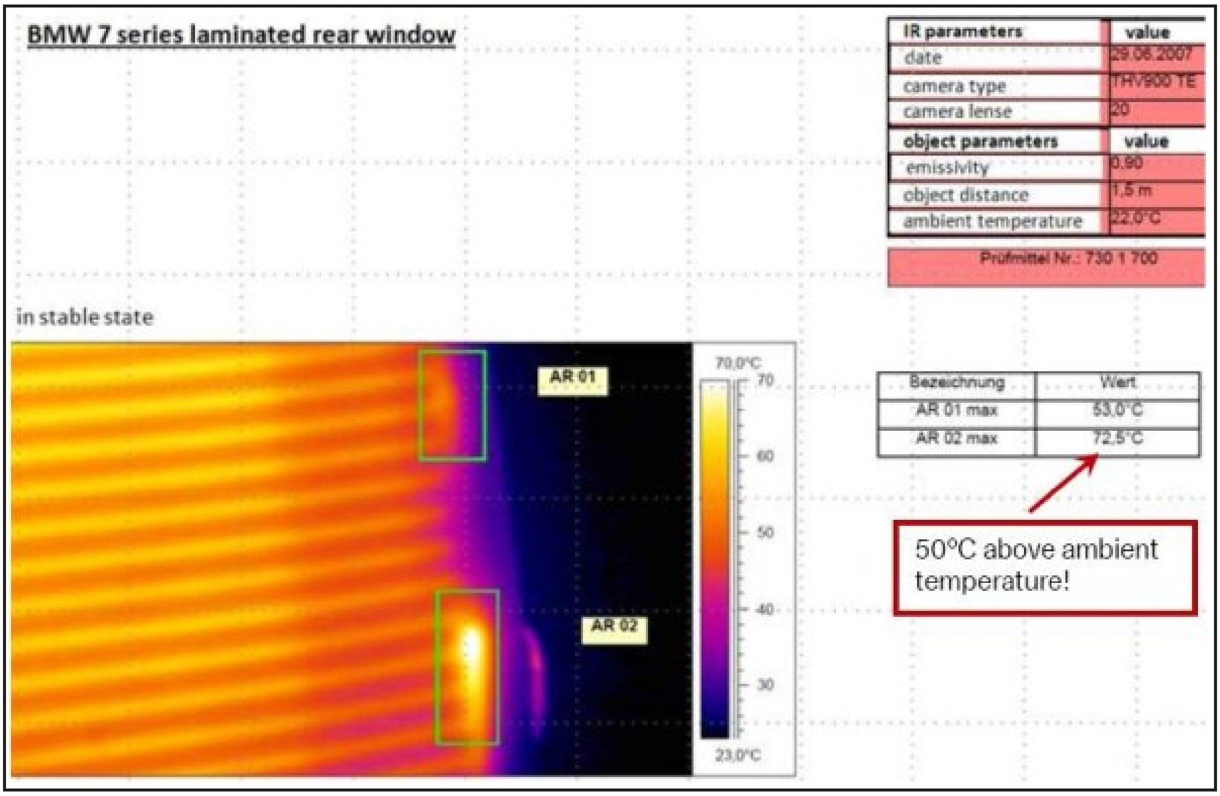


Figure 54 Elevation of temperature in heating grid connector of a rear window during defogging (Pinsker 2009b)

Another measurement was conducted at Volkswagen showing the temperature curve at a rear window defroster (Rakus 2009).

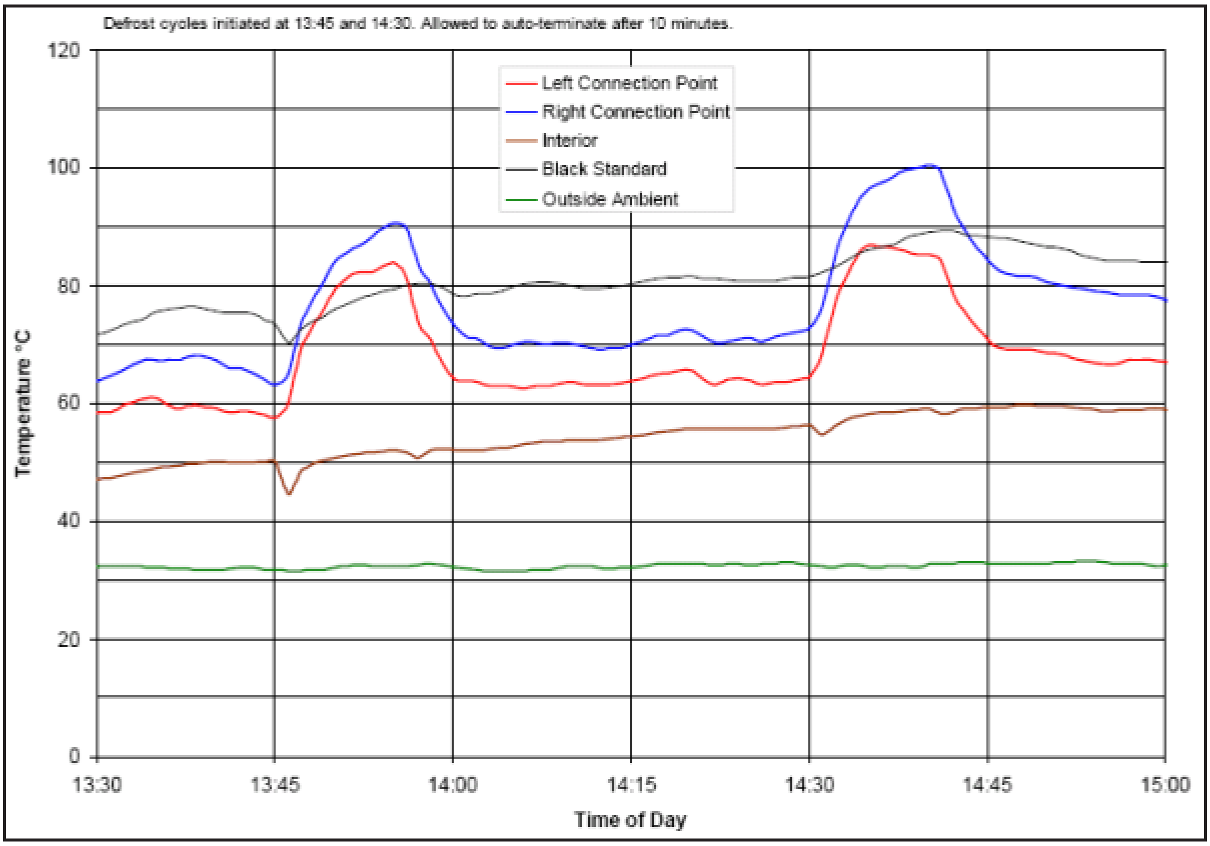


Figure 55 Temperatures measured at a rear window defroster (Rakus 2009)

At an ambient temperature between 30 to 40°C, the maximum temperature measured was around 100°C.

The Antaya high temperature tests do not scatter the vehicle and glass manufacturers worries (Pinsker 2009b). They say that Antaya presents high-temperature tests at 105°C. Tests performed at slightly higher temperatures (110°C) failed due to the low solidus point of the solder, according to the stakeholders (Pinsker 2009b). ACEA et al., however, did not submit any evidence for this.

The car and glass manufacturers state that currently they do not know the tolerances of the melting point of the solder alloy. To ensure proper operation of safety-features like front and rear window heaters under all environmental conditions that may occur in the life-cycle of a car, the car manufacturers typically require testing at a minimum of 10°C above the maximum temperatures measured under real-life conditions at the installation locations.

The stakeholders further on state that in the production process, high temperatures mainly occur during the drying phase of paint refurbishing / respray (Pinsker 2009b). Running at lower temperatures is generally possible, but will lead to longer drying periods and thus higher cost. Currently, maximum temperatures reached during certain paint refurbishing processes exceed 110°C (Pinsker 2009b). If these processes cannot be used due to the low melting point of the solder alloy, new processes need to be developed and investments will be necessary, which will require a longer leadtime than currently planned (Pinsker 2009b).

Also to be considered the refurbishing/respray process at the repair garages for vehicles in use: some use an infrared lamp, which locally heats up areas to be cured, and as it is high power infrared radiation, it could lead into high temperatures on soldering, if used on an area close to a connector (Pinsker 2009b).

The stakeholders say that, if the European Industry is forced by legislation to put on the EC market products, which are not suitable for countries where high temperatures occur and to manufacture different products for those countries, this will be highly detrimental to the competitiveness of the European manufacturers against their competitors whose main market is not the EC. It also will be in contradiction with the conclusions of the CARS 21 High Level Group which were supported by the EC Commission, the European Parliament and the Council (Pinsker 2009b).

**Priorities in the review process**

In the face of the multitude of information and facts presented, and given the contrary statements and opinions of the involved stakeholders, the reviewers would like to point out the corner stones of the review process.

*Piority of vehicle manufacturers' testing and qualification criteria*

The vehicle manufacturers' testing and qualification procedures are taken as the base for testing and evaluation. The vehicle manufacturers are responsible for the reliability and safety of their vehicles. Based on experiences and scientific knowledge, they have developed testing and qualification criteria in order to make sure their vehicles suffice the reliability and safety requirements. Failures at least damage the brand image, but might also endanger life. The vehicle manufacturers should hence not be forced to adopt a material outside their testing and qualification criteria.

*Individual versus joint testing and qualification*

Normally, each car manufacturer or glass manufacturer performs his own tests to qualify materials. This is not possible in this review process due to time and other constraints. A joint testing program is hence required.

This implies several problems. The first one is the setup of a testing and qualification procedure. The vehicle manufacturers' testing and qualification procedures are at least partially different. This problem was experienced during the setup of the Joint Testing Program (Joint Testing Group 2009). Although there are standard tests, there is no standard test program defined, which all vehicle manufacturers apply identically. And there is nothing like an official European Union or European Commission test program, or a test program supported or required by the Commission, as Antaya claims.

While all or almost all vehicle manufacturers apply the four ageing procedures in the Joint Test Program, the parameters of these procedures are individual to each vehicle manufacturer, as well as, at least in parts, the testing and acceptance criteria (Joint Testing Group 2009). Further on, there is a range of ageing procedures and tests, which are individual to single vehicle manufacturers.

As Antaya points out in several of its stakeholder comments, the standard way of approving a material therefore is to work individually with a vehicle manufacturer and/or its supply chain following the vehicle manufacturers testing and qualification procedure. The material will then be qualified for specific applications, e. g. on a specific glass of one or several car models.

This review process, however, forced a deviation from this procedure. It must be decided whether lead in solders for soldering on glass actually can be banned after 2010 in all applications on all glass of all vehicles with new type approval of all vehicle manufacturers. The decision would be easy if the material had been qualified by each vehicle manufacturer for all its applications. As this is not the case, a Joint Test Program had to be set up to which the vehicle manufacturers agreed, which took time and numerous discussions, and required compromises from many of the vehicle manufacturers involved.

The vehicle manufacturers' procedural priority has its limits where the requirements are not plausible in their contents or timings. Art. 4 (2) (b) (ii) requires the replacement of lead where its use is avoidable. The vehicle manufacturers have to aspire legal compliance, which implies their due cooperation in the review and evaluation process.

*Priority of Joint Testing Program over other test results*

The priority of the vehicle manufacturers testing and qualification procedures consequently results in giving priority to the Joint Testing program over other test results submitted in case of conflicting results. The Joint Testing Program was set up with involvement and agreement of the vehicle manufacturers and other stakeholders. This does, however, not mean that other test results are not taken into account during the review. They are used as supporting evidence, or as complementary information.

**Reviewers' conclusions**

The core task of the review process is to find out whether the state of science and technology enables avoiding the use of lead for soldering on glass in vehicles. Art. 4 (2) (b) (ii) only allows an exemption if the use of lead is unavoidable.

The situation can be described as follows from the review point of view:

- The lead-free solders performed well in the joint testing program.
- There are remaining concerns on the low melting points of the lead-free alloy.
- There are different views on the timing of implementing lead-free soldering in glazings.

In the Joint Test Program, the lead-free solders did not exhibit specific weaknesses in the ageing procedures and tests performed. The lead solders preformed well. Compared to the lead solders, their performance was at least not inferior in the pull testing and the infrared inspection after ageing tests 1 to 4, and the lead-free solders caused less microcracks in the glass than the lead solders.

*Necessity of field testing and available field data*

The priority given to the vehicle manufacturers testing and qualification procedures has direct consequences for Antaya's claim that in-field testing of the lead-free solders is not required. All vehicle manufacturers involved had agreed that the lead-free solders had to pass the Joint Test Program, and then would have to undergo an in-field test (Joint stakeholder working group 2009). The vehicle manufacturers had set out around one year of field testing in the very beginning of the Joint Testing Program.

Antaya claims that the indium based lead-free solder alloy is in use in numerous cars already and that therefore field experience is available. The only clearly documented cases of "on the road" use are two different car types or models of two different manufacturers. Further information Antaya has submitted shows that Antaya is involved in development and qualification activities with its lead-free alloy at several OEMs and glass makers or other suppliers (Antaya 2009f).

PPG, a glass maker, confirms that a solder of the composition 30Sn65In0.5Cu4.5Ag was applied in

- the GM "U" Van (Chevrolet Venture, Pontiac Montana and Oldsmobile Silhouette)
  It was used in an integrated circuit replacing the antenna in the windshield. The design was in use from around 1999 to 2001 or 2002 (Antaya 2009d).
- the Ford "T" Bird
  The alloy was used in a heated wiper circuit along the bottom edge of the windshield. Around 70,000 units of this vehicle were built from 2002 to 2005 (Antaya 2009d).

PPG applied the indium-based lead-free solder because of its low melting point to avoid breakage of the glass or of the silver, as PPG had to solder to silver screened annealed glass. PPG was not notified of any damages or failures of its product in the vehicles (Antaya 2009d). The fact that the design using lead-free solders was only used for around 3 years thus does not go back to failures, but has other reasons, which are not known to the reviewers. The same applies to the short production time of the Ford T Bird.

PPG adds that this is no way an endorsement of Antaya's indium based solder as it is up to each manufacturer to test and evaluate materials they use (Antaya 2009d). Different silvers, paint compositions and processing parameters can all affect the reliability of the final product. PPG further on explains that they ¨have never used or validated any lead free solder for tempered automotive glass use. The significance of this is that none of the laminated parts carried any current greater than 5 amps (Beckim 2007). Heated backlight circuits, the majority of applications, require 20 to 30 amps of power."

The above field experience thus justifies claiming that Antaya's lead-free solders have proven to be a viable and reliable substitute in field for lead in the above application, beyond the laboratory test level. This confirms the positive result of the Joint Test Program in the laboratory. PPG states that there are numerous applications with different connectors on different prints and under different operating conditions, which may be individual for each car model (Antaya 2009d). According to PPG's statement, the lead-free alloy was operated with a maximum of 5 Ampere, not with 20 to 30 Ampere as in heated backlights.

Antaya is involved in qualification programs at several glass makers and vehicle manufacturers (Antaya 2009g), and reports some other vehicles that were put on the road just recently using the 49141-32-13-65 alloy, which is the lead-free alloy used in the Joint Test Program (Antaya 2009j).

*<u>Melting points of the lead-free alloy</u>*

Concerns are remaining on the low melting point of the lead-free alloy. Antaya had provided tests conducted at 100 °C and at 105 °C, which according to Antaya should prove that the lower melting point of the alloy is not of concern. According to the submitted tests (see Test I and Test II in the Annex), the tested samples have passed the tests.

ACEA et al. claim that temperatures in a car at certain solder joints may rise up to 130 °C. The vehicle manufacturers therefore do not accept the Antaya high temperature test results as a proof that the low melting point is of no concern. They maintain that the Antaya lead-free solders failed in tests at 110 °C already. ACEA et al. did, however, not provide evidence neither on the 130 °C temperature maximum nor on their claim that the Antaya alloy fails at 110 °C, and under which conditions this was tested. Available data from Volkswagen measured at the defogging/defrosting of a rear window suggest that temperatures of slightly above 100 °C may actually occur.

The Joint Test Program suggests that, besides the four tests adopted, additional tests may be required depending on the material properties of the lead-free alloy (Joint Testing Group 2009). This clause was inserted as Antaya (2009h) refused revealing the composition and material properties of its lead-free solder alloy. It was only on 22 May that Antaya finally provided official information on the lead-free alloy composition and on its solidus and liquidus temperature.

Ageing procedures and tests at high temperatures well over 100°C were not part of the testing program worked out with the vehicle manufacturers in the Joint Testing Program. With the solidus temperature of the lead solder being at 160°C, (Table 20 on page 156), the lead solders did not give reasons for concerns about possible effects from the alloy melting point. Even if the temperature at solder joint reaches 130°C, there are still 30°C safety margin to the solidus temperature of the alloy.

The Joint Testing Program states that such tests might be additionally required if material properties of the lead-free alloy would differ considerably from the material properties of the lead solder. The lower melting points are a considerable difference in material properties. As Antaya was not willing to provide the required data, the vehicle manufacturers were not able to have their concerns reflected in appropriate tests in the Joint Test Program.

Finally, the vehicle manufacturers express concerns on the high temperature capabilities of Antaya's lead-free alloy. According to the high temperature tests provided by Antaya (Test I and Test II in the Annex), the lead-free solder is capable to withstand certain mechanical burdens at higher temperatures of up to 105°C. Clear evidence is available that the heat grid connectors may heat up to more than 100°C under ambient temperatures of around 30 to 35°C. In some hotter climates with high humidity, defogging of backlights may be necessary despite of high ambient temperatures, which may result in possibly higher temperatures at the solder joint exceeding the 105 C. On the other hand, the vehicle manufacturers did not provide evidence that temperatures higher than 105 °C, up to 130 °C, as they had claimed, actually occur. As Antaya's high temperature tests show that the lead-free alloy has mechanical stability at 105°C, while the other stakeholders could not provide evidence for their opposing statements, the expiry date of the exemption should include heating grid applications.

Given the around 60 C lower melting point of the lead-free alloy, it is at least clear that the safety margin for higher temperatures in terms of temperature distance to the melting point is small and may cause problems. As Antaya had refused until May 2009 to reveal the composition and the melting point of the alloy, and alloy samples were not available, there was no opportunity for glass makers and the vehicle manufacturers to check the viability of the lead-free alloy under extreme temperature conditions so that non-confidential information would be available for the review process.

As the material exhibited good performance in the prevention of microcracking, increases of the melting point might be possible at still satisfying ductility to prevent microcracks. This would require adaptation and development work.

The overall situation thus does not justify lifting the expiry date for specific applications, in which high temperatures may occur.

*Discontinuation of the exemption*

The overall picture shows that lead is no longer unavoidable in solders for soldering on glass in vehicles. Art. 4 (2) (b) (ii) thus in principle requires revoking the exemption. As the implementation may need time, and as it is not ultimately clear whether the lead-free alloy actually can replace lead in all applications, an appropriate transition time will be necessary allowing a safe and reliable shift to the use of lead-free alloys wherever possible. The remaining question to be clarified thus is whether the current expiry of exemption 8b at end of 2010 for new type approved vehicles is appropriate in this respect.

**Appropriate expiry date**

The stakeholders' comments on an appropriate transition period until the expiry of exemption 8b are widely different. Antaya claims that the current expiry date at end of 2010 is appropriate, which corresponds to around 19 months of transition time. The vehicle and glass manufacturers claim 54 months of transition time as appropriate, which translates into an expiry date in end of November 2013 (see page 166 ff).

Antaya states that there is no evidence that the lead-free alloy is not a drop-in solution. It can be implemented with just minor changes within a short time in each application, and without requiring more than standard technologies already available in most of the glass plants.

It is correct, that an evidence is not available that the lead-free solder is not a drop-in solution. The results of the joint test program at least show that in most cases the lead-free alloy passed the tests without prior optimization of connectors, glass and soldering, as Antaya had stated.

Vice versa, however, there is no evidence that the lead-free alloy is a drop-in solution in each and every case, as the testing program as well as other available evidence cannot cover each and every application. It is thus, contrary to Antaya's statement, not inconceivable that in some cases further development works might be required. PPG, the glass maker confirming the use of Antaya's lead-free solders in GM and Ford cars (Antaya 2009d), stated that "the automotive application of this new technology will require validation and performance testing before indium based lead free solder could be certified for use in production. The lead time for this type of effort typically requires a 2 year minimum to complete exposure testing and an additional 1 year lead time to establish supply" (Beckim 2007).

The glass and vehicle manufacturers have set up a worst case scenario. The field testing time has been extended from one year to 18 months, which does, however, not affect the total timing due to the parallelization of this step with other stages of the transition. The steps where these stakeholders indicate additional time needed are those cases where the lead-free alloy cannot be considered a drop-in (Figure 52 on page 163) and requires additional development works, changes of process equipment in glass plants, etc. However, it may not be necessary that the lead-free alloy actually is a drop-in in every case. Exemption 8b in its current version bans the use of lead in new type approved vehicles only in order to avoid retrofitting into existing or already developed vehicles. The new type developments and qualifications may require development works and even changes to the processing equipment anyway.

There is no clear evidence that either the one or the other position on the expiry of exemption 8b is completely correct. The alloy may actually work as a drop-in solution for many applications. Lifting this exemption would ban the lead in each and all applications for soldering on glass. For some applications, more development and adaptation might hence be required with more time. PPG, as a stakeholder not directly involved in this or the previous review process, points out three years of transition time in the glass plant (Beckim 2007). Additionally, some time may be needed at the vehicle manufacturers.

Taking into account all the information and aspects raised, the reviewers recommend shifting the expiry date to end of 2012. The expiry of the exemption on the one hand should accommodate the requirements of Art. 4 (2) (b) (ii) to substitute lead where its use is no longer unavoidable, and the transition period of around 40 months on the other hand should leave sufficient time to adequately develop and implement the shift to lead-free soldering in the supply chain and with the vehicle manufacturers:

- The introduction of the lead-free alloy can be prepared and implemented in the vehicles, which are under development for type approval after 2012 following the established development and qualification procedures.
- This transition period of 40 months, although well below the requested 54 months, should be long enough to prepare and implement the use of the lead-free alloy in the supply chain for the vehicles with new type approval after 2012.
- This transition period should be long enough on one hand to find out possible problems with the low melting point alloy in high temperature applications, and to improve and adapt the lead-free alloy if possible. It should as well be long enough to allow applying for specific exemptions in case lead-free solutions prove to be not appropriate for some applications.
- The transition period should be short enough to accommodate the requirements of Art. 4 (2) (b) (ii) to substitute lead in all applications where it’s use is no longer unavoidable. As the expiry date is not lifted off, vehicle and glass manufacturers will have to continue with the implementation of lead-free soldering solutions.

### Exclusion of soldering in laminated glazings

Soldering in laminated glazings was excluded from the Joint Test Program. Antaya had not tested its solders for this application (Joint stakeholder working group 2009; Antaya 2009h). At a meeting of the Joint Testing Group, Antaya suggested integrating soldering in laminated glass into the testing program, but would need the glass makers' support for the supply of the laminated glass. The glass makers opposed this plan stating that soldering in laminated glass would be product and technology development and that the Joint Testing Program focuses on testing solutions, which Antaya had claimed to have, not those that have to be developed (Joint stakeholder working group 2009).

Antaya (2009h) admits that none of its test results submitted to the review process proves that the lead free solution works in the "in lamination" application. Antaya (2009h) explains that the chemical and physical relationship between the buss bars, the wires and the connectors are exactly the same as those "on-glass" as opposed to "in-glass". Antaya has for many years supplied leaded solder parts for use "in-glass and on-glass" with identical results. Antaya has successfully converted leaded on-glass applications over to lead free.

Antaya points out that soldering in laminated glass, however, needs an autoclave machine and all the customary expertise of an automotive glass plant (Antaya 2009h). Antaya complains that the glass companies refused cooperation in the Joint Testing Group for testing of the lead free solder in the in-glass application. For Antaya , it is apparent therefore that since the glass companies have refused to test the lead free solution, and Antaya cannot test the lead free solder parts without the cooperation of at least one glass company, there is something of a stalemate (Antaya 2009h). It is Antaya's contention that the exemption should be removed since the in-glass technology is substantially identical to the proven on-glass technology. Furthermore, if the glass companies are allowed to "stonewall" the Commission by refusing to cooperate in tests designed to remove the exemption, the requirement of the ELV Directive can never be met. The coordinated obstruction of the glass manufacturers is entirely inconsistent with the will of the Commission and the Commission should take this opportunity to send the appropriate message (Antaya 2009h). Antaya therefore believes that this issue may fall beyond the boundaries of the technical and scientific assessment and be more political in nature.

The reviewers' task is the technical assessment of the progress of science and technology in order to adapt exemption 8b. As a matter of fact, no evidence is available that Antaya's lead-free solders work for soldering in laminated glass. The reviewers' can only give recommendations based on publicly available technical and scientific information. The assessment of political issues is beyond the reviewers' mandate, as Art. 4(2)(b)(ii) does not allow such arguments as justification of exemptions or their repeal.

It is therefore recommended to exclude soldering in laminated glass from the ban of lead until there is evidence that a solution is available. To promote the technical and scientific progress towards a lead-free solution, it is recommended to review this exemption in 2014. The stakeholders will then have to show that they have undertaken steps to achieve compliance with the material bans in the ELV Directive.

#### 4.17.6 Final recommendation

It is recommended to maintain the expiry date in exemption 8b, but to shift it to the end of 2012. It is further on recommended to introduce a specific exemption for soldering inside laminated glazings and to set an expiry date in 2014. While the proposed lead-free solution could sufficiently prove that it can be a substitute for lead in solders in glazing applications, there is no evidence that the solution works for soldering inside laminated glass. Art. 4 (2) (b) (ii) thus would allow the continuation of the exemption.

The recommended wording is:

> *Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing in vehicles type approved before 1 January 2013.*

and

> *Lead in solders for soldering in laminated glazings; review in 2014.*

#### 4.17.7 References exemption 8b


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## 4.18 Exemption no. 10

*"Electrical components which contain lead in a glass or ceramic matrix compound except glass in bulbs and glaze of spark plugs"*

### 4.18.2 Terms and definitions

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| Curie temperature | temperature at which ferromagnetic materials become paramagnetic |

### 4.18.3 Background

This exemption was reviewed in 2007/8 during the review of Annex II of the ELV Directive (Gensch et al. 2008). The corresponding exemption in the Annex of the RoHS Directive was reviewed in 2008/09 (see final report of the previous review of RoHS Annex (exemption 7c) (Gensch et al. 2009).

During the review of exemption 7c of the RoHS Directive, it was found that lead can be replaced in the dielectric ceramic materials of low voltage capacitors. To adapt the exemptions for lead in ceramics to scientific and technical progress, and in line with the Commission's approach to make exemptions as application-specific as possible, the consult-