**Submitting Stakeholder Comments- Antaya Technologies Corporation**

**Annex II Directive 2000/53/EC - ELV Directive – Exemption No. 8i**

"*Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing*"

The stakeholder comments herein submit the new technical data on the performance and reliability of the proposed lead-free indium-based solder in various application environments including substantial test results, data, the evaluations in the vehicle manufacturers' qualification programmes, as well as the real world field performance.

The comments also address the core concern related to the melting temperature of the proposed lead-free indium-based solder as the result of the review assessment in January 2009 to extend the exemption until 2012.

The comments, further, answer the specific questions set forth in the review Guidance Document.

## (I) Background

In our last comments submission, we provided the highlights in the following areas related to the proposed lead-free indium-based solder:

I. Underlying scientific and technical basis of indium-based, lead-free solders
II. Manufacturability
III. Indium natural abundance and commercial availability
IV. Summary of tests and test data
V. Direct comparison with lead-containing solders
VI. Suitability for the applications under exemption 8i

For information on the technical background regarding the above areas, which is not reiterated in this submission, refer to the last report.

As a result of previous reviews in 2008 and 2009, the stakeholders set up a joint working group, which were open to all vehicle manufacturers and glass makers. Dr. Otmar Deubzer was designated to moderate and to coordinate the discussions and the activities of the group. Consequently a test programme was agreed upon by the stakeholders. The results of the extensive test programme, which became available in mid 2009, indicate that the proposed lead-free indium-based solder performed equal to or better than its lead-containing counterpart. The findings of the Deubzer working group were reported as follows:

**11.5.6 Summary of results from joint testing programme**

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. [18] [6] The lead-free solder joints caused less micro cracks 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 programme, the lead-free solders could not be found to be not viable on any of the glass and connector technologies tested.

Antaya [21] had additional tests conducted at external laboratories. The tests were the same or identical tests like in the joint test programme. The results underpin the findings from this joint testing programme.

**11.5.7 Conclusions from the test results**

There were no significant performance differences of the lead-free and the lead solder in the joint test programme. [18] [6] 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.

Some stakeholders have raised a concern about the "capabilities" of the 65 alloy when the service conditions pass 105$^{o}$C. The Deubzer Report dated September 2009, uses a BMW claim as the basis for the high temperature concerns.

## (II) Objections to higher Temperature issue

- BMW claimed in their submission that temperatures up to 130$^{o}$C may be achieved in certain circumstances. The "evidence" for this assertion was a thermal image of a BMW backlight showing a temperature of 72.5$^{o}$C at the connector, some 50$^{o}$C above the ambient temperature of 22.0$^{o}$C when under electrical load. This increase in temperature is known as the "rise". Antaya rejects the claim that 130$^{o}$C is possible for the following reasons:
    - The evidence submitted by BMW is obviously flawed. (*See Exhibit 1, BMW Submission Claim)* Looking at the image, one can see clearly that a hot spot

has occurred on one terminal causing it to rise 50$^{o}$C while the other has risen only 31$^{o}$C. When shown this image, industry experts, have unanimously concluded that the “hot spot” reflects either a failed part or a seriously sub-optimal design. The very purpose of a heated grid is to conduct the heat evenly to the center of the grid. The BMW submission suggests exactly the opposite.

  - BMW’s claim that temperatures of 130$^{o}$C are possible is based upon the theory that all temperature rises are equal. In fact, there is substantial real life evidence to the contrary. Tests conducted on the very same BMW backlight by Trialon, an independent automotive laboratory, show that the temperature “rise” from power declines as the ambient temperature increases. (*See Exhibit 2*). Specifically, the maximum temperature rise when the ambient temperature is 80$^{o}$C (which BMW theorize is possible and we don’t dispute) on any connector was measured at 4.56$^{o}$C. Thus, the highest temperature on the connector is in fact 84.56$^{o}$C, not 130$^{o}$C.

- In addition to discrediting the BMW submission temperature claim, Antaya commissioned two separate studies in order to determine the highest possible temperature in “real life conditions” on the terminal. As summarized in Exhibit 7, (The Edag Report) a reasonable determination of the maximum possible temperatures on the terminal on the hottest day in European history can be summarized as follows;

  Highest Actual Measured Terminal Temperature Before Power:
  77.3$^{o}$C + 5.5$^{o}$C (delta) equals **82.8$^{o}$C**.

  Highest Actual Measured Terminal Temperature Under Power:
  87.4$^{o}$C + 5.5$^{o}$C (delta) equals **92.9$^{o}$C.**

  "Delta" is defined as the difference in temperature between the hottest day during the test, and the hottest day ever recorded in Europe.

- Antaya submits that most, if not all of the adjacent components are specified to operate at temperatures not to exceed 85$^{o}$C to 105$^{o}$C *See Exhibit 3, Automotive Glass Component Materials High Temperature Limits*. Antaya is aware of several glass technology systems (e.g. active roof glass, encapsulation and lamination) that are known to fail at temperatures in excess of 85$^{o}$C. Are we to believe that the OEM’s are proposing to replace all materials used in the cabin with materials specified beyond their current temperature limits?
- As a commentary, it should be noted that even if you believe that the temperature rise is possible, a minor software change could deactivate the rear grid when the ambient (cabin) temperature reaches a certain level. The fact that no OEM has chosen to install this simple feature as a safety precaution, clearly demonstrates that the OEMs do not believe in the 130$^{o}$C claim. Of course touching a terminal at 130$^{o}$C would severely burn a passenger and yet OEMs routinely leave terminals exposed to passengers’

touch. Are we to assume that the OEMs don't believe that the temperatures become elevated to 130$^{o}$C, or would not burn the occupants?

- Antaya commissioned a medical student to research the impact of temperatures such as those contemplated on the human body *(Exhibit 4).* Not surprisingly the report confirms that it is not physically possible for someone inside a vehicle at 85$^{o}$C to even be able to power up the rear defroster.

## (III) Summary of Performance and Properties of the Lead-free Indium-based Solder System

There is a different set of challenges and demands in soldering devices onto automotive glass. Given a similar magnitude of mismatch of thermal expansion coefficients among materials to be jointed, some solders that are suitable for soldering to ceramic or silicon devices, or in other electronic applications, are not suitable for soldering to automotive glass. One of the key properties that the solder alloy needs to possess is that the solder alloy has a melting point (*liquidus*) that is low enough to not create undue thermal stress and residual stress that may cause cracking of the automotive glass during the soldering process and thereafter. Yet the liquidus temperature is still high enough not to soften (or excessively weaken) during the service life of a car even under the most extreme, harsh environments. Another key property is that the solder imparts both strength and ductility to meet the performance requirements.

In comparison with the lead-containing solder, the proposed lead-free indium-based solders have demonstrated the required performance and offered the following key performance merits:

- Environmentally-friendly lead-free solder meeting requirements of OEMs, their Environmental Policies, and the ELV Directive
- Balance in mechanical properties in strength and ductility
- Elimination of micro-cracking
- Wettability on commonly used silver-containing metalized electrical contact surface
- Environmental stability
- Shelf stability
- Desired manufacturability
- Drop-in solution requiring no greater optimization than is customary with lead solders

## (IV) Supporting evidence and test results

During the last submission and review, the solder alloy identified as Alloy 65 (30Sn65In0.5Cu4.5Ag) has a *solidus* temperature of 109ºC and a *liquidus* temperature of 127ºC. This alloy demonstrated through the Joint Test Programme an overall performance equal to or better than its lead-containing counterpart using tests submitted by the automotive glass industry and OEMs. A comprehensive and representative range of glass types was tested, with 1,026 connectors across 5 global glass manufacturers, 9 OEMs and 14 vehicle programs. This alloy has been approved, in accordance to the SAE / USCAR-40 (Society of Automotive Engineers /USCAR Lead-Free Solder Validation Test Plan.)

The solder (Alloy 65) has been used in approximately 2 million vehicles for on-glass power and signal applications since 1998. Current shipments from Antaya supply nearly 100,000 lead free parts per month for vehicles on the road in Europe, Asia, and North and South America. Vehicles that have used this alloy extend to various vehicle types/models and designs including sport coupe, sedan (saloon), small and large sport utility vehicles, minivans and trucks. All connector types are available, and are used in power and signal applications on windshields, side glass and backlights.

***Exhibit 5 Vehicle and Connector Types with Lead-free Solder,*** lists the vehicles and connectors with part numbers and volume, indicating that this solder has been validated for vehicle production in substantial quantities, across multiple OEMs, glass companies, countries and applications. These programmes include a wide variety of glass thickness, tint, and installation angles. Significantly, the material has been validated in EVERY vehicle programme for which the material was tested including programmes with Guardian, Yaopi, Pilkington, AGC, Vitro, and PGW. For clarity, after 12 years, the 65 alloy has never failed to meet the performance standards required by any specific programme.

The alloy has been validated using several established application equipment and methods including resistance soldering, inductance soldering, hot-air soldering, and soldering iron.

Vehicle warranty data reflects that the solder alloy has performed reliably without reported failures that can be attributed to the performance of the solder alloy.

In summary, the Joint Testing Programme with involvement and agreement of the vehicle manufacturers has shown the positive results in the laboratory described previously. Twelve years of field data, reflecting “real world” conditions reinforce confidence in the performance of the lead-free material and the parameters established by the Joint Test Group. Collectively, the results have proven that the lead-free solder alloy 65 is a viable and reliable substitute for leaded solders in “electrical glazing applications on glass”.

## (V) Extreme High Temperature Solution

To address the extreme high temperature concern reported in the last review assessment, modifications to the alloy have been made to elevate the performance range of the lead free material above and beyond 105$^{o}$C, without sacrificing any of the required properties and performance for electrical glazing applications on glass. A specific objective of this material optimization effort was also to deliver well balanced properties in the prevention of microcracking and other potential problems. The effort was accomplished with the support of suppliers, Case Western Reserve University and independent testing laboratories under the advice and consultation of Dr. Jennie S. Hwang, a widely recognized, and independent worldwide authority on lead free solder development and implementation. **Dr. Hwang has kindly provided a brief report attached hereto as Addendum I and has offered to field technical questions from the Consultant.**

From the work described, a modified indium-based solder system designated as Alloy B6 emerged. This increases the melting range in both solidus and liquidus temperatures while possessing all the other desirable properties for electrical glazing applications on glass. The operating temperature of the B6 alloys are in excess of 125ºC.

The higher melting range offered by Alloy B6 enables the solder joint to perform at significantly higher service temperatures than 105$^{o}$C if needed. The Joint Test Programme called for a High Temperature Storage Test according to UNECE Global at 90 ºC for 500 hours. In consideration of the high temperature concerns described previously, the B6 alloy was subjected to an extreme high temperature test of 500 hours at 125 ºC with a ½ kg weight. *See Exhibit 6, Test Report Antaya B6-01 High Temperature Exposure.*
The solder system B6 is commercially available in mass production.

Comparing with the lead-containing solder, Alloy B6, like the Alloy 65 which as previously noted is on approximately 2 million vehicles, requires a lower soldering temperature, which in turn offers additional advantages over its lead-containing counterpart.

- Lower soldering process temperature than its lead-containing counterpart enhances the glass integrity (free of microcracks)
- Lower soldering process temperature than its lead-containing counterpart reduces the thermal stress as a result of the highly mismatched thermal expansion coefficients of the components of the assembly.
- Lower soldering process temperature than its lead-containing counterpart minimizes the residual stress
- Lower process temperature alleviates silver leaching (scavenging) during soldering process to accommodate the silver-metallized glass and to maximize silver-glass interface integrity, as well as the overall solder joint integrity
- Lower soldering process temperature help energy-saving

The proposed lead-free indium-based solder is commercially available and can be used as a drop-in without major changes in the manufacturing infrastructure.

## (VI) Answers/comments to specific Questions

1. *Is there any evidence that the melting points of the proposed lead-free indium based solders would require the continuation of the exemption after 31 December 2011? If you provide test results, please explain the background of the tests. In particular how the test conditions relate to real life conditions.*

   While it is not unreasonable for some OEMs to express concern that the melting points of the lead free solders are generally lower than the lead solders, all the Real Life data supports the Test Standards that have been in place for twenty years (90 ºC). Real Life data was gathered in Seville, España, described as the "hottest place in Europe," and

Death Valley, California (described as the “hottest place on earth”) and demonstrates a worst case scenario including variables such as tint, window angle and thickness. The temperature on Test Day in Death Valley was higher than the highest temperature ever recorded in Europe (in Seville as it happens). *See Exhibit 7, Edag Report on Real World Extreme High Temperature and Exhibit 8, Death Valley Test Report DV 090109v2*

The temperature rise argument made by BMW is a non-issue. Not only is it unsubstantiated, it is entirely negated by the simple software “fix” which de-activates the heated grid when the cabin reaches a specified temperature.

When it comes to Real Life, there is nothing more persuasive than the simple fact that in 12 years on 2 million vehicles, Antaya has not received one warranty claim related to the solder or its melting point in an industry which is famous for diligent and exhaustive application of quality standards and procedures.

If one is willing to dismiss the Real Life Data and the 12 years of evidence, and instead rely on the unsubstantiated claims of one or two manufacturers (note Deubzer comment: “the vehicle manufacturers did not provide evidence that temperatures higher than 105 °C, up to 130 °C, as they had claimed, actually occur”), then the B6 alloy is available for immediate use. The B6 has been independently certified to pass even the most extravagant temperature claims.

The solder (Alloy 65) has been successfully used in vehicles for on-glass power and signal applications since 1998. Vehicles that have used this solder include all the various types/models and designs including coupe, sedan, small and large sport utility vehicle, minivan, and truck. Connectors are used in power and signal applications on windshields, side glass and backlights. The Alloy 65 has even been validated for use on the little used, but emerging polycarbonate glazing products.

2. *Is there any evidence that the use of lead-containing solders is unavoidable for other reasons than the low melting point of the indium-based lead-free solders?*

No, there is no evidence that the continued use of lead-containing solders is unavoidable.

Moreover, in order to meet the request of higher melting solders than the last submission (Alloy 65) for any possible higher service temperatures, a solder system (Alloy B6) having a higher melting range while delivering all other desired properties has been developed and made available since last review assessment.

3. *Which applications covered by exemption 8i require the continued use of lead-containing solders?*

   None known. As previously noted, the lead free material is in use in all applications.

4. *If applicable, please provide an alternative wording of exemption 8i and/or a new date or the expiry of the exemption.*

   *"Lead in solders in electrical glazing applications on glass except for soldering in laminated glazing in vehicles type approved before 1 January 2012.*
   *and*
   *Lead in solders for soldering in laminated glazings; review in 2012."*

Since the last review, Antaya has launched 13 new lead free programmes with 13 identified programmes approved for production. Antaya believes that based upon the evidence, new programmes can be launched in approximately 90 days from RFQ.

It is estimated that each OEM has only 13% of their vehicles type approved each year. With our experience in validating several new lead free programmes each year, there will be no issue in launching the type approved vehicles for 2012 in the same timeline.

## (VII) Summary comments

The joint test programme, collaboratively commissioned by the stakeholders, reported that the proposed indium-based lead-free solder performed equal or better than its lead-containing counterpart. The lead free solder is widely and successfully used worldwide. Claims of temperatures in excess of 100°C are not supported by real life data.

Arguments pertaining to temperature rise (associated with power) are entirely negated by a simple software fix.

The production of even higher temperature lead free alloys has adequately addressed the only remaining concern of the industry.

The lengthy duration of the review process has provided the industry adequate time to react to the requirements of the reviews (5+ years) and the ELV Directive (10+ years).

Hence, the use of lead-containing solders is avoidable. There is no further justification to prolong the use of environmentally hazardous lead-containing solders.

The exemption 8i in the Annex to the ELV Directive should be removed and the current expiry of the exemption should remain as is.

## (VIII) List of Exhibits

**Exhibit 1: BMW Submission Claim**

**Exhibit 2: Trialon Test Report 25112 BMW Backlite Temperature Rise**

**Exhibit 3: Automotive Glass Component Materials High Temperature Limits**

**Exhibit 4: Heat Stroke and Cutaneous Burns**

**Exhibit 5: Vehicle and Connector Types with Lead Free Solder**

**Exhibit 6: Test Report Antaya B6-01 High Temperature Exposure**

**Exhibit 7: Edag Real World Extreme High Temperature Report, Seville Spain 2010**

**Exhibit 8: Death Valley Test Report DV 090109v2**

**See Also Addendum I, Dr. Jennie S. Hwang.**

# Addendum I

***September 5, 2011***
**Comments Submission - Stakeholder Consultation on the ELV exemption 8(i)**

To serve as a reliable solder interconnection in a highly thermal-expansion mis-matched system, such as a metallic connector soldered on a glass substrate in electrical glazing applications on glass, the solder material requires the balanced properties. These balanced properties need to be capable of accommodating the stresses generated during soldering process while enabling the proper mechanical behavior and desirable physical and chemical stability during the designated product service life.

The properties and performance of the proposed lead-free indium-based solder have been designed from both product field service and manufacturing perspectives. In addition to the required performance during the product service life, the soldering process to manufacture the product is equally critical to the product's reliability in its real life.

The soldering process temperature is important because it is normally the highest temperature that a product is expected to experience, with few exceptions.

**<u>Field Service Considerations (References 1 - 3)</u>**

In the real world performance, solder joints are exposed to the conditions that induce both fatigue and creep processes, which operate interactively. These fatigue and creep processes are caused by the temperature excursion and fluctuation as the result of circuitry functions, power on-and-off, and the external environmental temperature exposure. These temperature changes inevitably generate cyclic thermal stress, thus cyclic strain on solder joints.

Heat generated from electronic circuits during the power-on of an electrical system follows the well-known Joule's law. The heat will then be gradually dissipated to external environment while power is off, through the basic heat transfer mechanisms of conduction, convection, and radiation, making the system reach ambient temperature again. Many such temperature cycles during the service of an electronic system are inevitable.

There are always mismatches in coefficients of thermal expansion (CTE, $\Delta\alpha$) among the materials and components to be joined. As a result, a cyclic shear strain ($\Delta\gamma$) will be imposed on solder joints by coupling the temperature cycles and the mismatches in CTEs. The larger in the mismatches in CTEs, the higher the shear strain is generated.

The real stress and strain state in solder joints is further complicated by the additional existence of local thermal gradients ($\Delta T$) due to heat dissipation and local mismatches in CTEs between solder and soldered materials. Zero strain state is ideal, but it does not exist even when the mismatches in CTEs ($\Delta\alpha$) of the materials and components to be joined are eradicated by sophisticated materials design.

At a given solder joint geometry and for a system comprising the components being rigid in relation to solder joints, the imposed shear strain on solder joints is related to the thermal expansion and the temperature differential by the following equation:

$\Delta\gamma \sim \Delta\alpha \;\; \Delta T / h$

Where
$\Delta\alpha$ is the differential in CTE of soldered components;
$\Delta T$ is the temperature excursion; and
h is the solder joint height.

To accommodate such accumulative cyclic strains, both strength and ductility must be a part of solder alloy properties. The proposed lead-free indium-based solder is designed to provide such a balance.

## Soldering Process Considerations (References 4 & 5)

When considering the temperature factor in the entire life cycle of a soldered product, the harshest or the highest temperature that an assembled system is exposed to is often the soldering temperature, not the service temperature. This applies to most products across the industry sectors including the automotive industry.

The higher the soldering process temperature, the more induced stress is generated. The lower soldering temperature minimizes the thermal stress induced during soldering process. In electrical glazing applications on glass, the lower soldering temperature helps alleviate the commonly observed micro-cracks on glass.

Thus, the ability to lower the soldering process temperature while maintaining all other required properties is always a welcome advantage. As the soldering temperature is primarily dictated by the melting temperature (liquidus temperature) of the solder alloy used for the application, the most desirable melting temperature of a solder alloy is to be as low as feasible yet capable of providing the mechanical, thermal and electrical integrity under a set of service conditions.

Overall, comparing with the lead-containing solder, the fact that the proposed indium-based lead-free alloy requires a lower soldering temperature than its lead-containing solder offers additional benefits, including:

- Enhancing the glass integrity;
- Alleviating microcracks in glass;
- Reducing the thermal stress as a result of the highly mismatched thermal expansion coefficients of the components of the assembly;
- Reducing the residual stress;

- Minimizing the commonly occurring silver leaching (scavenging) during soldering process to accommodate the silver-metallized glass and to maximize silver-glass interface integrity, as well as the overall solder joint integrity;
- Helping energy-saving when using the reduced soldering process temperature required to make solder joints.

**Efforts to Respond to the Request from 2009 Review**

However, in order to respond to the request from the last review of 2009 for a higher melting temperature alloy than the originally proposed Alloy 65, the effort has been made to elevate the melting range of the solder alloy above and beyond 105$^{o}$C, without sacrificing any of the required properties and performance for the electrical glazing applications on glass. As a result, B6 alloy system was developed, which offers about 20$^{o}$C increase in both solidus and liquidus temperatures. Most importantly, B6 alloy continues to maintain the balanced properties in strength and ductility to deliver essentially microcrack-free assemblies.

**Summary Comments**

In my assessment, the indium-based lead-free system offered by Antaya Technologies Corporation is an appropriate and practical lead-free solder for such applications as covered in exemption 8i.

The joint test programme, collaboratively commissioned by the stakeholders, has reported that the proposed indium-based lead-free solder performed equal or better than its lead-containing counterpart. Data and test results conducted by the full slate of stakeholders including the glass suppliers, vehicle OEMs and independent laboratories have provided the substantive supporting evidence. It is a viable lead-free substitute for the lead-containing solders and is commercially readily available.

Overall, the state of technology and science has profoundly advanced in lead-free solders during last several years. Solutions are available and the viable lead-free solders are commercially available for additional exempted applications.

Hence, the use of lead-containing solders in the electrical glazing applications on glass is avoidable. There is no further justification to prolong the use of environmentally hazardous lead-containing solders.

The exemption 8i in the Annex to the ELV Directive should be removed and the current expiry of the exemption should remain as is.

Respectfully submitted,

Jennie S. Hwang, Ph.D., D.Sc.
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## References:


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