Alternatives assessment

Alternatives to SnPb solder for First Solar's transition from Series 4 to Series 6 manufacturing

First Solar

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Methodology: Report of the National Academy of Sciences "A Framework to Guide Selection of Chemical Alternatives"[1]

Summary:

Rank	Alternative	Rationale
1	Welding	Potential for achieving cost, reliability, life cycle environmental impact, and manufacturability goals by switching from a) electrically connecting junction box terminals to PV module with solder to b) mechanically connecting junction box terminals to PV module with welding.
2	SnPb solder	Incumbent material used for electrically connecting junction box terminals to PV module. Uses regulated substance (Pb compound) with low cost, proven durability and manufacturability, and competitive life cycle environmental performance.
3	Pb-free solder (96.5%Sn/3.5%Ag, 57%Bi/42%Sn/1%Ag, 58%Bi/42%Sn, 96.5%Sn 3%Ag, 0.5%Cu)	Potential for achieving manufacturability goals with modest increase in cost, additional testing needed for long-term durability, limited change to life cycle environmental impact, and proactive substitution of a regulated substance (Pb compound).
4	Adhesives ((electrically conducting and non-conductive)	Not investigated due to limited data.

Outcome:

Series 6 module manufacturing is utilizing welding to connect junction box terminals to the PV module as an alternative to SnPb solder used in Series 4 module manufacturing.

[1] http://www.nap.edu/catalog.php?record_id=18872

Step 1: Identify Chemical of Concern

The substance of interest for this assessment is SnPb solder for use in First Solar PV module junction box terminals.

Step 2: Scoping and Problem Formulation

Based on the ROHS Directive, electronics put on the market in the EU cannot contain Pb compounds at levels in excess of 0.1% in a homogenous material. Although PV is excluded from ROHS, there is an opportunity to proactively evaluate alternatives to the SnPb solder used in the junction box as First Solar transitions its production lines from Series 4 to Series 6 PV modules.

Evaluating alternatives will require assessment of environmental, technical, and economic aspects. Given the competitive solar market, a successful alternative will need to address the dual need for low cost per Watt produced and robust product quality, reliability, and durability. In addition, the alternative should reinforce First Solar's status as providing the industry leading eco-efficient PV technology on a life cycle basis.

Steps 3 and 4: Identify potential alternatives and Determine if Alternatives are Available

As the broader electronics industry has transitioned to Pb-free products, alternatives to SnPb solder have been implemented, with SnAgCu formulation being the most common alternative (e.g., SAC305; 96.5%Sn 3%Ag, 0.5%Cu)[2]. Within the PV industry, Pb-free solders are also available in the market, with most alternatives containing bismuth (e.g., 96.5%Sn/3.5%Ag, 57%Bi/42%Sn/1%Ag, 58%Bi/42%Sn)[3].

Outside of soldering, other alternatives for electrical connections include adhesives[4] (electrically conducting and non-conductive) and welding, which involves a mechanical junction created by melting.

Step 5: Assess physicochemical properties

A key physicochemical property of solder is its melting point, with a lower melting point preferred for manufacturability.

Solar Solder Alloys		Melting point
Examples of Pb-Containing Alloys	62Sn/36Pb/2Ag	~179°C
	60Sn/40Pb	~186°C
Examples of Pb-Free Alloys	96.5Sn/3.5Ag	~221°C
	57Bi/42Sn/1Ag	~139°C
	58Bi/42Sn	~138°C

[2] Zhou, X., Nixon, H., Ogunseitan, O.A. et al. Environ Model Assess (2011) 16: 107. https://doi.org/10.1007/s10666-010-9227-1
[3] Jones, J. Assessment of Global Lead-Free Solar Cell and Module Manufacturing, GTM Research, 2018.
[4] Li, Y., and C.P. Wong. Recent advances of conductive adhesives as a lead-free alternative in electronic packaging: Materials, processing, reliability and applications. Materials Science and Engineering R Reports, 51(1-3), 1-35, 2006, https://doi.org/10.1016/j.mser.2006.01.001

Some Pb-free solders have high melting points which can decrease throughput since it takes longer to solder, and may affect module reliability if soldering is done poorly. For example, an excessively high soldering temperature can make the solder hard and brittle, which can lead to reliability issues. For Pb-free products with low melting points, there is some concern that it may be hard to process in subsequent steps, such as lamination[5].

Step 6: Assess Human Health, Ecotoxicity, and Comparative Exposure

Pb and Pb compounds are regulated substances with potential for adverse effects on human health and ecology, with children and pregnant women identified as susceptible groups even at low levels of exposure.[6] Pb and Pb compounds are also classified as a probable human carcinogen.[7] Pb-free solders utilize Ag and Bi, instead of Pb.

With respect to potential human and ecological exposure to materials in PV modules, the manufacturing and end-of-life phases are the product life cycle phases with the highest potential for emissions and exposure. Due to the enclosed and automated nature of PV module manufacturing, the end-of-life phase can be the focus for health assessment. The standard federal leaching test (USEPA Method 1311; TCLP) is used to estimate potential emissions from leaching of waste disposed in landfills. TCLP limits for Pb and Ag are the same, 5 mg/L[8], and there is no TCLP limit for Bi.

Step 7: Integration of Information to Identify Safer Alternatives

From a hazard perspective, replacing SnPb solders with SnBi solders would reduce hazard. From an overall product safety perspective, the effect of the alternative on product quality, reliability, and durability would also need to be understood[9]. Poor solder connections can be a failure mode for PV modules, which can affect product safety and longevity[10]. Solders are also encapsulated in the PV module, limiting the potential for emissions. Metals recovery from recycling can also limit the potential for emissions from product end-of-life[11].

In addition to Pb-free solders, the use of welding as an alternative to soldering could result in both reduction of potential hazard associated with Pb compounds and maintenance of product quality, reliability, and durability. As with Pb-free solders, welding as an alternative to soldering would have to take into account manufacturability and whether existing manufacturing equipment and processes are compatible with welding.

Step 8: Life Cycle Thinking

A comparative life cycle assessment (LCA) of solders was conducted by USEPA[12], with no single alloy having overall superior environmental performance. The Pb-free solders outperformed SnPb solders in 6 of the 16 impact categories, including occupational noncancer, occupational cancer, public noncancer, aquatic ecotoxicity, eutrophication,and renewable resource use. Pb-free solders containing Ag could typically not outperform SnPb solders due to the significant impact of Ag extraction and processing.The primary environmental risks associated with Pb-containing solders are human health toxicity and ecotoxicity. For Pb-

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[5] Jones, J. Assessment of Global Lead-Free Solar Cell and Module Manufacturing, GTM Research, 2018.
[6] https://www.epa.gov/lead/learn-about-lead#effects
[7] https://cfpub.epa.gov/ncea/iris2/chemicalLanding.cfm?&substance_nmbr=277
[8] 40 CFR §261.24
[9] Pecht, M., T. Shibutani, L. Wu. A reliability assessment guide for the transition planning to lead-free electronics for companies whose products are RoHS exempted or excluded, Microelectronics Reliability,
Vol. 62, 2016, pp. 113-123.
[10] IEA PVPS. Review of Failures of Photovoltaic Modules. Report IEA-PVPS T13-01:2014.
[11] Turbini, L. J., G. C. Munie, D. Bernier, J. Gamalski, D. W. Bergmann. Examining the Environmental Impact of Lead-Free Soldering Alternatives. IEEE Trans. Electr. Pack. Manuf., Vol. 24, No. 1, 2001.
[12] Geibig, J. R., & Socolof, M. L. (2005). Solders in electronics: A life cycle assessment. EPA 744-R-05-001, US Environmental Protection Agency.

free solders, the predominant environmental concerns are associated with resource depletion and energy consumption. LCA conducted by Chalmers University of Technology also found higher global warming potential impacts for Pb-free solder due to the increased production of Sn in the Pb-free system and because of the greater amount of energy required for application of the Pb-free solder[13].

Step 9: Optional Assessment

To complement the discussion of technical alternatives and environmental and life cycle impact considerations above, this section includes assessment of cost for alternatives to SnPb solder. Pb-containing alloys are lower priced than Pb-free alternatives. For example, metal prices for Bi were more than 4.5x higher than Pb in 2017 and the price for Kester's Pb-free PV solder is ~2x more expensive than SnPb solder. The price of Pb-free solder containing Ag is also higher than SnPb solder largely driven by the high cost of Ag ($553/kg in 2017)[14]. The overall impact on module cost per Watt will be smaller than the above due to small amount of solder used per module (~0.5 g per junction box). As the broader electronics industry transitions to Pb-free solders, there is also a supply chain risk from continuing to use SnPb solder due to expected reduction in suppliers.

In addition to cost considerations, reliability evaluations for Pb-free solders have yet to be conducted for electrical products with expected lifetimes as long as PV modules, creating some uncertainty around product longevity.

Step 10: Identify Acceptable Alternatives and Refer Cases with No Alternatives to Research and Development

As discussed in Step 2, a successful alternative to SnPb solder will need to address the dual need for low cost per Watt produced and robust product quality, reliability, and durability, while reinforcing First Solar's life cycle product environmental footprint advantage. While Pb-free solders have been implemented in the broader electronics industry and in PV manufacturing, they have a higher cost, lack long-term durability testing, and do not show overall superior life cycle environmental performance compared with SnPb solder.

Because of the inconclusive nature of the solder alternatives assessment, the criteria for a successful alternative may be better achieved by replacing soldering with welding, assuming it meets manufacturability requirements. Welding is a high temperature process and can involve inert gases and filler metals, which would need to be compatible with the junction box design and assembly.

Step 11: Compare or Rank Alternatives

Potential alternatives to use of SnPb solder in the PV module junction box are ranked in the table below.

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[13] Ekvall, T. and A.S.G Andrae. Attributional and Consequential Environmental Assessment of the Shift to Lead-Free Solders. Int J LCA 11 (5) 344 – 353 (2006).
[14] Jones, J. Assessment of Global Lead-Free Solar Cell and Module Manufacturing, GTM Research, 2018.

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Step 12: Implement alternatives

Implementing an alternative to SnPb solder will involve multiple stakeholders such as product management, manufacturing engineering, supply chain, EHS, legal, and sustainability. Introduction of a new material and/or manufacturing process will take place within First Solar's change management system and the quality and reliability group's product readiness framework. The alternative will be piloted, tested, and ramped to full volume production, and subject to re-evaluation as the product design is updated.

Step 13: Research / De Novo Design

Additional research on the long-term durability of Pb-free solders will help future decision-making if soldering is reconsidered as a preferred approach over welding for connecting junction box terminals to the PV module.