



Final report dated 06.09.2023

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## MIW2023

# The 11th edition of the Metallization and Interconnection Workshop for Crystalline Solar Cells

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Source: ©CSEM 2023



**Date:** 6<sup>th</sup> September 2023

**Location:** Neuchatel

**Publisher:**

Swiss Federal Office of Energy SFOE  
Energy Research and Cleantech  
CH-3003 Bern  
[www.bfe.admin.ch](http://www.bfe.admin.ch)

**Co-financing:**

CSEM SA  
Rue Jaquet-Droz 1  
CH-2002 Neuchatel  
[www.csem.ch](http://www.csem.ch)

**Subsidy recipients:**

CSEM SA  
Rue Jaquet-Droz 1  
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**SFOE contract number:** ST/502554-01

**The authors bear the entire responsibility for the content of this report and for the conclusions drawn therefrom.**



## Zusammenfassung

Die 11. Ausgabe des Metallization and Interconnection Workshop for Crystalline Solar Cells (MIW) fand am 8. und 9. Mai 2023 in Neuchâtel in den Gebäuden von Microcity statt [1]. Das Programm umfasste 23 mündliche Vorträge, darunter die Eröffnungssitzung, die von Prof. Christophe Ballif, einem ehemaligen Becquerel-Preis, gehalten wurde, und 5 Posterpräsentationen. Die 15 besten Abstracts wurden für eine Sonderausgabe im SolMat-Journal ausgewählt. Mehr als 100 Teilnehmer haben sich angemeldet, davon 85, die vor Ort dabei sein konnten, darunter ein besonderer Gast: Prof. Marin Green von der UNSW. Der gesellige Teil des Workshops umfasste eine Bootsfahrt zum Abendessen auf dem Neuenburgersee und den Besuch der CSEM- und EPFL-Microcity-Einrichtungen für Photovoltaik-Forschung und -Entwicklung.

## Résumé

La 11<sup>ème</sup> édition du Workshop de Métallisation et d'Interconnexion des Cellules Solaires Cristallines (MIW) a eu lieu les 8 & 9 mai 2023 à Neuchâtel dans les bâtiments de Microcity [1]. Le programme comprenait 23 présentations orales, dont la séance d'ouverture présentée par un ancien prix Becquerel, le Pr Christophe Ballif et 5 présentations de posters. Les 15 meilleurs résumés ont été sélectionnés pour un « special issue » de la revue scientifique SolMat. Plus de 100 participants inscrits dont 85 sont venus sur place, en particulier nous avons eu le grand plaisir de recevoir le Pr Marin Green lors de l'atelier. La partie sociale de l'atelier comprenait un dîner en bateau sur le lac de Neuchâtel et la visite des installations de recherche et développement pour le photovoltaïque du CSEM et de l'EPFL-Microcity.

## Summary

The 11<sup>th</sup> edition of the Metallization and Interconnection Workshop for Crystalline Solar Cells (MIW) took place on May 8 & 9, 2023 in Neuchâtel in the buildings of Microcity [1]. The program included 23 oral presentations, including the opening session presented by a former Becquerel price, Prof. Christophe Ballif and 5 poster presentations. The 15 best abstracts have been selected for a special issue in SolMat journal. More than 100 participants registered with 85 that could join onsite including a special guest: Prof. Marin Green from UNSW. The social part of the workshop included a boat-trip diner on the lake of Neuchatel and the visit of the CSEM and EPFL-Microcity facilities for photovoltaics research and development.



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## Abbreviations

CTE: Coefficient of thermal expansion

MBB: Multi busbars

MIW: Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells

MPPT: Maximal power point tracker

POE: Poly-olefin elastomer

PV: Photovoltaics



# 1 Introduction

## 1.1 Description of the MIW2023

The 11th edition of the Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells took place in May 2023, as a live event in Neuchatel Switzerland, but also including online participants. Scientific contributions were presented on various relevant topics including high throughput printing, electroplating, soldering and interconnector bonding. A common theme was the search towards metallization and interconnection solutions for next generation solar cell concepts that drastically reduce the consumption of metals that are limited in supply, notably silver, and are compatible with the extremely high output manufacturing scenarios of the anticipated Terawatt era.

## 1.2 Sponsors 2023

The Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells had 10 sponsors for the 2023 edition (see below). Without these sponsors it would have not been possible to make the workshop with the same budget.



Fig. 1.1 : Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells sponsors for the 2023 edition.

## 1.3 Program of MIW2023

The program of the MIW2023 was separated in 6 sessions for oral presentation and 1 session for poster and it included 23 oral presentations, including the opening session presented by Prof. Christophe Ballif and 5 poster presentations.



Christophe Ballif	CSEM/EPFL	<b>Opening (MIW2023 organizers)</b>
Padhamnath Pradeep	SERIS	<b>Introductory talk</b>
Glatthar Raphael	Univ. Konstanz	<b>Session I: Screen-printed metallisation : state-of-the-art and beyond</b>
Tokiko Misaki	Asada Mesh	Screen-Printed metallization for industrial solar cells – current perspectives and future opportunities
		Fundamental microscopic studies on the etching behavior of silver pastes on poly-Si/SiO <sub>x</sub> passivating contacts
		Deformation Behavior of Screen Mesh in Screen Printing and Its Effect on Printing Results
		<b>Session II: Multi-busbars/wire soldering</b>
Dominik Rudolph	ISC Konstanz	Improvement of solder interconnections applied on back contact solar cells with low-temperature copper paste busbars
Jonas Marten	KIT	Highly conductive coated wire for interconnection of solar cells with TECC-Wire technology
Rik van Dyck	imomec	Investigation of Multi-Wire Interconnected Lightweight PV modules Using Micro-Computed Tomography
		<b>Poster session</b>
Florent Pernoud	CEA	Recent developments of HJT screen printing process at CEA-INES
Janis Andersons	Univ. Tweente	High Aspect Ratio Triangular Front Contacts for Solar Cells Fabricated by String-printing
Alejandro Borja Block	CSEM/EPFL	Challenges of black metallic interconnects for integrated PV module application
Daniel Ourinson	FhISE	Paste-based Silver Reduction for iTOPCon Solar Cells
Iñaki Cornago	CENER	TiSi <sub>2</sub> and LiFT as potential alternatives to silver and screen printing for solar cells electric contacts
		<b>Session III: Ag reduction in low temperature pastes</b>
Alexis Barrou	CSEM	Life Cycle Assessment of Minerals and Metals for PV: Case Study with the Silicon Heterojunction Technology
Sebastian Pingel	FhISE	Progress on the reduction of silver consumption in metallization of SHJ solar cells
Mariana Bertoni	Arizona State University	Performance and Accelerated Testing of Reactive Silver Inks Metallization of Silicon Heterojunctions with 90% less Silver
Maximilian Pospischil	HighLine Technology	Optimizing solar cell metallisation by parallel dispensing
		<b>Session IV: Copper-based cell metallisation</b>
Veyssel Unsur	Necmettin Erbakan University, ODTU-GUNAM	Screen Printable Fire Through Nickel Contacts for Crystalline Silicon Solar Cells
Thad Druffel	Bert Thin Films/Univ. North Carolina	Screen Printable Copper Pastes for Silicon Solar Cells
Agata Lachowicz	CSEM	Stability of Mini-modules with Copper Plated Heterojunction Solar Cells
		<b>Session V: Silicon heterojunction cell metallisation and LT interconnections</b>
Linjia Zhang	Suzhou Silver Materials Co.	Research and development of low temperature paste for silicon heterojunction solar cells
Angela de Rose	FhISE	Low-temperature metallization & interconnection for silicon heterojunction and perovskite silicon tandem solar cells
Germain Rey	CEA	Silicon heterojunction solar cells: solder, process and equipment qualification
Rémi Monna	CEA	Reduction of silver usage in ECA based busbar interconnection
		<b>Session VI: ECA based interconnections technologies</b>
Vincent Barth	CEA	Methodology of ECA material characterization and qualification
Maria Ignacia Devoto Acevedo	ISC Konstanz	Validation of methodology to determine the contact resistivity of ECA-based bonds grounded on end-contact resistance measurements using redundant and modified TLM test structures
Julian Weber	FhISE	Electrically conductive adhesive-free interconnection of shingle solar cells
Veronika Nikitina	FhISE	Shingling meets perovskite-silicon heterojunction tandem solar cells

Fig. 1.2 : Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells program 2023.

All the presentation are open-source and accessible online on the link here:

<https://miworkshop.info/presentations-2023/>.

Special Issue of the 11<sup>th</sup> Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells in Solar Energy Materials and Solar Cells (SolMat), should be ready to be published in end of September: <https://www.sciencedirect.com/journal/solar-energy-materials-and-solar-cells/special-issues>

## 1.4 Social event and Networking

The social part of the workshop included first a welcome reception on Sunday 7<sup>th</sup> of May at 18h close to “La Case-à-Choc” in the “Restaurant L’Interlope”. On the Monday evening a boat-trip diner on the lake of Neuchatel was organised to present to the international participant the beauty of the Lake-region. On the Tuesday afternoon the visit of the CSEM and EPFL-Microcity facilities for photovoltaics research and development was organised. 3 Masters and 2 PhD students from EPFL could help the workshop and follow the presentations and the networking event to make some scientific contact for their future work and research opportunities.





Fig. 1.3 : Welcome reception on Sunday 7<sup>th</sup> of May at 18h close to “La Case-à-Choc” in the “Restaurant L’Interlope”.



Fig. 1.4 : Boat-trip diner on the lake of Neuchâtel to present to the international participant the beauty of the Lake-region.





Fig. 1.5 : Networking time during standing coffee break and standing lunch of Monday.



Fig. 1.6 : Market place discussion to make the people know each other with technical discussion topics.



Fig. 1.7 : 60 people made the tour of the CSEM and EPFL-PVLab laboratories.

## 1.5 Participants

The subscription to the MIW2023 included 55% on early bird, 10% on Student early bird, 5% on online early bird, then 19% on Regular, 3% on regular student and 6% on regular online ticket. For the food organisation, 21% was vegetarian and 3% vegan. 3 people have food allergies, this is important to take into account.

MIW2023



Metallization & Interconnection  
WORKSHOP 2021  
for Crystalline Silicon Solar Cells

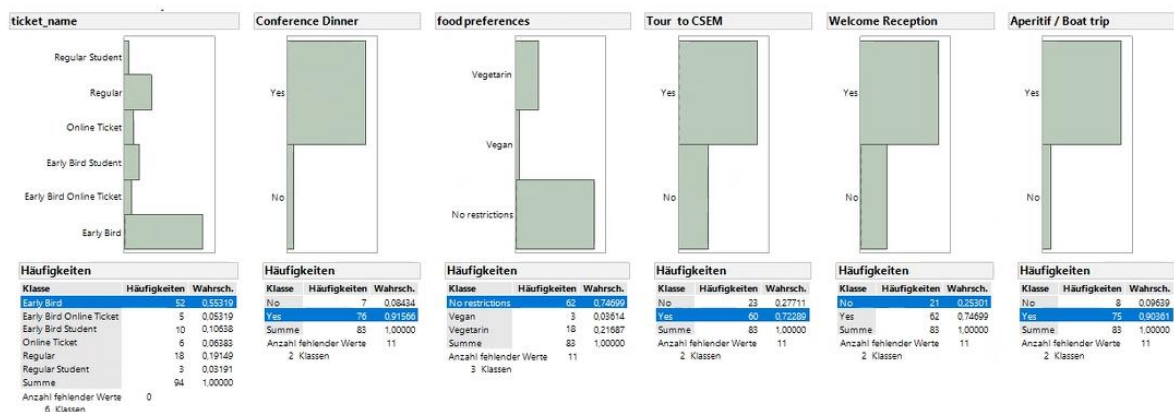


Fig. 1.8: Participant subscriptions.

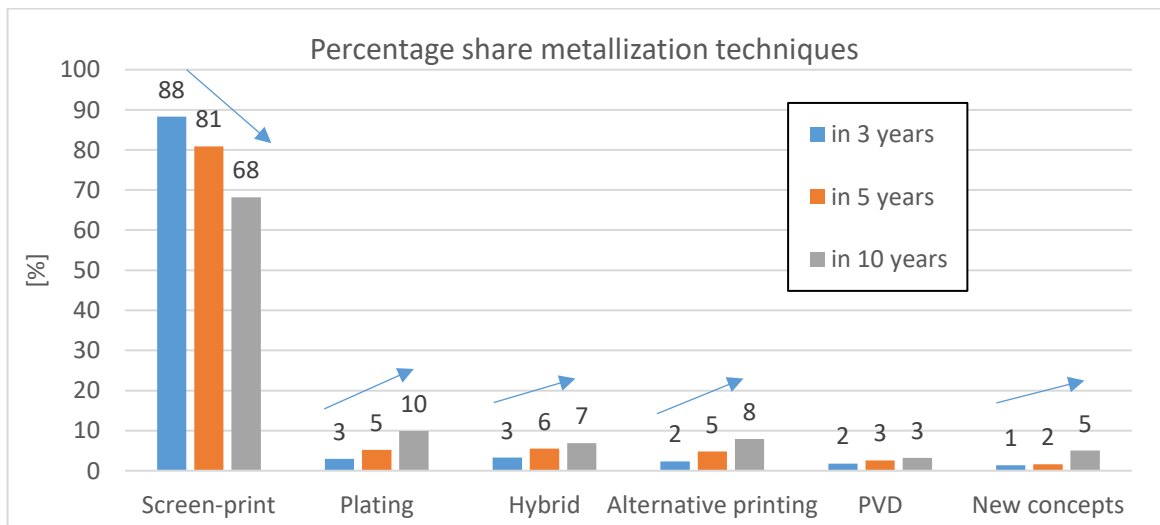


## 1.6 SURVEY ON TRENDS IN METALLIZATION AND INTERCONNECTION

This part summarizes the trends in metallization and interconnection technologies based on the traditional survey questionnaire completed by the participants of the 11<sup>th</sup> Metallization and Interconnection Workshop. These results are compared to the surveys done during the previous workshop editions starting in 2008. The 11<sup>th</sup> edition has been a hybrid event with about 15% of online participants mostly due to Covid-19 traveling restriction in Asia. About half of the participants filled the survey disclosed below.

As shown in Figure 4, participants anticipate a decrease of the market share of screen printing in the coming years, reaching 2/3 of actual share within a decade. Alternative printing and plating will grow similarly to reach between 8 and 10% share in 10 years, respectively. Hybrid, new concepts and PVD metallization should represent about 15% share in total in the same timeframe.

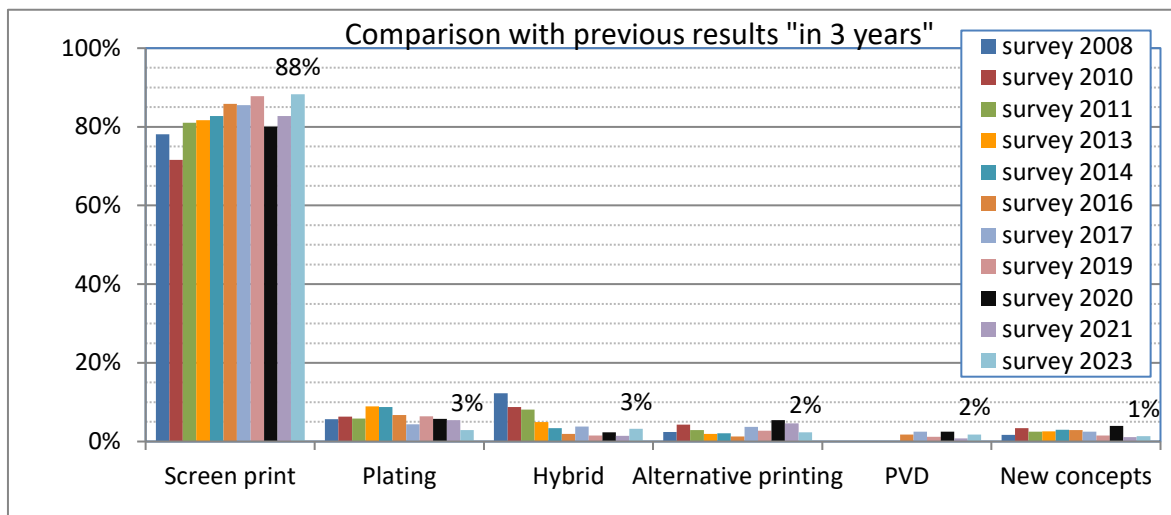
Interestingly, when comparing to the previous surveys (see Figure 5), screen printing is predicted to keep a larger market share in particular for the forecast “in 10 years” compared to the older surveys (2008-2016). Trends are generally similar for the three forecasts (3, 5 and 10 years) with a stronger effect “in 10 years”. For plating, the predicted share reached a maximum in 2013 of 24% of metallization share in 10 years, compared to 10% in 2023. This maximum in 2013 might corresponds to the highest silver price observed in April 2011 at more than 1000 €/kg, with a value always above 700 €/kg until 2013. The percentage between hybrid (printing + plating) and alternative printing are reversing with increase interest on hybrid technology compared to new printing concepts.



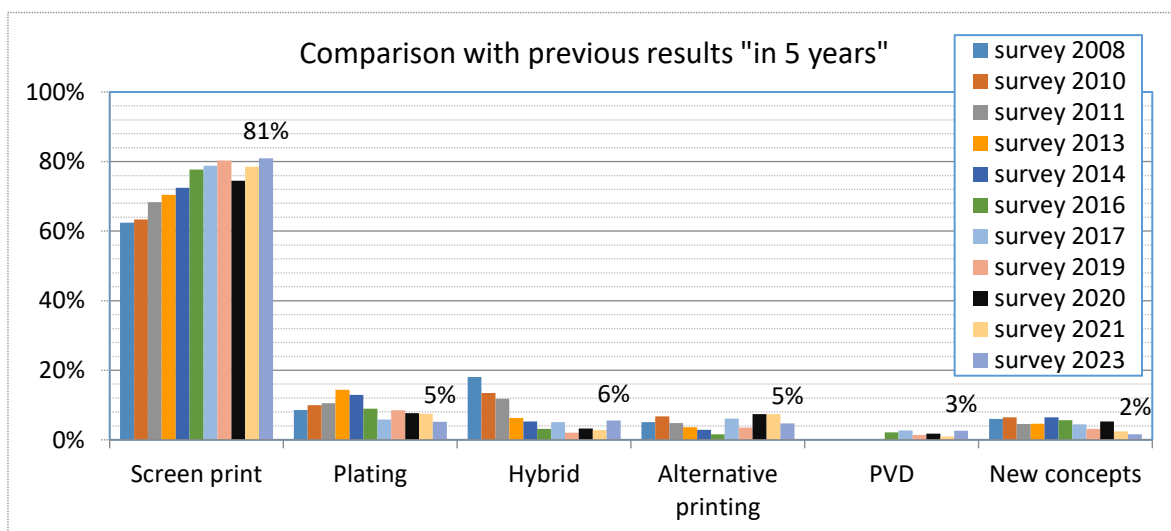
**FIGURE 4.** Results of the 2023 survey about the expected proportion of the different metallization techniques between screen-printing, plating, hybrid (screen-printing + plating), alternative printing, PVD and new concepts in 3, 5 and 10 years.



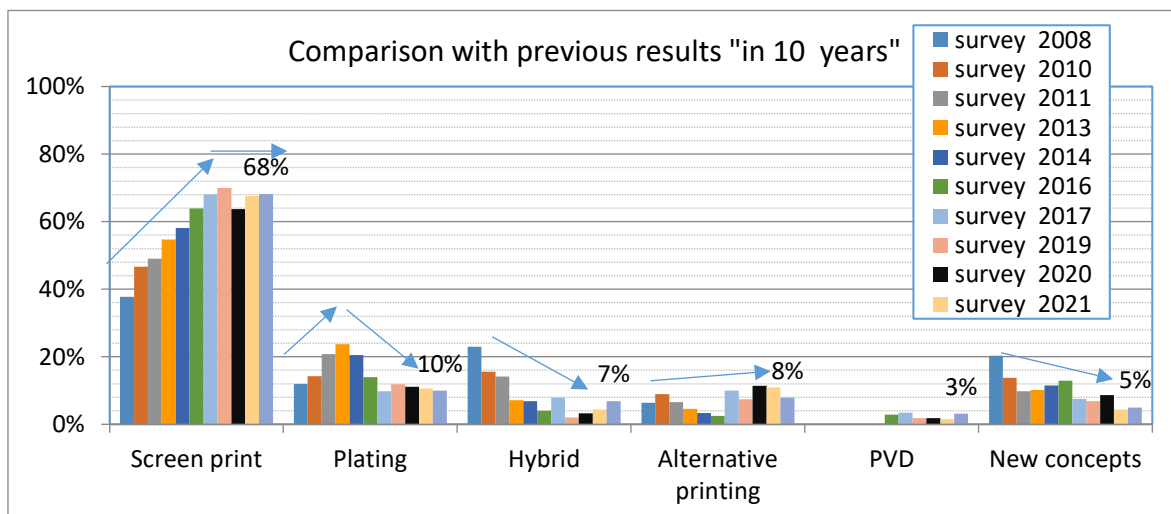
a)



b)



c)



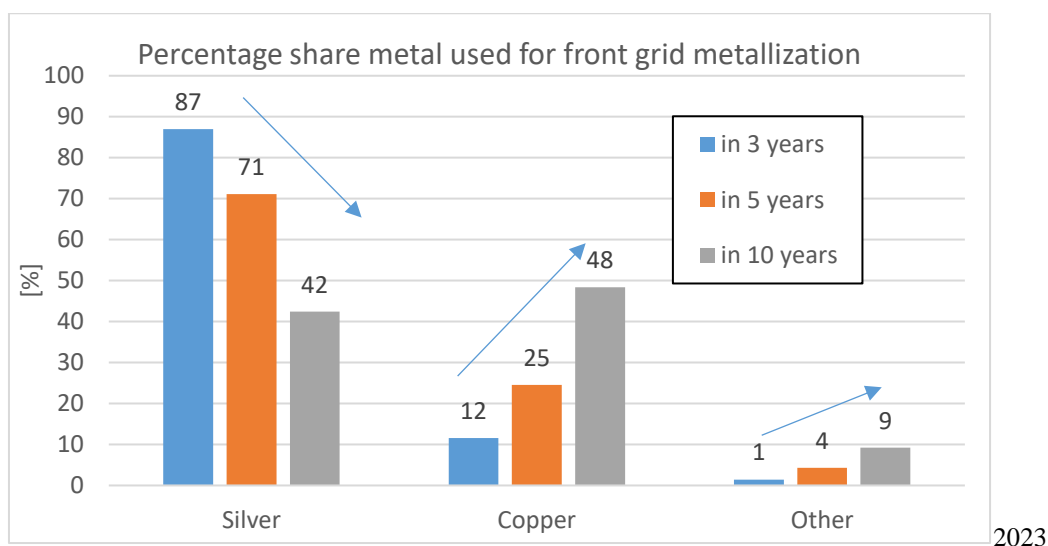
**FIGURE 5.** Comparison of the results to the question: “What will be the percentage share of metallization techniques in solar cell production in X years?” for all surveys in 2008, 2010, 2011, 2013, 2014, 2016, 2017,



2019, 2020, 2021 and 2023 in a) in 3 years, b) in 5 years and c) in 10 years. Arrows on in c) are guides for the eyes. The displayed percent numbers always refer to the actual survey 2023.

For the next 5 years, silver is expected to be the main metal used for the metallization as shown on Figure 6, but in 10 years from now copper needs in metallization will overpass silver with 48% for copper and 42% for silver. Copper share increases fivefold from market share “in 3 years” to “in 10 years”. New metals will increase to 9% market share in 10 years.

Figure 7 presents the evolution of survey answer for materials share in metallization. The evolution shows a regained confidence in the mid-term replacement of silver, in particular ‘in 10 years’ with a strong comeback of copper higher than in 2011 and a silver share which is the lowest ever recorded. As mentioned earlier, the reasons for predicting in 2011 a reduced silver share was certainly material price at that time. In 2023, price is again a concern, but the prospect of production in the Terawatt range in the coming decade raises major risks of forthcoming silver shortage. Interestingly, the plating market share in 10 years is estimated at only 10%, whereas copper share is projected to be 48%. The difference is most probably related to the emergence of copper-based paste for printing which then would represent 38% or the total market share!

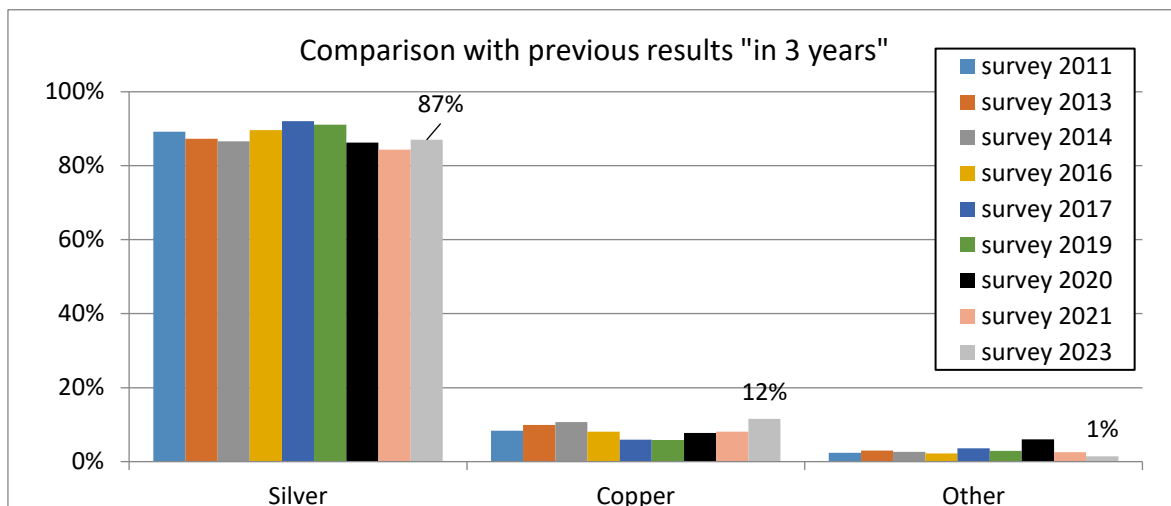


**FIGURE 6.** Results of the 2023 survey to the question: “What will be the percentage share of metals used for the front grid metallization?”

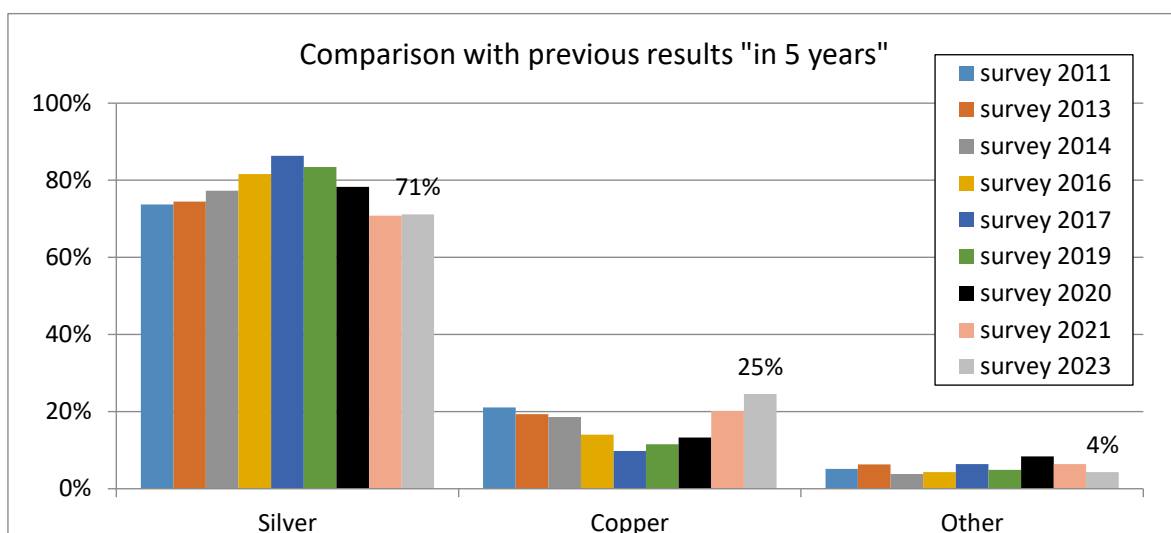




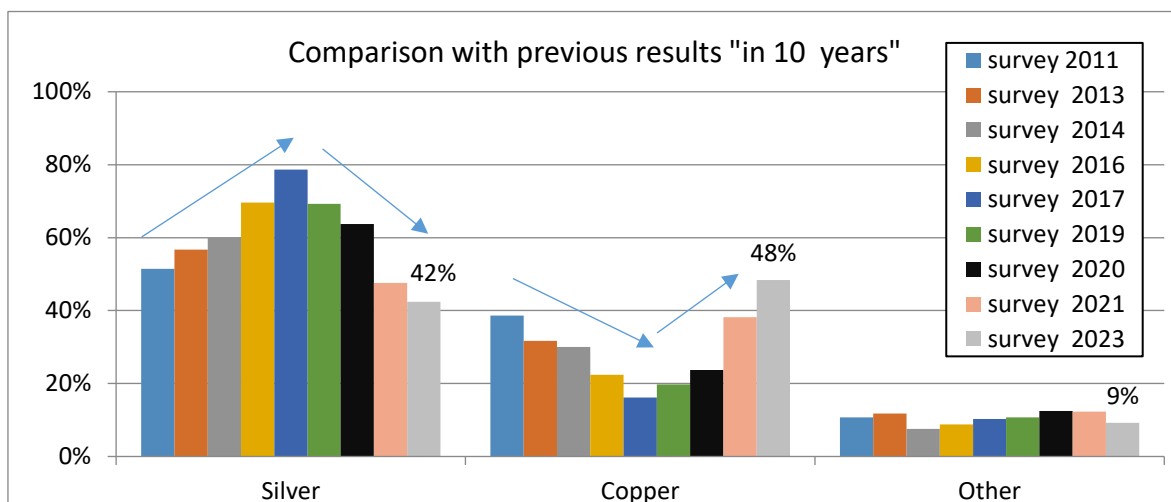
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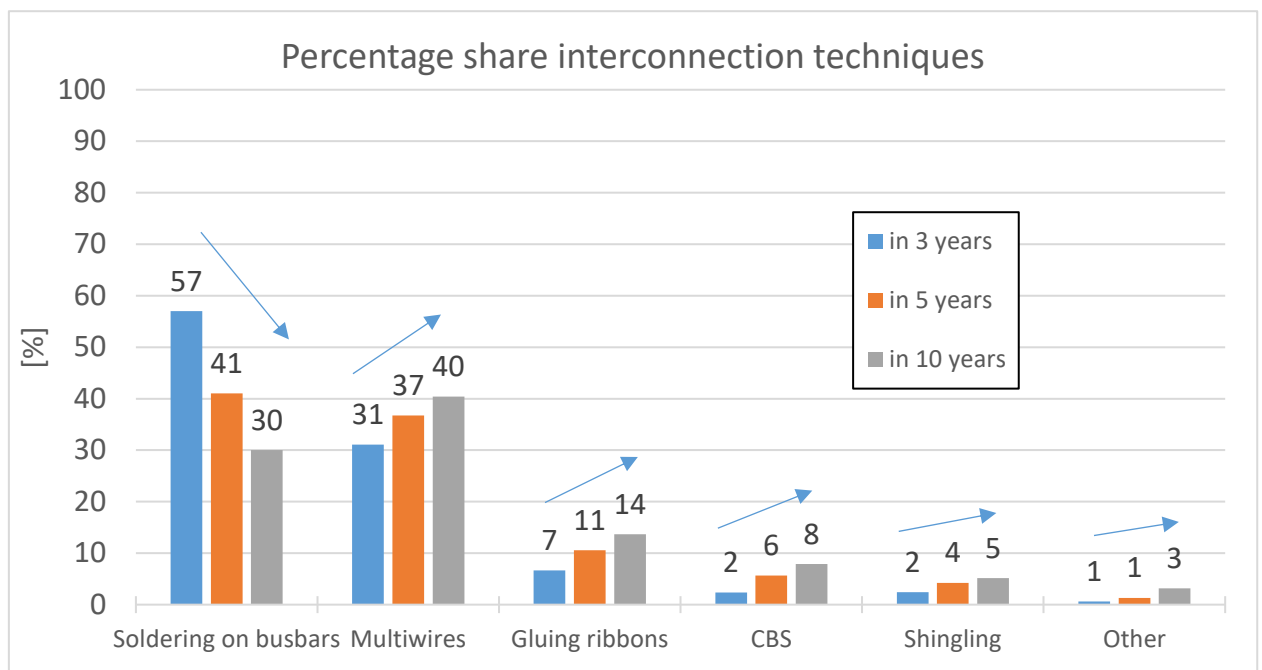
**FIGURE 7:** Comparison of the results to the question: “What will be the percentage share of metals used for the front grid metallization in X years?” for all surveys in 2008, 2010, 2011, 2013, 2014, 2016, 2017, 2019, 2020, 2021 and 2023 in a) in 3 years, b) in 5 years and c) in 10 years.





Interconnection technologies are expected to diversify as shown in Figure 8, with a strong reduction of the classical soldering on busbars and a growth for all the other interconnection approaches. In particular, multiwire will reach nearly 40% of interconnection technologies used in production in 2033. Electrically conductive adhesive (ECA) is expected to be used in ribbon gluing, cell shingling and in some cases for the interconnection of back-contact cells using conductive back-sheet (CBS). These three technologies will represent about 27% of the interconnection share in 2033.

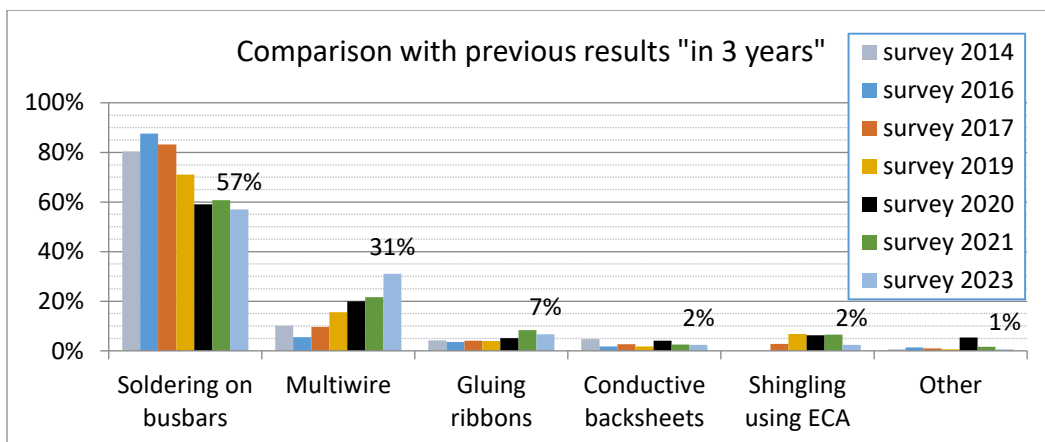
A noticeable change compared to the previous survey (Figure 9) is the expected share of ribbon gluing increasing and of shingled cells strongly decreasing.



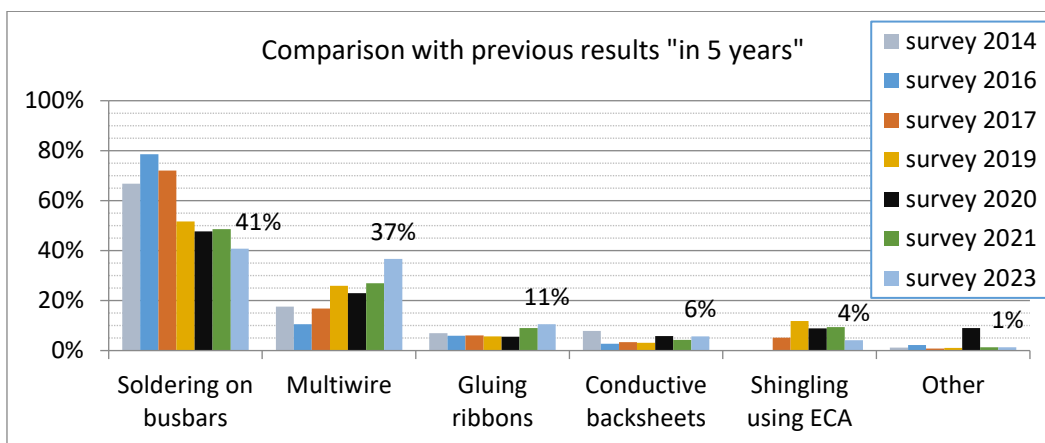
**FIGURE 8:** Results of the 2023 survey about the expected proportion of the different interconnection techniques between soldering on busbars, multi-wire, ribbons gluing, conductive back-sheet (CBS), cells shingling and other concepts in 3, 5 and 10 years.



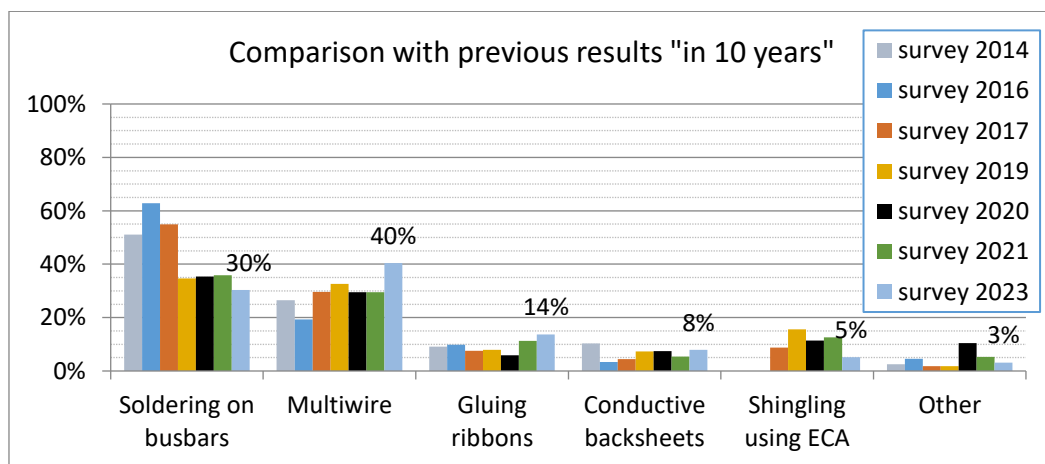
a)



b)



c)



**FIGURE 9:** Comparison of the results to the question: “What will be the percentage share of interconnection technologies in production in X years?” for all surveys in 2014, 2016, 2017, 2019, 2020, 2021, and 2023 in a) in 3 years, b) in 5 years and c) in 10 years.



## 2 Next steps

Next edition of the Metallization and Interconnection Workshop for Crystalline Solar Cells (MIW) will be hold in France by CEA-INES in Autumn 2024.

Special Issue of the 11<sup>th</sup> Workshop on Metallization and Interconnection for Crystalline Silicon Solar Cells in Solar Energy Materials and Solar Cells (SolMat), should be ready to be published in end of September: <https://www.sciencedirect.com/journal/solar-energy-materials-and-solar-cells/special-issues>

## 3 References

[1] <https://miworkshop.info/>, on 06.09.2023