

Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra Federal Department of the Environment, Transport, Energy and Communications DETEC

Swiss Federal Office of Energy SFOE Energy Research and Cleantech Division

Final report dated 06.09.2023

# **MIW2023**

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



Source: ©CSEM 2023



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Date: 6th September 2023

Location: Neuchatel

#### Publisher: Swiss Federal Office of Energy SFOE Energy Research and Cleantech CH-3003 Bern www.bfe.admin.ch

#### Co-financing: CSEM SA

Rue Jaquet-Droz 1 CH-2002 Neuchatel www.csem.ch

#### Subsidy recipients:

CSEM SA Rue Jaquet-Droz 1 CH-2002 Neuchatel www.csem.ch

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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 11ème 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 bellow). 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.

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Sebastian Pingel   FilSE   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 SHJ solar cells     Maximilian Pospischil   HighLine Technology   Optimizing solar cell metallisation by parallel dispensing     Necreentin Erbakan   Necreentin Erbakan   Necreentin Erbakan     Veysel Unsur   Necreentin Erbakan   Sereen Printable Fire Through Nickel Contacts for Crystalline Silicon Solar Cells     Thad Druffel   Ber Thin Films/Univ. Notrith Carolina   Sereen Printable Copper Pastes for Silicon Solar Cells     Agata Lachowicz   CSEM   Saability of Mini-modules with Copper Plated Heterojunction Solar Cells     Linja Zhang   Suzhou Siliver Materials C.   Research and development of low temperature paste for silicon heterojunction solar cells     Gemain Rey   CEA   Suiton heterojunction sait rellization and LT interconnections     Remi Monna   CEA   Silicon heterojunction solar cells     Remi Monna   CEA   Silicon heterojunction solar cells     Vincen Barth   CEA   Silicon heterojunction solar cells     North Carolina   New Collicon of silver usage in ECA based busbar interconnection     Remi Monna   CEA   Me			Session III: Ag reduction in low temperature pastes
Contention     Contention     Contention       Mariana Bertonin     Arizona State University     Performance and Accelerated Testing of Reactive Silver Inks Metallization of Silicon Heterojunctions with 90% less Silver       Maximilian Pospischil     HighLine Technology     Session IV: Copper-based cell metallisation       Veysel Unsur     Necmettin Erbakan     Keremettin Erbakan       University, ODTU-     Seren Printable Fire Through Nickel Contacts for Crystalline Silicon Solar Cells       GUNAM     Seren Printable Copper Pastes for Silicon Solar Cells       Agata Lachowicz     CSEM     Stability of Mini-modules with Copper Plated Heterojunction Solar Cells       Linja Zhang     Suzhou Silver Materials     Research and development of low temperature paste for silicon heterojunction solar cells       Ageta de Rose     RhISE     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       Maria Ignacia Devoto     CEA     Metodology of ECA material characterization and qualification       Maria Ignacia Devoto     CEA     Validation of metodology to determine the contact resistivity of ECA-based bonds grounded on end-contact resistance       Maria Ignacia Devoto     Research	Alexis Barrou	CSEM	Life Cycle Assessment of Minerals and Metals for PV: Case Study with the Silicon Heterojunction Technology
Maximilian Pospischil   HighLine Technology   Optimizing solar cell metallisation by parallel dispensing     Maximilian Pospischil   Session IV: Copper-based cell metallisation     Veysel Unsur   Necmettrin Erbakan     Nievrestry, ODTU-   Creen Printable Fire Through Nickel Contacts for Crystalline Silicon Solar Cells     GUNAM   Bert Thin Films/Univ.     Notrd Carolina   Screen Printable Copper Pastes for Silicon Solar Cells     Agata Lachowicz   CSEM     Stability of Mini-modules with Copper Plated Heterojunction Solar Cells     Surghou Silver Materials   Stability of Mini-modules with Copper Plated Heterojunction Solar Cells     Linja Zhang   Suzbou ISilver Materials     Angela de Rose   FhISE     Germain Rey   CEA     Silcon heterojunction solar cells collication and perovskite silicon tandem solar cells     Germain Rey   CEA     Silcon heterojunction solar cells collection solar cells     Vincent Barth   CEA     Maria Ignacia Devoto   CEA     Acevedo   CEA     Acevedo   Validation of methodology to determine the contact resistivity of ECA-based bonds grounded on end-contact resistance mass using redundant and modified TLM test structures     Juian Weber   FhISE   Electricall	Sebastian Pingel	FhISE	Progress on the reduction of silver consumption in metallization of SHJ solar cells
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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   Keim Jonna CEA Reduction of silicor add publication solar cells: solder, process and equipment qualification   Vincent Barth CEA Methodology of ECA material characterization and qualification   Vincent Barth CEA Methodology of ECA material characterization and qualification   Maria Ignacia Devoto Northodology of ECA material characterization and qualification   Acevedo Yalidation 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			Session V: Silicon heterojunction cell metallisation and LT interconnections
Germain Rey     CEA     Silicon heterojunction solar cells: solder, process and equipment qualification       Rémi Monna     CEA     Reduction of silver usage in ECA based busbar interconnection       Vincent Barth     CEA     Methodology of ECA material characterization and qualification       Maria Ignacia Devoto     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	Linjia Zhang	Suzhou iSilver Materials Co.	Research and development of low temperature paste for silicon heterojunction solar cells
Remi Monna     CEA     Reduction of silver usage in ECA based busbar interconnection       Session VI: ECA based interconnection stechnologies     Marking and a languar and publication       Vincent Barth     CEA     Methodology of ECA material characterization and qualification       Maria Ignacia Devoto     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	Angela de Rose	FhISE	Low-temperature metallization & interconnection for silicon heterojunction and perovskite silicon tandem solar cells
Session VI: ECA based interconnections technologies       Vincent Barth     CEA       Maria Ignacia Devoto     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	Germain Rey	CEA	Silicon heterojunction solar cells: solder, process and equipment qualification
Vincent Barth     CEA     Methodology of ECA material characterization and qualification       Maria Ignacia Devoto     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	Rémi Monna	CEA	Reduction of silver usage in ECA based busbar interconnection
Maria Ignacia Devoto 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			Session VI: ECA based interconnections technologies
Acevedo     ISC Konstanz     measurements using redundant and modified TLM test structures       Julian Weber     FhISE     Electrically conductive adhesive-free interconnection of shingle solar cells	Vincent Barth	CEA	Methodology of ECA material characterization and qualification
Acevedo     ISC Konstanz     measurements using redundant and modified TLM test structures       Julian Weber     FhISE     Electrically conductive adhesive-free interconnection of shingle solar cells	María Ignacia Devoto		-
Julian Weber FhISE Electrically conductive adhesive-free interconnection of shingle solar cells	Acevedo	ISC Konstanz	
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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: <u>https://miworkshop.info/presentations-2023/</u>.

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: <u>https://www.sciencedirect.com/journal/solar-energy-materials-and-solar-cells/special-issues</u>

## 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 Neuchatel 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.



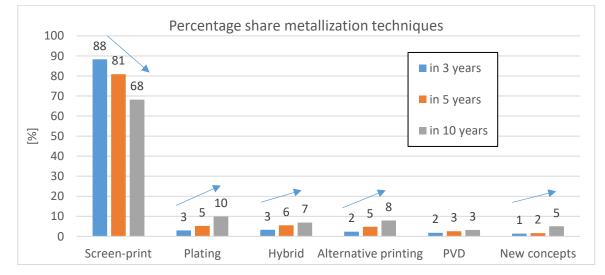
Fig. 1.8: Participant subscriptions.

#### 1.6 SURVEY ON TRENDS IN METALLIZATION AND INTERCONNECTION

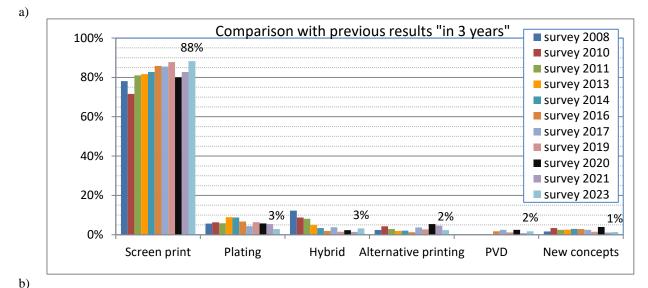
This part summarizes the trends in metallization and interconnection technologies based on the traditional survey questionnaire completed by the participants of the 11<sup>th</sup> Metallization and Interconnection Workshop. These results are compared to the surveys done during the previous workshop 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.

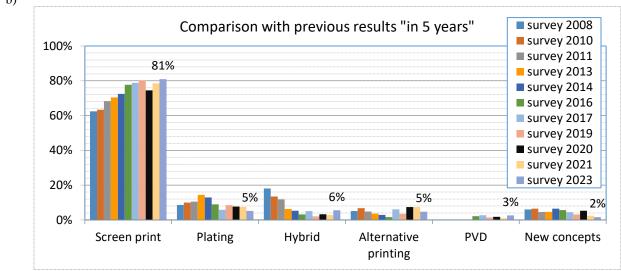
As shown in Figure 4, participants anticipate a decrease of the market share of screen printing in the coming years, reaching 2/3 of actual share within a decade. Alternative printing and plating will grow similarly to reach between 8 and 10% share in 10 years, respectively. Hybrid, new concepts and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

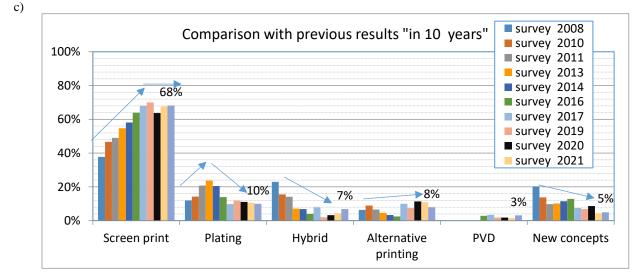
Interestingly, when comparing to the previous surveys (see Figure 5), screen printing is predicted to keep a larger market share in particular for the forecast "in 10 years" compared to the older surveys (2008-2016). Trends are generally similar for the three forecasts (3, 5 and 10 years) with a stronger 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 silvers price observed in April 2011 at more than 1000  $\varepsilon/kg$ , with a value always above 700  $\varepsilon/kg$  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.







**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!

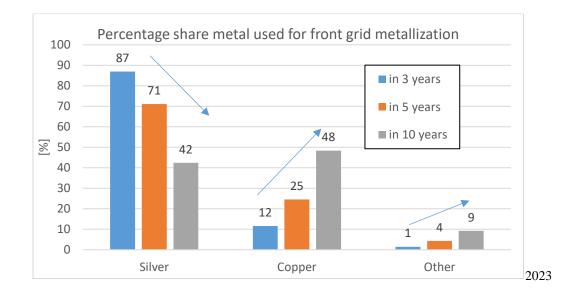
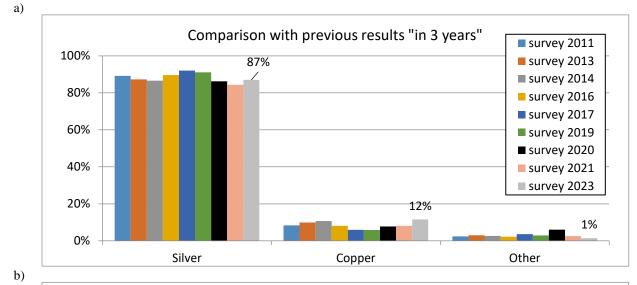
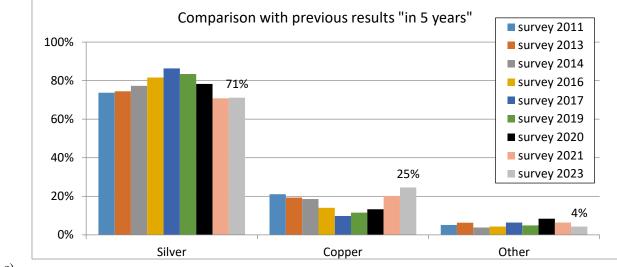
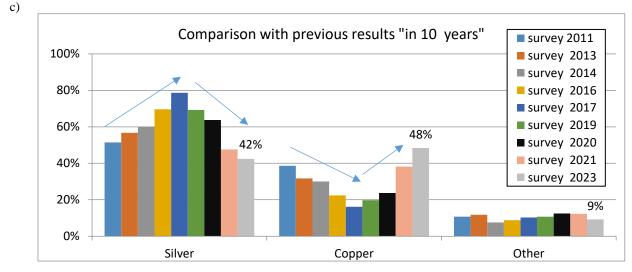
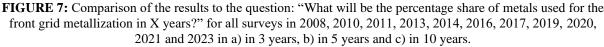


FIGURE 6. Results of the 2023 survey to the question: "What will be the percentage share of metals used for the front grid metallization?"









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.

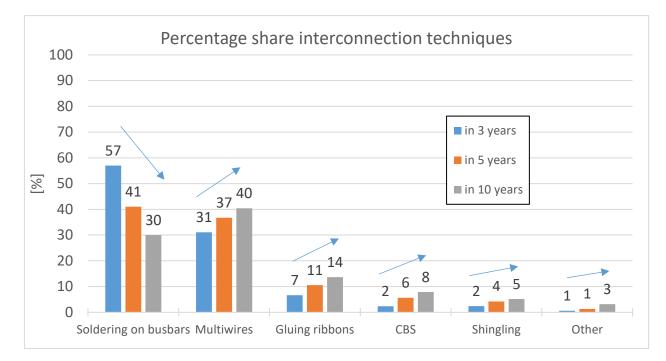
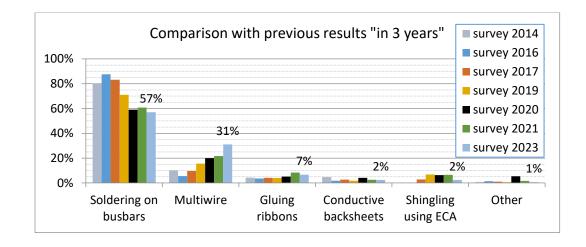
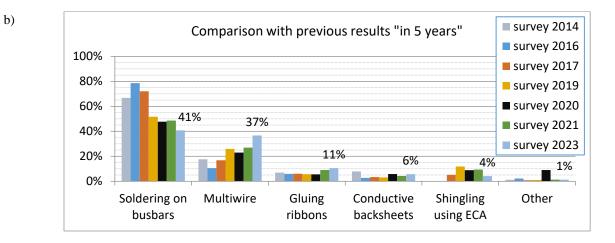
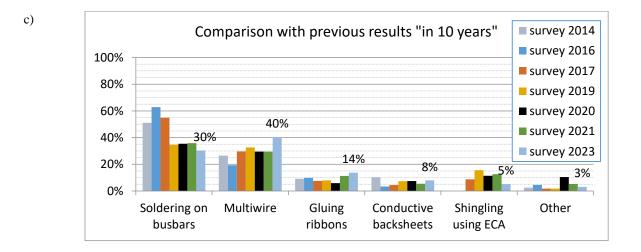


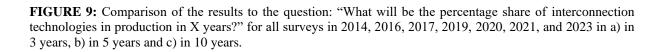
FIGURE 8: Results of the 2023 survey about the expected proportion of the different interconnection techniques between soldering on busbars, multi-wire, ribbons gluing, conductive back-sheet (CBS), cells shingling and other concepts in 3, 5 and 10 years.

a)









## 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: <u>https://www.sciencedirect.com/journal/solar-energy-materials-and-solar-cells/special-issues</u>

## 3 References

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