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Increase the competitiveness of the EU PV manufacturing industry

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High-performance low-cost modules with excellent environmental profiles for a competitive EU PV manufacturing industry

HighLite- Deliverable report

D3.4 - Production of sufficient cell precursors by month 24.

Disclaimer/ Acknowledgment

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About HighLite

The HighLite project aims to substantially improve the competitiveness of the EU PV manufacturing industry by developing knowledge-based manufacturing solutions for high-performance low-cost modules with excellent environmental profiles (low CO_2 footprint, enhanced durability, improved recyclability). In HighLite, a unique consortium of experienced industrial actors and leading institutes will work collectively to develop, optimize, and bring to high technology readiness levels (TRL 6-7) innovative solutions at both cell and module levels.

HighLite consortium members

Document information

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Document history

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PU	Public	X
CO	Confidential, only for members of the consortium (including the Commission Services)	

Publishable summary

Deliverable D3.4 is the continuation of deliverable 3.1 and is directly related to the activities of task T3.1. The main objective of this task is the production of sufficient quantities of cell precursors needed for the development of cells and modules in other tasks and work packages of the HighLite project.

CEA-INES was responsible for the fabrication and distribution of the silicon heterojunction cells (SHJ) with a metallization pattern dedicated to shingle assembly (in T4.1). Some splits were integrated in these batches, essentially on metallization configuration (interconnection design, different paste tests). Almost 5000 of additional shingle devices were successfully produced in the last reporting period. The total of 8689 SHJ cells were produced and were available for partners in work packages WP4, WP5, and WP6. This number was higher than originally anticipated (8000) and explained by the increased demand for BAPV and BIPV module production needed to be ready for module mounting for WP6 by the end of summer. Typical efficiency was in the range of 22.8%, depending on the metal scheme applied. Best cell produced was measured at 24.1%. Furthermore, first promising results on integration of SHJ shingle devices on very thin 90µm wafer were also obtained, demonstrating that such cell/wafer configuration is fully compatible with the Highlite SHJ shingle technology.

During last reporting period alternative cell configurations and concepts were tested as well, along with the work package targets and overall project objectives described below, with a specific focus however on edge repassivation trials. Indeed, besides the specific shingle needs, adapted cell configurations were also manufactured, needed especially for the cut step optimization and edge repassivation trials (tasks 3.2).

Valoe Cells, in cooperation with ISC, was responsible for production of large area IBC cells in its pilot line starting with patterning and screen-printing layouts optimized for assembly of ½ cut-cells. In the last 12 months Valoe Cells has produced over 5000 Zebra IBC cells that were shipped to partners in T4.2 for the cutting tool and module line testing and the production of BAPV modules. For the manufacturing of high efficiency BIPV modules, additional 300 high efficiency Zebra-IBC cells have been purchased from the external source. The overall number of available IBC cells was 9358 which is slightly lower than initially estimated (10000) and can be explained by lower-than-predicted demand of cells in T4.2 (Development of advanced equipment for assembly of IBC cut-cells), which was the main beneficiary of cells in M1-M24. Typical efficiency of cells, produced at Valoe Cells and shipped to partners in T4.2, was 20.0-21.5%. The quality of produced cells was lower-than-expected due to a still ongoing ramp-up of the line and unavailability of high quality silicon wafers.

Contents

List of acronyms, abbreviations and definitions

Abbreviation	Definitions
WP	Work package
SHJ	Silicon heterojunction
CEA-INES	French National Institute on Solar Energy
WP	Work Package
BAPV	Building Applied PhotoVoltaic
BIPV	Building Integrated PhotoVoltaic
VIPV	Vehicle Integrated PhotoVoltaic

1. Introduction

This deliverable is related to work package 3 - novel layers and processes implemented in existing solar cell pilot lines. This work package focuses on the implementation of novel layers and processes to maximize the efficiency of thin SHJ and IBC cut-cells. The main objectives of this work package are to:

- Generate a high volume of cells for the project partners: target was to produce 8000 SHJ and 10000 Zebra-IBC cells before M24
- Demonstrate best SHJ cell with efficiency ≥23.5% (full-size)
- Demonstrate best IBC cell with efficiency ≥24.5% (full-size)
- Demonstrate effective progress either on cut-step, either on edge repassivation to prove that less than -0.2% ABS losses can be measured on final cut cell (¼ cell or smaller size)
- Improve overall CoO and CO2 footprint: improve efficiencies, work on thin wafers, reduce silver consumption

Deliverable D3.4 is a direct continuation of deliverable 3.1 already submitted, and gives an update on the global progress made on the cell production line towards the different project objectives. It reports on the manufacturing of large quantities of cells at existing solar cell pilot-lines, installed at CEA INES and Valoe Cells, to support activities in this WP and in other WPs.

Table 1: Overview of deliverable D3.4

Deliverable Number	Short deliverable name	Lead beneficiary	Type	Dissemination level	Due date
D3.4	Production of sufficient cell precursors by month 12	Valoe Cells	D	PU	M24

2. Technical details

2.1. Production of SHJ cells

CEA-INES is in charge of the fabrication of silicon heterojunction solar cells (SHJ) for the Highlite project. A total need of ~8000 shingle was estimated at the beginning of the project for M24 needs. This high number being driven in particular with the need to build several modules, in different BAPV, BIPV and VIPV configuration, to be afterwards mounted and monitored all along the last project year (WP6).

To generate the SHJ cells requested in the project, CEA-INES kept working on its production pilot-line, called LabFab (*Figure 1*) located in France. This line is fully equipped with industrial equipment, allowing the fabrication of high volume of cells in real industrial environment. Full production chain is thus insured, from carrier wafer loading to final cell metallization and IV sorting.

It is worth to note that despite some site closure because of the Covid-19 lockdown situation, we were able to keep the machines running most of the time, and to catch-up some of the induced delays to always fulfil in-time any partner cell request.

Figure 1: Picture of CEA_INES SHJ production pilot-line

2.2. SHJ Shingle Cell Configuration

Compared to the work conducted in D3.1, the shingle overall integration scheme has not been significantly modified. Indeed, we still work with adapted metal pattern (deported busbars) allowing the generation of 6 SHJ shingles out of a mother wafer (M2 size). Cells are still bifacial, allowing increased module productivity when mounted in adequate conditions. We kept Double-printing for the front metal grid to compensate for the increased metal line resistance.

To close the gap with standard SHJ devices, and explore the different technological options to enhance the competitiveness of the technology, slight adjustments have been tested all along the last year, impacting in particular the metal design:

- Alternative metal line pattern to reduce the consumption of silver
- Modification of the busbar design, especially to test lower cell to cell overlap configuration during the final interconnection
- Thin wafer integration: thicknesses down to 90µm tested on the production line.

- Slight integration process modifications to generate "Record" batches and demonstrate the full potential of the SHJ shingle configuration

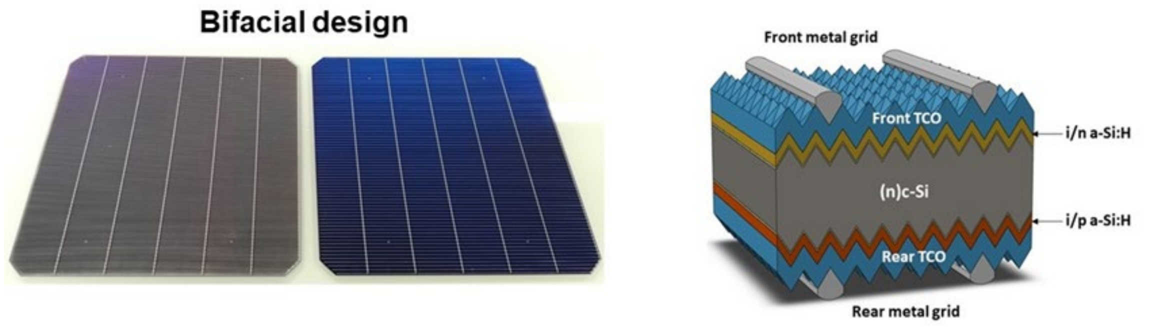

Figure 2: Typical Shingle cell configuration produced on INES pilot-line for the Highlite project needs.

2.3. Production of IBC cells

Valoe Cells, together with ISC Konstanz, is in charge of manufacturing sufficient amount of IBC cells, needed for partners in work packages 3, 4, 5, 6, and 7. As it was already reported in D3.1, the upgrade of IBC cell production line at Valoe Cells factory was delayed. As to cope with its obligation to the HighLite project, Valoe Cells installed a smaller semi-automatic line to produce IBC cells required for the project-related activities in M1-M24. Zebra IBC cells, used for the manufacturing of BAPV modules, were produced in this line. Additional cells were also manufactured while the ramping-up of main IBC production line. The quality of latter cells was lower and they were mainly used for the setting up of the cutting tool and module assembly line at Valoe Oyj. All cells, produced at Valoe Cells, were in 5BB layout. High efficiency 6BB IBC cells, needed for the production of BIPV modules, were purchased from the third party.

Figure 3: IBC cell production line at Valoe Cells

3. Results

3.1. Production of SHJ cells

3.1.1. Typical SHJ cell production results

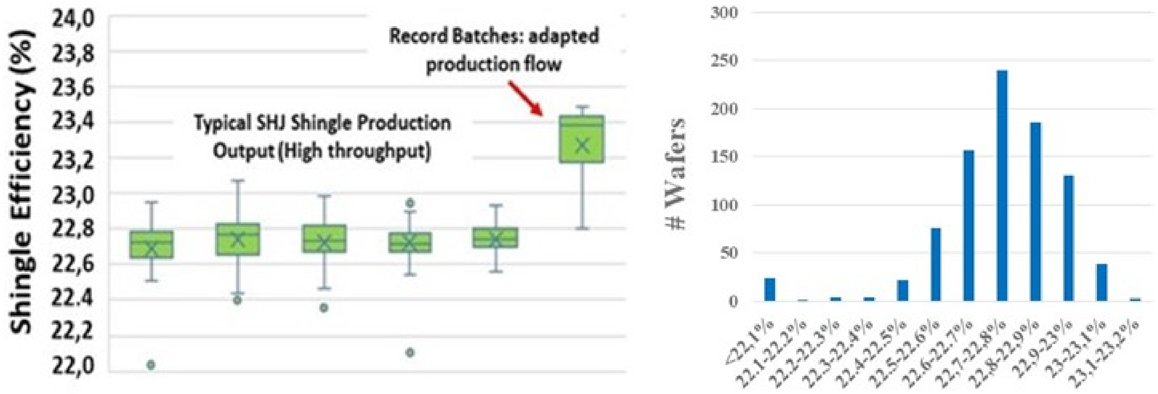

Figure 4: Typical production SHJ Shingle Batches outputs (~1000 wafers production)

Several production batches were run to generate the different shingle cells. With global improvement on the pilot-line, and slight process optimization, batch average efficiencies were stabilized at 22.8%, with best cell over 23% in full production mode. This is a very promising result, showing the high potential of the technology despite the constraints brought on the metal grid resistance because of the deported busbars. Most of the SHJ shingle cells were produced in this configuration, with stable batch to batch reproducibility for most of the conducted runs.

3.1.2. SHJ Record Cell

As seen in *Figure* 4, significantly higher performance batches were generated as well on the production line. We call them “Record” batches, as they undergo strictly through the similar integration flow, but we allow the possibility to reduce a bit the overall line throughput to relax the constraints on automation especially, reducing strongly by this mean the associated defectivity brought by the belts/and or pickers. This optimization, combined with specifically tuned TCO allow us to clearly boost the Shingle efficiencies, with average batches over 23% produced. This fully demonstrates that Shingle SHJ cell configuration is capable of reaching very high efficiency, and we strongly close the gap with standard SHJ devices produced in similar conditions.

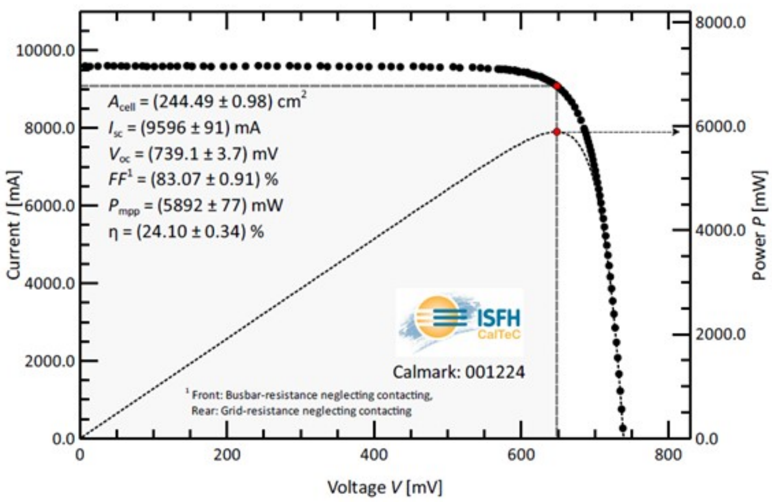

Figure 5: Record SHJ Shingle Full cell certified at 24.1%

Several cells in the record configuration were produced, but global volume achievable remains limited because of the throughput limitations. However, with proper post-process cell treatment, we were able to increase even further the record efficiencies, with in particular a record cell certified at 24.1%.

With these excellent results, we can already confirm that **one of the main global WP3 task has already been successfully achieved**, as significant amount of cells with efficiency > 23.5% were produced, with record cells over 24% even demonstrated.

3.1.3. Complementary production batches

While most of the produced cells followed the standard integration flow described previously, it is worth to note that several alternative cell configurations were also integrated to generate important data for the project. Examples of such batches, with their main purpose, are described below. They will be included in the global follow-up of produced cells as well, as they were either internally used by CEA for cut and edge passivation trials, or distributed to the project partners for similar experiments.

We can mention firstly very promising integration of SHJ shingle devices on a very thin wafer. Standard industrial wafers were integrated and thinned down to 90µm at CEA-INES, before standard industrial integration. Very promising first morphological and electrical results were obtained, demonstrating that such cell/wafer configuration is fully compatible with the HighLite technology developed. Use of thin wafer is in particular very important for cost issues, but also to fulfil the ambitious LCA objective to reduce the CO2 consumption.

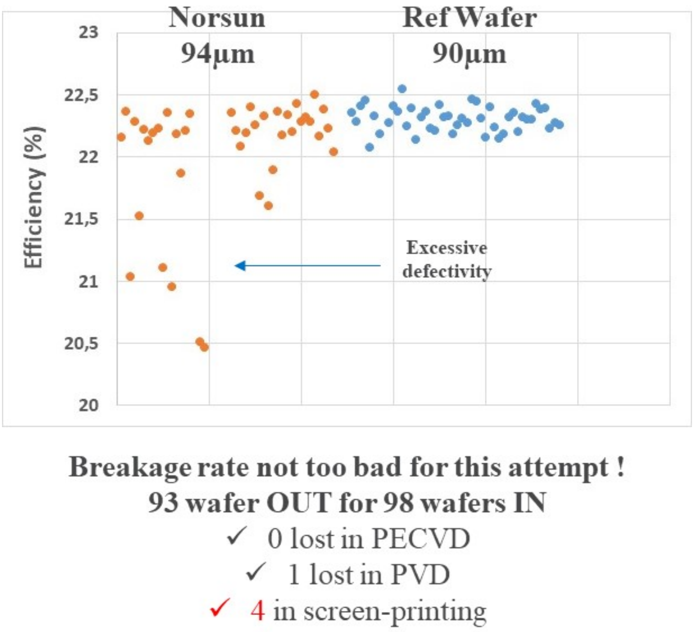

Figure 6: Typical electrical and morphological outputs obtained for the integration of SHJ shingle technology on very thin wafer.

The other very promising technique is the development and integration of newly developed ingot fabrication at CEA-INES. The main idea is to perform a 45° rotation of the ingot before the squaring, to align the natural mechanical cleavage edges, with the desired final cut-lines (generally positioned perpendicular to the metal lines, and parallel to the busbars for the shingle cells). These samples are important for the cut developments (alternative cut technique), for the edge repassivation trials (smooth edge, without laser cut seems mandatory if edge repassivation is required), but we also need to check if such wafers are still compatible with industrial integration (especially mechanical breakage). Several integration batches were initiated with this as well on the production pilot line, and typical outputs are presented below.

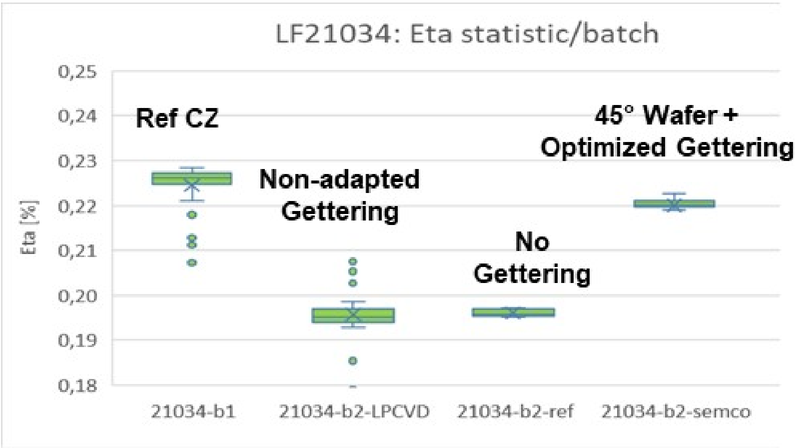

Figure 7: Example of successful integration of 45° Rotated ingot wafer on the CEA-INES production line. An additional gettering step is necessary to compensate for the lower initial ingot quality (not linked to the 45° squaring step, but to the lower quality of the initial full ingot growth).

3.1.4. Summary of produced cells

Several production batches were launched to generate the different SHJ cells requested. The main volume was dedicated to cell fabrication in a standard shingle configuration. Most of the associated shipments were destined to AMAT for string integration before distribution to the concerned project partners. As mentioned in previous section, alternative cell configurations were generated, produced and shipped to partners as well, to insure that all other WP developments could be as well achieved in time and quality.

Table 2 summarizes the total amount of cells produced by CEA and shipped to partners in different work packages, along with their main associated objectives. Detailed tracking sheet is also available on the project internal shared website, updated as accurately as possible by the different partners. As one can see, a total of ~8689 SHJ wafers were effectively finalized for the project at M24, so fully in-line with initial projects needs and assumptions. Slight differences (increased cell production volume) can be easily explained by the increased demand just before the BAPV and BIPV module production, needed to be ready for module mounting for WP6 at the end of the summer.

Table 2: Summary of the different SHJ cells produced for the Highlite project M1-M24.

Cell Configuration	# Cells	Shipped to	Main Objective
Shingle Production Batch#1	382	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#2	770	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#3	564	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#4	421	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#5	800	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#6	300	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#7	250	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#8	500	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Shingle Production Batch#9	1800	AMAT-BACCINI	WP4-WP5, Interconnection, Module
Half-Cell and Shingle SHJ cells	232	3DMicromac	WP3, Cut optimization
Thin Wafer Shingle Production	100	Not shipped Yet	WP4-WP5, Interconnection, Module
Half-Cells (BB0 and BB6)	50	UL (+ WP7)	WP7 Round-Robin + Extra-wafers
Precursors, and BB6 Cells	80	IBS	WP3, repassivation trials
BB5, BB6 and BB0 Cells	40	AMAT-BACCINI	WP3.5, IV tool developments
45° Rotated Wafers	600	CEA-INES + WP3 partners	WP3,2: Cut-losses, Repassivation
M6 Cut Wafers	200	3DMicromac	Cut-losses on upscaled wafer
Precursors, Half-Cells, and BB5 Cells	~1000	CEA-INES	WP3.2 cut and edge repassivation trials
Shingle Production Batch#10	600	Not Shipped Yet	Waiting for WP5 Schedule / requests
Total	**8689**		

3.2. Production of IBC cells

3.2.1. Typical IBC cell production results

The production of IBC cells was done by smaller scale semi-automatic line. This line was not fully automated and involved significant manual handling. No inline testing tool was available for smaller scale line thus each produced cell had to be tested manually using an offline tool. Several batches of cells, of varying quality and electrical parameters, have been produced and shipped to partners in the HighLite project. The amount of cells produced in each batch varied from 95 to 1159.

The quality of manufactured cells was dependent on the quality of silicon wafers used. Due to the worldwide trend to switch production to larger size cells (M6 and higher) it was complicated to purchase small amounts of G1 size wafers, needed for the project. Silicon wafers of varying (and mostly lower) quality were purchased from several suppliers. No high efficiency cells could be produced from the lowest grade silicon wafers (bulk resistivity ~0.5 Ohm*cm). Silicon wafers with typical bulk resistivity of ~1 Ohm*cm were mostly used for the manufacturing. Typical batch efficiency distribution of such cells is represented in *Figure 8*. Only cells with efficiencies above 20% were provided to partners in T4.2 whereas lower efficiency cells were used for internal purposes. Highest efficiency IBC cells were produced using high quality precursors (bulk resistivity over 3 Ohm*cm), purchased from external sources. The average efficiency for this group was close to 22.0%. It is important to note that at the time of production of cells for the HighLite project, no sizeable amount of good quality G1 size silicon wafers could have been purchased and, thus, only average quality wafers were used. This limited the overall efficiency of produced IBC cells to values between 20.0% and 21.5%.

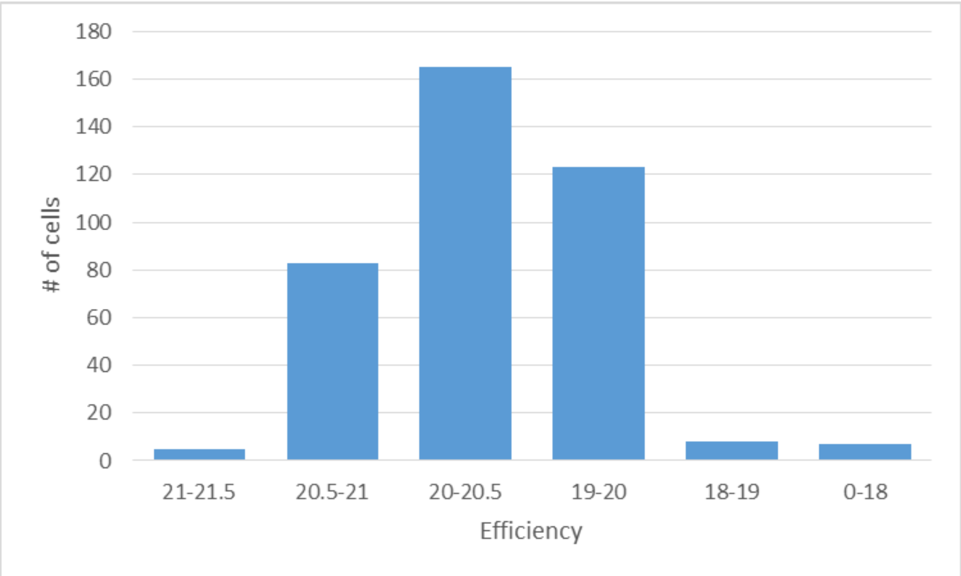

*Figure 8: Typical efficiency distribution of IBC cells, produced from medium quality silicon wafers (bulk resistivity ~ 1Ohm*cm), Batches outputs (~500 wafers production)*

3.2.2. Summary of produced cells

Table 3 summarizes the total amount of IBC cells generated by Valoe Cells and purchased externally that were shipped to partners in different work packages in M1-M24. This information was taken from the project internal shared website, in which tracking of produced, requested, and sent cells in regularly updated by all partners involved. The total amount of IBC cells, provided to project partners during M13-M24, was 5681. This number was higher than originally predicted and it helped to catch-up with the overall production of IBC cells, which was delayed in M1-M12. The overall number of available IBC cells was 9358 which was slightly lower than initially estimated (10000) and can be explained by lower-than-predicted demand of cells in T4.2 (Development of advanced equipment for assembly of IBC cut-cells), which was the main beneficiary of cells in M1-M24.

Table 3: Summary of the Zebra IBC cells produced for the Highlite project M1- M24.

Shipment	IBC cell description	**Cell efficiency [%]**	**Number of cells**	**Shipped to**
old	Produced in M1-M12	22.4-23.05	3677	WP3,WP4, WP5
1	M2 size cells , baseline process	17+	95	Valoe (WP4)
2	G1 size cells	22.0	170	Valoe (WP4&WP5)
3	baseline process	20-22	260	Valoe (WP4)
4	M2 size cells for cutting tool testing	17-21	650	Valoe (WP4)
5	G1 size cells for cutting tool testing	17-21	577	Valoe (WP4)
6	G1 size cells for cutting tool testing	17-21	696	Valoe (WP4)
7	G1 size cells, baseline process	18+	778	Valoe (WP4)
8	G1 size cells, baseline process	18+	996	Valoe (WP4)
9	G1 size cells for the production of BAPV modules	20+	1159	Valoe (WP4&WP5)
10	6BB Zebra IBC cells for the production of BIPV modules. Purchased from the third party.	23.5	300	Valoe (WP4&WP5)
	TOTAL		9358	

4. Risks encountered and expected impacts

4.1. Risks/problems encountered

No specific risk / problem was encountered for the SHJ production. Unavailability of high-quality n-type G1 size wafers at the time of making was a point of concern for the production of IBC cells. The Covid-19 lockdown did not impact significantly the production-line, and the delay due to the site closure was easily caught-up afterwards.

4.2. Expected impacts

The production of cells is very crucial to the overall success of HighLite project. In the first 24 months, task 3.1 was able to produce sufficient amounts of IBC and SHJ cells. Cells were produced in timely manner so project partners did not experience any delays in their activities.

5. Conclusions

Valoe Cells, ISC Konstanz, and CEA INES were responsible for manufacturing of IBC and SHJ cells that are required for the successful execution of planned tasks several work packages of HighLite project.

CEA-INES produced and shipped more than 8000 SHJ cells to different project partners. Most of produced cells had a metallization pattern dedicated to shingle assembly (in T4.1). Additionally, alternative cell configurations were also manufactured, especially for the cut step optimization and edge repassivation trials (tasks 3.2). Cells with different metallization patterns, were also produced and exchanged with partners, either for characterization Round-Robin (WP7) or IV tool set-up developments (WP3.5).

Valoe Cells, together with ISC, produced and shipped more than 9000 IBC cells to partners in WP4, WP5, WP6, and WP7. The number was lower than originally predicted but it fully satisfied the needs of project partners. Produced cells had a metallization pattern and screen-printing layouts optimized for assembly of ½ cut-cells, used in T4.2. Quality of manufactured cells varied. Only higher quality cells were used for the manufacturing of BAPV and BIPV modules. The rest of cells were used by partners for the testing of cell cutting tool and module assembly line.

The needs of project partners were monitored and fulfilled using online detailed tracking sheet available to all partners on the project internal website. From this list, it appears clearly that every request for IBC and SHJ cells was fulfilled successfully. Hence, t**he main goal of deliverable D3.4, the production of sufficient amount of SHJ and IBC cell precursors, was completed successfully.**

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[i] **Deliverable Type**
Please indicate the type of the deliverable using one of the following codes:
R Document, report
DEM Demonstrator, pilot, prototype
DEC Websites, patent fillings, videos, etc.
OTHER
ETHICS Ethics requirement
ORDP Open Research Data Pilot
DATA data sets, microdata, etc.

[ii] **Dissemination level**
Please indicate the dissemination level using one of the following codes:
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