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Sustainable Photovoltaics Integration in buildings and Infrastructure for multiple applications

SPHINX - Deliverable report

D4.1 – Design pilot line

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Version	Date	Editing done by	Remarks
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Content

1 Introduction

1.1 Location of the pilot line and a generic shingle matrix product

Deliverable D4.1 aims at describing the design and planning of a 20 MW pilot line for integrated photovoltaic products. The pilot line is located in the facilities of Fraunhofer ISE in Freiburg, Germany. The map in Fig. 1 shows approximately the location in Germany. Most machines of the pilot line are in the “Module-TEC” of Fraunhofer ISE. The building is shown in Fig. 2. As the department “Module Technology” moved into this building during December 2023, the condition of the tools and processes is still under construction.

Fig. 1: Location of Fraunhofer ISE in Germany

Fig. 2: Building in Freiburg, Germany, where the pilot integrated PV production line is located.

The pilot line of the SPHINX project is intended to produce integrated photovoltaic modules using the shingle matrix technology[1]. A module in the size of approximately 1,6 m² with this technology is shown in Fig. 3. The basic structure of this module in form of a cross section view is shown in Fig. 4, whereas one essential material, the bussing connector is missing in this figure.

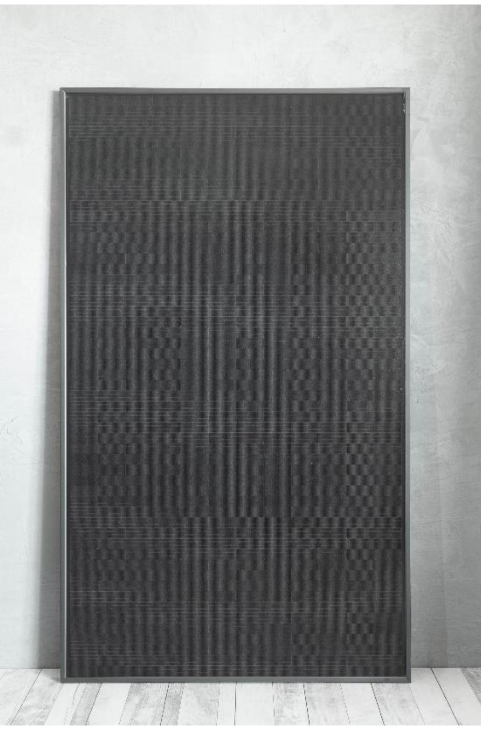

Fig. 3: Appearance of shingle matrix module of approximately 1,6 m² in size

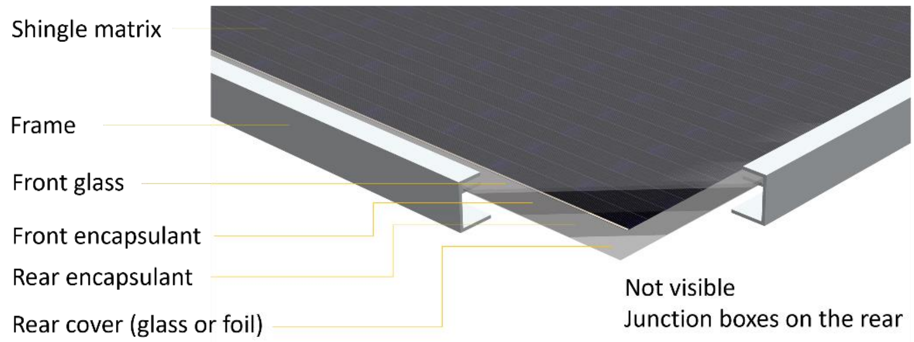

Fig. 4: Cross sectional representation of a shingle matrix modules and the individual components

[1] D. von Kutzleben, T. Rößler, M. Mittag, J. Weber, S. Sigdel, N. Klasen, P. Zahn, A. Kraft, and D. H. Neuhaus, "Development of Shingle Matrix Technology for Integrated Applications" in *8th World Conference on Photovoltaic Energy Conversion*, 2022.

1.2 Known limitations of the SPHINX pilot line

The pilot line is intended to encompass the process steps of solar cell preparation and characterization as well as module fabrication. Due to limited resources and the governing organizational structure of Fraunhofer ISE, the pilot line has certain limitations. It is important to understand the limitations in order to comprehend the decisions. Furthermore, the status of planning and machines available of today is different from what is forecast during the duration of the SPHINX project. Additional equipment not included in the SPHINX project that influence the design and throughput of the production line may become available within the next years.

Among the limitations are the different locations of some machines since they are organizationally linked to other units of Fraunhofer ISE (e.g. cell backend).

In addition, the department relies on providing a highly flexible module production and research beyond the scope of SPHINX, making some process steps not efficiently automatable (e.g. framing). The technical and scientific personnel of the institute have contracts based on the collective agreement. It is unclear whether shifting work to achieve the specified throughputs is contractually possible at all. That said, the throughput of the product line is likely limited by these factors.

2 Methods

The deliverable report explains the process steps of the Sphinx pilot line and current state of the machines. In the final version of the deliverable a simulation using Siemens Tecnomatix as indicated in Fig. 5 is planned. Furthermore, the pilot line assessment is aided by an ISE cost model called "SCcost."[2]

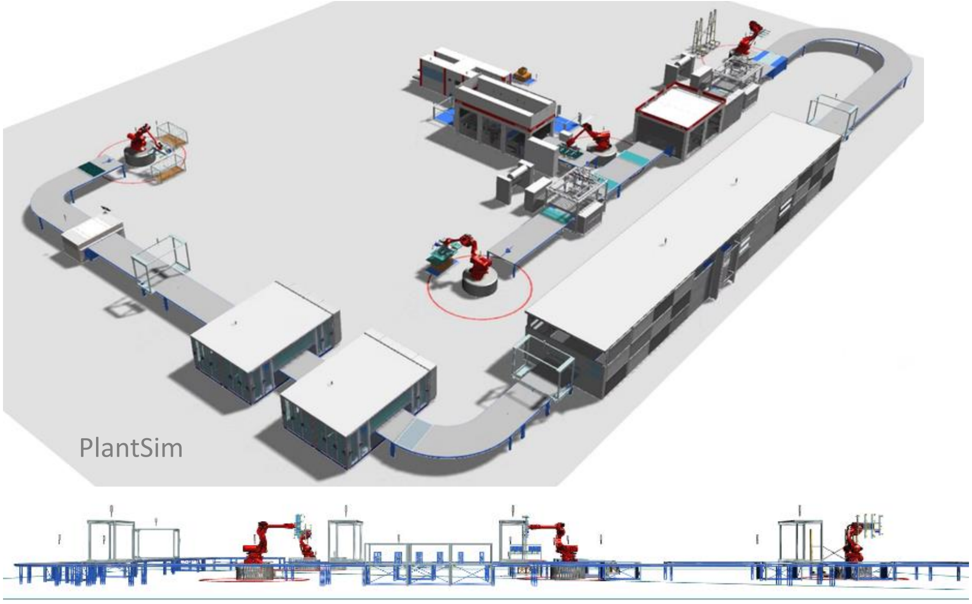

Fig. 5: Illustration of a "PlantSim" simulation of a photovoltaic production line using Siemens Tecnomatix

[2] Nold S., Techno-ökonomische Bewertung neuer Produktionstechnologien entlang der Photovoltaik-Wertschöpfungskette: Modell zur Analyse der Total Cost of Ownership von Photovoltaik-Technologien. Dissertation: Fraunhofer Verlag, 2019

3 Results & Discussion

3.1 Process steps for shingle matrix production

The essential process steps that the pilot line must encompass are shown in Fig. 6.

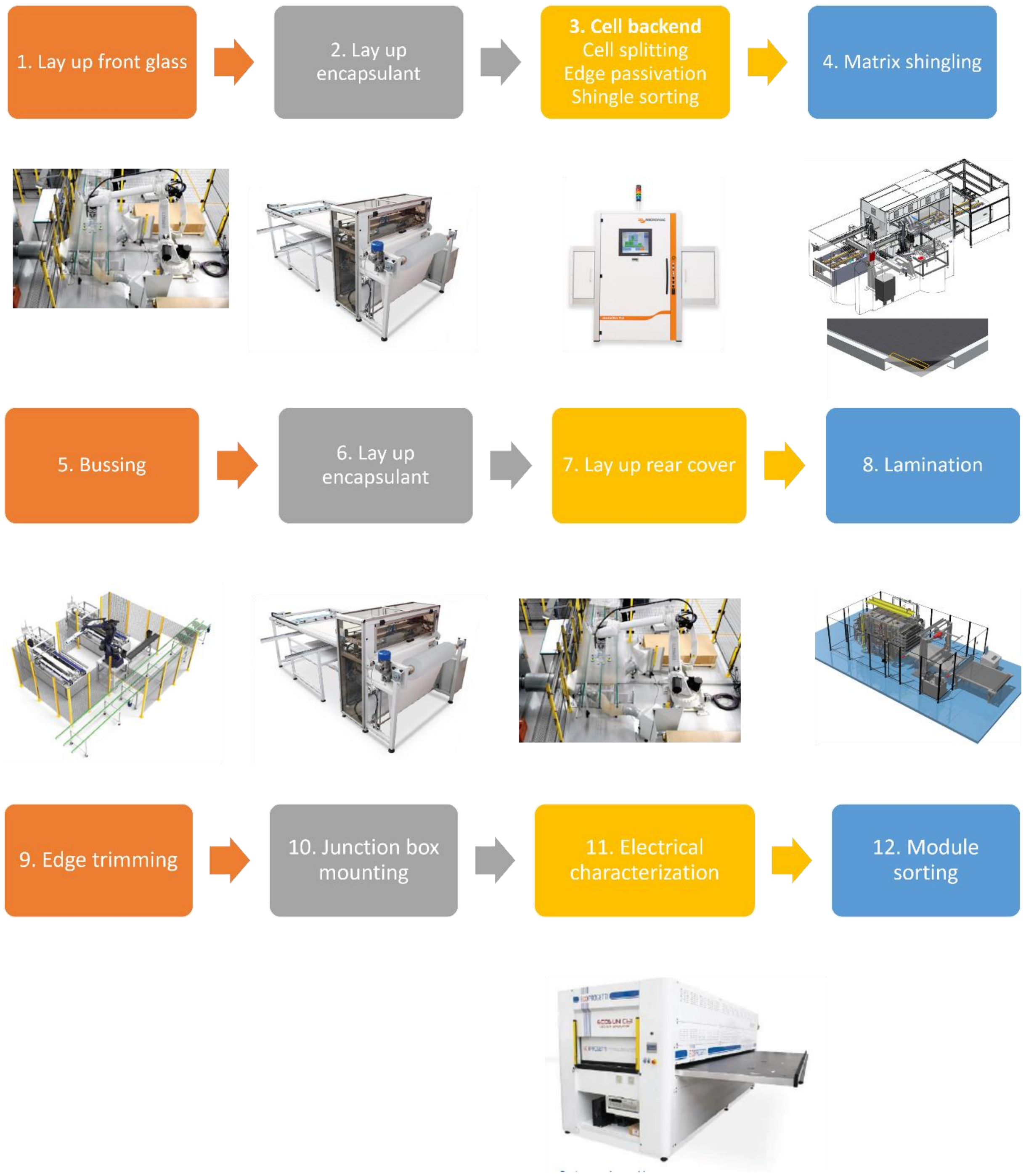

Fig. 6: Process sequence for fabrication of shingle matrix modules

The front glass of the PV device is loaded on a table or conveyor belt (1) and the front embedding film is positioned on the glass (2). Usually, step 1 utilizes a robot to move and position the glass. It is likely not possible – within SPHINX - to procure and install such a robot. Step 2 consists of an automatic foil cutting machine which will likely be available within Sphinx. Simultaneously, in step 3, the solar cells are prepared for processing in the module line, which is called the cell backend. The backend of the solar cells is divided into cell splitting, edge passivation, including annealing, shingle cell sorting. In the 4^{th} step, the matrix is assembled and bonded using the individual shingles. The process is done in the shingle matrix stringer.

Within the scope of SPHINX the machine called “Shirkan 1” is utilized. The “Shirkan 1” has throughput limitation with around 2800 shingles per hour. The industrial version of this machine is called “Surface” and commercialized by the company M10 Solar Equipment GmbH. The throughput is 12000 shingle per hour.

In step 5, bus connections to the matrix are established, with connectors directed to the junction box locations. Moving to step 6, the second layer of the embedding film is cut and placed onto the matrix. This is followed by step 7, where the rear glass or rear foil is cut and positioned.

Step 8 involves the lamination of the module, with a preceding electroluminescence inspection to ensure quality. The module edges are then trimmed in step 9.

Finally, in step 10, junction boxes are mounted, and frames are attached. The final module is characterized in step 11 by measuring the I-V characteristics and again electroluminescence.

The modules are sorted into different power categories according to their I-V characteristics.

3.2 Production line planning

In the overview of the production line in the Module-TEC at Fraunhofer ISE, as shown in Fig. 7, the main area measures 45 m in length and 30 m in depth. In addition to the module production facilities of the SPHINX production line, other facilities of the Module Technology department are located in these premises. The relevant stations for shingle matrix production are highlighted in colour in Fig. 7. One particular feature is station 1, the cell backend, which is currently not located on this site, and it is also unclear from a perspective whether it can be accommodated in the pilot line.

Many of the stations are predominantly manual, requiring a substantial amount of labour, yet offering considerable flexibility. Although certain key machines are either presently accessible or expected in the near future, full operational readiness for final characterization will take a few months from today. Presently, the constructed modules must undergo characterization either at the Callab Modules or at the facilities of a project partner. Tab. I summarizes the current status and near outlook of the process steps in the production line.

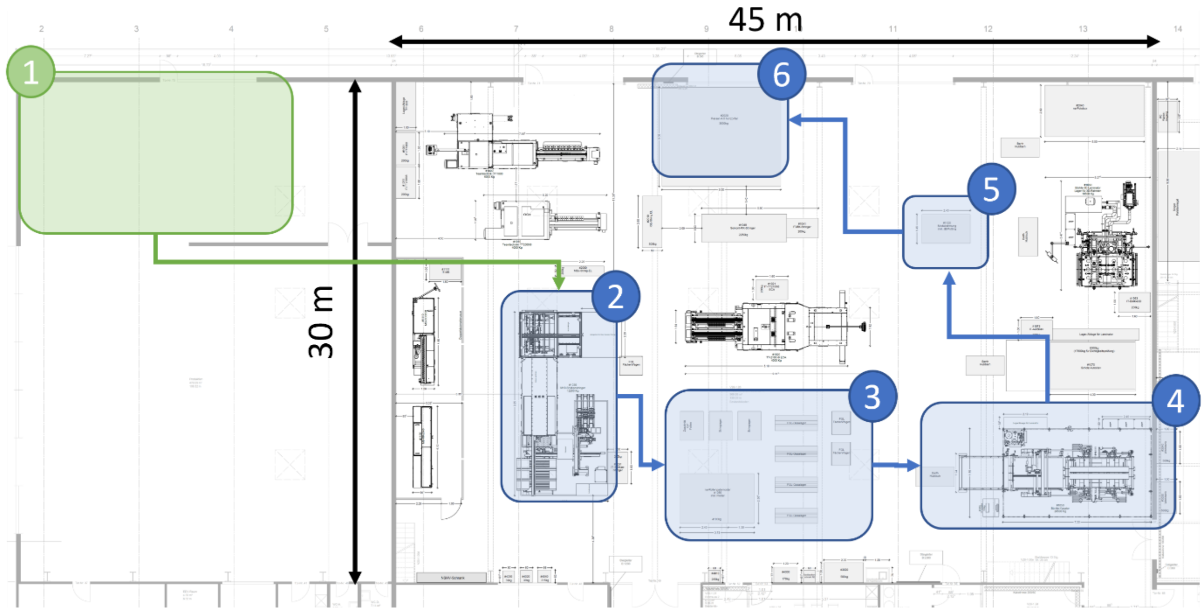

Fig. 7: Plan of the module production line

Tab. I: Current status of the pilot line's process steps

Location	Process step	Status by deliverable due date
1	Cell backend: Cell cutter, edge passivation and anneal, cell sorter, AGVs	External locations
2	Matrix shingle stringer	Running
3	Module layup area and bussing	Manual layup: Expected Q1 2024 Automatic: Expected Q3 2024
4	Lamination	Expected Q1 2024
5	Framing and junction box attachment	Manual: Expected Q1 2024 Automatic: Expected Q3 2024
6	Module tester	External location Our own tool: Expected 2025

At present, only a preliminary estimate of the pilot line's production capacity can be provided, under the assumption that the process steps occur in a shared production environment. It is crucial to reiterate that this condition does not reflect the reality. Furthermore, the estimation presupposes the theoretical operation of the line for 356 days a year, 24 hours a day. The outcomes of this approximation are detailed in Tab. II: Idealized and roughly estimated production capacity of the shingle matrix pilot line, indicating that, based on this estimate, lamination is the limiting process with a capacity of 22 MW per year.
Refinements to this approximation are planned for the final report of this deliverable.
Additionally, an initial draft of an SCost simulation for the production line has been conducted using preliminary input data. SCost, in general, enables a more detailed and realistic production capacity forecast. Enhanced results will be presented in the final version of the report.

Tab. II: Idealized and roughly estimated production capacity of the shingle matrix pilot line

Process	Designation	Idealized throughput per hour (pcs per hour)	Idealized capacity per year (MW per year)
1	Laser separation	12000 shingles	130
2	Edge passivation	37500 shingles	406
3	Shingle characterization	4000 shingles	43
4	Matrix shingling	2800 shingles	30
5	Bussing		260
6	Lamination	5 modules	22

4 Conclusion and Recommendation

In this report, we have presented a comprehensive overview of the current status of the SPHINX pilot line for the production of shingle matrix modules. The key machines are running after the move to the location in Freiburg Haid in the near future to support the project with shingle matrices as planned in the project.

5 Risks and interconnections

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
1	Equipment to be linked with an AGV is not or only to some extend available. Linking by AGV might be overengineered	3	3	If an AGV might be not feasible, the budget could be used to enhance throughput of the line on other process steps. Material budget might be then be required to be shifted to FhG ISE.
2	Throughput of 20 MW production line cannot be achieved. It is likely that a production-like environment (shift labour, 24/7 production) cannot be established at Fraunhofer ISE due to structural reasons.	1	3	We are optimistic to provide the planned number of modules in the project with the pilot line. Further investments in the production line and a "spin-out" is likely required, if economically feasible, to reach the desired capacity of 20 MW
3	Some of the planned process steps may not be technically available or with reduced capacity (e.g. cell splitting, bussing connection, module testing)	2	1	Planning of production ahead of time. Seeking alternative suppliers for process steps.

1) Probability risk will occur: 1 = high, 2 = medium, 3 = Low

5.1 Interconnections with other deliverables

The observed risks may interact with other deliverables in WP 4 such as D4.4 in which a reliable set of production data is required for the techno-economic analysis. If the machines cannot run in production-like mode, the data will likely be distorted and difficult to interpret.

6 Deviations from Annex 1

Presently, this deliverable report is preliminary. Particularly, we had to deviate from Annex 1 as we could not work on the Tecnomatix simulations of the pilot. This will be delivered during the review of this report.

7 Acknowledgement

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Project partners:

#	Partner short name	Partner Full Name
1	VOL	VOLTEC SOLAR
2	ETW	ETWAY S.R.L.
3	HLP	HELIUP
4	M10	M10 INDUSTRIES AG
5	UNR	UNIRESEARCH BV
6	Fraunhofer	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
7	ICARES	ICARES CONSULTING
7.1	BI	BECQUEREL INSTITUTE FRANCE
8	CEA	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
9	FSUNS	Freesuns SA
10	CSEM	CSEM CENTRE SUISSE D'ELECTRONIQUE ET DE MICROTECHNIQUE SA - RECHERCHE ET DEVELOPPEMENT
11	EPFL	ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE
12	SOP	SOPREMA

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