

Seamless-PV drives the implementation of new integrated photovoltaic (IPV) solutions in different market sectors. The objective is to develop advanced manufacturing equipment, processes and digitalisation strategies focusing on glass-glass lamination as well as lightweight composite and polymer-based technologies.

Facing at real industrial environments and different market demands and opportunities, Seamless-PV sets up six pilot line levels and 11 different IPV demo cases across Europe, divided between integration in noise barriers, buildings, electric vehicles, and agriculture.

The flexible pre-lamination machine: a step forward for integrated photovoltaics (IPV)

In this new Results summary, we talk about the results achieved through the collaboration between the partners CEA and Mondragon Assembly, this has led to realize a crucial demonstrator: the flexible in-line pre-lamination machine.



▲ Figure 1: View of the Machine tool at CEA's laboratory

The Technical Necessity: two-phase lamination

The fabrication of integrated photovoltaic modules requires highly customized solutions, which are difficult to mass-produce. The demonstrator was developed to improve production levels and it introduces a two-phase process:

- **Phase 1** (Pre-lamination): The machine creates PV pre-laminates or pre-encapsulated cell strings. These are intermediate components.
- **Phase 2** (Final integration): The pre-laminates are ready for subsequent integration or final lamination onto a wide range of substrates and shapes.

This division of the process aims to increase flexibility in the production of PV modules destined to integration in the built environment or any other suitable applications.

Design innovation: a "first-of-a-kind" prototype

The pre-lamination prototype, integrated equipment dedicated to flexibility, is considered "first-of-a-kind" in the field of flexible PV production.

Design inspiration: The tool is inspired by Roll-to-roll techniques typical of the polymer industry, but it has been adapted to handle materials with greater mass, such as crystalline silicon solar cells.

Operating principle: To ensure the stability of the cell stack during the process, a unique mechanism was implemented: the roller moves while the stack remains stationary.

Materials and length: It works on single strings of crystalline silicon solar cells, laminated with various encapsulating sheets. It can process strings longer than 1 meter.

Heating systems: Three different heat sources (radiant or conductive) have been implemented, with independent control via dedicated HMI commands.

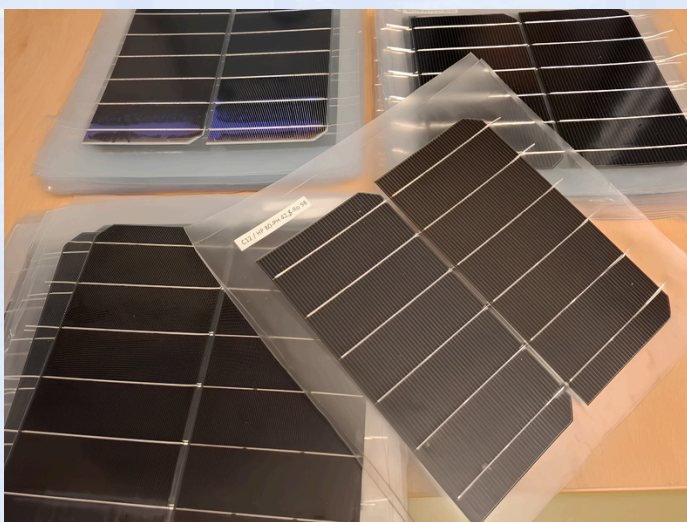
User interface (HMI): A touch-screen-based Human-Machine Interface (HMI) allows operators to create "recipes" to automatically control roller movement, speed, pressure, and the various heating systems.

Safety: Despite being a manual prototype, several safety features have been added. The tool is compliant with CE marking requirements under self-assessment, ensuring it can be used by qualified personnel.

Development and implementation

The tool was specified, assembled, and connected (electricity, compressed air) at the MASS workshop in Spain. Preliminary tests were conducted to evaluate conformity and the availability of sufficient power and control to produce the first pre-laminates.

Subsequently, the machine was installed at the CEA R&D laboratory in France. CEA researchers defined and optimized the pre-lamination process, studying the sensitivity of the results based on the temperature setpoints for the three heating sources. Different encapsulation materials have been screened to allow a stable and efficient production.



▲ Figure 2: Example of pre-laminates produced

Several dozen samples have been produced, and a process of record has been defined for the initial materials, consolidating CEA's capability to perform tests on this tool entirely dedicated to flexible PV production. Although the machine is compatible in terms of design and HMI software with an industrial tabber-stringer (provided by Mondragon Assembly), the loading and unloading operation remains manual in the current prototype phase, as the priority is on process control rather than increasing productivity.

The pre-laminates have been integrated in finalised PV modules, with glass/glass and glass/backsheet structures. Ageing tests have been carried on and passed according to IEC standards.

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