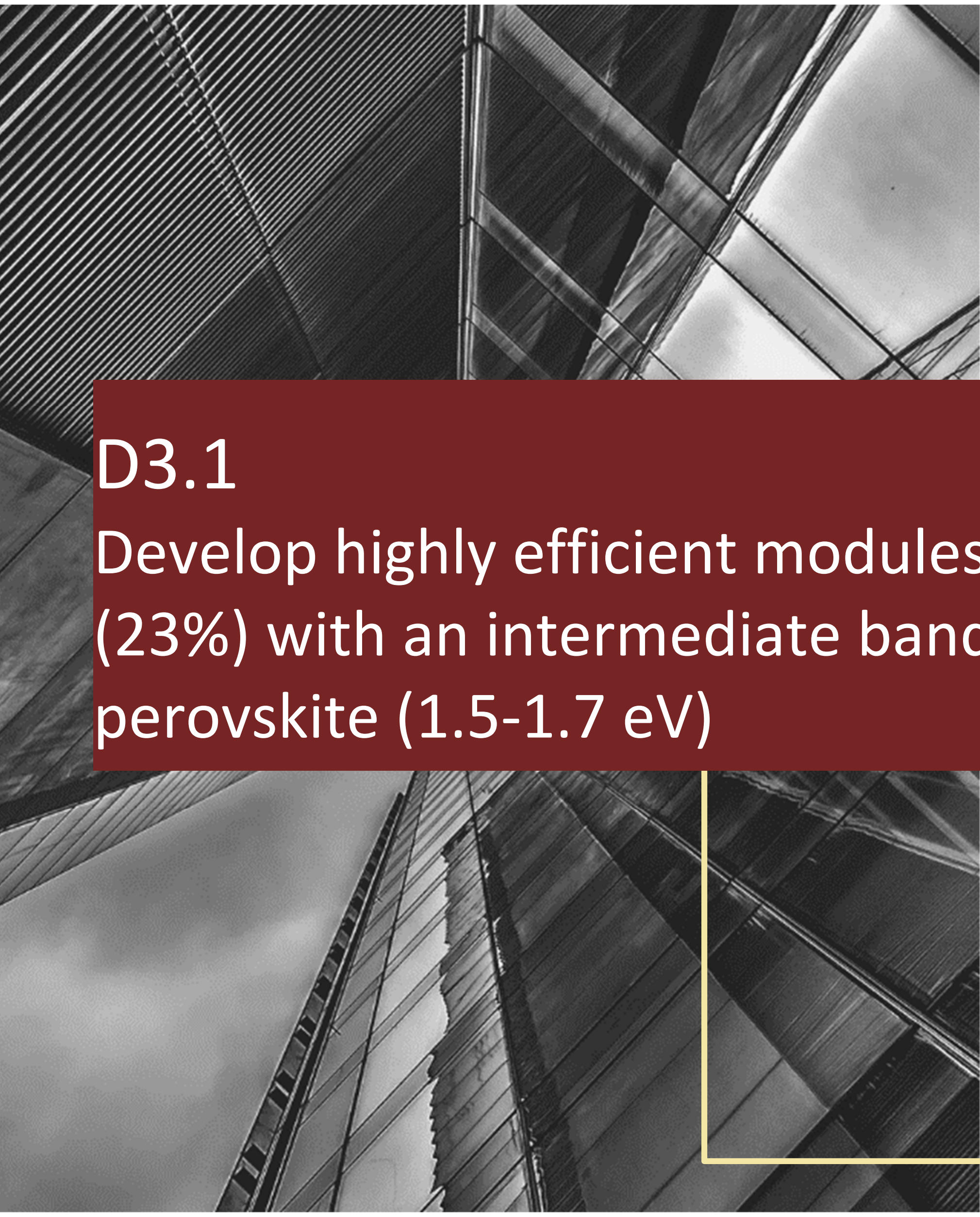
DELIVERABLE REPORT

VALHALLA



D3.1
Develop highly efficient modules (23%) with an intermediate bandgap perovskite (1.5-1.7 eV)

Deliverable D3.1
July-2025

PREPARED BY
CSEM
COORDINATED BY
UVEG

Funded by
the European Union

VALHALLA is a 3-year research and innovation project funded by the European Commission through the Horizon Europe Research and Innovation Action (RIA) grant N°101082176, responding to the call for a "*Sustainable, secure and competitive energy supply*" (HORIZON-CL5-2021-D3-03).

VALHALLA aims to develop perovskite solar cells and modules with power conversion efficiencies above 26 % (modules > 23 %) and extrapolated operational lifetime > 25 years, following an eco-design approach: employing harmful-solvent-free perovskite deposition, optimized use of materials, circularity, recyclability, scalable and low-cost manufacturing processes, to create a viable economic pathway for the European commercialization of this sustainable technology.

VALHALLA is formed by a multi-disciplinary consortium: 12 partners from 8 European countries; 3 industrial partners & 9 RTOs, covering the whole value chain of innovation from research centres to technology providers, end-users and market and policies.

Project info	101082176 – VALHALLA – (HORIZON-CL5-2021-D3-03)
Deliverable Title	D3.1 : Develop highly efficient modules (23%) with an intermediate bandgap perovskite (1.5-1.7 eV)
Lead Beneficiary	CSEM
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Approved by	Henk Bolink
Dissemination level	Public
Due date	31/07/2025
Submission date	04/08/2026
Version	V2
Linked to WP - task	WP3 – T3.1 Scaling up deposition methods up to 10x10 cm2 modules, T3.3 Encapsulation and T3.4 Performance assessment

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How to Cite
Adriana Paracchino, Quentin Jeangros (2025). Deliverable 3.1. Develop highly efficient modules (23%) with an intermediate bandgap perovskite (1.5-1.7 eV). in Project VALHALLA: Perovskite Solar Cells with Enhanced Stability and Applicability (No. 101082176). European Union. SENSITIVE/PUBLIC [Communicate on 04/08/2025].

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Abbreviations and acronyms list

Table 1. Abbreviations and acronyms list

Abbreviation	Meaning	Abbreviation	Meaning
STC	Standard Testing Conditions	FA	formamidinium
EDX	Energy dispersive x-ray spectroscopy		

1. Executive Summary

This deliverable is about showing a perovskite module demonstrator of active area 100 cm^2, with a target efficiency of 23% (power output of 23 mW/cm^2 in STC).

1.1. Description of the deliverable content and purpose

The objective of this deliverable is to demonstrate a 100 cm^2 module incorporating a perovskite absorber deposited either by sublimation or via a hybrid method. The hybrid approach involves sublimation of the PbI_2-CsBr layer followed by solution processing of the organohalide component. Due to limitations in our fabrication equipment, which restricts substrate size to 10 × 10 cm^2 for the laser scribing process, we assembled the ~100 cm^2 active area by electrically connecting nine individual minimodules (each 15.86 cm^2 on 5 × 5 cm^2 glass substrates) in parallel. Regarding the fabrication process, the uniformity of the sublimation process over a 15 × 15 cm^2 area—necessary to achieve an active area of 100 cm^2—was demonstrated in an internal deliverable at month 12 (D3.3-I). This confirmed homogeneity enables the fabrication of nine minimodules within a single sublimation batch.

For this deliverable we used a ~1.62 eV double-cation (Cs, FA), double-halide (I, Br) perovskite fabricated via the hybrid process at CSEM. This choice was motivated by the slightly higher efficiencies observed at the minimodule level compared to those achieved using the full sublimation process employed by UOXF and UVEG. This deliverable demonstrates two things: a) the possibility to interconnect cells on one substrate using laser-scribing methods and b) the interconnection between different substrates in a module.

2. Results

2.1. Module design and output

The interconnection with a parallel configuration of the module maintains the voltage output of a single minimodule (approximately 8 V), while the current outputs are added. In our design, each minimodule is directly connected to the busbars, allowing the current from each to be collected and summed at the busbar level. As a result, the current flowing through the series interconnection at the

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P2 laser scribe line remains unchanged with respect to the individual minimodule, thereby preserving the fill factor of the final module.

Figure 1 is a photo of the final module after some light soaking, showing early signs of light-induced degradation (yellowing).

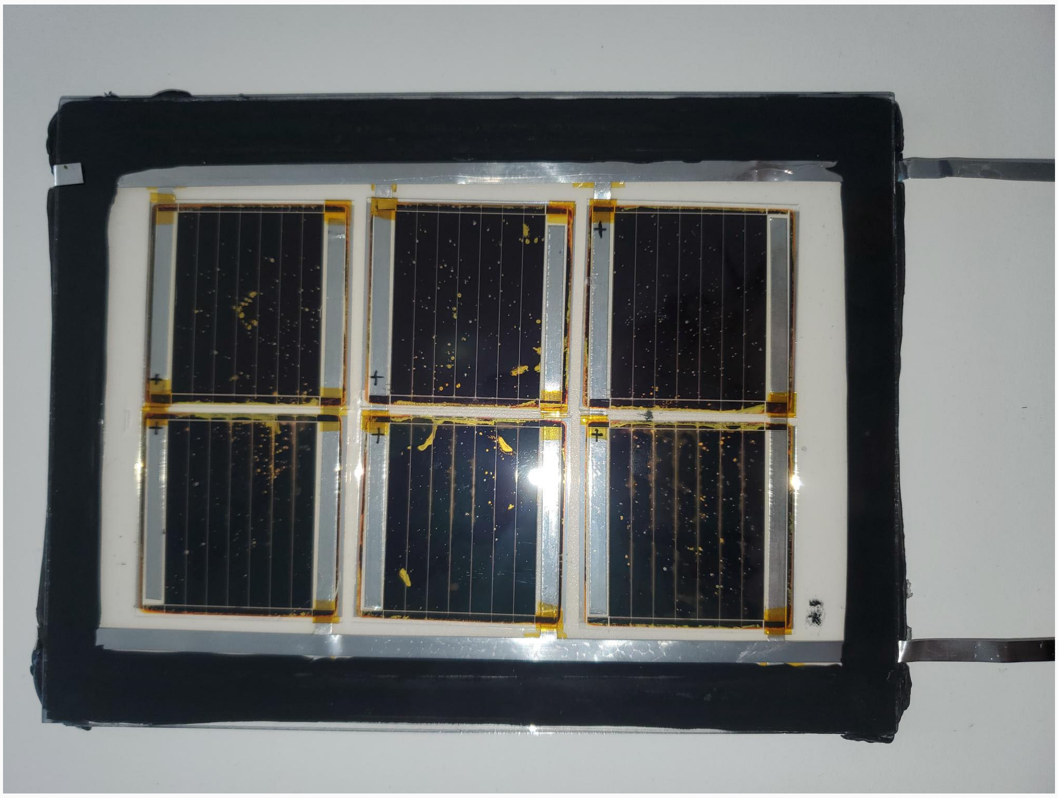

Figure 1 – A photo of demonstrator of 95.16 cm^2 active area obtained by connecting in parallel 6 modules of 15.86 cm^2 (on 5x5 cm2 substrates).

The individual perovskite minimodules exhibited efficiencies in the range of 15–16% prior to encapsulation. In the best-performing batches using the hybrid process, efficiencies reached up to 18%. Some batch-to-batch variability has been observed and is not yet fully understood. Notably, recent batches have shown the presence of ~100 µm-wide voids in the perovskite layer, which negatively impact the fill factor of the minimodules. Preliminary EDX analysis suggests that these crater-shaped voids may already be present in the inorganic template, and their origin is currently under investigation.

Following glass/glass encapsulation, the large module achieved a stabilized efficiency of approximately 14.6% (Figure 2). This moderate drop in performance is likely linked to the encapsulation process, which is carried out in ambient air and may be affected by elevated summer humidity. We hypothesize that early signs of degradation—such as yellowing—could be attributed to moisture trapped within the polyolefin encapsulant.

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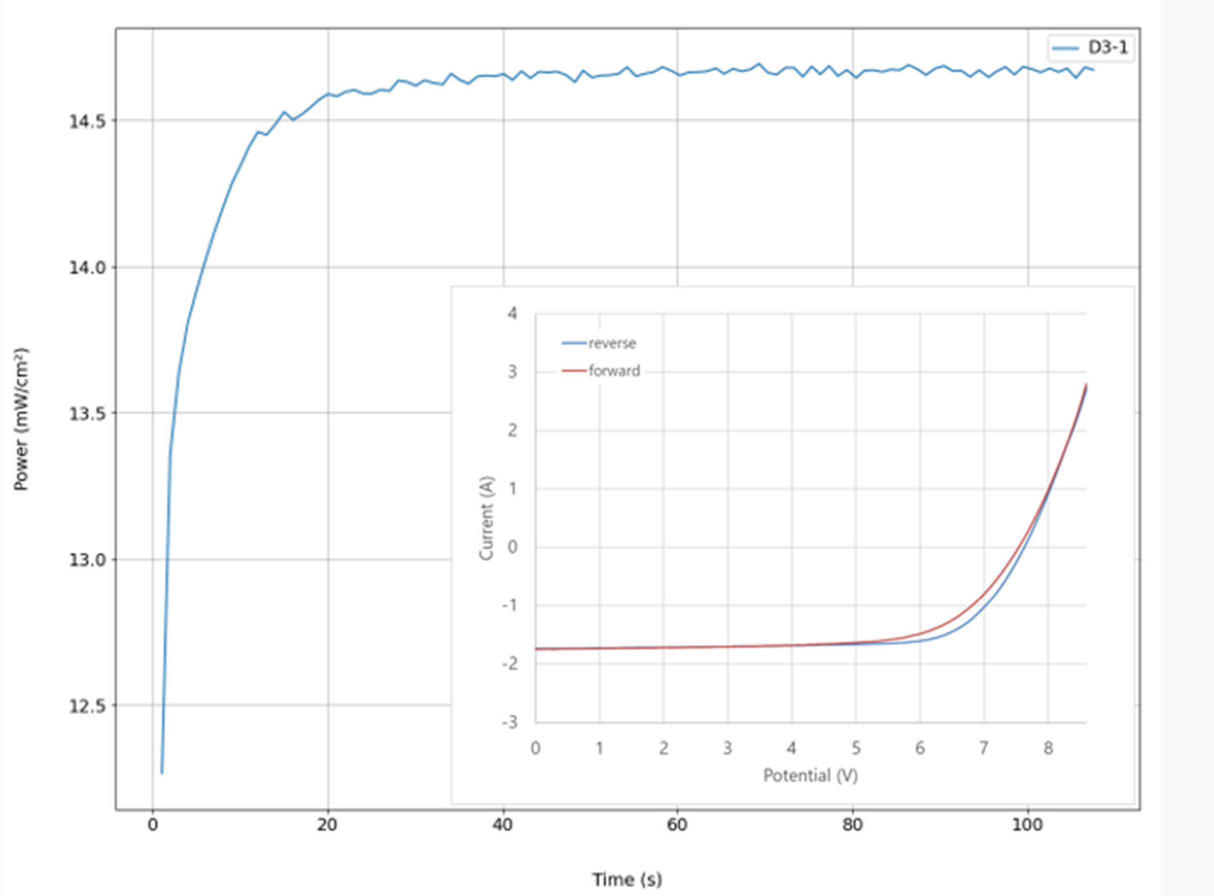

Figure 2 – Stabilized power output of the module of 95.16 cm2 and IV scans (inset).

2.2. Relation with other activities in the project

This deliverable relates to Task 3.1 (scaling up fabrication processes to 100 cm²) and Task 4.1 (outdoor testing of solar cells and modules).

Solar cells fabricated using the hybrid process in a humidity-controlled environment have demonstrated efficiencies around 18% and excellent outdoor stability. As reported in Deliverable D4.1, these cells showed no signs of degradation after 5 weeks of outdoor exposure and, remarkably, they still retain 90% of their initial power output after 15 months of continuous outdoor monitoring in Neuchâtel. The next step is to install hybrid-process modules outdoors in Catania and monitor their performance during the final months of the project, as part of Deliverable D4.2. This will support the demonstration of real-world TRL5 module stability. For D4.2, either individual minimodules or modules connected in parallel—such as those presented in this deliverable—can be used.

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3. Conclusions

In this deliverable, we demonstrated the possibility to interconnect cells on one substrate using laser-scribing methods and how to interconnect different substrates in a module. Scaling up the active area from 15.86 cm^2 to 95.16 cm^2 by connecting modules in a parallel configuration results in a moderate power output loss of less than 10%. This loss can be significantly reduced by interconnecting modules with optimized performance and by carefully controlling ambient humidity during the encapsulation process.

To this end, we will continue our efforts to fabricate higher-performing modules and further improve upon the results presented in this report. However, the main challenge in achieving 23% efficiency for modules with an active area of 100 cm^2 lies in the current performance of the 1 cm^2 cells, which still fall short of the 26% target. Given that scaling from 1 cm^2 cells to modules larger than 10 cm^2 typically incurs an efficiency loss of approximately 10%, improving the baseline cell efficiency remains a critical priority.

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