VIPERLAB

FULLY CONNECTED VIRTUAL AND PHYSICAL PEROVSKITE PHOTOVOLTAICS LAB

DELIVERABLE REPORT

D6.6 First draft of the Strategic Research and Innovation Agenda (SRIA) for European perovskite PV technology available

Version: 1.1
Date: 16.05.2023

FULLY CONNECTED VIRTUAL AND PHYSICAL PEROVSKITE PHOTOVOLTAICS LAB VIPERLAB

DELIVERABLE

D6.6 FIRST DRAFT OF THE STRATEGIC RESEARCH AND INNOVATION AGENDA (SRIA) FOR EUROPEAN PEROVSKITE PV TECHNOLOGY AVAILABLE

Project References

Project Acronym	VIPERLAB
Project Title	Fully connected **vi**rtual and physical **per**ovskite photovoltaics **lab**
Project Coordinator	Helmholtz-Zentrum Berlin
Project Start and Duration	1st June 2021, 42 months

Deliverable References

Deliverable No	D6.6
Type	Report
Dissemination level	Public
Work Package	6
Lead beneficiary	IMEC
Due date of deliverable	31.05.2023
Actual submission date	16.05.2023

Document history

Version	Status	Date	Beneficiary	Author
1.0	First Draft	10-05-2023	IMEC	Ivan Gordon
1.1	Review	15-05-2023	HZB	Natalia Maticiuc

DISCLAIMER

‘Fully connected virtual and physical perovskite photovoltaics lab' VIPERLAB is a Collaborative Project funded by the European Commission under Horizon 2020. Contract: 101006715, Start date of Contract: 01/06/2021; Duration: 42 months.

TABLE OF CONTENT

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

EXECUTIVE SUMMARY

The VIPERLAB project has committed itself to establishing a Strategic Research and Innovation Agenda (SRIA) for single-junction perovskite PV via the organization of three strategic workshops with all stakeholders. As starting point for the VIPERLAB SRIA, we took the chapter on single-junction perovskite PV from the recently published European Strategic Research and Innovation Agenda for Photovoltaics (EU-SRIA-PV)[1], drafted in 2022 by ETIP-PV and EERA-PV. At M24 of the VIPERLAB project, the first two workshops have been held and a first draft of the VIPERLAB SRIA for European perovskite PV technology is being drafted based on the outcome of those workshops. In this report, we describe the outcome of the two workshops in shaping the content of the VIPERLAB SRIA for perovskite single-junction PV technology.

The first strategic VIPERLAB workshop (D6.2) was organized in September 2022 as a parallel event to the WCPEC-8 conference in Milano, Italy. The approximate fifty attendees were mainly people belonging to the VIPERLAB stakeholder list, the VIPERLAB advisory board, the EERA-PV community, and the ETIP-PV community. This first workshop resulted in some clear recommendations to improve the content of the chapter on single-junction perovskite PV modules of the EU-SRIA-PV document. Moreover, it resulted also in the redefinition of three Key Performance Indicators listed for 2030.

The second strategic VIPERLAB workshop was organized on the 22nd of March 2023 during the "Energy Conversion and Storage Days" event organized by the Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany. The attendees were mainly people belonging to the VIPERLAB stakeholder list, the VIPERLAB advisory board, the (Perovskite) PV and the storage technologies research communities. This second strategic workshop (D6.5) succeeded in the identification of clear steps towards the definition of a unified roadmap and the definition of specific timelines for the three KPIs of the SRIA on single-junction perovskite PV modules, identified in the first strategic workshop.

The results of these two workshops together with the perovskite-PV chapter of the EU-SRIA-PV drafted by ETIP-PV and EERA-PV will form the basis of the VIPERLAB SRIA on single-junction perovskite PV. This VIPERLAB SRIA will be further fine-tuned in the final 18 months of the project via public consultations with stakeholders at various events and via the third strategic VIPERLAB workshop to be held in Q1 of 2024. This will result in the final version of the VIPERLAB Strategic Research and Innovation Agenda (SRIA) for European perovskite PV (D6.11) at M42 of the project.

[1] EU-SRIA-PV: The full document can be downloaded here: https://media.etip-pv.eu/filer_public/85/68/8568e2ee-ad42-4198-8211-27b703e15e1a/sriapv-fullreport_web.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

The results of the two workshops as well as the current status of the VIPERLAB SRIA have been also disseminated at the first public VIPERLAB event with industry and policy makers, scheduled in Brussels as part of the ETIP-PV conference on May 11, 2023[2].

1. Introduction

As part of the perovskite community building work, the VIPERLAB project has set itself the goal of developing and streamlining a European Research Area in the field of perovskite PV technology. One of the tools for achieving this is the creation of a joint European Strategic Research and Innovation Agenda (SRIA) for perovskite PV technology that will be widely accepted and supported by the European PV industry and research community. The VIPERLAB project has committed itself to establishing such a SRIA for perovskite PV by organizing three strategic workshops (one per year) where all stakeholders will be invited to come together with members of the VIPERLAB Consortium to work on such a SRIA.

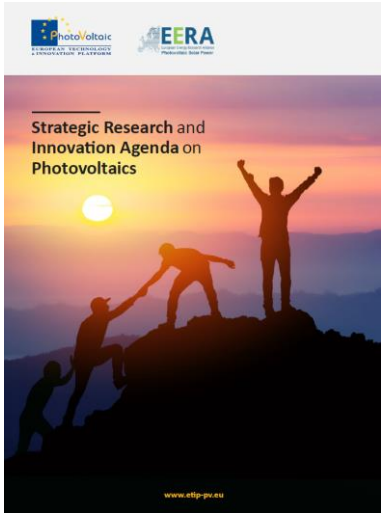

Figure 1. Cover of the EU-SRIA-PV document published by ETIP-PV and EERA-PV in May 2022.

At the start of the VIPERLAB project (June 2021), many of the consortium partners were involved in the drafting of the European Strategic Research and Innovation Agenda for Photovoltaics (EU-SRIA-PV) by ETIP-PV and EERA-PV. This EU-SRIA-PV document[3] was finalized after a public consultation and published in May 2022 (see Figure 1). It covers the whole range of photovoltaic science, technology, and applications in Europe, including but not limited to perovskite PV. The VIPERLAB consortium therefore decided to take the perovskite PV chapter of this EU-SRIA-PV as the starting point for its own VIPERLAB SRIA

[2] VIPERLAB First public event: https://www.viperlab-kep.eu/workshop.asp?i=26&t=VIPERLAB_first_public_Event

[3] EU-SRIA-PV: The full document can be downloaded here: https://media.etip-pv.eu/filer_public/85/68/8568e2ee-ad42-4198-8211-27b703e15e1a/sriapv-fullreport_web.pdf

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

for European perovskite PV technology. Moreover, the VIPERLAB consortium decided to focus its SRIA on single-junction perovskite PV technology.

At M24 of the VIPERLAB project, the first two workshops have been held and a first draft of the VIPERLAB SRIA for European perovskite single-junction PV technology is being drafted. In this report, we describe the outcome of the two workshops in shaping the content of the VIPERLAB SRIA for perovskite single-junction PV technology.

2. Outcome of workshop 1

The first strategic VIPERLAB workshop was organized in September 2022 as a parallel event to the WCPEC-8 conference in Milano, Italy[4]. The approximate fifty attendees were mainly people belonging to the VIPERLAB stakeholder list, the VIPERLAB advisory board, the EERA-PV community, and the ETIP-PV community. The program consisted of several introductory talks on the VIPERLAB project, the EU-SRIA-PV document, and the outcome of a prior VIPERLAB workshop on harmonization/standardization challenges for perovskites. These talks were then followed with some discussions in parallel groups on the content of the perovskite single junction module chapter of the EU-SRIA-PV.

KPI	Target Value 2030
LCOE (original)	LCOE of Pk-PV technology should be equal to or lower than that for c-Si
Efficiency (new)	Large-scale (> 1 m2) single-junction Pk-PV module demonstrators should be available with energy conversion efficiency above 23%
CO2 footprint (original)	The yield specific CO2 footprint of Pk-PV should be <80% of c-Si production and Pk-PV modules should be fully recyclable
CO2 footprint (remained)	The yield specific CO2 footprint of Pk-PV should be <80% of c-Si production and Pk-PV modules should be fully recyclable
Manufacturing (original)	Commercially available, Pk-based modules with an efficiency of > 23%
Manufacturing (modified)	Pk-based modules fully processed in Europe are commercially available and should comply with all European safety and toxicity rules across their whole life cycle

Figure 2. The original KPI's for perovskite PV by 2030 in red (as taken from the EU-SRIA-PV starting document) and the modified VIPERLAB KPI's in black.

[4] First VIPERLAB strategic workshop: https://www.viperlab-kep.eu/workshop.asp?i=9&t=1st_Viperlab__SRIA_Strategic_Workshop

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

The workshop resulted in some clear recommendations to improve the content of the chapter on single-junction perovskite PV modules of the EU-SRIA-PV document. In particular, we redefined the Key Performance Indicators listed for 2030 (see Figure 2). It also became clear from this workshop that further work is needed to add a clear timeline and clear priorities to this EU-SRIA-PV document for single-junction perovskite module R&D and this became the focus of the second strategic workshop.

3. Outcome of workshop 2

The second strategic VIPERLAB workshop was organized on the 22nd of March 2023 during the "Energy Conversion and Storage Days" event organized by the Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany[5]. Similarly, as the first workshop, this second workshop encouraged in-person attendance to perform round table discussions in small groups. In addition, a few participants attended the workshop virtually. In total around thirty-five people attended “in-person” and “online”. The audience consisted of people belonging to the VIPERLAB stakeholder list, the VIPERLAB advisory board, the (Perovskite) PV and the storage technologies research communities.

This second strategic workshop was a follow-up of the first strategic workshop (summarized above) and focused on the drafting of a roadmap and timeline to achieve the three identified KPIs for single-junction Pk-PV by 2030 as defined in the first strategic workshop.

The workshop succeeded in enabling the identification of clear steps towards the definition of a unified roadmap and specific timelines for the three identified KPIs of the SRIA on single-junction perovskite PV modules.

The outcome of the discussions in the break-out groups is summarized in this part. We divided the audience into three groups, each group focusing on defining a clear roadmap and timeline starting their discussion with one of the three identified KPIs of the SRIA (see Figure 2).

3.1 Large-scale demonstrators with efficiency > 23%

In this KPI, modules with stable efficiency above 23% on at least 1 m^2 area need to be established by 2030. Currently, large-area modules with 17-18% and small modules with 23% have been demonstrated, so this KPI seems feasible by 2030. However, one potential bottleneck might be that most perovskite-oriented companies in Europe are currently focused on tandem devices (e.g. Oxford PV).

The main challenge was defined as finding the right technology to perform a homogeneous large-area deposition which will be needed to achieve high efficiencies on large area. There

[5] Second VIPERLAB strategic workshop: https://www.viperlab-kep.eu/workshop.asp?i=24&t=VIPERLAB_roadmapping_workshop_for_perovskite_PV_technology_development_and_harmonization_in_Europe

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°101006715

are potentially several industrially viable technologies for this such as inkjet printing, slot-die coating, evaporation with linear sources, pulsed laser deposition for inorganic compounds, etc.

Therefore, a major intermediate goal that needs to be achieved before 2027 is to identify which of these large area deposition techniques can provide the required homogeneous growth of the perovskite PV layers on large areas. If no technique can be found for this, the back-up option will be to switch to cell-to-module fabrication for single-junction perovskite PV by growing the perovskite cell structures on smaller areas instead of directly at the module level size. This “plan B” would likely benefit from advancements in perovskite-on-silicon tandem technology.

Another point that should be carefully investigated is the stability of single-junction perovskite devices compared to tandem devices. Especially the reverse bias problems for single-junction perovskite might be more difficult to control.

Tool manufacturers in Europe will need to be involved from an early stage to ensure that we have suitable manufacturing tools for the emerging European PV perovskite industry that can enable manufacturing perovskite modules with efficiencies >23% reproducibly. The efficiency and size-related milestones were defined to enable reaching this KPI by 2030 (see Figure 3).

<table>
<tr><th>Year</th><th>Dimensions</th><th>Performance</th><th>Stability</th><th>Manufacturing</th></tr>
<tr><td>2023</td><td>2025 cm^2</td><td rowspan="3">18 % (mpp)</td><td></td><td rowspan="3">Focus on intrinsically scalable fabrication methods</td></tr>
<tr><td>2024</td><td rowspan="3">20 cm^2 x 20 cm^2 mini module</td><td>> 1000 hrs stability (based on T_{80}) demonstrated at:
85%rh/85°C
1sun/65°C</td></tr>
<tr><td>2025</td><td>20 % (mpp)</td><td rowspan="2">Demonstration of 1-year outdoor performance</td><td rowspan="2">Manufactured with scalable processes using green solvents</td></tr>
<tr><td>2026</td><td rowspan="2">22 % (mpp</td></tr>
<tr><td>2027</td><td rowspan="4">> 1 m^2 Module</td><td rowspan="3">23 % (mpp)</td><td rowspan="2">Ready for demonstration of 3-year lifetime</td></tr>
<tr><td>2028</td><td rowspan="2">Green manufacturing strategy for 1 m^2 module mass-production identified</td></tr>
<tr><td>2029</td><td rowspan="2">Demonstrated 3 yrs outdoor lifetime</td></tr>
<tr><td>2030</td><td></td></tr>
</table>

Figure 3. Efficiency and size-related milestones to enable reaching large-scale demonstrators with efficiency > 23% by 2030.

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N°101006715

3.2 CO_2 footprint smaller <80% of Si and fully recyclable

The following questions were identified that need to be answered in the SRIA for this KPI:
- Production: Should the CO_2 footprint be compared to c-Si fabricated in Europe or anywhere in the world?
- Production: What do current calculations/estimations take into account? Energy mix/source of the place of fabrication?
- Operation: How to factor in and reliably estimate the operational lifetime of perovskite PV?
- Recycling: Are there established recycling strategies? Who would be the recyclers, manufacturing industry or third parties? What are the incitements for recycling (toxicity but no significant monetary gain)? Will the industry have to come up with a "closed cycle" like the case of CdTe (FirstSolar)?

The following steps were identified that we can do within VIPERLAB to increase the success of reaching this KPI by 2030:

- **Step 1: Establish "state of knowledge"**
  Together with LCA experts (WP10) establish the current "state" of CO_2 footprint (and LCA) analysis and define the potential "lack of information" and needs for better estimation of CO2 footprint. What is the current state of knowledge?
  Recycling: here we might need to do an independent literature search and probably also reach out to Perovskite PV manufacturers to ask whether they consider this.

Question: How can LCA become a more integral part of the research process?
  - Initiate/prepare educational resources from WP10 as a starting point for more widespread education of PV scientists in LCA methodology.

- **Step 2: Define a "question catalogue"** regarding KPIs for Pk-PV defined in the SRIA to reach out to different stake-holders - especially industry - to gather more information.

- **Step 3: Define activities and resources that can be pushed/developed through VIPERLAB** that can contribute to enabling reaching and assessing the feasibilities of the KPIs.
  - Educational resources on KEP on LCA
  - JRAs of VIPERLAB generating output that can be collected/disseminated
  - Data infrastructure capturing full manufacturing, operation, and recycling potential of Pk-PV for better LCA

- **Step 4: Updated SRIA is ready by end of the VIPERLAB project** & identify strategy & stakeholders that can promote and continue to support the roadmap to ensure the Pk-PV KPIs get reached by 2030.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

Year	CO_2 footprint	Recyclability
2023	In collaboration with WP 10 of VIPERLAB: Compare LCA methods and difference in input parameters on predicted CO_2 footprint of Pk-PV compared to Si; define strategy to do reliable CO_2 footprint analysis including different global and regional scenarios.	Identify state-of-the art of recycling approached for Pk-PV and need for critical recycling steps
2024	By end of VIPERLAB: CO_2 footprint of Perovskite PV compared to competing technologies identified	By end of VIPERLAB: Needs, requirements and opportunities for module recycling identified
2025 2026 2027 2028 2029 2030	*Set target for CO_2 footprint of Pk-PV to be < 80% of Si will influence manufacturing approaches as well as required operational performance and lifetime of Pk-PV including end-of-life recycling.*	*Recycling concepts will be likely developed further by industry; yet unclear, which industry will be taking care of this; options are:* *- Module manufacturers* *- Recycling companies for other electronic devices* *- New specialized companies*

Figure 4. Yearly steps suggested to reach the milestone "CO_2 footprint smaller <80% of Si and fully recyclable".

3.3 Commercially available modules fully processed in Europe

By 2023/2024 a report on toxicity requirements and rules for perovskite PV should be published by the EC and this report should clearly state whether Pb is or will be allowed in PV Modules in Europe in the future. This will be crucial to determine the technology route of the perovskite-based PV technologies. More research is needed on toxicity issues and here VIPERLAB can help by updating the White paper on Pk-PV that was published in 2019 by EPKI[6]. Lead-free Pk modules are unlikely to be able to fulfil the "Commercially available modules fully processed in Europe" KPI by 2030. Therefore, public opinion is very important

[6] https://epki.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715

and the PV community needs to make sure that there is sufficient acceptance for a Pb-based product. We need a clear communication strategy for the advantages of the technology.
In-line Quality Control tools are required to achieve this KPI. An important question that needs to be addressed is how to better exploit synergies with tandem Si/PSK cells and modules.

Year	Toxicity	Deployment strategy
2023	Collect information on toxicity concerns and potential mitigation strategies	Develop unified communication strategies and initiatives to assess societal acceptance of Pb-based PV product development
2024	By end of VIPERLAB: Updating the White paper on Pk-PV that was published in 2019 by EPKI[7] including definition of measures to mitigate risks of Pb-based PV technology and development of societal acceptable perovskite PV products differentiating use cases.	
2025	*In case no alternative "Pb-free" materials identified, industrial deployment and large-scale utilization will depend on:* *- Product safety (Pb-leakage mitigation strategies)* *- use case (large-scale PV installations vs consumer products, space PV etc. …)* *- end of life recycling strategies*	
2026		
2027		
2028		
2029		
2030		

Figure 5. Yearly steps suggested to reach the milestone the "Commercially available modules fully processed in Europe".

4. Summary and outlook

The results of the two workshops held by the VIPERLAB consortium, summarized above, will form together with the perovskite-PV chapter of the EU-SRIA-PV drafted by ETIP-PV and EERA-PV the basis of the VIPERLAB SRIA on single-junction perovskite PV. This VIPERLAB SRIA will be further fine-tuned in the final 18 months of the project via public consultations with stakeholders at various events and via the third strategic VIPERLAB workshop to be held in Q1 of 2024. We aim to request feedback on the projected roadmaps and timelines from industrial stakeholders and will in particular contact the industrial companies represented in the advisory board of VIPERLAB. This will result in the final version of the VIPERLAB Strategic Research and Innovation Agenda (SRIA) for European perovskite PV (D6.11) that will be published at M42 of the project (November 2024).

[7] https://epki.eu/

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°101006715