FOTOPLAT

Hoja de ruta para la tecnología fotovoltaica

Contribución española 2016

Hoja de ruta para la tecnología fotovoltaica

Contribución española- Agosto 2017

Promueve

UNEF Unión Española Fotovoltaica

tecnalia

Financia

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

www.fotoplat.org

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1. Introducción

El trabajo de actualización de la hoja de ruta para la tecnología fotovoltaica en Fotoplat sigue las pautas trazadas en la primera versión del trabajo realizado en 2014, en la que se priorizó el alineamiento con las estrategias elaboradas a nivel europeo. Para ello, se asumieron como propios los planes de trabajo del *Joint Program in Photovoltaics* de la *European Energy Research Alliance (EERA-PV*), asegurando a través de las aportaciones de los socios españoles que la visión española quedaba bien reflejada en ellos.

También se trabajaron desde Fotoplat los objetivos estratégicos fijados finalmente en el documento "*SET Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV)*", que han servido de guía para la elaboración, por parte del *PV Temporary Working Group* creado para tal efecto, de un Plan de Implementación a nivel europeo, sobre el que Fotoplat viene realizando un estrecho seguimiento, con revisiones y aportaciones concretas.

En las próximas páginas se detallan los resultados de dichas actividades.

2. Hoja de Ruta para el Fotovoltaico – contribuciones de FOTOPLAT

2.1. Plan de trabajo para la Fotovoltaica Europea (EERA-PV)

El plan de trabajo de la EERA-PV se divide en ámbitos, coincidentes con los primeros cinco subgrupos de trabajo del grupo de Tecnologías de Fotoplat. Se puede decir que el trabajo realizado desde Fotoplat ha sido más que satisfactorio, al quedar incluidas la práctica totalidad de las aportaciones realizadas por instituciones españolas, por un lado, y al haber sido promotores de la necesidad de actualización del plan en algunos ámbitos, por otro. Prueba del protagonismo de nuestro país en la definición de la estrategia de la EERA-PV es que el subgrupo de Concentración Fotovoltaica haya estado liderado por el Instituto de Energía Solar de la UPM desde el principio (primero en la persona de Gabriel Sala y actualmente en la de Ignacio Antón), que el subgrupo de Sistemas Fotovoltaicos también cuente entre sus co-líderes con una persona de Tecnalia (Eduardo Román), y que también haya protagonismo español en la coordinación de tareas concretas definidas en algunos de los subgrupos.

En el anexo 1 se recogen los planes de trabajo de la EERA-PV tal y como están en la actualidad, que, como se ha explicado, son asumidos por Fotoplat como la hoja de ruta en la que trabajar en los próximos años.

2.2. Plan de Implementación en Fotovoltaica (SET-Plan)

Tras la definición de los objetivos estratégicos para el sector fotovoltaico europeo, fijados finalmente en un documento publicado en enero de 2016 con hitos de cara a 2020 y 2030 (*Declaration of Intent* para la PV), y que se incluye como anexo 2, se constituyó un Grupo de Trabajo Temporal en Fotovoltaica con la misión de definir un Plan de Implementación que fijase prioridades y líneas específicas de trabajo, tanto a nivel nacional como en el ámbito de la cooperación europea, con el horizonte del año 2020, con el objetivo de poder alcanzar los objetivos estratégicos ya adelantados en la *Declaration of Intent*.

Dicho grupo consta de veintiocho personas, entre representantes de los países miembros interesados (España está entre ellos), de la industria y de asociaciones europeas relacionadas con el sector (la *European Technology and Innovation Platform* – Photovoltaics ETIP-PV, la ya mencionada EERA-PV, principalmente), entre las que se encuentran Inmaculada Figueroa, del Ministerio de Economía y Competitividad, en coordinación con Pilar Gómez de CDTI, y Emiliano Perezagua, de Consultores de Energía Fotovoltaica SL. Con ambos se ha mantenido una estrecha comunicación desde Fotoplat, ofreciendo apoyo en la definición de líneas de trabajo y su priorización. Este trabajo de seguimiento se ha realizado a partir de debates en el seno del Grupo de Tecnologías de Fotoplat, comunicaciones por correo electrónico con todos los socios, no sólo los miembros del Grupo de Tecnologías, e incluso un debate en la propia Asamblea anual de Socios.

En la tabla 1 se listan las prioridades resultantes de los debates mencionados, que se trasladaron al *Temporary Group*, incorporándolas a sus debates.

Target 1: To propose a set of high efficiency photovoltaic technologies exploring their technical and economic viability:

1. High efficiency silicon based tandem solar cells (combining with III-V semiconductors, thin films or perovskites) and novel structures for high efficiency solar cells (i.e., intermediate band solar cell, silicon-heterojunction and back-contact cells, heterostructure transistor-type solar cells,…)
2. Advanced CPV solar cells, modules and trackers (cost-effective 4 to 6 junction solar cells, improved optics, optimal thermal management, development of characterization tools for industrial production, standardization needs,…)

Target 2: Reduction of the system cost by covering the different steps in the value chain

3. Silicon feedstock: Very low cost metallurgical silicon solar grade with quality enough to obtain cell and module efficiencies similar to those using conventional polysilicon
4. Development of new-generation thin crystalline silicon devices by combining epitaxy and other kerf-loss technologies, such as liquid-phase laser-crystallised silicon on glass with advanced solar cell processing such as silicon-heterojunction emitters and back-contact schemes.
5. Manufacturing processes of PV modules with new materials aiming at LCOE reduction: reduced lamination time and temperature, encapsulation with thermoplastic polyolefins
6. Research on low-cost and high-performance BOS elements (next generation of PV inverters, integration of electronics into the modules,…).

Target 3: Further enhancement of lifetime, quality and sustainability:

7. Reduction of Operation & Maintenance (O&M) costs and improvement of PV yield by implementing new techniques (Data mining for diagnosis, prognosis and forecast, Short term forecast of production, Computer vision on board Unmanned Aerial Vehicles,…) and developing advanced quality control procedures
8. Manufacturing processes and designs of PV modules with new materials aiming at a reduction of the environmental impact and an increase of their recyclability

Target 4: Enabling mass realisation of "(near) Zero Energy Buildings" by Building-Integrated PV (BIPV)

9. Further development of integrated building-PV software simulation tools to support the early design phases.
10. Development of advanced PV building components by applying added-value concepts such as flexible and/or semi-transparent module elements.
11. Improved module architecture for BIPV applications: light management strategies, module materials optimization (glass, encapsulation materials, coatings…), implementation of latest cell technologies, including bifacial solar cells

Target 5: Major advances in manufacturing and installation

12. New strategies of interconnection technologies for several cell technologies (lowering costs of materials and processes).
13. Outdoor plug&play energy conversion and management modules, augmented reality tools to help during installation and operation stage

Tabla 1. Prioridades de I+D para España en el marco del Plan de Implementación Europeo, atendiendo a los objetivos establecidos en la Declaration of Intent

En una segunda fase y tras recoger las aportaciones de todos los países y representantes implicados, el Temporary Working Group propuso seis actividades, en las que se sigue trabajando actualmente, cuya breve descripción se muestra en la tabla 2.

Nº	Type of activity	Description
1	**PV for BIPV and similar applications**	This proposal aims at developing a market pull approach for innovative and integrated PV solutions that will allow a faster market uptake of new PV technologies and a more intensive and multi-functional use of the available surface area in Europe, including quality and reliability. On the one hand, for BIPV it seems likely that thin film technologies (especially CIGS) are well suited. Therefore, a combined development of thin film and BIPV is suggested. On the other hand, BIPV solutions based on other PV technologies can also offer attractive solution. Sub-activities could cover bifacial applications and PV installations on roads & waterways.
2	**Technologies for Silicon Solar Cells and Modules with higher quality**	Silicon wafer based PV holds by far the highest PV market share. The aim of this activity is to implement advanced laboratory technologies for high-performance silicon-based cells (≥24%) and modules in high-throughput industrial manufacturing processes, materials and equipment, including quality and reliability. This will also support the European PV industry to strengthen its global position. Sub-activities could cover PERX and HJT technologies as well as bifacial applications and environmental aspects.
3	**New technologies & materials**	Crystalline silicon based solar cells as well as some thin film technologies are gradually reaching their theoretical efficiency limit. The most promising approach (at least on the short and medium term) to go beyond this limit are tandem technologies. One option is III/V-semiconductor or perovskite top cells on silicon bottom cells. Another option is a stack of two thin-film cells. A third route is the development of cost-effective concentrating PV (CPV). The aim of this activity is to bring these technologies to an economically feasible level. Therefore the cell processing needs to be scaled on industrial level and the cost needs to be reduced. New materials and the combination of two cell technologies need new interlayer development. Also the stability needs to be enhanced (or maintained if already sufficient). In the end the environmental impact of these new materials needs to be evaluated including quality and reliability.
4	**Development of PV power plants and diagnostic**	The aim of this activity is to develop and demonstrate business models and streamline the processes for effective operation and maintenance of residential and small commercial plants in order to keep the plant performance and availability high over the expected lifetime. Especially advanced monitoring is key, due to

		incompatibility and the accompanying extra costs this is often not done according to good industry practices.
5	**Manufacturing technologies (for cSi and thin film)**	A further reduction of costs for silicon wafer based PV and thin film technologies will rely on the implementation of high-throughput industrial manufacturing processes. Advances in this field will also strengthen the European manufacturing industry. Sub-activities could cover aspects of Industry 4.0.
6	**Cross-sectoral research at lower TRL**	With respect to high level R&D, European research labs are still the leading institutions worldwide. A closer cooperation of these labs could help maintaining this position in order to support European industry with cutting edge research results. On a topical level activity 6 covers all the other activities selected by the TWG PV.

Tabla 2. Actividades definidas por el PV Temporary Working Group para el Plan de Implementación

En el anexo 3 se incluyen algunos de los documentos de detalle de dichas actividades, básicamente aquellos en los que se está haciendo más seguimiento desde Fotoplat. Junto con la descripción de los principales objetivos y actividades propuestas, se detalla una propuesta de financiación de dichas actividades, principalmente a través de programas nacionales de ayuda a la I+D+i.

Este documento del anexo3 está datado en Agosto 2017. Actualmente se está trabajando en la versión definitiva del Implementation Plan, que se hará pública próximamente y se realizará una nueva versión del presente documento.

ANEXO 1 Description of Work (DoW) of the Joint Programme on Photovoltaic Solar Energy (Planes de trabajo de la EERA PV)

Description of Work (DoW) of the Joint Programme on *Photovoltaic Solar Energy*

Version: 2017-1.1

Last modification date: 16.01.2017

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SUMMARY OF THE JOINT PROGRAMME ON PHOTOVOLTAIC SOLAR ENERGY

Within the framework of the European Energy Research Alliance (EERA), a joint programme on Photovoltaic Solar Energy (EERA-PV) is running that is based on the Integrated SET plan and aims to contribute to a large extent to the R&D needs of the European Solar industry regarding the cost reduction of PV systems and solar electricity.
EERA-PV is set up to increase the effectiveness and efficiency of PV R&D through alignment and joint programming of R&D of its member institutes.

The EERA-PV joint programme has a broad scope and covers the following research areas:

- Silicon Solar cell Technology, including materials, cells and modules
- Inorganic Thin film PV
- Organic PV and organic-inorganic hybrid technologies such as perovskites
- Concentrated PV (CPV)
- PV systems and applications
- Mobility and Training and use of Infrastructures

1. Vision 2020 - 2030

The European Energy Research Alliance (EERA) is an alliance of European public research centres and universities. It is one of the cornerstones of the European Strategic Energy Technology Plan (SET-Plan). EERA brings together more than 175 research centres and universities. Actively working together on 17 joint research programmes, they build on national research initiatives. In a Joint Programme, research organisations in different European countries work together on shared priority setting and research projects. The EERA Joint Programmes are aligned with the priorities for low carbon technologies defined in the SET-Plan.

The key objective of the European Energy Research Alliance (EERA, www.eera-set.eu) is to accelerate the development of new energy technologies in support of the Strategic Energy Technology (SET) plan by pooling and integrating activities and resources, combining national and Community sources of funding and maximising complementarities and synergies. EERA aims to strengthen, expand and optimise EU energy research capabilities through the sharing of world-class national facilities in Europe and the joint realisation of pan-EU programmes. The EERA Executive Committee has identified Photovoltaic Solar Energy as one of the priority research areas for joint programming.

The EERA Joint Programme on Photovoltaic Solar Energy aims to increase the efficiency and effectiveness of research in the area of photovoltaics. The programme covers relevant research aspects including cost reduction (materials as well as manufacturing), efficiency improvement and increase of lifetime and reliability. EERA-PV covers several PV technologies such as crystalline silicon (i.e. wafer-based) solar cells, inorganic thin-film solar cells, organic PV, organic-inorganic hybrid technologies such as perovskites and concentrated PV. In addition, aspects concerning systems, specific applications and services are put in focus as well as mobility and training of researchers.

This programme strongly links to existing and emerging initiatives such as the European Technology & Innovation Platform PV (ETIP PV), various stakeholder groups as well as the Horizon 2020 programme. Important documents such as the Strategic Research Agenda, the Implementation Plan of the Technology Platform, the Integrated Roadmap as well as the Issues paper No. 2 have been used to identify and discuss the priority areas of interests with the key stakeholders.

This joint programme is based on a long term research strategy (2010 – 2020), derived as a starting point from the Strategic Research Agenda of the European Photovoltaic Technology Platform, (see **¡Error! No se encuentra el origen de la referencia.**) and adjusted to the Integrated Roadmap as well as the Issues Paper No. 2, Initiative for Global Leadership in Photovoltaic (PV) Solar Energy.

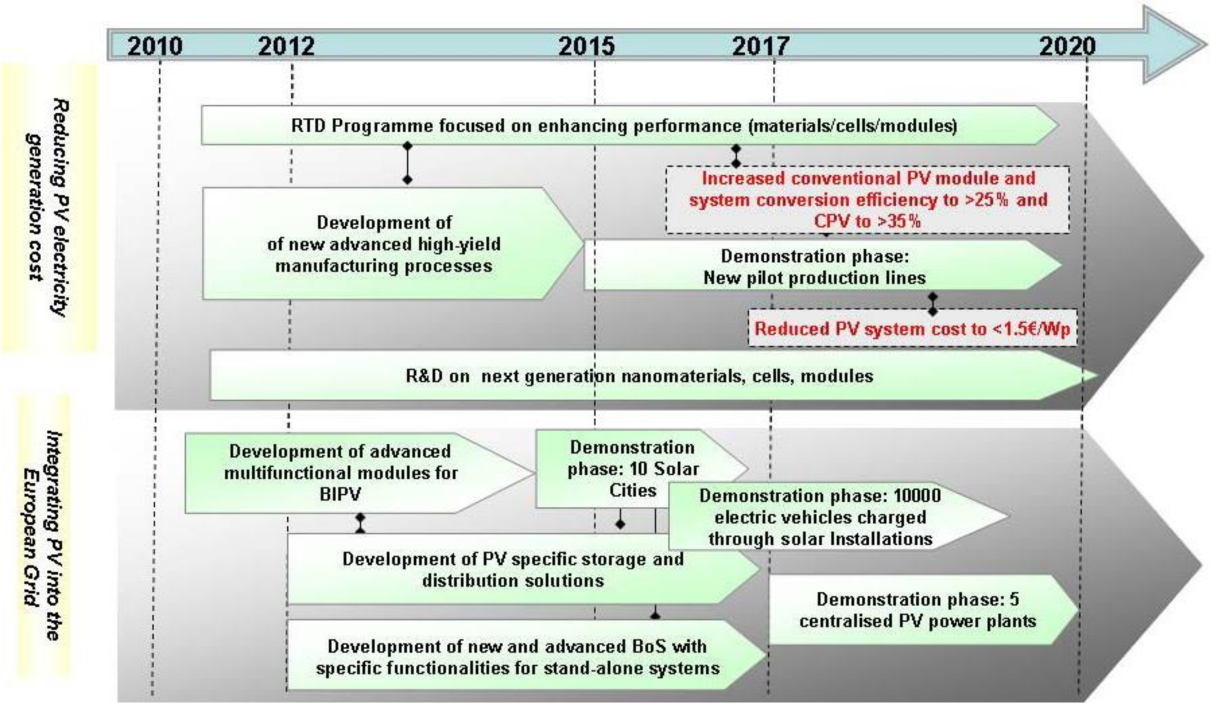

Figure 1 **Indicative roadmap for PV**

As a result, the following research areas have been selected for joint programming activities:

- Silicon Solar cell Technology, including materials, cells and modules
- Inorganic Thin film PV
- Organic PV and organic-inorganic hybrid technologies such as perovskites
- Concentrated PV (CPV)
- PV systems and applications
- Mobility and Training and use of Infrastructures

It means that now, this Joint Programme covers most aspects of solar photovoltaics, along the value chain from solar cells to modules and systems for several applications. Downstream the value chain, the objectives are to offer new integrated services and cost efficient solutions for the European citizen.

Finally, the EERA Joint Programme on PV complements the Integrated Research Programme (IRP) on Photovoltaics (of which the project acronym is CHEETAH), which was submitted in January 2013 in response to the IRP call and started beginning of 2014 for a duration of 48 months. A high number of EERA PV members are partners of this CHEETAH project, which falls into the category of Coordination and Support Action and Collaborative Project (**CSA-CP**), combined in a closely co-ordinated manner:

- Integrating activities to lay the foundations for long-lasting research cooperation,
- Exchange of researchers,
- Joint activities to foster the use of existing research facilities
- Joint research activities,
- Transfer of knowledge activities

2. Added value

The EERA Joint Programme on PV provides added value through strategic leadership and by speeding up the realization of SET-plan goals.

Strategic leadership
Aligning the research activities of the participants fosters strategic leadership internally as well as externally. Internal effectiveness and efficiency are created by increasing common understanding among participants. The foreseen activities include exchange of information in workshops and through round robin testing, the design of standard procedures, protocols, and methodologies, the setting-up of expert-based joint white papers, research agendas and technology overview, in particular with a focus on the identification of topics for research funding.
Improved common understanding allows the participants to develop a clear vision on applications of current research and the needs for future research. An appropriate interface with industry to exchange needs and visions on (the applications of) pre-commercial research is built into the structure of the programme. A dialogue with government bodies is ongoing to communicate future research funding needs.

Speeding up the realization of SET-plan goals
The programme is built on other SET-plan initiatives. The Strategic Research Agenda and the Integrated Roadmap form the starting point for the discussion on priority areas. This close match optimizes the programme's impact and is a requirement to boost the impact of PV on electricity production. The programme is complementary, as it focuses on precompetitive, medium- to long-term research, and shares the ETIP PV objective of lowering the costs of electricity generation.

3. Objectives of the Joint Programme on Photovoltaic Solar Energy

The European Commission has challenged the PV community to set new, ambitious and EU-relevant targets for 2020 and beyond, in particular concerning the implementation of the Integrated Roadmap.

Recently the PV stakeholders together with the European Commission outlined strategic targets for PV solar energy in the issues paper No. 2. EERA-PV has been an integral part in defining the corresponding R&I actions and is targeting to contribute to these goals and to developments beyond 2020 through Europe-wide programming and aligning of R&D activities in member states. The objective of EERA-PV is to accelerate the development of Photovoltaic Solar Energy to an energy technology that can be implemented at a very large scale by key research institutes in Europe. The PV industry needs developments regarding reduction of electricity generation costs as well as the integration into the electricity infrastructure. EERA-PV focuses primarily on cost reduction of PV systems, through enhancement of performance, development of low-cost, high-throughput manufacturing processes, and improvement of lifetime and reliability of PV systems and components. The programme is broken down into six sub-programmes, for which the following main goals have been set:

Silicon Technologies
- Development of silicon for very high efficiency solar cells
- Development of feedstock and wafers from upgraded metallurgical grade (UMG) silicon

Thin-Film Photovoltaics
- Enhancement of efficiency leading to improved performance-to-cost ratio of 0.5 €/Wp
- Development of new materials and technologies for very low-cost, large-area modules
- Development of high-yield, high-throughput manufacturing technologies

Hybrid and Organic Photovoltaics
- Laying foundation for improving performance and lifetime of OPV devices
- Increase effectiveness and efficiency of OPV R&D through building a library of materials and developing common protocols for screening of materials

Concentrated PV
- Development of
-

PV systems
- Development of

Education and Training and use of Infrastructures
- Optimize use of EERA R&D facilities through easier access for partners
- Identify needs for new or upgraded R&D facilities
- Promote exchange of researchers in joint programmes

4. List of milestones 2017-2020

5. Participants

		Total	SP1			SP2	SP3	SP4	SP5	SP6
			1.1	1.2	1.3					
AIT	Austria									
CEA-INES	France									
CENER	Spain									
CHOSE	Italy									
CIEMAT	Spain									
CNRS	France									
CRES	Greece									
CREST	United Kingdom									
DTU	Denmark									
ECN	Netherlands									
EMPA	Switzerland									
ENEA	Italy									
EPFL	Switzerland									
Fraunhofer - ISE	Germany									
FZ Jülich	Germany									
Günam - METU	Turkey									
HZB	Germany									
IFE	Norway									
IHT - RWTA Aachen	Germany									
IKZ	Germany									
IMEC	Belgium									
LNEG	Portugal									
NPL	United Kingdom									
SINTEF	Norway									
Tallinn Univ.	Estonia									
TECNALIA	Spain									
TUBITAK	Turkey									
University Milano-Bicocca	Italy									
Univ. Utrecht	Netherlands									

UPM	Spain									
UPVLC	Spain									
VTT	Finland									
ZSW	Germany									

SP1 = silicon technologies
SP2 = (inorganic) thin film PV
SP3 = hybrid and organic PV
SP4 = concentrated PV
SP5 = PV systems
SP6 = education and training and use of infrastructures

6. Infrastructures and facilities

The use of infrastructures and facilities is, together with Education, Mobility and Training, a specific activity in the Joint Programme (SP6).

7. Management of the Joint Programme on Photovoltaic Energy

The joint programme is coordinated by one or two Joint Programme Coordinator(s) (JPC), who are in charge of the strategic focus, organize the setting up of targets, research topics and the description of work, ensure the implementation of the governance structure and organize meetings of the Joint Programme. Moreover, the JPCs are the main contact point and will ensure efficient links to stakeholders inside and outside of EERA, e.g. towards the EERA secretariat, the EERA Executive Committee, the European Commission, the ETIP PV etc. The JPCs will act in line with the rules and principles outlined in the Governance Structure and guard that also the participants of the joint programme act in line with the governance rules.

The Management Board will also ensure efficient links with (emerging) initiatives such as the Solar Europe Industry Initiative and the EIT/KIC on Energy. A delegation of the Steering Committee will meet at least once a year with a representation of the Solar Europe Industry Initiative and with a representation of the EIT/KIC on Energy to discuss research priorities and transfer of knowledge.

The joint programme is managed by the Joint Programme Management Board (JPMB) consisting of the coordinator(s) of the joint programme and the leaders of the sub-programmes.
The Management Board will meet in person or via conference calls at least on a quarterly base to monitor and evaluate progress (both content wise as well as with respect to participation) and initiate follow up of the current planned activities as well as activities to expand the programme.

Ensuring transparency and maintaining a democratic structure in line with the general principles of the EERA is a key responsibility of the Management Board. The Management Board will actively aim to expand the programme with additional partners that can provide a relevant contribution to the running programme and foreseen new activities.

The main decision making body of EERA JP PV is the Joint Programme Steering Committee (JPSC), which includes all members of the JP. Full members of the JP each have one vote in the JPSC. Associated members of the JP have no voting rights in the JPSC but can participate in all JPSC meetings. The JPSC will meet at least once a year to take important decisions and to discuss the status and development of the JP.

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SUB-PROGRAMME 1: *Silicon technology (Si-PV)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *SIPV-5*
Last modification date: *06-01-2017*

Summary

1. Vision

Wafer-based crystalline silicon (c-Si) technologies completely dominate the PV industry and accounted for more than 90% of the global PV production capacity in 2015. The key factors for their enduring success have been a continuous increase in efficiency of industrially produced c-Si solar cells combined with a remarkable decrease in production cost along the entire production value chain. Research, development and innovation at research facilities and in the PV industry in Europe have played a major role in this development. Further research and development is also required for the PV industry to proceed on the successful cost reduction path in the future.

Over the past years, the global PV industry has been strongly affected by a severe production overcapacity, triggering rapid price erosion and consolidation in the industry. In spite of a growing global PV market in coming years and the industry shakeout, strong price competition will remain. This puts a severe threat on the competitiveness and hence the survival of the European industry in the field of c-Si PV.

However, Europe’s PV sector is set apart from its international competitors by a strong knowledge base and a highly innovative industry supported by a world-leading research community. Research, development and innovation were and will continue to be the cornerstones that will enable Europe to compete in the field of c-Si PV into the future. For this to happen, a coordinated effort of all players involved - research institutions, industry and political actors - is necessary.

2. Research roadmap

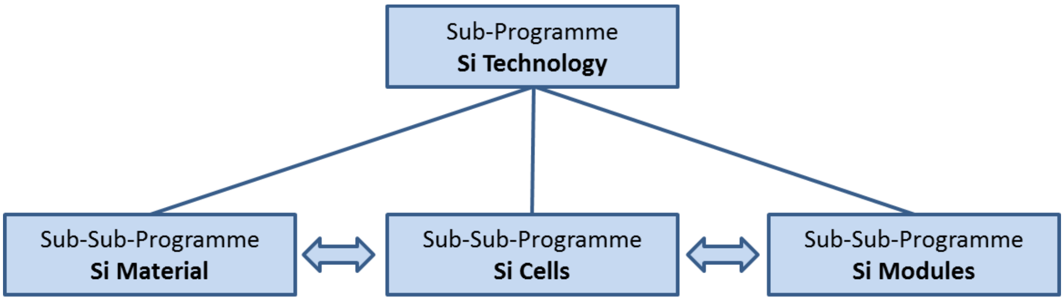
The central aim for this work programme is to maintain and secure the competitiveness of the EU industry in the field of c-Si PV through research, development and innovation. In this period a close link with the industry will be more important than ever. The work programme of the EERA JP PV sub-programme on Si Technologies will be closely coordinated with the activities of the SEII and its implementation plan.

The main drivers for c-Si technology research are cost reduction and performance enhancement throughout the product lifetime. To accelerate progress on these drivers, the following four research themes have been identified as focus areas for this Sub-Programme:

- ✓ *Production technologies*
- ✓ *Material quality and its effect on c-Si solar cell and module performance*
- ✓ *Ultra-thin c-Si solar cells and modules*
- ✓ *Ultra-high efficiency c-Si solar cells*

These four research areas cover a wide range of activities and require a combination of disciplines that are often not available at a single research institute. Therefore, collaboration between partners will be essential to realise the ambitious objectives.

This Description of Work is based on a substantial past effort. One essential step was the creation of the sub-programme Silicon Technology in EERA JP PV in 2013. In the previous work programme (2010-2013) research related to Si technologies was covered in two sub-programmes, namely Silicon Materials and Module Technology. Although significant progress was made, it was noted that synergy effects could be increased by integrating research activities on Si technologies into one sub-programme. Moreover, the essential topic of Si solar cells needed to be included. The new sub-programme on Silicon Technologies brings together important research players along the entire value chain of production. The sub-programme is further divided into three sub-sub-programmes on Si material, Si cells and Si modules, which will closely work together in order to achieve common objectives on Silicon Photovoltaics.



The sub-programme Si Technology is divided into three sub-sub-programmes, which follow the value chain from Si Material via Si Cells to Si Modules.

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3. Objectives 2017-2020

…

4. Sub-programme activities

<u>Task 1</u> Infrastructure

<u>Task 2</u> Workshops and webinars

<u>Task 3</u> Networking and mobility

<u>Task 4</u> Round robins and protocols

<u>Task 5</u> Roadmap and funding

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M1.1			
M1.2			
M1.3			

M1.4			
M1.5			

6. Participants and Human Resources

Institute	Total committed per year*
Total	

*Units are expressed in Effort per year (PM/12)

7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: "Research Infrastructures for Solar Energy: Photovoltaic Power" call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *SI-PV*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *SI-PV*

See section on IPR of the Joint Programme.

11. Contact Point for the sub-programme on *SI-PV*

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SUB-PROGRAMME 2: *Thin-film inorganic photovoltaics (TF-PV)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *TFPV-01*
Last modification date: *06-01-2017*

DESCRIPTION OF THE RESEARCH ACTIVITIES

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Summary

1. Vision

Thin-film photovoltaics is about to become a key technology globally, with growth rates likely to surpass those of the present Si wafer-based PV industry. However, this industrial approach is still in a critical stage of its development, and international competition is becoming increasingly tough. The most immediate challenge is therefore the transfer of sound laboratory-based knowledge into the ability to master large-scale production. In turn, problems observed in industry provide an important feed-back loop defining scientific tasks that have to be investigated more closely in the laboratories. It is of immediate importance that the EERA partners meet these requirements, a task that is facilitated by R&D at intermediate scale. Within this decade, improved approaches for thin-film technologies with significantly higher through-put and efficiency must be ready for industry to ensure the required cost reduction. Moreover, world-wide research efforts are aiming at new materials and device concepts that enable a major breakthrough beyond the horizon of present-day technologies. Such disruptive progress can only be expected by gaining detailed insight into the underlying physical principles of thin-film and nanostructured multi-layered materials and devices. A broad scale of activities with new materials and concepts will promote the discovery and development of devices which hold a great potential for huge cost reductions on a long-term basis.

The final goal of the sub-programme thin film photovoltaics is well described by the roadmap for photovoltaic technologies developed in the Strategic Research Agenda of the PV-Technology Platform:

> *"Strategic goals are a further dramatic reduction of turn-key system prices, the development of a broad portfolio of options and technologies rather than a limited set, and the development of next generation thin film technologies."*

All in all, the research programme has to cover the whole spectrum from fundamental materials research to the development of devices and prototype technologies in order to satisfy short, medium, and long-term perspectives and contribute to the competitiveness of the European PV industry at present and in the future.

The sub-programme TF-PV will strongly interact with the sub-programme module technology due to the monolithic module fabrication and the development of large scale processes and equipment. For systematic development of advanced TF-PV, intensive R&D activities are needed by means of materials and device analysis and modelling covered by the sub-programme infrastructure and education, too. In the long run merging activities with activities of the sub-programme organic photovoltaics is expected due to the incorporation of inorganic/organic hybrid systems.

2. Research roadmap

- Thin-film tandems for high efficiency: e.g. chalcopyrite/perovskite; silicon/perovskite; other material combinations (collaborate with SP1 for Si bottom cells and SP3 for perovskite top cells)
  - Tunnel junction materials (p-doped TCO for perovskite-based top cells)
    - Selective contacts (HZB, Jülich)
    - modelling/simulation of the TJ and contact selectivity (in terms of band offsets, surface recombination mechanisms, etc) (Jülich, HZB)
  - Optimize band gap of bottom cell chalcopyrite material (HZB)
  - Find inorganic wide-band gap material as top cell absorber

        - Computational screening of (low dimensional) lead halide perovskites, (collaborate with SP3) (Jülich)
    - Light management in tandem devices (Jülich)
    - Interconnection and module technology for tandem devices (3, 4 terminal, Wafer+thin film…) (HZB, Jülich)
    - High efficiency thin film on flexible substrates for Product Integration Photovoltaic (PIV) or Building Integration PV (BIPV)

- Increasing reliability, reducing metastability effects of thin film devices
    - Stability of contact materials and interfaces (TCOs, intermediate layers…) (Jülich, HZB, TUT)
    - Stability of absorbers (Perovskites) (collaborate with SP3)
    - Development of new absorbers (2D materials, SnS(Se),…) (TUT)

- Reducing the use of toxic and/or rare materials
    - Indium free TCOs (Jülich, HZB)
    - Replace Ag by Cu
    - Pb-free Perovskite (collaborate with SP3) (Jülich)
    - Develop nanomaterials
    - Improve Cd free buffer layer
    - Increase the efficiency of Inorganic Thin film based on earth abundant elements (i.e CZTS , CMTS..)
    - 2D materials

- Reducing the production cost of thin film devices
    - Increasing production speed (HZB)
    - Use of low-cost flexible substrates for thin film devices

- Development of TCO with better conductivity and higher transmission
    - Alternative device architectures reducing the TCO demands
    - Low-cost processes for such TCOs
    - Combination of TCOs with AgNWs
    -
- Reduce environmental footprint of thin film production
    - Non-vacuum processes (non-sputtering deposition, PECVD, low temperature)

- Measurement technology
    - Standards for reliable measurements of metastable devices (Jülich)
    - Characterization of tandem devices (Jülich)
    - Characterization of 2D materials (TUT)

- Integrated systems for Solar fuels and storage (PV+X)
    - Electrochemical reactions (water splitting, CO_2 utilization) (Jülich, TUT)

  - Thin film batteries (Jülich)

3. Objectives 2017-2020

- Workshops (thin film tandem devices, reliability, characterization methods…)
- New project proposals from WP2 as successor for CHEETAH WP9
- Provision of infrastructure (currently CHEETAH or just without any formal issues => just a database and announcement required)
- Trainings, staff exchange <u>including</u> joint research
- *other*

4. Sub-programme activities

<u>Task 1</u> Infrastructure

<u>Task 2</u> Workshops and webinars

<u>Task 3</u> Networking and mobility

<u>Task 4</u> Round robins and protocols

<u>Task 5</u> Roadmap and funding

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M2.1			
M2.2			
M2.3			
M2.4			
M2.5			

6. Participants and Human Resources

Institute	Total committed per year*

Total	

*Units are expressed in Effort per year (PM/12)

7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: "Research Infrastructures for Solar Energy: Photovoltaic Power" call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *TF-PV*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *TF-PV*

See section on IPR of the Joint Programme.

11. Contact Point for the sub-programme on *TF-PV*

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 3: *Hybrid and Organic Photovoltaics (HOPV)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *HOPV-3.1*
Last modification date: *2016/09/29*

DESCRIPTION OF THE RESEARCH ACTIVITIES

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Summary

The field of Hybrid and Organic Photovoltaics (HOPV) span a range of mono- and multi-junction photovoltaic technologies including polymer or small molecule based solar cells and hybrids, such as Dye-Sensitized Solar Cells (DSSC), Perovskite Solar Cells, as well as combination of these with other silicon or thin film based PV technologies in tandem configurations. HOPV is the most promising candidate for ultra-low cost solar cells and **HOPV have significant potential for contributing to the 2050 visions of the SET-plan**.

The promises of HOPV include 1) ultra-low module costs, 2) low capital investment for set-up of mass production facilities, 3) fast and easy processing, 4) system installation costs much lower than for traditional PV and 5) very low energy pay-back time. At the same time, properties such as flexibility, semitransparency, colour tuning offer easy integration of HOPV in various environments, such as building integrated photovoltaics (BIPV) for nearly Zero-Energy Building (nZEB). The research challenge is to lay the scientific foundation for improving lifetime and efficiency to a level where HOPV become viable technologies for bulk electricity production, while maintaining low production costs. EERA PV sub-programme 3 establishes a common platform that enables much easier collaboration between the growing number of groups involved in HOPV field facilitating the achievement of the research goals. The platform provides networking, mobility and educational activities among the research groups, as well as serves as a base for defining a common roadmap for the technology development.

The first part of the document presents the overview of the roadmap constructed by the members of the sub-programme. The roadmap describes the important challenges of the HOPV field today and serves as a guide for directing the research and the funds towards the common goals. The second part lists day-to-day activities and tasks within the sub-programme.

1. Vision

HOPV research is largely pre-competitive through polymer and small molecule solar cells and DSSC, which already have marketed products. Perovskites based technologies in the meantime are maturing in exceptionally fast pace. Presently, the HOPV technologies target both low power applications such as power supplies for consumer electronics and building integrated applications where control of colour and transparency as well as design issues are of primary importance. The following characteristics are premises for readiness of HOPV: 1) ultra-low module costs; 2) low capital investment for set-up of mass production facilities; 3) competitive efficiency and guaranteed lifetime; 4) control of aesthetical aspects and design and integration; 5) remarkable performance in special conditions (e.g. transparency vs efficiency outdoors and in low level lighting).

HOPV is mentioned prominently in the Strategic Research Agenda produced by the EU PV technology platform in the chapter on Emerging and Novel technologies. It is part of the activities oriented towards ultra-low cost photovoltaics. These activities have been further worked out in the Implementation Plan associated with the Strategic Research Agenda
(ftp://ftp.cordis.europa.eu/pub/technology-platforms/docs/pvtp-sra-2011-2_en.pdf).

The Solar Europe Industry Initiative (SEII) was established as a result of the SET plan by EPIA and the EU PV technology platform. The SEII produces every three years an implementation plan indicating a list of priorities on which common efforts should be focused. The implementation plan (IP) is in line with the SRA and both documents serve as important input for the working programme in H2020. In the most recent version of the SEII IP 2013-2015, HOPV is part of thin film & emerging/novel technologies. According to Strategic Research Agenda in terms of the industrial manufacturing aspects the long term target of HOPV constitutes **>10% efficiency module with production cost of 0.3 €/W**

for BIPV and large-scale power generation. EERA PV sub-programme 3 will work towards achieving this target with efficiencies >20% instead (due to recent advances in the field).

2. Research roadmap

The overall objective is to align European activities within HOPV research to lay the scientific foundation for improving lifetime, efficiency and cost efficient processing to a level where HOPV becomes viable technology for electricity production in application areas and conditions commonly not accessible by standard (cSi) PV technology. The roadmap of the HOPV technology in SP3 has been identified by the members of the sub-programme and constitutes a range of research priorities that represent important challenges to be addressed. SP3 team will work towards obtaining funding for solving the challenges laid out in the roadmap. The research priorities are outlined in the table below and clarified in the following text.

Research areas	Materials and Devices	Stability	Cost and Upscaling	Demonstration and Market
1	Reduction of use of toxic and rare materials. Exploring “green” materials.	Identifying factors limiting stability of HOPV	Scalability of different manufacturing processes and their integration in a high-throughput and cost effective manufacturing process	Exploiting the potential of HOPV – demonstrating unique applications
2	Multiscale modelling to identify novel materials and understand their limitations	Chemical and morphological stabilization and identification of intrinsically stable materials	Identifying or developing optimal packaging, interconnection and (system) integration strategies	Increasing HOPV awareness among product designers
3	Hybrid tandem structures and theoretical models for their design	Protocols and models for device lifetime determination and prediction	Development of quality control methods for upscaling and production monitoring. Monitoring annual yield.	Identifying and disseminating the market of HOPV
4	Standards for characterization of HOPV devices and materials			

Materials and devices: It is vital to eliminate any toxic or rare materials in the production process of HOPV devices in order to assure low environmental impact and very low cost of the technology in the future. Significant research is therefore needed for exploring novel abundant materials with low environmental footprint (research area RA1). Theoretical approach with advanced multiscale modelling as well as lifecycle analyses may significantly aid in the process of identifying such materials (RA2). The modelling can additionally help understanding the limitations of the materials and eliminating these. Multijunction structure is one of the research priorities in SRA document, which highlights the importance of finding novel tandem configurations that can boost the efficiency. Hybrid tandem structures, which are based on combination of organic, hybrid and inorganic technologies (such as for example combination of perovskites and c-Si) show large potential for high efficiency technology and will therefore need a thorough investigation (RA3). Finally, characterization of novel materials and devices has proven to be rather challenging and systematic testing and data collection is necessary for developing procedures attuned to the emerging technologies (RA4). For the latter, the lessons learned from SOPHIA and CHEETAH projects can be utilized.

Stability: Identifying the factors limiting the stability of HOPV under specific stress conditions, such as light exposure (indoor/outdoor), heat, humidity, mechanical and electrical stress, is vital for understanding and improving the durability of HOPV based products (RA1). Improving the stability of existing materials via chemical and morphological modifications and exploring novel intrinsically stable materials is another research priority (RA2) that must be carried out in parallel with the first one. Due to significant differences between the existing inorganic and emerging HOPV technologies, the latter require alternative characterization methods including sample preconditioning that will accommodate the sophisticated photovoltaic behaviour of HOPV as well as will allow predicting the performance of long lasting device under different ageing conditions (RA3).

Cost and upscaling: Investigating and optimizing the scalability of different manufacturing processes (i.e. solution processing, physical deposition, material synthesis, others) and their integration in a qualitative, high-throughput and cost effective manufacturing process is an important step for upscaling of the technology, which has often been taken for granted, but is highly relevant and important for the current stage of HOPV development (RA1). An important step for upscaling is identifying or developing optimal packaging, as well as interconnections and system integration strategies for flexible technologies that will maintain or improve the durability of the modules (RA2). Quality control methods and systems are additionally necessary for upscaled production, which must allow also for verifying annual yields of PV systems based on single- and multi-junction modules and calculating system level costs (RA3).

Demonstration and market: It is vital to exploit the strengths of HOPV technology (advantages, such as flexibility, light weight, colour variety) and demonstrate applications, which are not easily accessible by other photovoltaic technologies (RA1). This can be combined by the increased exposure of the technology to the product designers (RA2). An example for the latter can be a design competition of HOPV products on European level. It is important also to identify and disseminate the suitable market where HOPV will show the competitive edge (RA3).

3. Objectives 2017-2020

The overall objective is to align European activities within HOPV research to lay the scientific foundation for improving lifetime, efficiency and cost efficient upscaling to a level where HOPV becomes a viable technology for new PV applications and bulk electricity production. A list of objectives have been defined that will constitute the day-to-day tasks and work flow of the sub-programme

- ✓ *Provision of infrastructure*: to create a platform for sharing the infrastructure among the sub-programme partners in order to avoid duplications and fragmentations and develop a common European infrastructure system (infrastructure is explained in section 7)
- ✓ *Workshops and webinars*: to conduct instructive workshops and webinars for educating students, researchers and industry about the latest HOPV achievements and scientific advances
- ✓ *Networking and mobility*: development of an environment for systematic networking of EERA PV sub-programme community and frequent exchange of researchers and students among EERA partners
- ✓ *Protocols and round robins*: Improve the possibility to share data and reproduce experiments in different laboratories by structuring round robin and interlaboratory study plans. Utilize the gathered data for developing protocols for device characterization
- ✓ *New project proposals*: Networking on determining the important challenges of the field (roadmap) and constructing proposals for funding applications

4. Sub-programme activities

Task 1 Infrastructure

Currently the sub-programme partners are benefiting from infrastructure shared via the CHEETAH project, as is described under paragraph “Infrastructure”. The task is to identify or develop additional projects and programmes that will extend provision of infrastructure among the SP3 partners upon CHEETAH project completion.

Task 2 **Workshops and webinars**

EERA PV SP3 partners currently benefit from workshops and webinars organized primarily within CHEETAH and limited amount of other similar European projects. The task is to identify additional programmes and projects relevant to HOPV that will enable participation of EERA members and systematically disseminate among EERA SP3 members. The target is to assure at least 5-6 workshops and webinars per year made available for SP3 partners.

Task 3 **Networking and mobility**

Meetings among the sub-programme partners are primarily conducted via the CHEETAH project as satellite events or via online teleconferences. Exchange of the stuff among partners is also realized primarily through CHEETAH. Similar to the webinars and workshops the task is to identify additional programmes and projects, which will enable the meeting of the SP3 partners or exchange of the stuff. Such programmes will actively be disseminated among the partners.

Task 4 **Round robins and protocols**

The task is to organize at least 1 round robin characterization study of HOPV per year within SP3 and utilize the data for aiding the development of testing protocols for HOPV. The experiments constitute production of test samples, accurate testing of initial performance, pre-conditioning of devices and stability testing under controlled environments. The experiments will follow with data analyses and preparation of report.

Task 5 **Roadmap and funding**

The task is to periodically discuss the primary challenges of the field and constantly refine the roadmap described in this document. A common forum will be developed for discussing the possibilities for constricting a joint proposal for application for funding. The target is to develop and submit one proposal every year by utilizing the roadmap.

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M3.1	*Round robin studies of HOPVs*	*Report*	*14*
M3.2	*Proposal for funding*	*Submitted*	*18*
M3.3	*Round robin for preconditioning of HOPV*	*Report*	*26*
M3.4	*Second proposal submission in case of no success*	*Submitted*	*30*
M3.5	*Round robin for stability of HOPV*	*Report*	*38*

6. Participants and Human Resources

Institute	Total committed per year*
DTU	3,2
ECN	1,1
IMEC	0,6

VTT	0,8
Imperial College	0,8
CEA-INES	0,5
ENEA	1,0
CIEMAT	0,5
HZB	1,5
Fraunhofer ISE	0,9
ZSW	0,5
LNEG	1,0
UTV	3,0
UNIMIB	2,3
FZJ	1,0
NPL	1,2
CENER	1,0
CNRS	1,2
Total	21,7

*Units are expressed in Effort per year (PM/12)

7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: "Research Infrastructures for Solar Energy: Photovoltaic Power" call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *HOPV*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *HOPV*

See section on IPR of the Joint Programme.

11. Contact Point for the sub-programme on *HOPV*

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EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 4: *Concentrated Photovoltaics (CPV)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *CPV-01*
Last modification date: *06-01-2017*

DESCRIPTION OF THE RESEARCH ACTIVITIES

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Summary

1. Vision

Concentrator photovoltaic (CPV) technology has demonstrated the highest efficiencies ever achieved by any solar technology at the cell, module, and system levels. Unlike other PV technologies, the gap between record efficiency cells or modules and commercial devices is very small. CPV technology can boast of having not only record efficiencies in the lab, but also of commercially available CPV systems with demonstrated module efficiencies above 35% at the module level and AC system efficiency reaching 30%. In addition, the last decade has shown that these efficiencies are increasing faster than in any other technology (e.g. about 1% absolute per year for III-V multi-junction (MJ) solar cells), and efficiencies of over 50% can be realistically expected for the coming years.

The heart of CPV technology relies on high levels of knowledge in a broad range of fields: optics, material science, semiconductor device technology, and complex manufacturing processes. This required expertise makes imitation by less advanced economies more difficult, and could preserve the current European strategic position in this field for a long time.
Finally, CPV is the only technology that allows any future highly efficient solar cell, even with significantly higher cell costs compared to conventional solar cell technologies, the opportunity to become economically usable for electricity generation. In other words, this means that CPV is a short cut to market that should be ready open and for new achievements or breakthroughs in the development of high efficiency solar cells.

Recent experience in CPV technology at industrial level proved that efficiency is actually a very powerful driver for the cost reduction of the generated electricity, demonstrating a learning curve with a faster rate than conventional PV. Such experiences have also proven that CPV is ready for the PV market from a technical point of view, showing high productivity and reliability in the long term. Important progress has also been made in other key aspects, such as the bankability and insurability of the technology. However, the industrial experiences of large companies, such as Soitec (formerly Concentrix), also showed that efficiency alone is not enough to compete with the impressive cost reduction of conventional PV compared to CPV, which can be attributed primarily to its relative advantage in installed capacity (three orders of magnitude higher).

The development of CPV requires learning by doing to take advantage of the economies of scales to reduce cost. Unfortunately, this will have probably to be done without the public support and feed-in tariffs which fostered the quick growth of conventional PV in the last two decades. Focusing on niche markets in the short term may be key to continued progress with the technology. Nevertheless, CPV has one strength which may make it successful: it can benefit from the progress in other adjacent technologies with enormous market development. The aerospace industry will continue to promote the efficiency improvement and cost reduction of multi-junction solar cells for use in space; the illumination market based on LEDs is intensively developing parallel chip assembly and encapsulation technologies that are very similar to CPV needs. The conventional PV market will continue to contribute progress in Balance of System (BOS) costs, including installation and trackers that can be leveraged by CPV, as well as new materials that are useful for both technologies.

The underlying raison d'etre for CPV is high efficiency. In the short term, four and five junction cells are the most suitable candidates for reaching 50% efficiency. The technology has passed from lattice matched solar cells to metamorphic, inverse grown, and wafer bonding, providing a clear roadmap to improve the efficiency based on better use of the solar spectrum. The world record for the direct conversion of sunlight into electricity has been established by the end on 2014, reaching 46% at about 500 suns with a four-junction solar cell based on wafer bonding technology.

Beyond the record efficiency at reference conditions, the design of MJ cells must be carefully carried out according to the optics transmittance and to specific spectral characteristics in different climatic regions worldwide, in order to reduce losses due to spectral mismatching. While cell optimization for maximum power at certain reference conditions is straightforward, maximizing the energy harvested at a specific location is a challenge. One must consider the strong impact of irradiance, spectrum, temperature, and wind speed not only on the cells, but also on the optics performance. Efficiency progress should be accompanied by a better understanding and performance modelling of the whole system at a specific location. Improving the matching of cells and optics, site climate, and the spectral performance are key research objectives for optimizing the use of any new cell technology.
In addition to the development of better cells, the effective overall progress will need an intensified effort on developing and standardizing optics, whose cost requirement demands specific developments for CPV, but benefiting from the progress in materials and manufacturing processes of other industries which open new opportunities to reduce cost.

Another key aspect that CPV should address in the coming years is the cell encapsulation and thermal management. In this regard, the explosive growth of lighting industry based on LED in involving intensive development of technologies and manufacturing processes that can be easily adapted to CPV needs, but especially to the emerging sub-technology of Micro-CVP, a term which stands for CPV architectures employing cells with dimensions of less than 1 mm2. Specific actions to adopt such technologies to CPV applications should be carried out.

Beyond the development of the modules, CPV also requires progress in tracking systems, which have already demonstrated reliability and performance, but must be reduced in cost. A better structural integration among modules and trackers offers a clear path to reduce steel material and cost,. It should be noted that the investment in tracking hardware, which is offset by CPV's higher efficiency, returns the advantage of not only increasing daily energy generation by approximately 30%, but of keeping power output high towards the end of the afternoon, when electrical use peaks in most European countries. The fact that the CPV production curve better matches the demand curve should, in the long run, reduce the amount of electrical storage required in a future energy grid. Regarding the rest of BOS, improvements in conventional PV can be directly used in CPV.

Europe is strategically positioned to be a leader in CPV, due to a unique mixture of an advanced industry, research centers, and skilled scientists covering all of the required areas of expertise from cell to system. The current status and the high technology required combine to make CPV Europe's best chance to recover a leadership role in photovoltaics. We can imagine two parallel lines of research and development to make this a reality: on the one hand, developing very efficient solar cells via the efficient use of the solar spectrum, and on the other hand improving the optics, receivers, cooling, housing and tracking subsystems toward a reduced set of optimal solutions with proven reliability and manufacturability. In this regard, some standardization in the CPV architectures may be necessary, based on past successful experiences, not only from the technical point of view but also from the potential capability to reach the cost targets.

In addition to the above vision based on High Concentration PV operating at well over 100X, Low to Medium concentration level systems, using are gaining significance for several companies and laboratories as a consequence of the high efficiency (>20%) achieved by several conventional mass-produced silicon solar cells. Although LCPV cells may require small modifications respect to the one sun cells, the ability to use existing high volume production lines make the LCPV approach a feasible option.

And last, but not least, CPV must be open to novel ideas and technologies since it may be the conduit to bring them to the PV market: novel cell architectures beyond multi junction III-V solar cells for high concentration and silicon cells for medium-low concentration, alternative concepts such as luminescent solar concentrators (LSCs) with potential capability for building integration, cross-fertilization with other sectors, hybridization with other technologies such as solar thermal and desalination, etc.

Research roadmap

The main objective of any PV technology is the reduction of the levelized electricity costs, with the challenging target of approaching 5 €cent/kWh in the next decade. For the case of CPV, reducing LCOE is achieved by combing ultra-high efficient solar cells with optical concentration. So a focus on both of these two elements, on the one hand the solar cells, and on the other the means to concentrate the sun light on the devices, hold the key to reach the objective.

A holistic approach is required in CPV to ensure that the improvement in a particular sub element such as the cell, encapsulation, optics, module assembly,... actually translates into an enhancement in the system performance and real reduction in electricity cost. This demands intensive cooperation between experts and researches of different fields of knowledge as well as cooperative and demonstration actions to integrate progress achieved in prototypes and field experiences.

According to the preceding vision of CPV, research activities should be aimed at the achievement of the following objectives.

Development of Ultra-High efficiency solar cells

Ultra-high Photovoltaic (PV) conversion efficiency can only be achieved by optimally exploiting the solar spectrum. The multi-junction (MJ) approach, wherein the solar cell is essentially a stack of multiple solar cells, each composed of different materials and optimally converting a certain spectral band, has demonstrated to be the most effective and practical approach for high efficiency solar cells.

At the moment, the clearest avenue for continuing to increase efficiency, with a roadmap to approach 50%, is the development of four junction cells, which currently hold absolute records for laboratory cells, in the near term, followed by a move to 5 junction architectures in the medium term. Material and process development are needed to promote cell efficiency progress. In this regard, intense research in novel materials and ternary alloys are needed, particularly aiming at the development of sub-cells with a bandgap value around 1 eV and the cell engineering by means of the metamorphic and wafer bonding approaches.

Apart from efficiency, cell development should also be focused on cost reduction, so intensive research must be carried out not only to improve cell performance alone at reference conditions but to ensure the final system efficiency at different operating conditions and climates. Consequently, objectives O.1 focused on cells and O.2 centered in on optics and module development, must go hand in hand.
For CPV development at larger scales, it is imperative that abundant materials be used. For this reason, research activities should aim at the reduction of scarce materials and move forward other alternatives. Particularly, the use of Germanium (Ge), currently used as a substrate for the III-V epitaxial growth of MJ cells, must be minimized by promoting the use of thinner Ge substrates, substrate reuse in epitaxial growth, and finally the development of III-V epitaxial growth on silicon to eliminate Ge entirely.
As an alternative to very high concentration solar cells based on III-V semiconductor, medium and low concentration also

Lines to achieve the objective:

- L1.1 Improvement of 3MJ structures
- L1.2 Development of 4MJ and 5 MJ solar cells.
- L1.3 MJ cells on Silicon substrates.

Optimization and cost reduction of proven and reliable optics, receiver and modules

While a wide variation of CPV architectures have been proposed in the past, very few of these proposals have proven that they can provide the manufacturing feasibility, economic viability, and reliability required for a commercial CPV solution. Such dispersion of efforts constitute a waste of valuable efforts and resources. Thus, to promote CPV technology in the short-term the activities within this objective should prioritize research on proven, reliable and low cost solutions by solving the still remaining and well identified problems and limitations. This additionally ensures a move toward CPV product standardization, which would promote market competition, ensure supply chains, product replacement and finally increase customer’s confidence.

The concentrator optics are a key element to achieve high performance and low cost, which can only be achieved if both optics and cells are correctly tuned. So far, the High-CPV architecture based on Fresnel lens together with triple junction solar cells has demonstrated the best cost-performance-ratio due to two reasons: the capability of such optics to be directly manufactured in parquets and constitute closed modules similar to conventional PV modules; and Fresnelization allows very thin optics and a clear path to high volume precision manurfactruing. Nevertheless the inherent limitations of current state-of-the-art refractive optics (chromatic aberration and temperature dependence) may limit future improvements in High-CPV performance based on 4 or 5 junction solar cells. Consequently, research lines to improve optical performance based on refractive parquets must remain open, aiming at the development of novel materials and manufacturing process to reduce cost, the use of new optical designs to reduce the chromatic limitations, and to ensure that the optics continue to work well with newest cells designs.

Conversely, reflexive optics has superior performance potential but showed much higher manufacturing cost in the module architecture and generally worse real performance so far. There are several reasons for this: reflexive parquets have not been successfully manufactured to date, so many single units must be assembled to constitute a CPV module, adding to cost and potentially to alignment errors; reflexive optics cannot easily arranged in Fresnel architectures, leading to high aspect ratios and stronger impact of manufacturing errors which limits its real performance; module architecture usually require the use of several optical stages for thermal reasons and to limit self-shadowing. Consequently, research activities should be focused in overcoming those limitations for the case of module applications. Alternatively, other alternatives such as large dishes or parabolic troughs which showed better potential for reflexive optics can be revisited.

From wafer to module, cells are commonly first assembled in substrates or carriers that integrates cell attach, electrical connections, means for heat exchange and electrical insulation, protective by-pass diodes and optionally secondary optical elements. These elements have a strong influence on the reliability of the final product, so the inclusion of new products or processes must be accompanied by careful reliability test to ensure long-term stability at operating conditions. Research on novel materials and manufacturing process for the cell encapsulation and assembly is essential to overcome one of the bottlenecks from the point of view of the cost.

Particular attention must be given to the development of secondary optics and its attachment to the cell. Two stage optics improve significantly the optical performance of the system leading to superior manufacturing and assembly tolerances. Nevertheless, the secondary optics (SOE) has to withstand particularly harsh operating conditions in terms of light flux, thermal stress and UV exposure. As a consequence, long term stability has been in doubt and is one of the pending issues of the technology, which requires specific effort to ensure high performance and reliably of receivers with SOE, considering the challenging cost target for these elements. More recently, alternatives to traditional glass SOE have appeared such as direct SOE overmolding on the cell which opens new research pathways to reach the desired cost.

Module manufacturing and component assembly is other part of the technology with much room for improvement. The module design and manufacturing process determines the performance loss of the final product caused by misalignments and mismatch losses, and the assembly precision requirements are critical.

Two critical aspect are clearly identified that can be addressed with specific target funding. On the one hand, the common risk of water condensation inside the module when dew point is reached at operating conditions, which significantly degrades performance and long term stability of the module. This requires specific research in reliable and cost effective solutions. A second aspect to be pointed out is the integration of modules and the tracking structure. In most commercialized designs, despite the inherent stiffness of the modules, they act as a pure load for the structure and tracking elements which are designed to support that load. A joint design and assembly of modules and the structure would allow a significant reduction of material consumption and cost.

One strength of CPV technology that has yet to be taken advantage is the many features in common with other industries such as electronics and lighting. In this context, CPV can benefit from the developments of materials and manufacturing processes carried out in those industries, particularly in the LED-based lighting industry, whose technologies are particularly suited to the emerging sub-technology of Micro-CPV. This term stands for CPV architectures that are similar in size to conventional solar PV systems, but with greatly increased efficiency and performance levels, employing cells with dimensions of less than 1 mm2. The compactness of the final Micro-CVP modules make possible to address a full roll-to-roll module manufacturing which would constitute a real breakthrough to bring down the cost. Specific actions to adopt such technologies to CPV applications must be carried out.

The manufacturing processes and production chains are a cross-cutting issue to achieve the extreme cost target needed for the market development of the technology. The best processes in terms of productivity and cost must be identified and should determine the CPV architecture and subparts design. Strong cross-linking between CPV designers and manufacturing industries must be promoted, providing funding opportunities to get novel concept from the laboratory to the prototype and demonstration level involving expert team covering from the deep knowledge of the technology to the product development.

Lines to achieve the objective:

L2.1 Development of refractive optics for enhanced performance and reduced cost.

L2.2 Development of reflexive optics for enhanced performance and reduced cost.

L2.3 Improvement of cell-on-carriers and receivers

- Low cost materials for thermal management and electrical insulation
- Assembly and manufacturing materials and process
- Secondary attachment or over-molding

L2.4 Improvement of module architecture:

- Performance: angular tolerance, water condensation.
- Minimization of mismatch losses in module assembly
- Integration with tracker structure

L2.5 Development of Micro-CPV and cross-fertilization with lighting industry materials and manufacturing process

L2.6 High productivity manufacturing chains, from wafer to module
L2.7 Standardization of modules for improving market confidence

Cost reduction and of tracking systems, including a focus on simplifying work in the field

An inherent characteristic of CPV is its limited angular aperture caused by the concentrator optics, which involve the uses of high accurate tracking systems to aim at the Sun disc with precision well below 1º and commonly in the range of 0.1º. But this brings the significant advantage of increasing daily energy generation by approximately 30% compared to static systems, and keeping power output high towards the end of the afternoon, when electrical use peaks in most developed countries.

The impact of the tracking system on the final cost of the generated energy is very high, not only in the cost of the product itself, but also through the installation (foundation, wiring, electric conduits,...), maintenance and operation of the plants. Specific actions for the development of trackers to reduce cost must be carried out, focusing on installation aspects. Additionally, novel concepts based on integrated designs of module and supporting structure opens a clear pathway to reduce cost, as defined in O.2. Other areas of research include trackers that make more intelligent structural to reduce material use, such as the use of cable-stayed structures as opposed to the cantilevered structures commonly used.

Lines to achieve the objective:

L3.1 Cost and performance optimization of tracker systems
L3.2 Field installation optimization, maintenance and surveillance or plants

Development of procedures and equipment for CPV testing, calibration, reliability and quality control

In the last years, a tremendous effort has been made in the CPV community to develop standards applicable to CPV technology to promote confidence in the PV market. The results is an increasing number of international standards already approved and a far more under current development, covering design qualification, rating and energy modelling, technical specifications, safety. Nevertheless, the lack of a standard CPV product, the variety of architectures and the continuous evolution of the technology demands also continuous research, particularly in the development of characterization methods and reliability aspects to be adapted to new cell technologies, materials,, and components.

It is particularly necessary to develop procedures, tools and equipment adapted to the constant evolution of the cell technology. At this particularly moment, the pass from three junctions to four or five junction constitutes an important challenge because of the requirements demanded to the spectral content of the light source. The combination of very strict spectral conditions, demanded by multi-junction solar cells, and very narrow angular tolerance imposed by the optics, constitutes an inherent challenge of the technology, mainly for indoor characterization and quality control on the production line.

Manufacturing of CPV modules demands high precision and very low mechanical tolerances because of the critical alignment of optics and cells, which requires the development of specific procedures and tools for an early and fast control of the manufacturing parameters in order to detect and correct immediately any defective processing. One potential advantage of CPV technology is its capability of been assembled close to final markets and plant installation sites. In this business model, high value components (cells, receivers, optics, manufacturing and control equipment) could be manufactured in Europe, while module assembly and tracking structures is done in locally close to the market.

Regardless of module assembly location, but even more local production, it is imperative the development of quality control tools for the production lines, particularly to check if misalignments are within the strict tolerances needed.

The development of specific reliability and accelerated tests for CPV components is other issue that must be addressed. Most of the accelerated tests included in the CPV normative are basically a replica of broadly accepted test in the electronic or conventional PV industries. Nevertheless, some of the CPV components operate under very specific and unique conditions, and require specific qualification and reliability test that allow the inclusion of new development in the product, reducing design and time-to-market cycle times. For instance, one difficulty in ensuring the reliability of the Secondary Optics Element and its optical union to the solar cell is the lack of tests to accelerate the singular operating conditions of such elements in terms of intense light flux, thermal stress and UV exposure.

Lines to achieve the objective:

- L4.1 Development of characterization and rating methods
- L4.2 Quality control process and equipment
- L4.3 Qualification and reliability test for specific CPV components and sub-parts.

Energy forecast, operation, and recycling of CPV generators.

Estimating the energy yield with a low uncertainty of any renewable energy-based plant is a key step to determine project profits and consequently achieve bankability, and concentrator PV (CPV) plants are no exception. In fact, since potential PV installations are valued by the energy generated with a certain probability, simply reducing uncertainty in energy modeling can enhance the value of a PV plant and reduce its LCOE. To reach low uncertainty in the calculation of the expected energy of systems whose inputs are random by nature, a good understanding of the CPV system behavior and meteorological resources is mandatory. Furthermore, as long as PV and CPV penetration in the energy mix increases, grid owners and operators would demand accurate energy predictions to ensure the quality of the system.

In fact, when compared with PV modeling, several specific issues should be given extra attention in the case of CPV: the reduced worldwide sources of DNI data compared to global irradiance; the higher uncertainty in DNI models and expanded time series compared to global; the stronger spectral dependence of multi-junction solar cells; the optics performance which is strongly influenced by temperature; the greater soiling sensitivity of CPV compared to PV; and he stronger influence of wind speed, not only through convention but also affecting pointing errors in the tracker.

Furthermore, given the wide variety of CPV systems, combining, different type of optics, cells, cooling,... these factors will not affect the output in the same way for all designs. In this regard, there is a clear need of better understanding of the energy performance of CPV systems and standardized models and procedures for the quick adaptation of those models to a specific CPV technology, to be used by independent engineers in due diligences, plant commissioning, power plant evaluation.

There are also unknowns in the operation and maintenance of CPV plants. One of the most significant one is the influence of the soiling and the cleaning strategies to be implemented, which involves the development of new cleaning methodologies and specific equipment to optimize water consumption and operating cost and maximize energy production.

The decay rate of the nominal CPV power of a plant is another key parameter when calculating the effective profit of a CPV project. The long term operation and performance of CPV is a constant doubt in this technology. Despite some large CPV plants with more than 10 years of existence have already demonstrated an outstanding performance and very low degradation rates, there have already been other non-successful experiences. Many of the wide variety of CPV solutions proposed so far did not reached sufficient maturity level, resulting in poor long-term stability and reliability. The identification of reliable and stable materials, designs and technologies and the discard of unreliable ones is essential to promote the market penetration of the CPV technology. The determinations of such decay rate requires a specific research based on the combination of current experimental know-how with the basic theory of degradation and reliability.

The potential of CPV recycling is also an open question that must be addressed. CPV recycling is expected to be far easier than conventional PV because of the shape of the modules and the type of majority materials: glass, aluminum, plastics, and steel. The knowledge of the recoverable capital could be a significant incentive for CPV's commercialization and for this reason should be investigated further.

CPV systems already have already demonstrated lower energy payback times in Southern Europe than flat-plate Silicon PV, which is mainly due to the smaller cell area and hence lower amount of energy needed for the production of cells in CPV systems. Moreover, higher efficiencies lead to lower energy payback times as more energy can be produced from similar system components. In order to further optimize the environmental impact of CPV technology, studies on life-cycle assessment should be conducted to determine the best solutions.

Lines to achieve the objective:

L5.1 Energy modelling of CPV generators
L5.2 CPV maintenance, replacement parts and recycling
L5.3 Cleaning strategy and equipment

Development of cells and receivers for low and medium CPV

The scope of this objective is to address the specific and distinctive challenges of low and medium CPV systems not covered in the other objectives. As an alternative to high concentration solar cells based on III-V semiconductor, medium and low concentration may provide a market opportunity to novel emerging cell technologies whose efficiency and cost structure is closer to conventional PV, benefiting from high efficiency inherent to concentration. There is currently an intensive research focused on high efficiency solar cells based on silicon, thin films, tandem cells, metal wrap trough solar cells, which could be potentially used medium and low CPV systems (concentration level below 100). The activities, within this objective, should focus on cell engineering to adapt such cell technologies to CPV applications.

The distinctive element in this type of CPV systems is the receiver, which resembles conventional PV modules, but in which encapsulation materials and process must be completely different in order to withstand concentrated light. Beyond concentration levels as low as five or ten, dedicated metallic heatsinks must be used. Consequently, cells for low and medium CPV must be directly attached to metallic elements, unlike conventional (flat-plate) PV cells, which are totally surrounded by dielectric materials. The combination of adhesion, thermal conduction and electrical insulation between cells and heatsinks is a unique and challenging requirement in low and medium CPV systems. This should be one of the specific research priorities within this objective.

The development of low cost cooling systems is other specific research to be addressed. Regarding passive cooling based on heatsinks, the challenge is the reduction of aluminium weight to reduce cost. Recent developments in folding of thin metal sheets should be investigated. Active cooling could also be an alternative, especially for the applications with a secondary used of the heated fluid.

Lines to achieve the objective:

L6.1 Solar cells for medium and low concentration

L6.2 Encapsulation materials and processes for CPV receivers at low and medium concentration

L6.3 Active and passive heat dissipation

Future, novel and alternative CPV concepts

The previous objective were focused on the evolvement of the CPV to promote its market penetration, prioritizing funding activities on proven technologies that have had already had significant market background and shown great potential so far in terms of cost achievements, reliability and performance.

Nevertheless, as an advanced solar technology, CPV should not close the door to new developments, promising technologies or novel or alternative concepts that with sufficient development, may constitute a breakthrough in the technology.

Within this objective, research on a wide variety of topics is proposed, with the only point in common that require longer time to market. Any novel technology must demonstrate not only performance or a potential competitive advantage, but also a path to low manufacturing cost and above all long-term reliability. This last condition involves making qualification and reliability test and long term tracks of outdoor exposure data from the beginning on of the development. So the umbrella of this O.7. covers long-term research on alternatives to the short-term path to CPV commercialization, while also recommending a development path that so that these technologies may profit from lessons learned in previously developed CPV architectures.

O7.1 Novel high efficiency cell architectures.

Multijunction solar cells have clearly demonstrated not only the highest efficiency, but also ease of industrialization and cost potential reduction. Nevertheless, the variability of the solar spectrum limits the capability of transferring the improvements in efficiency to a real increase in annual energy production. So an increase in the number of junctions would probably need also the implementation of other cell architectures beyond the classical monolithic approach and series connection.

One promising pathway to enhancing the efficiency of the cell over the course of the day as opposed to at one particular spectral condition, is the inclusion of multiple terminals for the separate extraction of power from each subcell, rather than serially connections of today´s two terminal cells. This development may be combined with inexpensive DC-DC converters at each cell to addionally keep each subcell at its max power point, and to prevent the need for the number of cell-to-cell interconnections to scale with the number of terminals.

O7.2 Advanced optics for enhanced performance

The two main characteristics of CPV optics are high efficiency and low cost per unit of aperture area, which limits the number of solutions that can be effectively be used. Nevertheless, certain approaches such as the Micro-CPV defined in O.2 provide further opportunities to alternative optical concepts that are worth exploring further to promote, for example, close integration among cells and optics such that the air gap is eliminated, embedded solar tracking mechanisms in the optics to create “quasi-static” modules, solutions for capturing diffuse light in addition to direct light by combining high-efficiency and cost cells with low-efficiency and cost cells.

O7.3 Luminescent concentrators (LSC)

Low weight, high theoretical concentration factors, ability to work well with diffuse light and no needs of sun tracking or cooling apparatuses are some of the potential advantages of of Luminescent concentrators (LSC). Today, LSC-PV systems have received great impulse thanks to the modern building architectures that have inspired PV application of colorful windows. LSCs are slabs of transparent material doped with a fluorophore. The refractive index of the host higher than the environment traps a fraction of the emitted photons by means of total internal reflection. Photons are then collected at the edges of the LSC to produce electric power by means of PV cells. The use of commodity plastics (PMMA) and consolidated industrial processes offer encouraging means to include solar energy to the built environment.

Up to now, however, LSCs have been plagued by unfavorable mechanisms that hinder their ability to deliver light to PV cells, including fluorescence quenching due to dyes aggregation. Recently, the research on LSC-PV systems has been focusing on obtaining high power conversion efficiencies (PCE) by enhancing the spectral absorption window of the LSC, therefore increasing the number of available photons. A stacked device with PCE of 7.1% is the highest value ever reported for LSC-PV systems. Nevertheless, maximum PCE for LSCs was recorded for PMMAs embedding perylene-based fluorophores. Lumogen F Red 305 is considered the state-of-the-art for LSC applications but at a cost of 7,500 €/kg it is hampering LSC economic viability. To overcome the limited performances a real breakthrough in LSC technology, both in terms materials and a better understanding of the fundamental physics, is needed to for commercial competitiveness. Regardless, the potential returns in terms of the advantages discussed in the previous paragraph are more than sufficient to warrant investment in this area.

O7.4 CPV towers and dishes, hybridization with other technologies

Despite the high efficiency of CPV, a significant part of the sunlight is lost as waste heat. The profitable use of that residual heat would reduce the cost of the energy generated. There is a clear path in the field of hybridization of CPV systems with other energy technologies to reduce the LCOE that should be explored and intensive research should be activated.

CPV towers and dish systems offers probably the better chance for the hybridization with other technologies, particularly solar thermal energy (CSP), where CPV would mainly contribute to efficiency and CSP would provide energy storage and dispatchability. This line demands specific research on several aspects and strong cooperation between both sectors. Regarding the CPV part, system optimization must be addressed, mainly at the cell level for optimum energy conversion; development of actively cooled receivers; progress in solar cells with large areas for dense array receivers; research on solar cells with operating at temperatures above 350°C. Regarding the utilization of the residual heat research should focus on the use of processes that can use thermal energy at medium temperatures, such as desalination and solar air conditioning (absorption heat pump).

3. Objectives 2017-2020

1. Dissemination, education and communication
    a. Workshops (CPV standardization and lessons learned). White paper with good practices in CPV
    b. Provision of infrastructure
    c. Trainings, staff exchange including joint research

4. Sub-programme activities

<u>Task 1</u> Infrastructure

<u>Task 2</u> Workshops and webinars

<u>Task 3</u> Networking and mobility

Task 4 Round robins and protocols

Task 5 Roadmap and funding

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M4.1			
M4.2			
M4.3			
M4.4			
M4.5			

6. Participants and Human Resources

Institute	Total committed per year*
Total	

*Units are expressed in Effort per year (PM/12)

7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: “Research Infrastructures for Solar Energy: Photovoltaic Power” call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *CPV*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *CPV*

See section on IPR of the Joint Programme.

11. Contact Point for the sub-programme on *CPV*

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 5: *PV systems (PVsys)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *PVsys-01*
Last modification date: *06-01-2017*

DESCRIPTION OF THE RESEARCH ACTIVITIES

Table of Contents

Summary

1. Vision

Photovoltaic technology permits the conversion of solar energy directly into electricity. It is a very smart process to generate environmentally-friendly, renewable electrical energy. PV systems can supply electrical energy to a specific consumer or to the electric grid. It has the potential to play an important role in the transition towards a sustainable energy supply system covering a significant share of the electricity needs of Europe. From 0.3% of Europe's electricity needs in 2008, PV with 81,5 GW of cumulative installed capacity connected to the grid at the end of 2013 and a yearly production estimated close to 80,2 TWh, it already covers as much as 3% of the annual electricity demand in Europe only five years later and 6% of the peak electricity demand (more than 15% in Italy and Greece, and more than 13% in Germany). The potential for PV installations by 2020 is at least twice as high as the levels foreseen in the National Renewable Energy Action Plans NREAPs. According to the European Photovoltaic Industry Association (EPIA) it looks reasonable to expect that 4-5% penetration for PV could be reached even in the low growth case, pushing towards 200 GW installed capacity or even more in Europe (in the accelerated scenario) by 2020 [EPIA 2014].
PV systems could also contribute to the security of future energy supply, provide environmentally energy services and enhance economic and social welfare. Low cost and high efficiency photovoltaic systems could become a key technology for the future.

In recent years the cost of electricity generated from PV has declined gradually as the technology behind it has become more efficient and as the number of installations has grown, often more rapidly than even the most optimistic predictions. Over the next few years, these trends are expected to continue and intensify. A recent study carried out by EPIA, with support from strategic consulting firm A.T. Kearney and based on an extensive analysis of five EU markets (Germany, France, Italy, United Kingdom and Spain), has considered how rapidly PV will become more cost-effective in the coming years. The study concludes that, under the right policy and market conditions, PV can be competitive with grid supplied electricity in some markets as early as 2013 (and by 2014 is already true) and across all market segments in the EU by 2020. Moreover, PV electricity is today already a notable alternative to diesel generators in stand-alone applications (especially in areas with significant hours of sunlight). As a result of the expected significant reduction in PV system prices, PV will be able to fulfil its potential as a major source of the world’s electricity generation [EPIA 2011].

In addition to appropriate market conditions, Research and Development – “R&D” – is crucial to the further development of PV technologies. Performing joint research addressing well-chosen issues can play an important role in achieving the critical mass and effectiveness required to meet the sector’s ambitions for technology implementation and industry competitiveness.

Table 1, obtained from the Solar European Industrial Initiative (SEII) report, PV Implementation Plan 2013 – 2015 [SEII-2013], summarises PV technology state-of-the-art and major objectives/milestones for the next 10 years (numbers and ranges are indicative because of the spread in technologies, system types and circumstances, etc.).

Table 1: PV technology state-of-the-art and major objectives/milestones for the next 10 years (numbers and ranges are indicative because of the spread in technologies, system types and circumstances, etc.)

Metric		BASELINE	TARGETS	
		2012	2015	2020
CAPEX for large systems – 2.5 MWp (€/Wp)[5]		1.1-1.6	0.9 – 1.1	0.8-1
Module efficiency (%)[6]	c-Si (high efficiency[7])	16-19 (20.5[8])	17.5-20.5 (22)	>21
	TF	8-14	12-16	14-20
	HCPV	29-32	32-35	38-40
	LCPV	18-21	>22	>24
Inverter lifetime (years)		>15	>25	> 30
Module 80% guaranteed power output time (years)[9]		25	30	>35
System performance ratio (%) [10] (for residential systems)		≈75	≈80	≈85
PV Production forecasting error / Root Mean Square Error (RMSE) (%) (for single plants and day-ahead predictions)[11]		8-11	Further reduction	Further reduction
Efficiency for novel technologies (% on module level)		NA	NA	>25
Efficiency for emerging technologies (% on module level)		4-5	6-8	>10
Performance stability of organic solar cells (years)[12]		<5	5 -10	>10

[5] The system price depends not only on technology advances, but also on the maturity of the market (which includes industry infrastructure as well as administrative costs).
[6] The efficiency as expressed here represents the total area efficiency of the module. The module efficiency affects the BoS (balance of system) cost. However, many more parameters define the BoS costs as these parameters impact the efficiency at PV array level. All KPIs for efficiencies refer to commercially available modules, not to cells or modules efficiencies achieved in laboratories.
[7] The efficiency as indicated between brackets refers to high efficiency c-Si PV modules, which are also sold at higher prices compared to the other c-Si PV modules.
[8] High efficiency commercial modules
[9] Because the lifetime of a PV project is rather difficult to estimate, we prefer to approach this by using the guaranteed power output. At the moment, most module manufacturers offer such guaranteed power output for a number of years. The current standard is 90% of the rated capacity after 10 years and 80% after 25 years. These values are however more conservative than the proven lifetime of certain PV projects which can be 30 years or even higher. Moreover, 25 years represents a conservative industry-wide average, including all PV technologies.
[10] The performance ratio (PR) that is described by international standards (IEC 61724) is the difference between the modules' (DC) rated performance and the actual (AC) electricity generation and is directly linked to the kind of installation. Key factors are also average module temperature, early faults detection and system design that also defines short and/or longer-distance shading effects. Normally for utility scale the PR is assumed around 5% higher.
[11] Considering larger PV portfolios and aggregated PV power at a regional level this error can go down to 4.5-5.5%. Such improvements are very important for the system operators for capacity management and scheduling.
[12] This encompasses the intrinsic stability of the materials used in the active layer, the stability of the cells' nanomorphology and the stability of the contact between metal conductors and organic semiconductors. The figures here reflect the roadmap for applications of organic solar cells starting from small electronic applications as it is the status today to BIPV applications until 2015 and grid connected applications until 2020.

The main objective of the SEII is the reduction of the cost of PV generated electricity, more widely known as the Levelized Cost of Energy (LCOE) (€/kWh). The main pillars of the first roadmap, also supported by the recent Strategic Energy Technology (SET) Plan [SET PLAN 2014], have been in the advance research chapter, the cost reduction and conversion efficiency improvement of the PV technologies (modules and systems), increased lifetime of PV systems, reliability of all components and sustainability of materials and manufacturing processes. Within the industrial research and demonstration approach, new multi-functional PV solutions (incorporating new technologies, system designs and system integration) in order to reduce the cost, or strategies for sustainably integrating PV in the energy system and in the built environment at reasonable cost, are proposed as well. Great cost abatements in manufacturing have been made possible by the numerous innovations that have moved "LAB to FAB" and the achievement of multi gigawatt production capacities. The deployment of all PV technologies has followed a rapid expansion as well, making PV one of the important players in the EU electricity generation mix (Rooftop PV systems have become the first energy source in 2012 by installation capacity, overcoming offshore wind and gas [IEA-PVPS 2013]).

[SEII 2013] addresses the challenges reflecting the changing PV landscape. Europe is resolved to continue to play an important role in the large-scale global manufacturing and deployment of PV that lies ahead of us. This relates to the role of PV in the electricity mix of Europe as well as to the European industry supplying innovative and competitive products and solutions to markets worldwide.

Recognising the rapid development of the market and increased ambition for the contribution of photovoltaics in the near to medium term, evidenced by the adoption of binding 2020 renewable energy targets in Europe and the establishment of the Solar Europe Industry Initiative (SEII) as part of Europe's Strategic Energy Technology Plan [SET Plan 2014], the EU Photovoltaic Technology Platform updated the Strategic Research Agenda (SRA) to address the rapid technological developments required for these new challenges and opportunities. This second edition is intended to perform a similar function to its predecessor in terms of informing the research programmes of the EU and the Member States. The SRA presents the key topics to support the European PV industry in maintaining and strengthening its position in a highly competitive and rapidly innovating global market [EU PV TP 2011].

PV systems can be implemented in a range of applications, sizes and situations, meeting a wide range of power needs. The user encounters PV technology at the system level and requires it to be reliable, cost-effective and look attractive. The module cost will remain the highest single cost item for some time to come. Nevertheless, in order to meet the cost targets required for high PV penetration, substantial and consistent system-level cost reductions must be made alongside those for the PV module. In Table 16, of the Strategic Research Agenda for Photovoltaic Solar Energy Technology, 2nd Edition, 2011, the research priorities for Balance of System at the component level are presented [EU PV TP 2011].

Table 16. Research priorities for **Balance of System at the component level** – time horizons for first expected application of research results in (pilot) manufacturing and products.

	2011 – 2016	2016 – 2025	2025 – 2035 and beyond
Industry manufacturing aspects	■ Increased inverter reliability and lifetime to achieve >20 years of full operation ■ Low-cost electronic components including new design strategies and new materials ■ Microinverters and DC / DC solar optimisers for both retrofit use and embedded in PV modules. Assessment of lifetime of these components ■ New storage technologies in pilot units for large field trials and assessment of lifetime and cost ■ General purpose tracking platforms for high efficiency module options of all kinds ■ Low-cost support structures, cabling and electrical connections for domestic and large ground based PV systems	■ Increased inverter reliability and lifetime to achieve >30 years of full operation	Too soon to be determined
Applied / advanced technology and installation (incl. O&M) aspects	■ Adaptation of battery management systems for new generations of batteries ■ Highly reliable, low-maintenance components for stand-alone systems ■ Component development for minimisation of system losses (e.g. modules with tolerance to partial shading, modules for operation at a system voltage >1000V) ■ Low-cost control and monitoring of system output, including using appropriate measurement protocols	■ Innovative storage technologies for small storage capacities (1-10 kWh) ■ Advanced modules for BIPV applications – multi-functional, self-cleaning, construction elements, new design solutions ■ Strategies for centralised system monitoring (e.g. web based) ■ Interaction of PV with other decentralised generation	■ Modules with integrated storage, providing extended service lifetimes (40 years)
Basic research / fundamentals	■ PV inverters optimised for different PV module technologies	■ Power electronics and control strategies for improving the quality of grid electricity at high PV penetrations	■ Technologies for high capacity storage (>1MWh) ■ Alternative storage technologies

In Table 17 of the Strategic Research Agenda for Photovoltaic Solar Energy Technology, 2nd Edition, 2011, research priorities for Balance of System (BoS) at the system level and/or interactions between PV system and the grid are presented. This table only contains research priorities that deliver results that can be applied before 2025. It is too soon to determine research priorities that will be applied in longer time horizons.

Table 17. Research priorities for **Balance of System at the system level and or interactions between PV system and the grid** – time horizons for first expected application of research results in products and applications. This table only contains research priorities that deliver results that can be applied before 2025. It is too soon to determine research priorities that will be applied in longer time horizons.

	2011 – 2016	2016 – 2025
Industry manufacturing aspects	■ Standardisation of system components to facilitate economies of scale in manufacture and simplify replacement ■ Prefabricated ready-to-install units, particularly for large grid-connected systems	Too soon to be determined
Applied / advanced technology and installation (incl. O&M) aspects	■ Assessment of value of PV electricity, including for meeting peak demand, and as an uninterruptible power supply when combined with a storage device ■ Tools for early fault detection ■ Assessment of long term average local radiation potentials and forecasts of solar insolation ■ New protection criteria for inverters due to the high density of PV systems in the European grids (voltage and frequency controls, voltage dips immunity, output power control, etc.) ■ Short term PV production forecasts both on single plant side and on portions of the electric grid based on satellite meteorological data	■ Management of island microgrids with high share of PV generators ■ Development of efficient incentive management for PV systems ■ Billing and metering schemes for PV in off-grid PV systems ■ Bringing the lifetimes of different components into line with each other above 25 years ■ Updating fault-detection tools for advanced system designs ■ Active inverters able to control the insertion of electric loads according with PV production
Basic research / fundamentals	■ Development of technology for high voltage systems ■ (> 1000 V)	■ New concepts for stability and control of electrical grids at high PV penetrations

2. Research roadmap

Much of the R&D efforts in recent years have focused on the development of high efficiency cells and modules at low cost. However, Balance of System (BoS) components (including the inverter) are also an important part of the value of the PV system and, accordingly, the reduction of their cost along with performance enhancement is considered very important for the overall PV industry. In addition, NREL recently published that 'soft costs' (non-hardware BOS), now represent the largest aspect of solar installation pricing in the US [NREL 2013]. Lower cost manufacturing processes that will result in an increasingly reliable component with longer-term performance is a key goal. New components e.g. power optimizers, micro-inverters, new battery technologies developed for PV applications, further safety components should be assessed against the reliability and cost reduction criteria. Inverters have already achieved the desired efficiencies. However the current focus is mainly shifted to the functionalities, the diagnostic, control and communication features that should be included in order to comply with the grid integration requirements and also to extending the life time in different operating conditions. Even though each component has specific needs and deserves a dedicated R&D path, it is only through a systemic approach based on the interaction of each component, that a real optimization of the whole system can be achieved. Different applications with different PV technologies will require different BoS solutions.

In comparison to standard ground mounted PV systems, photovoltaic modules and systems may also integrated in the build environment.
The multifunctional role of the Building Integrated PV (BIPV) application makes this an important sector to be developed. Especially taking into consideration future targets on zero energy buildings and smart cities, but provides a challenge in the predominance of relatively small capacity systems. Facades of commercial and public buildings represent a vast and largely unexploited, market segment available to almost all PV technologies. Even though

there are minimum technical requirements for a successful integration of BIPV in buildings, this application has to fully convince architects and designers of its versatility and additional functionalities and to meet the criteria for economic viability.
Furthermore, for PV systems, inherent security mechanisms have to be developed which assure their electrical and other safety requirements. In order to substitute construction materials, in particular, BIPV has to show its capability of generating electricity, without compromising the basic functions of the building envelope (e.g. thermal insulation and illumination) while respecting national building codes.

The main focus of the sub-programme 5 is on Photovoltaic systems. This includes the planning/design of such systems and the use of suitable components (like PV modules, mounting- or integration systems, inverters, monitoring etc.) for various applications (ground mounted, building integrated, floating etc.), as well as their efficient and reliable operation. Beside the reliability and performance the cost efficiency in installation and operation will be addressed.
The sub-programme 5 will not include the grid integration aspects and system interaction analysis, since these activities are well covered by other technical programmes and expert networks (e.g. IEA PVPS, ETIP, SolarPower Europe).

The main objective is to collect existing national roadmaps, strategies, ongoing activities and key results related to PV systems, in order to identify the future needs for research in Europe and potential fields of activities for the EERA PV partners.

3. Objectives 2017-2020

The aspects to be covered are:

- Design, planning and engineering (methods and tools) of the system
- guidelines for optimum transportation, installation, configuration, fulfilment of safety requirements (including fire safety) and monitoring/evaluation
- technical requirements for components
- Environmental requirements (LCA, LCC, recycling)
- Performance and reliability requirements and analysis methods for modules-, inverters and system for the related application (e.g. analysis in the field)
- Increased energy yields/reduced system losses
- Operation & Maintenance: Fault prediction and long term reliability of systems, increased manageability of PV systems.
- Cost reduction of BOS (potential and trends)
- Increasing the ‘value’ of the PV power generation (self-consumption, business models, forecasting...)
- Analysis of actors and stakeholders (now and in the future)
- Storage as enabling technology (tbd)

The following areas are addressed in the PV system activities

1) PV systems standard applications
    a. Ground mounted systems
    b. Roof top installations
    c. (Off-Grid)

2) PV systems for special applications

a. building skins (this is basically the BIPV part)
b. Landmarks
c. Agriculture – water-based applications
d. Mobile low-power applications (electronics, wearables)
e. Transport: Automotive (EV, trucks, buses, feeders, E motorbikes), Sailing (vessels, leisure yachts), bikes…)
f. Aerospace (UAV, Drones…)
g. Space (satellites, Rovers)

Activities:

1) Inventory of completed or ongoing relevant projects
2) Summary of results of projects and studies of the participating partners
3) Compilation of white paper, position papers to relevant topics (according to available competence, results and in cooperation with other networks)
4) Elaboration, definition and update of European research agenda (based on ongoing and future activities of partners)
5) screening national, trans-national and international calls and share it with the EERA group
6) setting up new initiatives and coordination within EERA PV
7) Forming peer groups for joint projects and studies
8) Exchange and interaction with standardization committees
9) Exchange and interaction with stakeholders and pressure groups

Coordination with

- ETIP http://www.etip-pv.eu/
- SolarPower Europe http://www.solarpowereurope.org
- SolarUnited https://www.solar-united.org/
- EUREC http://www.eurec.be
- IEA PVPS http://iea-pvps.org/
- EERA SmartGRids, EERA Smart Cities

Balance of system (BoS):

In order to achieve higher PV penetration levels, a further cost reduction in installation of a PV system is needed (the so call soft costs). A major effort has been made in reduction of the cost of the PV module (which has traditionally been the most costly component). However, in order to meet the cost targets required for high PV penetration, significant system-level cost reductions must be made along those for the PV module. Since desired efficiencies are already achieved in power electronic devices, apart from reducing costs, main efforts must be focused on improving reliability and offering new functionalities related to manageability of PV source. At the balance of system level, the highest priority is given to the **development of inverters**, **electrical storage devices**, **energy management systems** (EMS) and **new component / solutions designs** for specific applications.

The research agenda focuses on harmonization of system components, including component lifetime, such as module specifications to fulfill the requirements of BoS in order to reduce initial cost and to simplify replacement and modification of systems in the future. Moreover, BoS specifications should be harmonized with grid codes and communications protocols. Control and monitoring strategies development are also important to optimize system performance, while retaining simplicity of operation. Furthermore, BoS plays a significant role in the interaction of PV systems with the grid at high PV penetration scenarios.

At the BoS component level, highest priority is given to (1) the development of inverters, (2) storage management devices, (3) energy management systems and (4) new designs for specific applications. More in detail, the proposed activities deal with the following issues:

- Low-cost durable mounting structures, cabling and electrical components (e.g. PV connectors, DC switchgears, further safety components, etc.) for small or large PV systems. Holistic design of module and mounting structure to minimize cost. Components for reducing system losses e.g. modules and inverters for operation at a system level >1000 V and modules for operation under partial shading or different working conditions are included here.
- Improved overall performance and lifetime of modules for different climate conditions.
- Improved overall performance, efficiency, lifetime and low-cost power electronic devices (i.e. inverter lifetime >20 years of operation), including PV DC-DC optimizers (microinverters and other distributed MPPT architectures to enhance Performance Ratio (PR) under heterogeneous working conditions. (aso to be integrated in modules)
- Low cost monitoring and fault detection/prediction systems in order to improve reliability and energy yield (PR as well), including centralised system monitoring (e.g. web based).
- Energy management and communication systems to meet peak demand and offer other grid services, including short term PV production forecasts and active load management.
- Inverters for PV hybrid systems including storage to improve PV value through manageability in grid-connected and isolated microgrids.
- Low-cost, high-accuracy tracking systems/platforms (single and double axis) for different applications, including CPV systems (low and high concentration PV systems).
- Development of Battery Management Systems (BMS) for electricity storage systems in order to reduce lifecycle system costs (€/kWh) by maintaining performance in PV applications.
- Approaches for the integration of the storage component into the module, to provide a single product that is both low-cost and straightforward to use in stand-alone and remote applications (including considerations of operating temperature).

BIPV

Despite the cutbacks in incentive programs for PV installation in Europe, which has been the main market for PV installations in the past few years, the installed capacity of solar power plants per year continues to increase, reaching 35% growth rate in 2011 and 24% in 2012 or 25 GW and 31 GW in absolute terms. In monetary terms, the market has shrunk from €95 billion in 2010 to €75 billion in 2012, but is expected to surpass its previous peak again by 2015. Together with an increasing number of PV installations, the need for accessible free areas continues to grow. In this context, the estimation of the needed installation capacity per country is tremendously higher [Henning12] in order to meet the energy needs. In order to provide energy production close to the place of consumption, already sealed areas will need to be used to install the necessary capacity to reach renewable energy targets as intended by the European Commission's policies [EC11]. Also, currently 70% of the installations in Germany are rooftop installations of up to 100 kW [EC09]. Integrating PV into buildings can sublimate building components and reduce construction costs or may even replace entire technical systems (e.g. shading). In this context, building optimization stimulates the development of emerging building envelopes in highly energy consuming climate regions by developing tailored assessment solutions for complex embedded façade systems. Next to the sole technical implementation of PV, buildings have to meet aesthetical requirements arising from the work of architects, real estate developers, and finally from Society. If integrated successfully, BIPV can be incorporated into the building fabric with ideal designs and structures and with a sensible energy concept. Addressing aspects of solar buildings like the architectonic value and interior comfort are topics of high interest in solar architecture [IEA-SHC-Task41]

Beside regulatory issues, the main technical research needs in die field of BIPV are

1. *Technical development*
   - (a) Development of innovative technical solutions
   - (b) Low-cost manufacturing process and BIPV-product optimization
2. *Demonstrators*
   - (c) New PV system design approaches (including modelling tools)
   - (d) Demonstrators for innovative use of BIPV components and large scale demonstration
3. *Standardization and testing*
   - (e) New testing methods and harmonization of PV standards
   - (f) Models and tools in order to allow reliable energy rating

Next, objectives of the research theme BIPV are given in more detail:

- (a) Development of innovative technical solutions (combination of ICT and electronic devices) to increase the self-consumption ratio of PV electricity in residential and tertiary buildings (commercial /industrial), and generally speaking, to enhance the integration of systems in the built environment in order to reduce the overall costs and the environmental impact. Further, linking PV systems to grid communication systems (e.g. IEC 61850-7-420 — Communications systems for Distributed Energy Resources (DER)) for energy management and building automation mechanisms.
- (b) Industrial automated low-cost manufacturing process and control methods, including development of new flexible equipment for different production lots with different geometries (e.g. small or large production lots, flexible compounds, different substrates). One essential step within this frame of work is the optimization of BIPV product performance, long term higher energy output and improved optical appearance at reduced costs (Euro/m²) together with inherent security mechanisms with design & electronic devices. Methods for refurbishment with multi-usable BIPV-technologies (e.g. usable for refurbishment and new buildings). The aim is to decrease manufacturing costs for the elements and address a bigger market by mass production or pre-fabrication.
- (c) new PV system design approaches for BIPV applications:

- Inverter design: String Inverter, Micro-inverter, DC power optimizer,
- System design: AC bus, DC bus,
- Development of modeling software to automize the rather difficult design optimization of the BIPV system
- Building design: sizing of building components suitable for PV generation units, unit interconnection
- PV module/cell design: New cell and modules design approaches for flexible (in form, size and voltage output) applications in system integration.

(d) Demonstrators for innovative multifunctional use of BIPV components, (e.g. new materials, new substructures, new building envelope type) in order to supplement other building components, generate added value (e.g. active or passive cooling, day light usage, shading etc…), or show methods to achieve (i) outstanding architecture combined with (ii) innovative technical solutions (iii) and /or high BIPV-integration densities. Outstanding solutions shall lead to a multiplication value by the proof of concept of large scale demonstration for BIPV, providing the necessary/traditional building functions, complementary to the European Energy Performance of Building Directive (EPBD) including energy generation and aesthetics and according to relevant building codes.

(e) Development and establishment of new testing methods and harmonization of PV standards and building standards. (-> 5.3). Further development of standards and regulations (also towards unification) for BIPV components, economic models and BIPV components testing.

(f) Models and tools in order to allow reliable energy rating and power rating adjusted to the building behavior in a certain built surrounding and under different constraints (climatic, thermal loads, multifunctional usage)

4. Sub-programme activities

Task 1 Infrastructure

Task 2 Workshops and webinars

Task 3 Networking and mobility

Task 4 Round robins and protocols

Task 5 Roadmap and funding

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M5.1			

M5.2			
M5.3			
M5.4			
M5.5			

6. Participants and Human Resources

Institute	Total committed per year*
Total	

*Units are expressed in Effort per year (PM/12)

7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: “Research Infrastructures for Solar Energy: Photovoltaic Power” call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *PVsys*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *PVsys*

See section on IPR of the Joint Programme.

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EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 6: *Research infrastructures, mobility and training (PVinfra)*

A sub-programme within the joint programme on
Photovoltaic Solar Energy

Description of Work

Version: *PVinfra-01*
Last modification date: *16-01-2017*

DESCRIPTION OF THE RESEARCH ACTIVITIES

Table of Contents

Summary

1. Vision

The EERA participants have agreed to form a common research program in the field of Photovoltaic Solar Energy. The agreement proposes a step forward from the well-proven cooperation on a project basis between the European research institutes as promoted by the European Commission through the Framework programs towards a commitment of planning and implementing joint research programs including sharing and optimizing the use of research infrastructure and human resources. The development of agreements for access to research facilities, coordination of access and development of new joint research infrastructure is organized in this sub-program.

The partners behind the EERA Joint Program on Photovoltaic Solar Energy have a large variety of testing and experimental facilities which will be made accessible for future joint research activities. This subprogram on “Research infrastructures” deals on the one hand with the collaboration of existing laboratories and outdoor test sites and on the other hand with the common design and set-up of advanced or improved joint research facilities. Its goal is to provide European researchers with access to the best state-of-the-art research facilities in order to conduct basic and technological research, accelerate pre-normative research and promote the rapid transfer of research results into industrial standards for emerging PV technologies.

The large-scale deployment of photovoltaics results in a diversification of applications and technologies being developed:

- More and more types of materials are used and processed, in larger and larger quantities,
- The size of the photovoltaic module or product is getting larger and larger,
- The scope of applications is gradually extending : from the conventional ground-based systems to the concentrating systems (CPV) for larger power plants and from building-integrated products (BIPV) for zero-energy or energy-plus buildings to solar mobility. More and more interfaces have therefore to be addressed: grid interfaces, building codes, etc. More and more products and systems have to be industrialised and then tested and qualified.

Consequently, there is an increasing need for :

- Performing R&D on large and expensive pilot equipment close to industrial-scale equipment to speed up the innovation process and accelerate technology transfer to the industry
- Characterize in more comprehensive ways many types of materials and systems. System characterization is especially uneasy as the reference conditions are often not defined, due to the lack of standards and common performance evaluation procedures.

Most of these tasks require improved modelling and associated design tools. However, to validate these models and tools, to analyse the relevant physical phenomena and to provide independent and normalised performance data of materials, components and complete systems, characterisation and test facilities as well as basic research are needed. These facilities may be split into two categories:

- unique and outstanding facilities, of which a shared access could be useful to all the partners,

- similar test facilities existing within several organisations, but operated with various test procedures, under various climatic conditions, which would greatly benefit from a harmonised approach.

The "Implementation Plan" for the "Strategic Research Agenda" of the EU Photovoltaic Technology Platform, which has been developed with the active participation of the entire photovoltaic sector, highlights the key R&D priorities that must be undertaken. The greater coordination and the optimal use of research infrastructures within Member States are clearly mentioned. These two issues would also support many of the actions proposed by EPIA, the European Photovoltaic Industry Association, regarding the Solar Europe Industrial Initiative.

The background for having a separate subprogramme on research infrastructure is the importance for the advancement of the European research in photovoltaic solar energy by means of achieving as much synergy as possible between the EERA partners to improve their ability to perform state of the art experiments. The obtained data are essential for the design and deployment of photovoltaics and in the end to fulfil the SET Plan and the RES Directive.

2. Research roadmap

This subprogram will contribute to tackling research fragmentation, with a global approach covering all aspects of the value chain: from raw materials to solar modules and the various applications. This can only be achieved by pooling together scientists and infrastructures.

The objectives of the sub-programme are therefore to mobilize and coordinate EU research infrastructures in the field of photovoltaics, to optimize its use, make the most of its output and to create the conditions for the long-term development and enlargement of the photovoltaic energy research facilities, as well as to establish common R&D programmes, exchange researchers and creating synergies between the partners of the EERA joint research program in the field of Photovoltaic Solar Energy.

The specific objectives are:

- To identify outstanding EERA research facilities, which are or could be made accessible for all EERA partners under specific conditions to be defined.
- To design the necessary research facilities (upgraded or new ones) which are either missing due to new technological trends or not sufficiently available.
- To allow an easier access to some of them by developing modes of agreement on the use of partners facilities.
- To train researchers and students to the use of the research facilities.

A number of new facilities are required which are so expensive to realise and operate, that it is worthwhile to investigate the possibility of them being shared among different actors in the photovoltaic energy sector. The pooling of existing facilities such as test stations offers more value to the sector than operating them as single units.

3. Objectives 2017-2020

To develop a coordinated approach to using the partners' expertise and infrastructures more effectively, the work is structured around the following activities, which will set the basis for the accomplishment of the subprogram objectives:

3.1: A updated review of EERA research infrastructures

The research infrastructures cover laboratories, field test sites as well as pilot lines, and in some cases common design and set-up of new or upgraded research facilities. In the first phase of the joint program substantial effort will be directed towards establishing an inventory of EERA research facilities, which are or could be accessible for all EERA partners, and providing examples of research projects carried out with them. This will be performed in cooperation with the other subprograms of the EERA PV research programme.

3.2: Modes of use of partner's facilities

A shared access to research infrastructures and its results is an essential part of the photovoltaic joint programme. Granting access refers to partners as well as to external researchers involved in the implementation of future common R&D projects.

The main target of this activity is to define the modes of provision of access to partners' R&D infrastructures, its coordination, the researchers exchange as well as the conditions under which this will take place.

Given the large variety in the nature of infrastructures involved, several access modes shall be defined. Differences in the access modes might be related to the extent in which they are commercially operated, and to the degree in which they might be considered strategic to its operator.

3.3: Design the upgrade or the set-up of necessary research facilities

The objective of this activity is firstly to elaborate a list of the necessary research facilities which are either missing due to new technological trends or not sufficiently available, and are required to support the continuation of the European leadership in the photovoltaics sector. Secondly, proposals will be made for the design and the realisation of these infrastructures.

A specific action will be to participate in the application phase for a new ESFRI Research Infrastructure facility for its roadmap revision in 2012. If the application is successful, participation in design, construction and deployment of the infrastructure.

3.4: New joint research projects

The objective of this activity is to interact with the other existing or later upcoming sub-programs in order to identify new joint research projects that could:

- Be developed using the existing research facilities
- Improve the quality and services offered by the facilities, through improved and harmonised test procedures and models for simulation. The idea is to extend the services taking advantage of the specific competencies of each individual lab, and therefore supporting the application-specific and user-specific development of innovative products

Common R&D Programmes will focus on the following non-exhaustive list of issues:

- Improved characterisation of many types of materials : crystalline silicon, amorphous and microcrystalline silicon, organic and inorganic thin films, TCO, encapsulating polymers, etc.
- Accelerated Power and Energy Performance Measurements : preconditioning issues, energy output prediction
- Accelerated ageing modelling and testing
- Grid connected, BIPV, mobility applications
- Material development & characterisation
- Pre-Standardisation work

3.5. Common programs for education and training of scientists, students, and technicians

The goal of this activity is to improve the skills of the technical and scientific stuff up to a common standard, to disseminate special knowledge, especially in the field of analysis of photovoltaic materials and devices. E-learning will be especially developed.

4. Sub-programme activities

Task 1 **Infrastructure**

Task 2 **Workshops and webinars**

Task 3 **Networking and mobility**

Task 4 **Round robins and protocols**

Task 5 **Roadmap and funding**

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M5.1			
M5.2			
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M5.4			
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6. Participants and Human Resources

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7. Infrastructures

The structure for collaboration and using infrastructures has been developed in the SOPHIA project which was an FP7 project in the INFRA-2010-1.1.22: “Research Infrastructures for Solar Energy: Photovoltaic Power” call. The SOPHIA project had 20 partners and finished in Q1 2015. The CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP) in which most EERA-PV partners are involved continued the infrastructure work started in SOPHIA. The CHEETAH project will run until the end of 2017. After the CHEETAH project ends, EERA-PV will continue using the infrastructure tools and way of working developed within the SOPHIA and CHEETAH projects and will look for new means of funding the sharing of infrastructures within the domain of photovoltaics.

8. Governance of the sub-programme on *PVinfra*

See section on Governance of the Joint Programme.

9. Risks

Not applicable

10. Intellectual Property Rights of the sub-programme on *PVinfra*

See section on IPR of the Joint Programme.

11. Contact Point for the sub-programme on *PVinfra*

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ANEXO 2 SET-Plan – Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV)

EUROPEAN COMMISSION
RTD - Energy
ENER - Renewables, R&I, Energy Efficiency
JRC – Institute for Energy and Transport
SET Plan Secretariat

SET-Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV)

Purpose of this document

This document[1] is intended to record the agreement reached between representatives of the European Commission services, representatives of the EU Member States, Iceland, Norway, Turkey and Switzerland, (i.e. the SET-Plan Steering Group) and representatives of the SET-Plan stakeholders most directly involved in PV[2], on the implementation of the actions contained in the SET-Plan Communication[3], and specifically the strategic targets for the priority "Number 1 in renewable energy" for what concerns PV energy.

This agreement follows consultations with industry represented by the European Photovoltaic Technology Platform (PVTP) and the European Construction Technology Platform (ECTP), with the research community represented by the EERA Joint Programme on Photovoltaics (EERA JP-PV), and with academia via the European Platform of Universities in Energy Research & Education (EUA-EPUE), as well as a public consultation via the SETIS website[4] on an Issues Paper prepared by the Commission services[5]. It takes into consideration the corresponding input papers and public comments available on SETIS (https://setis.ec.europa.eu/towards-an-integrated-SET-Plan) and discussions in the SET-Plan Steering Group on 9 December 2015 with the participation of the relevant SET-Plan stakeholders mentioned previously.

The stakeholders agree to highly ambitious targets in an endeavor to maintain global leadership in the sector, to put forward their best efforts in a coordinated way between public and private sectors, and to jointly address all relevant issues in order to attain the agreed targets.

Brussels, 20 January 2016

1 This document has no legally binding character, and does not prejudge the process or final form of any future decisions by the European Commission.
2 The European Photovoltaic Technology Platform (PVTP), the European Construction Technology Platform (ECTP) and the EERA Joint Programme on Photovoltaics (EERA JP-PV).
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Introduction – Photovoltaic solar energy

All major future energy scenarios forecast a key role for photovoltaic solar energy (PV). PV has a huge global and European potential, making it an important building block for a secure and sustainable energy system. In several European countries PV already provides more than 5% of the annual electricity demand, a level originally anticipated to occur only after 2020. Based on current market trends, it is estimated that PV has the potential to meet 8% of the EU electricity demand in 2020 and 15% in 2030. If achieved, this would result in a considerable contribution to the reduction of CO_2 emissions, since the carbon footprint of PV systems is at least 10 times lower than that of fossil fuel-based electricity, with no CO_2 emissions during operation. However, PV has just reached 1% of global electricity supply and has harnessed only a small fraction of its vast potential. PV deployment could be accelerated by further enhancing light-to-power conversion efficiency, and reducing module and system prices as well as grid-integration bottlenecks. With innovations in these areas, the volume of modules manufactured in the coming decades could eclipse the figures of today's production.

The PV industry has changed dramatically over the last few years. In Europe, the rapid growth of the PV market has not resulted in a similar growth of the production capacity of solar cells and modules. Following an initial globally strong position, the EU PV industry has dramatically lost market share in 4-5 years and currently supplies around 5% of the total MWp produced[6], exposed to a strong competition.

Despite all these difficulties, the EU PV industry is still well positioned along the value chain, especially in the sectors of equipment manufacturing, inverter manufacturing, project business and installation. In addition, Europe still has research institutes on PV that maintain scientific leadership roles. Nevertheless, developing a strategy to build on the existing PV industrial and R&I base in Europe, with a view to re-launching cell and module manufacturing, is an extremely urgent need. Worldwide growth projections for PV are very high, with the cumulative installed capacity expected to triple over the next five years. In this context, Europe must continue to invest in Research and Innovation to be able to play an active role and ensure again a strong industrial position. Managing innovation efficiently, maintaining technology leadership and ensuring a full commitment of industrial stakeholders require a coordinated approach at the European level.

This can happen only through the achievement of ambitious system, cost and performance targets, as well as, regulatory and market design measures. System cost and performance are to a considerable extent interdependent and represent the actual drivers for the development of the sector. Indeed, increasing the efficiency of PV modules opens one path for reducing costs and allows for new industrial and market opportunities when accompanied by large scale manufacturing (at least 1 GW/year). As module costs account for around 50% of system costs, efforts need to be directed also at reducing the costs of Balance of System (BoS) technologies while introducing new functionalities for grid services. Furthermore, manufacturing of PV modules as building materials can develop to a world-wide market with huge opportunities for the European industry. Driven by policies towards Zero-Energy Buildings and subsequently Plus Energy Buildings (PEB), design and innovation with new Building Integrated Photovoltaic (BIPV) materials and concepts and combinations of energy efficient building materials with BIPV become essential parts of the development strategies of both the PV sector and the building sector. This calls for a multidisciplinary research and development programme involving, among others, the PV manufacturing

[6] Fraunhofer ISE "Photovoltaics Report", August 26, 2015

industry and the building materials industry as well as certification bodies. Breakthroughs in technology, applications and business models are required to transform today's BIPV niche market into a future mass market.

The combination of localised PV electricity, storage and local supply and demand management makes buildings the smallest unit of a smart grid of its own. Once the necessary technology and control mechanisms are developed, the step of linking multiple smart buildings will contribute to the widespread deployment of the smart grid technology. This requires the development of control systems for grid-feeding, self-consumption and local storage and standardisation of the interoperability of such control systems.

The achievement of the targets will depend not only on technological advances, but also on non-technological factors such as economies of scale (i.e. resulting from an increase in produced and installed capacity), risk-finance for first-of-a-kind manufacturing pilot lines and demonstration of small, commercial-scale PV power plants, the ability to take full advantage of the European Single Market, regulatory conditions, standards etc. In this context, international cooperation in energy research can also bring substantial benefits. These non-technological issues will have to be specifically examined at the subsequent stage of defining how to achieve the agreed targets.

Strategic Targets

Building on the Integrated Roadmap (IR) of the SET-Plan, public (EC and Member States/Regions) and private investment must focus on targeted R&I actions to achieve the following goals in terms of PV system performance, cost reduction, sustainability and innovations in BIPV products by joint efforts between the PV and the building sectors:

Agreed Strategic Targets in photovoltaic (PV) solar energy

Overarching goals: re-build EU technological leadership in the sector by pursuing high-performance PV technologies and their integration in the EU energy system; bring down the levelised cost of electricity from PV rapidly and in a sustainable manner to allow competition in electricity markets all over Europe. This will be achieved by:

1. Major advances in efficiency of established technologies (Crystalline Silicon and Thin Films- c-Si and TFs) and new concepts:
    - **Increase PV module efficiency by at least 20% by 2020** compared to 2015 levels;
    - **Increase PV module efficiency by at least 35% by 2030** compared to 2015, including with the introduction of novel PV technologies;
2. Reduction of the cost of key technologies:
    - **Reduce turn-key system costs by at least 20% by 2020** as compared to 2015;
    - **Reduce turn-key system costs by at least 50% by 2030** compared to 2015 with the introduction of novel, potentially very-high-efficiency PV technologies manufactured at large scale;
3. Further enhancement of lifetime, quality and sustainability:
    - **Increase module lifetime** to a guaranteed power output time (at 80% of initial power) to **30 years by 2020** and **35 years by 2025**;
    - **Minimize life-cycle environmental impact** along the whole value chain of PV electricity generation, **increase recyclability** of module components;
4. Enabling mass realisation of "(near) Zero Energy Buildings" by Building-Integrated PV (BIPV) through the establishment of structural collaborative innovation efforts between the PV sector and key sectors from the building industry:
    - **Develop BIPV elements**, which at least include thermal insulation and water protection, to entirely replace roofs or facades **and reduce their additional cost by 50% by 2020, and by 75% by 2030** compared to 2015 levels**, including with flexibility in the production process,** (table in *Annex I*);
5. Major advances in manufacturing and installation:
    - Increase large scale manufacturing concepts and capabilities by **demonstrating PV production capabilities of at least 20 m^2 per minute by 2020;**
    - **Develop PV module and system design concepts that enable fast and highly automated installation,** to reduce the installation costs of both ground-mounted arrays and PV building renovation solutions, **by 2020**.

Next steps

The stakeholders agree to develop within 6 months a detailed implementation plan for the delivery of these targets, determine joint and/or coordinated actions, identify the ways in which the EU and national research and innovation programs could most usefully contribute, identify the contributions of the private sector, research organizations, and universities, identify all issues of a technological, socio-economic, regulatory or other nature that may be of relevance in achieving the targets, and report regularly on the progress with the purpose to monitor the realisation of the targets and take rectifying action where and whenever necessary.

The stakeholders intend to use the European Technology and Innovation Platform on Photovoltaics as the main vehicle for discussing and agreeing on the implementation plan.

Annex I. BIPV detailed targets

<table>
<tr><td colspan="2" rowspan="3"></td><td colspan="3">BIPV's main applications</td></tr>
<tr><td>Roof integration</td><td colspan="2">Façade-integration</td></tr>
<tr><td></td><td>semi-transparent</td><td>opaque</td></tr>
<tr><td rowspan="3">Additional cost[1]

(€ / sq. m)</td><td>today (end 2015)</td><td>80-120

(roof-integrated modules)

130-200
(tiles, membranes)</td><td>150-350</td><td>130-250</td></tr>
<tr><td>2020</td><td colspan="3">50% reduction with regard to end 2015</td></tr>
<tr><td>2030</td><td colspan="3">75% reduction with regard to end 2015</td></tr>
</table>

ANEXO 3 Draft SET-Plan TWP PV Implementation Plan

Draft SET-Plan TWP PV Implementation Plan

Authors: ECN, PtJ-ESE

August 2017

Contents

Introduction

The Integrated SET Plan

The Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy (Energy Union strategy) is built on the ambition to achieve a fundamental transformation of Europe's energy system in a cost-effective way. This will be achieved by moving to more sustainable, smarter, more flexible, more decentralized, more integrated, secure and competitive ways of delivering energy to consumers. Most importantly, meeting this ambition will require that energy producers and suppliers innovate in terms of energy production, transportation and services. As innovation is the basis to the Energy Union, it is vital to support researchers and companies at key stages in the development of new products and processes.

The Strategic Energy Technology Plan (SET Plan) as part of the Energy Union strategy is at the forefront of European energy technology policy. The integrated SET Plan will identify those strategic priorities and actions needed to accelerate the EU energy system transformation in a cost-effective way. Renewable technologies are at the heart of the new energy system with photovoltaic solar energy (PV) as a main pillar.

Consequently, PV contributes to two of ten SET Plan Key Actions, namely to develop highly performant renewables and to reduce the costs of key renewable technologies.

Photovoltaic solar energy (PV) technology

All major future energy scenarios forecast a key role for photovoltaic solar energy. PV has a huge global and European potential, making it an important building block for a secure and sustainable energy system. In several European countries PV already provides more than 5% of the annual electricity demand, a level originally anticipated to occur only after 2020. PV currently covers approximately 3% of total EU electricity demand. It has the potential to at least double its share by 2020 and to contribute some 15% in 2030. If achieved, this would result in a considerable contribution to the reduction of CO_2 emissions, since the carbon footprint of PV systems is at least 10 times lower than that of fossil fuel-based electricity, with no CO_2 emissions during operation. On a global level, PV now contributes almost 2% of total electricity and installations show rapid growth[1]. By the end of 2017, the total installed capacity is expected to be around 400 gigawatt-peak (GWp). It could reach 1 terawatt-peak (TWp = 1000 GWp) shortly after 2020, according to the annual market analysis of the European PV sector association Solar Power Europe[2]. This all, however, only represents a tiny fraction of the longer-term potential. In a recent paper in the high-impact journal Science, a group of scientists from Europe, USA and Japan describe pathways towards 10 TWp in 2030[3]. This level of global installations is needed to have real impact on achieving the climate targets agreed in Paris. It would require a tenfold increase of annual global installations and obviously pose a huge challenge, but also a great economic opportunity.

[1] 2016 Snapshot of Global Photovoltaic Markets, IEA PVPV (2017)
[2] Global Market Outlook for Solar Power 2017-2021, Solar Power Europe (2017)
[3] *Terawatt-scale photovoltaics: trajectories and challenges*, Nancy M. Haegel et al., Science **356** (6334), 141-243 (2017).

PV deployment can be accelerated by further enhancing light-to-power conversion efficiency and reducing module and system prices as well as by removing energy system integration bottlenecks.

The PV industry has changed dramatically over the last few years. In Europe, the rapid growth of the PV market has not resulted in a similar growth of the production capacity of solar cells and modules. Europe has lost considerable market share in the past decade years. For instance in 2007, about 30% of the global photovoltaic modules manufacturing was done in Europe. In 2016 the share was about 3%[4]. The overall annual turnover of the European photovoltaic industry is estimated, currently, at EUR 5 billion. More than 60% of this figure goes to equipment manufacturing, 20% to inverter manufacturing, 9% to polysilicon production, and about 7% to cells and modules manufacturing[5]. These shares show that the EU PV industry is still well positioned in the upstream segments of the value chain, but is strongly challenged in the downstream parts. Importantly, Europe still has research institutes on PV that are able maintain a leading position in the highly competitive global science and technology arena. This provides a crucial basis for any ambition to maintain or regain market share in the global PV sector.

Developing a strategy to build on the existing PV industrial and R&I base in Europe, with a view to re-launching cell and module manufacturing, is an urgent priority for three main reasons: 1. There is the concrete risk that once the *central segment* of the PV value chain is lost, soon after the *upstream segment* (i.e. equipment for manufacturing cells and modules) follows because of the continuous interaction and exchanges between the two industrial segments which generally requires logistic proximity; 2. All the analyses point to an ever larger role for photovoltaics in the future global energy system. Ensuring a strong EU position in this industry provides a source of economic growth and for a continued important role in innovative energy technologies, and, importantly, increased energy independence; 3.The 'Clean Energy for All Europeans' proposal announced a *Clean Energy Industrial Forum* to support the EU manufacturing industry (included the photovoltaic industry) to take advantage of the growth opportunities arising as part of the energy transition.

In this context, Europe must continue to invest in Research and Innovation to be able to play an active role and ensure again a strong industrial position. Managing innovation efficiently, maintaining technology leadership and ensuring a full commitment of industrial stakeholders require a coordinated approach at the European level.

This can happen only through the achievement of ambitious system, cost and performance targets, as well as regulatory and market design measures. System cost and performance are to a considerable extent interdependent and represent the actual drivers for the development of the sector. Indeed, increasing the efficiency of PV modules opens one path for reducing costs and allows for new industrial and market opportunities when accompanied by large scale manufacturing. As module costs account for around 50% of system costs, efforts need to be directed also at reducing the costs of Balance of System (BoS) technologies while introducing new functionalities for grid services. Furthermore, manufacturing of PV modules as building materials can develop to a world-wide market with huge opportunities for the European industry. Driven by policies towards Zero-Energy Buildings and subsequently Plus Energy Buildings (PEB), design and innovation with new Building Integrated Photovoltaic (BIPV) materials and concepts and combinations of energy

[4] Photovoltaics Report, Fraunhofer ISE, 12 July 2017
[5] Assessment of Photovoltaics, Final report, April 2017, EUR 27985 EN

efficient building materials with BIPV become essential parts of the development strategies of both the PV sector and the building sector. This calls for a multidisciplinary research and development program involving, among others, the PV manufacturing industry and the building materials industry as well as certification bodies. Breakthroughs in technology, applications and business models are required to transform today's BIPV niche market into a future mass market.

The combination of localized PV electricity, storage or local supply and demand management makes buildings the smallest unit of a smart grid of its own. Once the necessary technology and control mechanisms are developed, the step of linking multiple smart buildings will contribute to the widespread deployment of the smart grid technology. This requires the development of control systems for grid-feeding, self-consumption or local storage and standardization of the interoperability of such control systems.

The achievement of the targets will depend not only on technological advances, but also on non-technological factors such as economies of scale (i.e. resulting from an increase in produced and installed capacity), risk-finance for first-of-a-kind manufacturing pilot lines and demonstration of small, commercial scale PV power plants, the ability to take full advantage of the European Single Market, regulatory conditions, standards etc.

SET Plan strategic targets on PV

This Implementation Plan describes the technological and non-technological R&I activities that need to be implemented in order to achieve the strategic targets adopted in the SET-Plan Declaration of Intent (DoI) on PV[6], as agreed in December 2015 by the representatives of the European Commission services, representatives of the EU Member States, Iceland, Norway, Turkey and Switzerland (i.e. the SET-Plan Steering Group), and representatives of the SET-Plan stakeholders most directly involved in the PV sector[7].

The DoI recognises that, building on the Integrated Roadmap (IR) of the SET-Plan, public (EC and Member States/Regions) and private investment must focus on targeted R&I actions. The overarching goals are to re-build EU technological leadership in the PV sector by pursuing high-performance PV technologies and their integration in the EU energy system as well as bringing down the levelized cost of electricity from PV rapidly and in a sustainable manner to allow competition in electricity markets all over Europe. To achieve these goals, activities targeting improvements on PV system performance, cost reduction, sustainability and innovations have to be carried out. Advances on BIPV products are expected by joint efforts between the PV and the building sectors.

This will be achieved by:

1. Major advances in efficiency of established technologies (Crystalline Silicon and Thin Films) and new concepts:

    - Increase PV module efficiency by at least 20% by 2020 compared to 2015 levels;

[6] SET-Plan Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV), Strategic Energy Technologies Information System (SETIS), https://setis.ec.europa.eu

[7] The European Photovoltaic Technology Platform (PVTP), the European Construction Technology Platform (ECTP) and the EERA Joint Programme on Photovoltaics (EERA JP-PV).

- Increase PV module efficiency by at least 35% by 2030 compared to 2015, including with the introduction of novel PV technologies;

2. Reduction of the cost of key technologies:

   - Reduce turn-key system costs by at least 20% by 2020 as compared to 2015;
   - Reduce turn-key system costs by at least 50% by 2030 compared to 2015 with the introduction of novel, potentially very-high-efficiency PV technologies manufactured at large scale;

3. Further enhancement of lifetime, quality and sustainability and hence improving environmental performance:

   - Maintain proven system energy output per year at least 80% of initial level for 30 years by 2020 and for 35 years by 2025;
   - Minimize life-cycle environmental impact along the whole value chain of PV electricity generation, and increase recyclability of system components (in particular: of modules);
   - Perform focused research and apply & progress eco-design requirements in preparation of implementing measures supporting maximum energy yield (kWh/kWp) and lowest life-cycle environmental impact;

4. Enabling mass realization of "(near) Zero Energy Buildings" (NZEB) by Building-Integrated PV (BIPV) through the establishment of structural collaborative innovation efforts between the PV sector and key sectors from the building industry:

   - Develop BIPV elements, which at least include thermal insulation and water protection, to entirely replace roofs or facades and reduce their additional cost by 50% by 2020, and by 75% by 2030 compared to 2015 levels, including with flexibility in the production process;
   - Recognize the importance of aesthetics in the activities of the implementation of NZEB;

5. Major advances in manufacturing and installation:

   - Make available GW-scale manufacturing technologies that reach productivity and cost targets consistent with the capital cost targets for PV systems;
   - Develop PV module and system design concepts that enable fast and highly automated installation, to reduce the installation costs of both ground-mounted arrays and PV building renovation solutions, by 2020.

Temporary Working Group

In line with the common principles guiding the preparation of the Implementation Plans within the Integrated SET Plan, a Temporary Working Group (TWG) on PV was set up. It is composed of 30 members forming a balanced group of SET Plan countries, Stakeholders and EC, see annex II.

- SET Plan countries are committed in principle to use their energy R&I national programmes and policies to implement some of the R&I activities that will be selected; and are preferably interested in developing and pursuing joint research with other countries. Country representatives in the TWG PV are government representatives, or nominated by their governments.
- Stakeholders are experts from ETIP[8] PV, EERA[9] and industry not organized in the ETIP.
- The EC facilitates and supports the TWG as needed in agreement with the Chair and Co-Chair.

The nomination of the Chair and Co-chair took place before the first WG meeting on invitation of the EC:

- Chair of the TWG PV: Christoph Hünnekes, Project Management Jülich, Energy System: Renewable Energies / Power Plant Technology, Head of Photovoltaics, Forschungszentrum Jülich GmbH, DE-Jülich

- Co-Chair of the TWG PV: Wim Sinke, Co-chairman European Technology and Innovation Platform Photovoltaics, ECN Solar Energy, NL-Petten

- Supported by EC: Fabio Belloni, Directorate-General for Research & Innovation, Directorate G – Energy, Unit G.3 , BE-Brussels

[8] European Technology & Innovation Platform
[9] European Energy Research Alliance

Priority technology actions (R&I Activities)

The process to define the priority technology actions (R&I Activities)

The core of the Implementation Plan is a selection of R&I activities to be carried out by the various actors (SET Plan countries, stakeholders and, within its mandate, the EC) in order to achieve the targets set in the DoI.

Since its installation in January 2017, the work of the TWG was mainly on the definition of priority R&I activities. A kick-off meeting of the TWG was held in Brussels on 25 January 2017. For the definition of R&I activities, a bottom-up approach was agreed upon. Therefore, a template was sent out to all TWG members after the meeting to collect topics for a long-list of proposals. Until mid-March a set of 53 topics all in accordance with the DoI was compiled, and being characterized by a technical description, concrete targets and priorities.

Following this step, the chair / co-chair of the TWG provided a proposal for a Short-list of 6 combined main activities by grouping the 53 individual topics. Until end of May the definition of these activities was discussed and refined within the TWG.

For each of the 6 activities a subgroup was established which elaborated a draft of the description of each R&I activity. The rapporteurs of the subgroups (see below) handled in first versions of the descriptions by mid-June which were commented by the chair / co-chair. Final drafts were received by mid-July. During this phase multiple phone conferences within the subgroups and between chair / co-chair and the EC coordinating officer took place.

TWG PV subgroups and lead:

No	Subgroup	Lead
1	PV for BIPV and similar applications	Otto Bernsen (NL - Netherlands Enterprise Agency)
2	Technologies for Silicon Solar Cells and Modules with higher quality	İlknur Yilmaz (TR - TUBITAK), supported by Prof. Rasit Turan[10] and Emiliano Perezagua (ES - Consultores de Energía Fotovoltica SL)
3	New technologies & materials	Stefan Janz and Simon Philipps (both EU - EERA PV and DE - FhG-ISE)
4	Development of PV power plants and diagnostic	Achim Woyte (BE - 3E)
5	Manufacturing technologies (for cSi and thin film)	Bernhard Dimmler (DE - Manz AG) and Philippe Malbranche (FR - INES)
6	Cross-sectoral research at lower TRL[11]	Otto Bernsen (NL - Netherlands Enterprise Agency)

[10] GUNAM - Center for Solar Energy Research and Applications
[11] Technology Readyness Level

The R&I Activities

The TWG elaborated a set of 6 technology-related priority activities for the future development of PV technologies and applications in Europe. For each priority, ongoing R&I activities (conducted at national and/or at European level and/or by industry) have been identified which already support the strategic targets. Additional R&I activities are considered important as the global PV industry is currently developing rapidly technologically as well as economically.

The 6 R&I activities reflect the prioritised strategic targets defined in the DoI.

1. PV for BIPV and similar applications

   The R&I activity on BIPV aims at developing a market pull approach for innovative and integrated PV solutions that will allow a faster market uptake of new PV technologies and a more intensive and multi-functional use of the available surface area in Europe, including quality and reliability.

   On the one hand, for BIPV it seems likely that thin film technologies (especially CIGS) are well suited. Therefore, a combined development of thin-film PV and BIPV is suggested. On the other hand, BIPV solutions based on other PV technologies can also offer attractive solutions. Sub-activities cover bifacial applications and PV installations on roads & waterways.

2. Technologies for silicon solar cells and modules with higher quality

   Wafer-based silicon (cSi) technologies have the largest market share (>90%) in the worldwide solar PV sector. The main objective of this Activity is to develop and implement advanced cSi PV technologies for high-quality, high-performance cells (≥24%) and modules in high-throughput industrial manufacturing processes, including (for the PV sector) new materials and production equipment. These products will serve as differentiator for the European PV industry by means of significant efficiency benefits and better performance related to sustainability aspects and recyclability of modules (PV Ecolabel, Ecodesign and Energy labels). Through this, the European PV industry will be able to strengthen its global position.

3. New technologies & materials

   Crystalline silicon based solar cells as well as some thin film technologies are gradually reaching their theoretical efficiency limit. The most promising approach (at least on the short and medium term) to go beyond this limit are tandem technologies. Concrete options are III/V-semiconductor or perovskite top cells on silicon bottom cells. Another option is a stack of two thin-film cells. A third route is the development of cost-effective concentrating PV (CPV).

   The aim of this activity is to bring these technologies to an economically feasible level. Therefore the cell processing needs to be scaled-up on an industrial level and the cost needs to be reduced. New materials and the combination of two cell technologies need new interlayer development. Also the stability needs to be enhanced (or maintained if already sufficient). In the end the environmental impact of these new materials needs to be evaluated including quality and reliability.

4. Development of PV power plants and diagnostics

   The aim of this activity is to develop and demonstrate business models and streamline the processes for effective operation and maintenance of residential and small commercial plants in order to keep the plant performance and availability high over the expected lifetime. Especially advanced monitoring is essential. Due to incompatibility and the accompanying extra costs this is often not done according to good industry practices.

   Aspects of energy system integration are included, but as an integral part of the PV system.

5. Manufacturing technologies (for cSi and thin film)

   Further reduction of system and generation costs (LCoE) for silicon wafer based PV and thin film technologies is strongly supported by the implementation of high-throughput, high yield industrial manufacturing technology. This includes production equipment (Capital Expenditure; CAPEX) and material (Bill of Materials; BOM) costs as well as product quality (efficiency and performance). Advances in this field will strengthen the European manufacturing industry. The introduction of new materials and cell/module designs enforces advances in the field of manufacturing technologies, including the introduction of Industry4.0 (“smart factory”) in PV, and will also strengthen the European manufacturing equipment industry.

6. Cross-sectoral research at lower TRL

   With respect to high level R&D, European research labs are still the leading institutions worldwide. A closer cooperation of these labs could help maintaining this position in order to support European industry with cutting edge research results.

   On a topical level this activity covers all the other activities described above, with a focus on the low TRL-parts of the total R&I programs.

Details of the R&I activities are attached as Annex I.

Annex I – R&I Activities

R&I Activity n. 1 - PV for BIPV and similar applications

PV for BIPV and similar applications (building integrated PV includes here the integration of PV into the infrastructure)	
Targets: Cost reduction of new PV integrated applications through technological and production related progress as well as upscaling national niche markets (reduce additional cost by 50% by 2020, and by 75% by 2030 compared to 2015 levels) and thereby accelerating the energy transition. Taking short term measures can still contribute to the goals already stated in the SET plan for 2020 and an economically viable GW size European market in 2030.	**Monitoring mechanism**: Compare total market size and application prices for integrated PV at the start (2017) and finish (2020) for each PMC (product market combination). Estimate added surface otherwise unused for PV. Cost reduction of integrated PV solution by square meter. Estimate progress of the learning curve in TRL levels of technology.

Description: The main policy drivers behind BIPV market growth in Europe is the fact that, being buildings responsible for more than one third of the final energy consumption of EU, there is an urgent need to make the EU building stock more energy efficient and smarter to accomplish the EU Energy and climate objectives[12]. A number of key requirements should be addressed by the supply chain to fully exploit the potential: flexibility in design and aesthetics considerations, demonstration of long-term reliability of the technology, compliance with legal regulations and cost effectiveness.

This activity aims at developing a complementary market pull approach to the technology development for innovative BIPV solutions in the build environment that will allow a faster market uptake of new integrated PV technologies and a more intensive and multi-functional use of the available surface area in Europe, whilst enhancing quality, reliability and live span of the BIPV products and reducing costs.

The added functionality of thin film technologies (such as CIGS, organic solar cells and possibly, in the longer term, perovskites) is well suited for specific market segments where flexible and semi-transparent solar cells are needed. Therefore, a combined development of thin film and BIPV is suggested but not exclusively as crystalline and hybrid technologies may still be competitive as well. The continued R&D effort into efficiency and quality improvement also needs to be paired with the integration issues of solar cells and modules into the build environment. Besides this R&D agenda, short term costs reductions will also have to be realized by re-organizing the value chain and scaling up local customized production by harmonizing markets at the finished end products level.

Thus, this activity underpins the strategic target of mass realization of "(near) Zero Energy Buildings" through the establishment of structural collaborative innovation efforts between the PV sector and key sectors from the building industry, namely the development of BIPV elements, which at least include thermal insulation and water protection, to entirely replace roofs or facades, including with flexibility in the production process while recognizing the importance of aesthetics in the activities of the implementation.

Additionally, PV integration into large infrastructural constructions like roads, railways and waterways will be covered which seem to hold a new and so far undiscovered potential.

[12] Proposal amending Directive 2010/31/EU on the energy performance of buildings COM/2016/0765 final - 2016/0381 (COD)

TRL: TRL 3 (experimental proof of concept) to TRL 7 (system prototype demonstration in operational environment)- depending on technology and application[13]

Total budget required: Generic PV funding budgets in the MS's already cover the higher cell and module efficiencies and some of the quality issues (see as well activities 2, 3, and 5). Specific R&D into the integration topics and production technologies, related to specific market segments, would require around 5 million €/y to reach critical mass and EU cooperation.

For joint demonstration and feasibility projects close to the market one would need additional 2-5 mil. €/y in total.

Expected deliverables	Timelines
Action lines: 1. EU market alignment for large scale BIPV deployment. (goal GW market before 2030 and cost reduction in the value chain)	1. starting Q4 / 2019 and follow-up at least until 2025
2. Joint R&D (goal cost reduction and customized high quality integrated products).	2. 2017 to 2022
3. Organise specific workshops.	3. 2018

Party / Parties *(countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
ongoing		
EU ETIP PV BIPV Working Group	workshops	
IEA PVPS Task15 – Austria, Belgium, Denmark, France, (Germany), Italy, the Netherlands, Norway, Spain, Sweden, Switzerland (and Canada, Japan, Korea)	R&I activity on international level: The objective of Task 15 is to create an enabling framework to accelerate the penetration of BIPV products in the global market of renewables, resulting in an equal playing field for BIPV products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues	Initially 190 PM foreseen (approx. 1.7 mill. €, mostly financed by contributing countries)
Germany, Netherlands, …	R&I on national level market oriented demonstration and short term product development[14]	approx. 4 mill. €/y 40,33 mil €/y plus 50 mil €/y
Solar ERA-Net participants	joint R&I activities between SET Plan countries (projects like "BIPV-pod", "PVme", …)	approx. 2 mill. €/y (NLD + DEU)

[13] Extension into TRL 8 cannot be covered in many countries by the funding agencies with some exceptions.
[14] both for NLD - generic for RES

…		
planned activities		
…	R&I on national level	Germany: new projects on BIPV with al volume of 7.6 mill € (thereof 5.6 mill € funding) are in the pipeline, …
Solar ERA-Net participants	joint R&I activities between SET Plan countries	
…		

R&I Activity n. 2 - Technologies for silicon solar cells and modules with higher quality

Technologies for silicon solar cells and modules with higher quality	
Targets: (from Declaration of Intent) Bring down the Levelised Cost of Electricity (LCoE), by: • increasing PV module efficiency by at least 20% by 2020 compared to 2015 levels; • increasing PV module efficiency by at least 35% by 2030 compared to 2015 levels; • improving product quality, reliability, stability and lifetime (the latter to 30 yrs in 2023 and 40 yrs in 2030); • improving (environmental) sustainability and bankability; • Improving applicability through better aesthetics, form freedom, function integration, and shade tolerance.	**Monitoring mechanism**: monitoring will be done by funding agency.
Description: Wafer-based silicon (cSi) technologies*) have the largest market share (>90%) in the worldwide solar PV sector, making this a very important Activity. The main objective of this Activity is to develop and implement advanced cSi PV technologies for high-performance cells (≥24%) and modules in high-throughput industrial manufacturing processes, including (for the sector) new materials and production equipment. These high-quality modules will serve as differentiator for the European PV industry by means of significant efficiency benefits and better performance related to sustainability aspects and recyclability of modules (PV Ecolabel, Ecodesign and Energy labels). Through this, the European PV industry will be able to strengthen its global position. *) *cSi includes PERX (PERC, PERT and PERL) and back-contact (IBC) mono- and bifacial designs as well as heterojunction technologies (HJT); all with advanced passivation schemes.*	
TRL: 3 - 7	
Total budget required: The overall PV funding budget in the participating countries Germany and the Netherlands varies between 60 and 90 million euros per year. There is no dedicated budget for cSi PV technologies but based on experience of the last years, approximately up to 70% of the total PV budget was used for funding in this part of sector.	
Expected deliverables	**Timeline**
• Cell efficiency 24% in industrial environment (with PERC).	5 years
• Module efficiency >22% with a module lifetime of >30 yrs at >80% power output.	5 years
• Demonstrated industrial processes for passivated contacts for cells with efficiencies >24% and >90% bifaciality.	5 years

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Silicon purification		
- Silicio FerroSolar, Aurinka PV, IES-UPM (Spain)	National funding and industry resources	tbd
Crystallization and wafering:		
- PVA Crystal Growing Systems GmbH, Fraunhofer-Center für Silizium-Photovoltaik CSP – project „Inno-Si": development of innovative silicon crystallization processes.	National funding and industry resources	~ 2.9 million euros total with ~ 1.9 million euros funding
- NexWafe GmbH, Fraunhofer-Center für Solar Energiesysteme ISE, Singulus Technologies AG, centrotherm clean solutions GmbH & Co. KG – project "EpiPower": epitaxially grown wafers.	National funding and industry resources	~ 5.5 million euros total with ~ 3.6 million euros funding
Cell technologies:		
- RCT Solutions GmbH, PV Crystalox Solar Silicon GmbH, PVA Crystal Growing Systems GmbH, Fraunhofer-Center für Silizium-Photovoltaik CSP, International Solar Energy Research Center Konstanz e.V. – project "KosmoS": development of high efficient n-type solar cells by industrially feasible processes	National funding and industry resources	~ 3.0 million euros total with ~ 1.9 million euros funding
- IES-UPM, TiM-UPV, NTCNano…(Spain)	National funding and industry resources	tbd
- Tempress Systems, Levitech, Exasun, Solmates, Roth & Rau NL, ECN, AMOLF, TU Delft, TU Eindhoven, Twente of University, other Dutch knowledge institutes and private companies within the TKI Urban Energy program	National funding and industry resources	~ 8 million euros total with ~5 million euros Dutch funding
Module technologies:		
- FhG-ISE – Project "PV-BAT400": development of bifacial silicon solar cells and modules with power densities of 240 W/m²	National funding	~ 11 million euros funding
- Mondragón Assembly, TiM-UPV, IES-UPM, NTCNano ...(Spain)…	National funding and industry resources	tbd
- ECN, AMOLF and DSM NBD, Tempress Systems, Heliox, other	National funding and	~ 4 million euros total

Dutch knowledge institutes and private companies within TKI Urban Energy program	industry resources	with ~2 million euros Dutch funding
HJT technologies: - Meyer Burger (Germany) AG, Fraunhofer-Institut für Solare Energiesysteme (ISE), Hennecke Systems GmbH, AIS Automation Dresden GmbH, Koenen GmbH, SOLARWATT GmbH, AEP Energie-Consult GmbH, EWE e. V., - project „HERA“: development of bifacial HJT solar cells	National funding and industry resources	~ 11,3 million euros total with ~ 7,5 million euros funding
- CIEMAT, UPC…(Spain)	National funding and industry resources	tbd
- ECN, TU Delft, TU Eindhoven, Tempress Systems, Levitech, other Dutch knowledge institutes and private companies within the TKI Urban Energy program	National funding and industry resources	~ 2 million euros total with ~1 million euros Dutch funding
Outlook on possible funding topics		
Cell technologies: - Evolutionary development of PERC technologies	National funding and industry resources (from Germany and the Netherlands)	prospective ~ 18 million euros funding
HJT technologies: - Development of HJT technologies with economic viability	National funding and industry resources (from Germany and the Netherlands)	prospective ~ 10 million euros funding
Industrially feasible passivated contacts Identifying and demonstrating industrially feasible cell concepts and production processes and equipment for passivated contacts for both polarities, to further improve PERX, HJT and IBC technologies SINGULUS (Germany) with various European industrial and institutional partners	National funding and industry resources (from Germany and other member states)	prospective ~ 15 million euros funding
Back contact cells technology - Development of IBC technologies with economic viability	National funding and industry resources (from Germany and the Netherlands)	tbd

Module Technologies Identifying and demonstrating industrially feasible and reliable contact and module technologies for highest efficiency cSi cells with passivated contacts, a module efficiency of >22 % with <80% degradation over a lifetime of >35 yrs.	National funding and industry resources.	tbd
European quality/sustainability “label or method” (Ecofriendly processes and products including materials) - CENER (Spain), Fraunhofer (Germany)...	National funding and industry resources.	Prospective (tbd) million euros funding

R&I Activity n. 3 - New Technologies & Materials

New multi-junction PV technologies for highest efficiencies at reasonable costs	
Targets: R&I Activity will help to achieve all 5 strategic targets of the DoI but mainly target: "Major advances in efficiency of established technologies and new concepts". More specific: to achieve efficiency targets above limits of existing individual PV technologies towards 35% (in 2-5 yrs) and 40% (in 5-10 yrs) with tandem structures of cSi, Thin Films (TF) and concentrating PV technologies.	**Monitoring mechanism**: funding agencies and stakeholder groups will monitor progress towards the targets.

Description: The dominant crystalline silicon wafer solar cell is converging to its theoretical efficiency limit. As efficiency improvement and cost reduction must proceed for successful power market development, approaches which can meet these needs are inevitable. The most promising one to further improve efficiencies are multi-junction (mj) technologies with Si or CIGS as bottom absorbers and with III/V semiconductors, perovskite, CIGS or other high-bandgap top absorbers, and the already available multi-junction technology concentrating photovoltaics (CPV). The aim of this activity is to raise these technologies to an industrial level. Therefore new ways of absorber layer fabrication, interface design and interconnection of the sub-cells have to be developed. Focus should be on the development and application of new materials, new cell and module concepts and of production equipment and related production processes. Furthermore quality and reliability needs have to be fulfilled and the environmental impact needs to be evaluated. The energy yield of these technologies in real conditions should also be clearly stated.

TRL: 3 - 7

Total budget required: Budgets required for each main topic is in the range of 15 – 50 Mio. €. Participation and collaboration of competing concepts and production equipment / processes will in most cases be an efficient solution bringing synergies. A proper handling of IP is important.

Expected deliverables	Timeline
For multi-junction devices on Si or CIGS:	
• Stable (years) efficiencies (>30%) for perovskite on Si / CIGS mj-cells	• 2 – 5 years
• New methods / tools for economic III-V absorber deposition and transfer	• 2 – 5 years
• Wide gap top cells (Perovskites, CIGS) (> 20%) based on economically viable production processes.	• 5 - 10 years
• Adaptation of Si / CIGS bottom cell	• 2 – 5 years
• Monolithic interconnection methods	• 2 – 5 years
• Life cycle analysis for whole fabrication route	• 2 – 3 years
• Demonstrations of economic tandem cells on industrial level	• 3 – 7 years
• Sustainable module solutions for multi-junction solar cells	• 5 - 10 years
• Energy yield in real conditions (spectrum and temperature variations)	• 2 – 5 years
• Advanced characterization and modeling methods / tools dedicated to multi-junction devices	• 2 – 5 years
For CPV:	
• New methods / tools for economic III-V absorber deposition and transfer	• 2 – 5 years
• High performance module with >40 % efficiency	
• Life cycle analysis for whole fabrication route	• 2 – 5 years
• Energy yield in real conditions	• 2 – 3 years
	• 2 – 5 years

<table>
<tr><th>Parties
(countries / stakeholders / EU)</th><th>Implementation instruments</th><th>Indicative financing contribution</th></tr>
<tr><td>multi-junction dev. on Si
FhG-ISE, Uni Freiburg, HZB, Merck, Heraeus</td><td>National funding and industry resources
Flagship project “PersiST”: development of perovskite/silicon tandem solar cells on cell level; improvement of efficiency, stability, eco-compatibility</td><td>≈ 5.5 million € total with ≈ 4.3 million € funding</td></tr>
<tr><td>CPV
Azur Space Solar Power, FhG-ISE, Orafol Fresnel Optics</td><td>National funding and industry resources
Flagship project “CPVMod”: development along whole value chain and demonstration especially in sunny regions to push acceptability</td><td>≈ 5.1 million € total with ≈ 2.9 million € funding</td></tr>
<tr><td colspan="3">Outlook on possible funding topics
(countries / stakeholders / EU)</td></tr>
<tr><td>multi-junction dev. on Si
confirmed partners
- TKI Urban Energy, ECN.TNO, Solliance, Radboud Uni. Nijmegen, Tempress
- FhG-ISE, Uni Freiburg
- IES UPM, CIEMAT, DHV Technologies
- IPVF, INES

further possible partners
- HZB, Merck, Heraeus, ISFH, Evonik, Meyer&Burger</td><td>Project with national / European funding and industry resources
- Stable (years) efficiencies (>28%) for perovskite on Si mj-cells
- New methods / tools for economic III-V absorber deposition and transfer
- Wide gag CIGS top cell
- Adaptation of Si bottom cell
- Monolithic interconnection methods
- LCA for whole fabrication route
- Demonstrations of economic cells on industrial level
- Sustainable module solutions for multi-junction solar cells
- Advanced characterization and modelling for multi-junction cells</td><td></td></tr>
<tr><td>CPV
confirmed partners
- FhG-ISE
- IES UPM, BSQ Solar, Solar Added Value, DHV Technologies, Tecnalia, CENER</td><td>Project with national / European funding and industry resources
- Development of new methods / tools for economic III-V absorber deposition and transfer
- High performance module with >40 % efficiency</td><td></td></tr>
</table>

further possible partners - Azur Space Solar Power, Orafol Fresnel Optics	- Life cycle analysis for whole fabrication route	
All thin film multi-junctions *confirmed partners* EMPA/FOLISOM, ZSW, IMEC, Manz CIGS	Project with national / European funding and industry resources Already existing consortium in horizon2020 “sharc25” as follow up project on CIGS-Perovskites and others; all expertise is already there on a high level - R&D on CIGS & Perovskite - R&D on CIGS & other thin film compound - Sustainable mj devices (resources, stability, LCA ...) - Manufacturability and economic assessment	Ca. 10 Mio.€ total and 4.5Mio.€ funding

R&I Activity n. 4 - Operation and diagnosis of photovoltaic plants

Operation and diagnosis of photovoltaic plants	
Targets: This Activity contributes mainly to Targets 3 of the Declaration of Intent: "Further enhancement of lifetime, quality and sustainability", by: On PV plant level, achieve common annual performance ratio (PR) including periods of unavailability and after correction for expected degradation in the field: 82% PR for residential and small commercial plants and 87% for other plants installed in 2020; and 85% for residential and small commercial plants and 90% for other plants installed in 2025. Today average PR values are around 78% for residential and 81% for the larger plants. The given targets are for a Western European moderate climate and accordingly lower or higher in warmer or colder regions, respectively.	**Monitoring mechanism**: Monitor national medians of annual PR of operational plants for year 1 and year 5 (end of warranty) of operation per member state and PV market segment.

Description:

The aim of this activity is to develop and demonstrate technical solutions, business processes and business models that can support high plant performance, availability and income at reasonable costs for advanced monitoring, operations and maintenance (O&M) over the expected lifetime of the PV plant. The three main drivers of Levelised Cost of Electricity (LCoE) reduction in practice are advanced monitoring, qualification of contractors for engineering, procurement and construction (EPC), and product testing. Today, in the segments of large commercial and utility scale plants above 500 kW, advanced monitoring is increasingly applied; with a large market potential world-wide. In the segments of residential up to medium-size commercial plants, only basic monitoring is on hand but advanced monitoring is barely available today. Specific objectives of this action are:

- advanced and automated functions for data analysis, fault detection, diagnosis, maintenance planning and/or reporting;
- interoperability, standardization and auto-configuration of sensors, data acquisition, inverters and communication systems within PV plants and between PV plants and central monitoring systems (Industry 4.0/internet of Things);
- easy-to-understand business models with quality KPIs for monitoring, O&M and asset management of residential up to medium-size commercial plants which transparently return the net benefit of better operations to the stakeholders involved.

Beyond the technical performance, income in future will increasingly be determined through the market value of the electricity in a given market environment, which is still member-state specific. Value may be created through aggregation and sales on spot or ancillary service markets or through energy management at the prosumer-side of the energy meter. In this respect, specific objectives are:

- Interoperability in terms of control and bidirectional communication between PV plants among each other, distributed energy management systems, and central control systems;
- Inclusion of aggregation and energy management into business models and KPIs for monitoring, PV plant O&M and asset management as listed above.

TRL:

- Advanced automatic functions for monitoring: target TRL 6-7 (Industrial research & demonstration)
- Interoperability, standardization and auto-configuration of PV plant components; Interoperability in terms of control and bidirectional communication between plants and

central systems: target TRL 7-9 (Industrial research & demonstration / Innovation & market uptake)

- easy-to-understand business models for monitoring, O&M and asset management of residential up to medium-size commercial plants; Inclusion of aggregation and energy management into business models and KPIs: target TRL 9 (Innovation & market uptake)

Total budget required: €60 million

Expected deliverables	Timeline
1. Industry-driven demonstration projects targeting advanced automatic functions for monitoring covering the different market segments (few projects per target with large impact) showing, for the first years of operation, a 5% PR increase over plants installed in 2017;	2022
2. Industry-driven demonstration projects targeting interoperability, standardisation and auto-configuration of PV plant components (few projects per target with large impact), reducing costs for monitoring compared to 2017 by 20%;	2022
3. Industry driven market uptake projects, with one or more of the following targets (several smaller projects per target):	
3.1. interoperability, standardisation and auto-configuration of PV plant components; reducing costs for monitoring compared to 2017 by 20%;	2022
3.2. interoperability in terms of control and bidirectional communication between plants and central systems; reduce costs for technically enabling market access and aggregation below 1% of LCOE.	2022
3.3. easy-to-understand business models for monitoring, O&M and asset management of residential up to medium-size commercial plants; 50% of new plants in this segment are followed up actively.	2022
3.4. the inclusion of aggregation and energy management into business models and KPIs; KPIs include a parameter reflecting the power value of the generated electricity.	2022

Party / Parties *(countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
1. Advanced automatic monitoring functions: industry (O&M services, monitoring, sensors, modules, inverters), MS & EU	1. National level (mixed funding public-private), joint R&I activities between SET Plan countries (EUREKA-EUROGIA, ERA-NET Cofund), EU level (Framework Program)	1. €20 million • Industry: 30-60% • Public: 70-40%
2. Interoperability, standardization and auto-configuration of PV plant components: industry (monitoring, sensors, inverters), MS & EU	2. Joint R&I activities between SET Plan countries (EUREKA-EUROGIA, ERA-NET Cofund), EU level (Framework Program, Interreg)	2. €20 million • Industry: 30-60% • Public: 70-40%

3. Market uptake 3.1. Interoperability, standardisation and auto-configuration of PV plant components: industry (monitoring, sensors, inverters, industry associations), MS & EU 3.2. Interoperability in terms of control: industry: (energy suppliers or aggregators, monitoring, PV O&M, PV asset managers) 3.3. Easy-to-understand business models for monitoring, O&M and asset management of residential up to medium-size commercial plants: industry (energy service companies, PV asset managers) (private & public sector), MS & EU 3.4. Aggregation and energy management: industry (energy suppliers or aggregators, monitoring, PV O&M and installation sector, PV asset managers, industry associations), MS & EU	3. EU level (Framework Programme, Interreg) due to the European dimension of unteroperability and standardization; Possibly Interreg for a Flagship project	3. €20 million • Industry: 30-60% • Public: 70-40%
One flagship project: A pilot for O&M and asset management of residential up to medium-size commercial plants built on one or several easy-to-understand business models and accessible monitoring solutions; showing how PR for this segment can be increased by 5 to 10% through professional operations. Parties: industry (energy service companies, PV asset managers, PV O&M services, monitoring software); public sector, e.g., social housing, municipalities, public energy suppliers; MS & EU		

R&I Activity n. 5 - Manufacturing technologies

Manufacturing technologies for silicon and thin-film PV	
Targets: (from Declaration of Intent) Bring down the Levelised Cost of Electricity (LCoE) through reduction of the module manufacturing cost (of ownership; CoO) by 25% in 5 yrs, and 40% in 10 yrs. This is done by reducing: - equipment cost by 30% in 5 yrs, and 50% in 10 yrs; - material cost by 20% in 5 yrs, and 40% in 10 yrs.	**Monitoring mechanism**: regular reporting by project partners related to set quantitative technical milestones as deliverables and regular assessment by high level industry, and professional supervisors, funding agency

Description: production equipment (Capital Expenditure; CAPEX) and material (Bill of Materials; BOM) costs and product quality (efficiency and performance) directly influence manufacturing costs and LCoE. A further reduction of manufacturing costs for crystalline silicon (cSi) and thin-film PV modules relies on the implementation of highly productive manufacturing equipment and processes (CAPEX) and reduced materials expenses (BOM). The introduction of new materials and cell/module designs enforces advances in the field of manufacturing technologies (including the introduction of Industry4.0 in PV) and will also strengthen the European manufacturing equipment industry. Achieving the main targets requires research and innovation (R&I) in the following fields and topics:

Material cost (BOM) reductions:

- use of input materials for cell/module production with reduced carbon footprint and (required) purity and enhanced availability of resources (including the development of alternatives);
- reduction of the amount of input materials needed by reduced thicknesses and higher material usage (material yield and recycling), and introduction of better materials.

Manufacturing equipment cost (CAPEX) reductions:

- increase of the productivity of large scale manufacturing equipment and processing by enhancement of:
  - throughput (wafers/time, module area/time);
  - yield (process and quality control, including by Industry4.0 features, such as self-learning);
  - availability (optimization of uptime and service time, a.o. by self-learning);
- replacing batch by in-line processing and parallelization of processing, handling and quality control;
- equipment for increased product size: thin-film modules to 1.5 - 2.5 m^2; optional: increased cSi wafer size or reduced wafer thickness;
- improved in-situ and off-line quality control;
- flexibility of back-end process for automated production for specialized modules (BIPV, consumer, automotive etc. products) with input from Activity 1.

Process and equipment alternatives:

- alternative processes and equipment for reduced CAPEX and BOM (in-line, non-vacuum, roll-to-roll, printing and laser-supported techniques, hybrid technologies);
- equipment and processes for new sealing concepts (further exploration of thermoplasts and other materials, smart coatings to replace front glass lamination, adaption to special climatic conditions and applications (integrated solutions).

TRL: depending on topic and present status R&I work could be advanced research (AR) but will mainly be industrial research & demonstration & innovation (iR&D&I) for improving actually used and next generation equipment, status and further increase of scaling. The TRL levels at start are 6-7 (with applied R&I at TRL 3-5), TRL levels at end 8-9 (with applied R&I at TRL 5-7).

Total budget required: industry-relevant prototype equipment is needed for demonstration and qualification, to fulfil the needs for rapid transfer to large scale manufacturing. Therefore the budgets required for each equipment topic is in the range of 10 – 50 Mio. EUR. R&I on materials and processes will have lower budget needs in first level R&I. Pilot lines in the range 50 to 200 MWp/a

nominal capacity may be necessary for pre-qualifications for large scale manufacturing. Participation and collaboration of competing equipment and module manufacturing companies will be an effective way to generate synergies in most cases. A proper handling of IP is important.	
Expected deliverables	**Timeline** (targets)
Proof of concepts in a (quasi-continuous) mode near large-scale manufacturing with (equal or better) product quality: - materials already in use but modified; - alternative materials; - prototype-equipment for large scale manufacturing (modified existing); - alternative processing and equipment.	- 3 – 4 years (BOM minus 20%) - 4 – 6 years (BOM minus 40%) - 3 – 4 years (capex minus 20%) - 4 – 6 years (capex minus 40%)

Party / Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
Today EU equipment making companies are well established and still market leader worldwide in most technologies. Most of these companies are placed in Germany, Switzerland, Italy and the Netherlands. A European module manufacturing industry with high market participation is small presently. For effective R&I, a larger scale manufacturing industry is important. Political decisions and regulations can play an important role. Accepted international collaborations might be important if added value can be shown on a high level for Europe. Parties ready and already active are e.g. in product manufacturing SolarWorld, Photowatt, Avancis, Solibro, Manz etc., in equipment manufacturing Meyer Burger (CH/DE), centrotherm (DE), Manz (DE), Singulus (DE), vonArdenne (DE), Tempress (NL), VDL (NL), AMAT (EU/USA), etc. and have to be supported by the existing world class institutions FhG-ISE, CEA-INES, EPFL-CSEM, imec, ISFH, ECN, ZSW and others). Proposed FLAGSHIP "Production equipment for high-tech large-scale productions for PV (with subgroups of cSi, thin films and combinations thereof), maybe together with spin-offs of display, electronics and storage technologies". Proposed FLAGSHIP: "Pilot lines" (cSi: wafer-cell-module, thin film: integrated) with relevant capacity of 300 MWp/a)	Many of the topics are with stakeholders from several member and associated states; therefore EU funding should be applied; if topics are dominated by stakeholders from one member state EU and national funding should be combined. For establishment of a Flagship project on "High-tech large-scale production equipment" EU lead funding is recommended. As a result worldwide competitiveness and leadership can be kept and secured.	As content and stakeholders are dominated by equipment and manufacturing industry all projects are based on private-public-partnership with shares of public funding from 50% to 25% depending on TRL levels i.e. maturity for commercial exploitation.
Running activities		
In Germany, the set-up of R&D	National funding	~ 14.2 million euros

infrastructure is supported. The infra-structure is situated at research institutes so that it can be used by the industry for a quick and easy testing and implementation of new processes into the manufacturing process as well as for the development of industry relevant processes. E.g. projects "CUT A" (Fraunhofer ISE) or "ProSolar" (ISFH) for advanced cSi modules or "VariFast CIGS" (ZSW) for CIGS technology.		funding
Project "FlexFab" (RCT Solutions, ISC Konstanz): Development of flexible manufacturing equipment for advanced cSi technology with system control via "Industry 4.0" / "smart factory"	National funding and industry resources	~ 3.0 million euros total with ~ 2.0 million euros funding
Project "Cheops" (Singulus, Fraunhofer ISE, camLine, MIB Messtechnik): Development of wet chemical multi-usage equipment including methods for self-testing to reduce equipment failures	National funding and industry resources	~ 3.8 million euros total with ~ 3.0 million euros funding

…

R&I Activity n. 6 - Cross-sectoral research at lower TRL

Cross-sectoral research at lower TRL	
Targets: Closer collaboration between national PV labs for the sake of shared costs in development of new technologies and supporting European industries to facilitate a shorter time-to-market (T2M).	**Monitoring mechanism**: number of collaborations of national labs and resulting co-operations with industry - monitored by national funding agencies

General Description: With respect to high quality R&D, national research labs in Europe are still the leading institutions worldwide. A closer cooperation of these labs could help maintaining this position in order to support European industry with cutting edge research results. The focus will lie on cost sharing in research and technology development and significant lower time-to-market (T2M) times.

On a topical level activity 6 covers innovation in all the other activities of this Implementation Plan, namely PV for BIPV and similar applications, technologies for silicon solar cells and modules with higher quality, new technologies & materials, operation and diagnosis of photovoltaic plants and manufacturing technologies, but will focus more on the innovation system as such.

The activity will build on existing research capacities. The implementation of joint activities between the labs may be taken up jointly by MS's but may also take place in the existing European Innovation system and EERA. Explicitly this activity should use but not duplicate any work done previously in the SET plan by the JRC, ETIP or Eranet / Cofund.

TRL: The TRL level may depend on the research topic but will lie between TRL 3 and 6.

Total budget required: As a first approach, no additional budget is needed as resources for national labs are already available and "only" have to be re-allocated for cooperation projects. However, additional budget will be needed if the demand for exchange becomes higher than provided. Furthermore, alignment of research implies the long term allocation of resources for R&D into the proposed program lines in order to avoid "stop and go" cycles of decisions based on a project level and individual calls.

Expected deliverables	Timeline
inventory of ongoing collaborations and additional opportunities	2018
joint R&D projects between national labs with relevance for the strategic targets outlined in the PV Implementation Plan	from 2018 on
co-operation between industry and labs based on the findings of the inter-lab co-operation	from 2020 on

Party / Parties *(countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
ongoing activities		
joint research on Thin-film solar cells within the solliance initiative between Belgian, Dutch and German research centres (http://solliance.eu/)	joint research	
transnational cooperation between leading European research-driven clusters within the EU project SOLARROK (http://www.solarrok.eu/)	joint research	approx. 2.2 mil. € from FP7-REGIONS
planned activities		
programs for an increased exchange of staff		approx. 25.000 € per person and year for travel and material expenses[15]
additional activities on joint usage of infrastructure like - PV test sites - ...		
initiate a (virtual) high performance computer centre for R&I on PV and maybe renewable energies in general[16]		eventually, new instruments on funding research infrastructure have to be developed on an European level
…		

[15] personal costs are expected to be beard by the home institution
[16] see for example the High Performance Computing (HPC) center at the National Renewable Energy Laboratory, https://hpc.nrel.gov/

Annex II – Members of the TWG

Member States (11)

member		alternate
Cypress - University of Cyprus	George E. Georghiou	Aris Bonanos
Belgium - Walloon region	Laurence Polain	
Belgium - Flemish region	Lut Bollen	
Estonia - Ministry of Economic Affairs and Communications	Siim Meeliste	
France - Ministère de l'Environnement, de l'Energie et de la Mer	Louise Oriol	
Germany – Project Management Jülich (PtJ) **(Chair)**	Christoph Huennekes	Johannes Lambert
Italy - National Research Council of Italy	Massimo Mazzer	
Netherlands - Netherlands Enterprise Agency	Otto Bernsen	
Norway - The Research Council of Norway (RCN)	Trond Inge Westgaad	Tor Ivar EIKAAS, RCN, Astrid STAVSENG, Ministry of Petroleum and Energy
Spain - Centre for the Development of Industrial Technology (CDTI)	Pilar Gonzalez Gotor	M. Luisa Revilla
Turkey - TUBITAK	İlknur Yilmaz	Cagri Yildirim

European Commission (4)

member		
DG RTD	Fabio Belloni	
DG RTD	Maria Getsiou	
DG ENER	Pietro Menna	
EC JRC	Arnulf Jäger-Waldau	

ETIP & Industry (15)

member		alternate
EUREC / ETIP PV Secretariat	Greg Arrowsmith	
Enel Green Power	Fabrizio Bizzarri	
Manz AG	Bernhard Dimmler	
DSM	Oscar Goddijn	Ellen Oerlemans
SETA Network	Silke Krawietz	

member		alternate
Becquerel Institute	Gaëtan Masson	
SolarWorld AG	Milan Nitschke	
Consultores de Energía Fotovoltica SL	Emiliano Perezagua	
EERA PV (Fraunhofer ISE)	Simon Philipps	Ivan Gordon
IMEC	Jef Poortmans	
ECN - (Co-Chair)	Wim Sinke	
University of Ljubljana	Marko Topič	
First Solar	Andreas Wade	
Singulus	Peter Wohlfart	
3E	Achim Woyte	