FOTOPLAT

Hoja de ruta para la tecnología fotovoltaica

Contribución española 2017

Promueve

UNEF
Unión Española Fotovoltaica

tecnalia

Financia

MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD

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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 Anexo 3 está datado en octubre 2017.

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

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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
- Durability and reliability of PV modules and systems
- Mobility and Training and use of Infrastructures

This Description of Work summarizes the work plan of the EERA-PV joint programme as agreed upon by the Management Board (MB) and Steering Committee (SC) of the joint programme. This Description of Work is a living document that is regularly updated (at least once a year) whenever the need arises and in agreement with both the MB and SC. To keep track of the changes, each new version gets a new version number which is indicated on the first page, together with the last modification date.

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, increased lifetime and durability of modules, 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 SET Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV) have been used to identify and discuss the priority areas of interests with the key stakeholders.

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
- Improved durability and reliability of modules and systems
- Mobility and Training and use of Infrastructures

Therefore, 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 citizens.

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. The CHEETAH project (www.cheetah-project.eu) started beginning of 2014 and will finish at the end of December 2017. A high number of EERA PV members are partners of this CHEETAH project, which focuses on the following topics:

- 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 with a focus on reducing material consumption for wafer-based, inorganic, and organic photovoltaics.
- 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, through webinars 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 various 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. Research priorities 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 European PV stakeholders together with the European Commission and the member states outlined strategic targets for PV solar energy in the issues paper No. 2 (the SET Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics). 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 the 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 seven sub-programmes, for which the following research priorities have been set:

Silicon Technology
- Further improvements in terms of cost and quality of Si materials: feedstock, ingots and wafers
- Development of high-efficiency low-cost c-Si solar cell and module production technology
- Study and development of radically new c-Si based solar cell concepts, such as silicon-based tandem cells to overcome the theoretical efficiency limit of 29.4%

Thin-Film Inorganic Photovoltaics
- Development of thin-film multi-junction devices to overcome the single-junction efficiency limits
- Development of p-doped wide band gap materials and tunnel junction for chalcopyrite/perovskite tandem devices
- Development of Inorganic wide-band gap materials as top cell absorber
- Improving the light management in thin-film photovoltaic devices, and especially in 2-terminal thin-film tandem devices.
- Reducing the use of toxic and/or rare materials in thin-film photovoltaics

Hybrid and Organic Photovoltaics
- Exploration of novel abundant materials with low environmental footprint and integration of these novel materials in multijunction structures to boost efficiencies
- Identification of factors limiting the stability of organic and hybrid devices and improvement of said stability via modifications of existing materials and development of new intrinsically stable materials
- 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
- Demonstrate applications for organic and hybrid solar cell technologies that exploit the strengths of these technologies

Concentrated Photovoltaics
- Development of ultra-high efficiency solar cells for CPV applications
- Optimization and cost reduction of proven and reliable optics, receiver and modules

- Cost reduction of tracking systems
- Development of procedures and equipment for CPV testing, calibration, reliability and quality control
- Energy forecast, operation, and recycling of CPV systems
- Development of cells and receivers for low and medium concentration CPV
- Development of future, novel and alternative CPV concepts

PV systems

- Design, planning and engineering (methods and tools) of PV systems
- Establishing guidelines for optimum transportation, installation, configuration, fulfilment of safety requirements (including fire safety) and monitoring/evaluation
- Study of technical requirements for components and environmental requirements (LCA, LCC, recycling)
- Increase energy yield of PV systems / reduce system losses
- Fault prediction and long term reliability of systems, increased manageability of PV systems.
- Cost reduction of BOS
- Increasing the 'value' of the PV power generation (self-consumption, business models, forecasting...)

Durability and reliability

- Assessment and modelling of stress climates being seen by PV modules
- Development of models for key failure modes
- Improvement of understanding of correlation between durability and key material properties
- Development of multi-stress testing procedures to ensure correlations between different stress factors are captured
- Improvement of certification tests to ensure long-term reliability (>35 years)
- Development of novel non-destructive, module scale metrology to assess state of materials and performance
- Development of more accurate models to determine the energy yield of modules over thier entire lifetime

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 and information

4. Participants

Partner	Country	SP1	SP2	SP3	SP4	SP5	SP6	SP7
AIT	Austria	x	x			x	x	x
CEA-INES	France	x		x	x	x	x	x
CENER	Spain	x		x	X	x	x	x
CIEMAT	Spain	x	x	x				x
CNRS	France	x	x	x	x	x	x	x
CRES	Greece	x				x	x	x
DTU	Denmark			x				x
ECN	Netherlands	x	x	x		x	x	x
ENEA	Italy	x	x	x			x	x
EPFL	Switzerland	x		x		x	x	x
FFCUL	Portugal	x	x	x		x		x
Fraunhofer ISE	Germany	x	x		x	x	x	x
FVB	Germany	x						x
FZ Juelich	Germany	x	x	x		x	x	x
HZB	Germany	x	x					x
ICIQ	Spain		x	x				x
IFE	Norway	x				x	x	x
IMEC	Belgium	x	x	x		x	x	x
Imperial	UK			X				x
LNEG	Portugal		x	X		x		x
Metu	Turkey	x	x	X		x	x	x
NPL	UK			x			x	x
NTNU	Norway	x	x					x
RWTH Aachen	Germany	x		x				x
Sintef	Norway	x				x	x	x
Tecnalia	Spain	x			x	x	x	x
Torino Uni	Italy			x				x
Tubitak	Turkey							x
TuT Tallinn	Estonia		x					x
Ukerc	UK					x	x	x
UNIMIB	Italy	x	x	x				x
UNIPI	Italy			x	x			x
UPM	Spain	x			x	x		x
UPV LC	Spain	x						x
Utrecht Uni	Netherlands	x		x			x	x
VTT	Finland			x				x
ZSW	Germany		x	x		x		x

SP1 = Silicon technology
SP2 = Thin film inorganic PV
SP3 = Hybrid and organic PV
SP4 = Concentrated PV
SP5 = PV systems
SP6 = Durability and reliability
SP7 = education and training and use of infrastructures

5. Infrastructures and facilities

The use of infrastructures and facilities is, together with Education, Mobility and Training, a specific activity in the Joint Programme (SP7).

6. 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 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.

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

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

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

Description of Work

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Summary

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 2016. 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.

This sub-programme aims at improving collaboration between research groups in the field of c-Si solar cells, developing new activities and projects, be a forum for networking, as well as a base for developing common roadmaps for future developments.

This Description of Work is based on a substantial past effort. One essential step was the creation of the sub-programme Silicon Technology in the EERA JP PV in 2013. In the first 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 current sub-programme on Silicon Technologies brings together important research players along the entire value chain of production.

1. Vision

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 goals of the work programme of the EERA JP PV sub-programme on Si Technology are in line with the goals defined in the SET Plan - Declaration on Strategic Targets in the context of an Initiative for Global Leadership in Photovoltaics (PV) 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 research themes have been identified as focus areas for this Sub-Programme:

- ✓ *Si materials: feedstock, ingots and wafers*
- ✓ *High efficiency c-Si solar cell and module production technology*
- ✓ *New c-Si-based solar cell concepts*
    - ✓ *Ultra-thin c-Si solar cells and modules*
    - ✓ *Ultra-high efficiency c-Si solar cells*

These 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.

2. Research roadmap

Si materials: feedstock, ingots and wafers: The efficiency, cost and environmental footprint of a c-Si solar cell and module depends for a large part on the Si materials used. Solar cell efficiency is highly dependent on the quality of the Si wafer, which again depends strongly on the feedstock and ingot production processes. There is room for further improvement (higher material quality at lower cost and with lower footprint) in this important part of the c-Si solar cell value chain, and several European companies and research groups are at the forefront of developments in this segment.

High efficiency c-Si solar cell and module production technology: Considerable progress has been made along the entire value chain of production for c-Si solar cells in increasing solar cell efficiency and reducing production costs, from Si feedstock production to solar cell and module manufacturing over the past decade. There is still potential for substantial further improvement in the manufacturing of solar cells and modules. Several European research groups are at the front of this development, and the largest share of equipment manufacturing is carried out in Europe. For a real breakthrough in terms of cost reduction and efficiency increase, new processes need to be evolutionary integrated into existing production lines. Moreover, new production lines with specifically designed equipment need to be implemented. The high-degree of automation of existing production processes sets a high benchmark for new technologies.

New c-Si-based solar cell concepts: Several radical approaches to the development of c-Si solar cells can potentially allow for either large reductions in production cost and environmental footprint or large increases in solar cell efficiency.

One promising alternative with respect to cost reduction is the c-Si thin-film lift-off technology in which epitaxial Si layers are grown and lifted-off from their parent substrate, resulting in a material of excellent quality and a thickness reduced to only a few tens of µm. In addition, depositing the active material directly from the gas phase provides a short cut eliminating the long and costly wafer fabrication technology flow and reduces kerf loss to almost nothing. However, to integrate such ultra-thin Si substrates into working devices with high efficiencies, new solar cell and module processes need to be developed as well as new wafer handling techniques. With the foundation of the company NexWafe in 2015, there is renewed industrial interest for this approach in Europe

With respect to efficiency increases, c-Si solar cells in lab and production are slowly, but steadily, approaching their theoretical efficiency limit of ~29.4%. Therefore, it is important to evaluate concepts for a second generation of c-Si-based solar cells which can reach even higher efficiencies while still being based on the successful and mature c-Si production technologies. One can distinguish between tandem approaches using a c-Si solar cell as bottom cell and spectrum management solar cells, utilizing concepts such as up-conversion, to increase the range of useable photons for c-Si solar cells.

3. Objectives 2017-2020

The overall objective is to align European activities within c-Si research to pave the way for industrial growth in this very important field. Below is a list of objectives for this 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 c-Si 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
- ✓ *New project proposals*: Networking aiming at developing project proposals

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 SP1 partners upon CHEETAH project completion.

Task 2 Workshops and webinars

Today, many of the EERA PV SP1 partners benefit from workshops and webinars organized by the CHEETAH project. In this task, the aim is to disseminate new programmes and projects relevant to c-Si that can involve EERA members. The target is to assure at least 2 workshops and webinars per year.

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 Development of Roadmaps and New project applications

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 joint proposals 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**
M1.1	*At least one workshop on Silicon Technology organised per year*	*Meeting*	*12,24,36, 48*
M1.2	*At least two funded proposals on Silicon Technology with EERA label submitted per year*	*Submitted*	*12,24,36, 48*

6. Participants

Partner	Country
AIT	Austria
CEA-INES	France
CENER	Spain
CIEMAT	Spain
CNRS	France
CRES	Greece
ECN	Netherlands
ENEA	Italy
EPFL	Switzerland
FFCUL	Portugal
Fraunhofer ISE	Germany
FVB	Germany
FZ Juelich	Germany
HZB	Germany
IFE	Norway
IMEC	Belgium
Metu	Turkey
NTNU	Norway
RWTH Aachen	Germany
Sintef	Norway
Tecnalia	Spain
UNIMIB	Italy
UPM	Spain
UPV LC	Spain
Utrecht Uni	Netherlands

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. 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-02*
Last modification date: *09-10-2017*

Summary

Thin Film Photovoltaics (TF-PV) is a term used for a number of different technologies which all have in common that the active layer has a thickness of several hundred nanometres to a few microns. The most common absorber materials are amorphous silicon (a-Si:H), cadmium telluride (CdTe) and copper indium gallium selenide/sulphide (CIGS, CIGSSe). While the commercial significance of amorphous silicon has declined in recent years, CdTe and CIGS are growing and, while still far behind the production volume of crystalline silicon (c-Si)devices, are produced on a GW per annum scale.

Thin film technologies require less material and have a lower energy demand for production than those based on c-Si. They can be implemented on a variety of substrates including flexible, light-weight and odd-shaped substrates and their properties,including low-light sensitivity, spectral response and thermal coefficient of V_{oc}, can be varied. Therefore, TFPV will have an important role in the future PV market. However, due to still low production volumes, prices are not competitive and the efficiency of commercial modules are in general lower than that of c-Si devices. Progress both in research and commercialisation is needed to make TFPV more competitive. In the EERA PV sub-programme 2, many groups from the field of TF-PV are working together to increase information exchange, mobility and to enable educational activities. As in other sub-programmes, technology roadmaps are defined and recently a White Paper on CIGS technology was written and distributed.

In this document the roadmap for thin film technology research is presented, together with current activities within the framework of EERA-PV and the currently running IRP, CHEETAH.

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 tandem devices

Since the efficiency of the best laboratory single-junction devices based on CIGS is now approaching the limits set by thermodynamics and technological restrictions, further major efficiency increases can only be expected from multi-junction devices. Therefore an important part of the research roadmap for the coming years is the development of thin-film tandem devices. With the recent development of devices exceeding 20% efficiency with absorber materials based on methyl ammonium lead halides, commonly called perovskites, new possibilities arise for thin film tandem devices. Perovskites have band gaps between 1.5 and 2.2 eV, making them ideal top cells. They can be deposited using low-temperature techniques, allowing the fabrication of top cells on chalcopyrite bottom devices without degrading those due to high temperatures. Possible combinations include e.g. chalcopyrite/perovskite, silicon/perovskite, cadmium telluride/ perovskite or other material combinations. Here, a collaboration with SP1 for Si bottom cells and SP3 for perovskite top cells will be essential.

Several sub-projects can be derived from the main task of constructing a tandem device:

a. p-doped wide band gap materials and tunnel junction for chalcopyrite/perovskite tandem devices

In order to combine the bottom p-CIGS-based cell with a top p-perovskite device, a p-doped, wide band gap material, that will also act as a tunnel/recombination junction, is needed. This material will be in the focus of research at HZB and FZ Jülich. Modelling/simulation of the tunnel/recombination junction and contact selectivity (in terms of band offsets, surface recombination mechanisms, etc.) as well as first-principles-based screening of a variety of large band gap materials will help to find alternative materials to the currently used organic hole conductor spiro-OMeTAD, which is prohibitively expensive and less stable than needed for a tandem device.

b. Inorganic wide-band gap material as top cell absorber

As the current hybrid perovskite materials have serious stability problems, they need to be replaced in the long run with stable, preferably inorganic materials. Finding new, large band gap absorber materials requires screening of a large number of compounds and determining their properties. At FZ Jülich, computational screening of (low dimensional) lead halide perovskites is under way.

c. Light management in tandem devices

In tandem devices, light management becomes important especially for 2-terminal devices because one of the individual cells will be current limiting. FZ Jülich is working on the optimization of the light management of tandem devices.

d. Reducing the use of toxic and/or rare materials

In compound semiconductor thin film devices, a variety of elements is used, some of which are rare or toxic or both. These have to be replaced in the long run. Specifically, indium should be replaced both in TCO and in CIGS absorber material. Both FZ Jülich and HZB are working on Indium free TCOs. Another important goal is to improve Cd-free buffer layers for CIGS to make the current CdS buffer layer obsolete. While some manufacturers like Avancis or Solar Frontier have already replaced CdS, others are still using it.

3. Objectives 2017-2020

The overall objective is to align European activities within the thin film PV research to lay the scientific foundation for improving efficiency and cost efficient upscaling. A list of objectives have been defined that will constitute the day-to-day tasks and work flow of the sub-programme

- ✓ Continuous update of the White Paper on CIGS by an international working group
- ✓ *Workshops and webinars*: to conduct workshops and webinars for educating students, researchers and industry about topics relevant for thin film devices (concepts for thin film multi junction cells, materials development for new absorbers and TCO, stability, replacement of toxic materials….). In particular, acquisition of project funding for a permanent working group to organize the international workshop on CIGS technology (IW-CIGSTech)
- ✓ *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)
- ✓ *Training, networking and mobility*: development of an environment for systematic networking of the EERA PV sub-programme community and frequent exchange of researchers and students for mutual training and common understanding among EERA partners
- ✓ *Protocols and round robins*: Improving the possibility to share data and reproduce experiments in different laboratories by structuring round robin and interlaboratory study plans. Utilizing 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 SP2 partners upon CHEETAH project completion.

Task 2 Workshops and webinars

Currently Workshops and webinars are organized as part of the CHEETAH activities but in the long run other means of financing these activities will have to be found

Webinars planned in 2017:

- Comparing XRF of CIGS materials, Round Robin, EMPA, Stephan Bücheler, 7/2017
- Characterization of microconcentrator devices, Maarja Grossberg, TUT, 9/2017

- Characterization of Kesterites, Webinar, Maarja Grossberg, TUT, 5/2017

Task 3 Networking and mobility

Meetings among the sub-programme partners currently only conducted via the CHEETAH project as satellite events or via online teleconferences or as side-events during conferences or workshops. Researcher exchange 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 SP2 partners or researcher exchange. Such programmes will actively be disseminated among the partners.

Task 4 Round robins and protocols

Round robin on thin film tandem devices (part of the CHEETAH project, WP3)
Round Robin on KESTERITE solar cells (TUT)

Task 5 Roadmap and funding

Apply for COST Actions project on SP2 themes.

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M2.1	Organization of the International Workshop on CIGS Technology (IW-CIGSTech)	Annual workshop	6,18,30, 42
M2.2	Evaluation of thin film tandem round robin (CHEETAH)	Technical paper	12
M2.3	At least one funded proposal on Thin-film Technology with EERA label submitted per year	Submitted proposal	12,24,36, 48

6. Participants and Human Resources

Partner	Country
AIT	Austria
CIEMAT	Spain
CNRS	France
ECN	Netherlands
ENEA	Italy
FFCUL	Portugal
Fraunhofer ISE	Germany
FZ Juelich	Germany
HZB	Germany
ICIQ	Spain
IMEC	Belgium
LNEG	Portugal
Metu	Turkey
NTNU	Norway
TuT Tallinn	Estonia
UNIMIB	Italy
ZSW	Germany

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

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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: *2017/10/09*

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 combinations 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. The EERA PV sub-programme 3 establishes a common platform that enables much easier collaboration between the growing number of groups involved in the HOPV field, facilitating the achievement of the research goals. The platform provides networking, mobility and educational activities among the research groups, and acts 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 at an 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 a 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. The 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 approaches 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. A multijunction structure is one of the research priorities in the SRA document, which highlights the importance of finding novel tandem configurations that can boost the efficiency. Hybrid tandem structures, which are based on the combination of organic, hybrid and inorganic technologies (such as for example a 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 a 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 have a 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 staff 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 staff.

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	*At least one funded proposal on Thin-film Technology with EERA label submitted per year*	*Submitted*	*12,24,36, 48*
M3.3	*Round robin for preconditioning of HOPV*	*Report*	*26*
M3.4	*Round robin for stability of HOPV*	*Report*	*38*

6. Participants and Human Resources

Partner	Country	SP3
CEA-INES	France	X
CENER	Spain	X
CIEMAT	Spain	X
CNRS	France	X
DTU	Denmark	X
ECN	Netherlands	X
ENEA	Italy	X
EPFL	Switzerland	X
FFCUL	Portugal	X
FZ Juelich	Germany	X
ICIQ	Spain	X
IMEC	Belgium	X
Imperial	UK	X
LNEG	Portugal	X
Metu	Turkey	X
NPL	UK	X
RWTH Aachen	Germany	X
Torino Uni	Italy	X
UNIMIB	Italy	X
UNIPI	Italy	X
Utrecht Uni	Netherlands	X
VTT	Finland	X
ZSW	Germany	X

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

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

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

Description of Work

Version: *CPV-02*
Last modification date: *09-10-2017*

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.

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 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 a lighting industry based on LED is beneficial since it involves 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 mm^2. 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 (LCPV) systems 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 with 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.

2. 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 listed in section 3.

3. Objectives 2017-2020

1. 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.

2. 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 a 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 constituting closed modules similar to conventional PV modules; and Fresnelization allows very thin optics and a clear path to high volume precision manufacturing. 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 processes 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 the newest cell 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 be arranged in Fresnel architectures, leading to high aspect ratios and stronger impact of manufacturing errors which limits its real performance; the module architecture usually requires the use of several optical stages for thermal reasons and to limit self-shadowing. Consequently, research activities should be focused on overcoming those limitations for the case of module applications. Moreover, 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, 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 processes for the cell encapsulation and assembly is essential to overcome one of the main 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 another 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 aspects 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 of 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 mm^2. 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 concepts from the laboratory to the prototype and demonstration level involving expert teams covering all fields from the deep knowledge of the technology to the product development.

3. Cost reduction 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 open a clear pathway to reduce cost. Other areas of research include trackers that make use of cable-stayed structures as opposed to the cantilevered structures commonly used.

4. 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 many 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 being assembled close to the 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 locally close to the market. Regardless of module assembly location or production location, the development of quality control tools for the production lines is imperative, particularly to check if misalignments are within the strict tolerances needed.

The development of specific reliability and accelerated tests for CPV components is another issue that must be addressed. Most of the accelerated tests included in the CPV normative are basically a replica of broadly accepted tests 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 tests. 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.

5. 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 the 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 that 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 reach sufficient maturity level, resulting in poor long-term stability and reliability. The identification of reliable and stable materials, designs and technologies and the discarding of unreliable ones is essential to promote the market penetration of the CPV technology. The determination of such decay rates 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 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.

6. 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 semiconductors, 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 for 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 processes 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 another 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 use of the heated fluid.

7. Future, novel and alternative CPV concepts

The previous objectives were focused on the evolution of current CPV technologies to promote its market penetration, prioritizing funding activities on proven technologies that have 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 all these topics require a 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.

7.1 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 the serial connections of today´s two terminal cells. This development may be combined with inexpensive DC-DC converters at each cell to additionally 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.

7.2 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 earlier 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.

7.3 Luminescent concentrators (LSC)

Low weight, high theoretical concentration factors, ability to work well with diffuse light and no need of sun tracking or cooling apparatuses are some of the potential advantages of Luminescent concentrators (LSC). Today, LSC-PV systems have received great impulse thanks to the modern building architectures that have inspired PV application of colourful windows. The building-integrated PV market is actually set to steadily increase, promoted by the European Energy Performance of Buildings Directive 2010/31/EU, which states that each new building should be made ‘nearly zero energy’ from 2020 onwards. LSCs are slabs of transparent material doped with a fluorophore. The refractive index of the host being 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 of 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.

7.4 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 offer 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 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).

4. Sub-programme activities

Task 1 Infrastructure

The task is to identify or develop new projects and programmes that will allow to share the use of infrastructure among the SP4 partners.

Task 2 Workshops and webinars

EERA PV SP4 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 CPV that will enable participation of EERA members and systematically disseminate among EERA SP4 members. The target is to assure at least 2-3 workshops and webinars per year made available for SP4 partners.

Task 3 Networking and mobility

Meetings among the sub-programme partners are primarily conducted via funded European projects as satellite events or via online teleconferences. Exchange of the staff 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 SP4 partners or exchange of the staff.

Task 4 Round robins and protocols/standardization

The task is to organize meetings and round robins to come to the development of common protocols and standardization for CPV. The experiments constitute production of test samples and test devices, accurate testing of performance, pre-conditioning of devices and reliability and stability testing under controlled environments.

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	*At least one funded proposal on CPV Technology with EERA label submitted per year*	*Submitted*	*12,24,36, 48*
M3.2	*At least one workshop on CPV technology organised every two years*	*Workshop*	*24, 48*

6. Participants and Human Resources

Partner	Country	SP4
CEA-INES	France	x
CENER	Spain	x
CNRS	France	x
Fraunhofer ISE	Germany	x
Tecnalia	Spain	x
UNIPI	Italy	x
UPM	Spain	x

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

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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: 15-*10-2017*

1. Vision

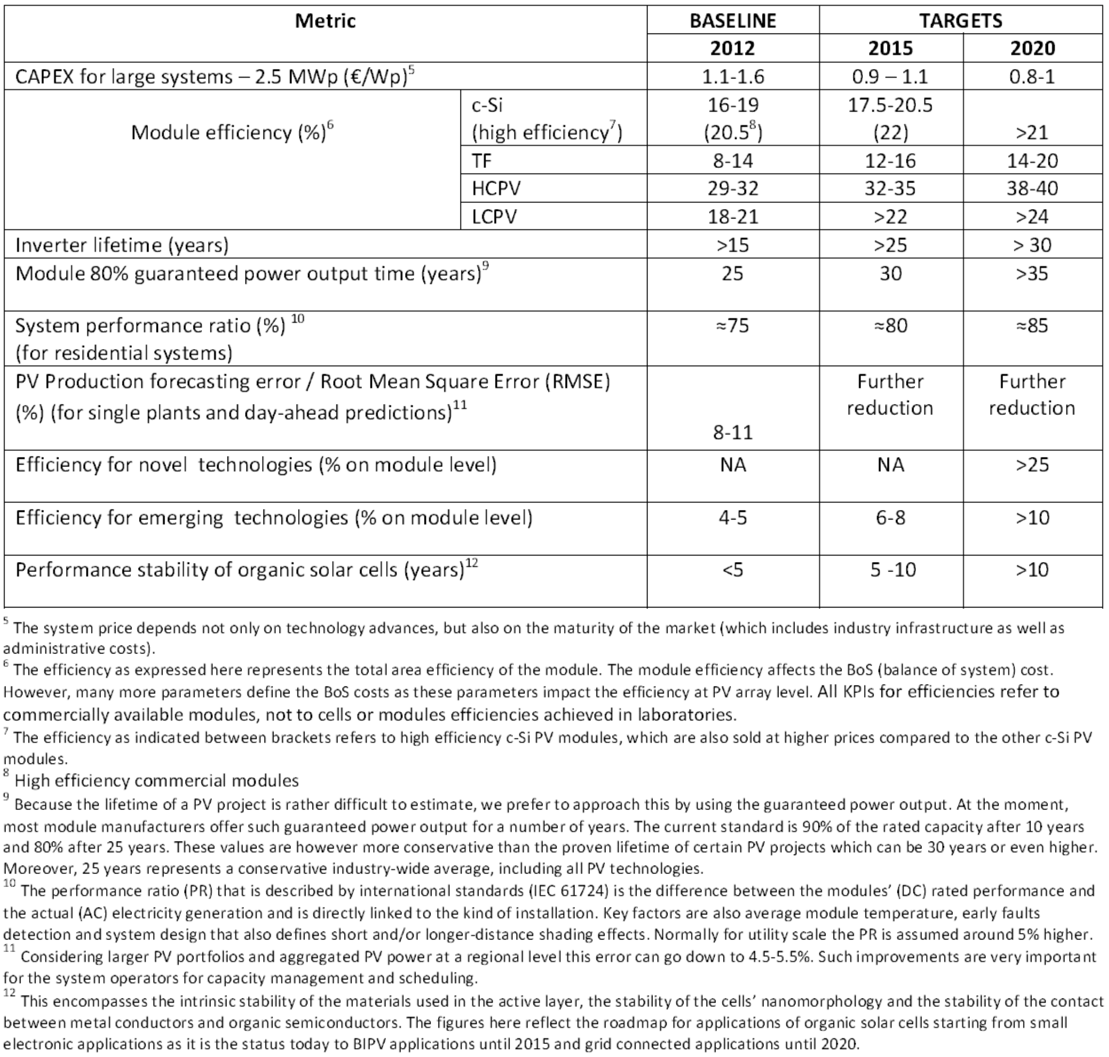
Photovoltaic technology permits the conversion of solar energy directly into electricity. It is a very smart process to generate environmental-friendly, renewable electrical energy. PV systems can supply electrical energy to a specific consumer or to the electric grid. It has the potential to play an 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.

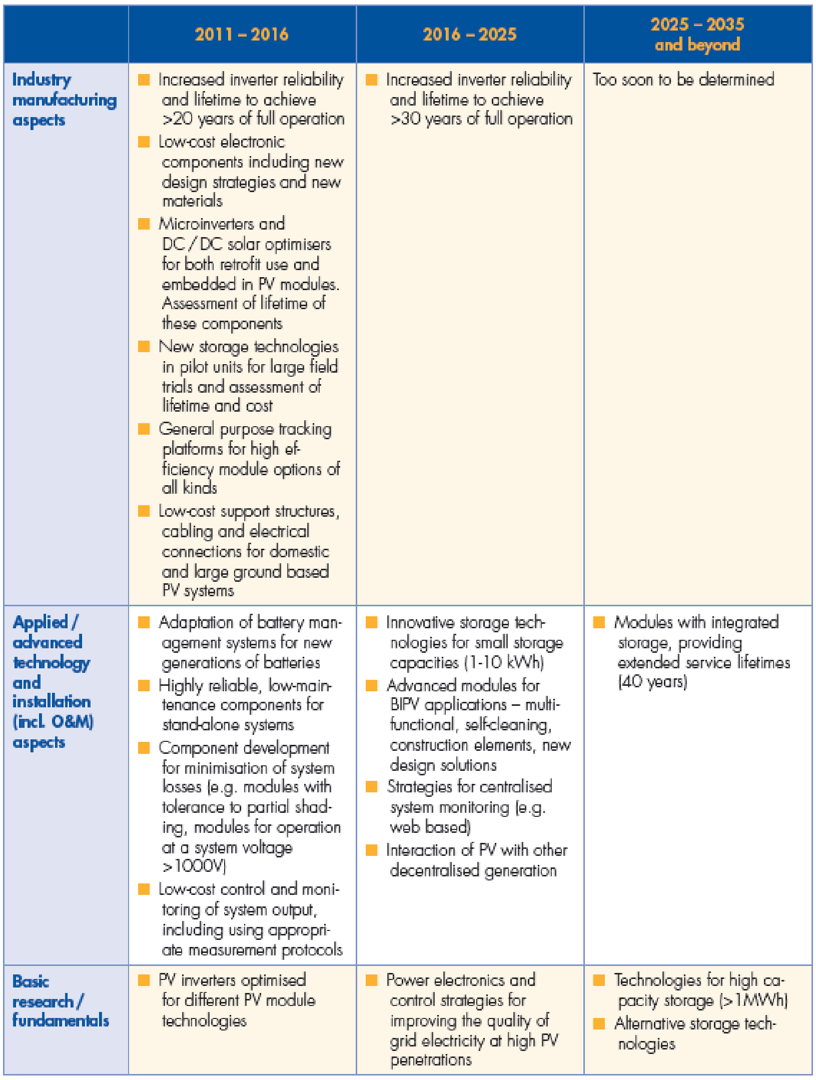
[11] Considering larger PV portfolios and aggregated PV power at a regional level this error can go down to 4.5-5.5%. Such improvements are very important for the system operators for capacity management and scheduling.

[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.

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.



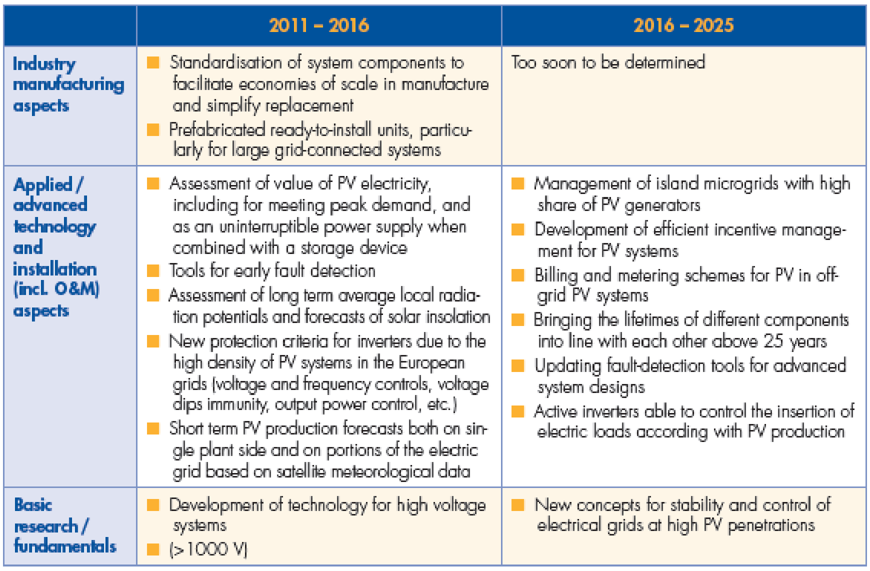
	2011 – 2016	2016 – 2025	2025 – 2035 and beyond
Industry manufacturing aspects	■ Increased inverter reliability and lifetime to achieve >20 years of full operation ■ Low-cost electronic components including new design strategies and new materials ■ Microinverters and DC / DC solar optimisers for both 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

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].

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

Many 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 be 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 (see also sub-programme 6) and performance, the cost efficiency in installation and operation will also 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 (in collaboration with the EERA JP on energy storage)

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 papers and 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, EERA Energy storage

Balance of system (BoS):

In order to achieve higher PV penetration levels, a further cost reduction in installation of PV systems 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.

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

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 the field of BIPV are

1. *Technical development*
   (a) Development of innovative technical solutions
   (b) Low-cost manufacturing processes 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 <u>innovative technical solutions</u> (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 <u>grid communication systems</u> (e.g. IEC 61850-7-420 — Communications systems for Distributed Energy Resources (DER)) for energy management and building automation mechanisms.

(b) Industrial <u>automated low-cost manufacturing process</u> 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 <u>BIPV product performance</u>, long term higher energy output and improved optical appearance at reduced costs (Euro/m²) together with inherent security mechanisms with design & electronic devices. <u>Methods for refurbishment</u> 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) <u>new PV system design approaches for BIPV</u> 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) <u>Demonstrators for innovative multifunctional use of BIPV components, </u>(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 <u>large scale demonstration for BIPV</u>, 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

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 SP5 partners upon CHEETAH project completion.

Task 2 Workshops and webinars

EERA PV SP5 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 PV systems and BIPV that will enable participation of EERA members and systematically disseminate among EERA SP5 members. The target is to assure at least 2-3 workshops and webinars per year made available for SP5 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 staff 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 SP5 partners or exchange of the staff.

Task 4 Round robins and protocols/standardization

The task is to organize meetings and round robins to come to the development of common protocols and standardization for BIPV and novel types of PV systems. The experiments constitute production of test devices and accurate testing of performance and reliability under controlled relevant real-life environments.

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 at least one proposal every year by utilizing the roadmap.

5. Milestones for 2017-2020

Milestone	**Title**	**Measurable Objectives**	**Project Month**
M5.1	*At least one funded proposal on PV systems and/or BIPV with EERA label submitted per year*	*Submitted*	*12,24,36, 48*
M5.2	*At least 3 webinars per year organised on BIPV and PV-systems related topics*	*Webinar*	*12,24,36, 48*

6. Participants

Partner	Country
AIT	Austria
CEA-INES	France
CENER	Spain
CNRS	France
CRES	Greece
ECN	Netherlands
EPFL	Switzerland
FFCUL	Portugal
Fraunhofer ISE	Germany
FZ Juelich	Germany
IFE	Norway
IMEC	Belgium
LNEG	Portugal
Metu	Turkey
Sintef	Norway
Tecnalia	Spain
Ukerc	UK
UPM	Spain
ZSW	Germany

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.

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EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 6: *PV Durability and Reliability (DU-REL)*

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

Description of Work

Version: *DUREL-01*
Last modification date: *15-10-2017*

Summary

PV Reliability has not been a sub-programme in previous work programmes of PV-EERA and any progress on reliability related activities has been reported in other sub-programmes. The summary given in this section is more a general assessment of what is currently going on in the field.

The focus is currently on the reliability of photovoltaics and here the effort is on the PV material. This is justified by the modules often being the most expensive element to replace in a PV system. However, system-focussed reliability is also important as there are some failure modes that only occur in a system context. An example is potential induced degradation, which is a very severe failure mode that only occurs in the context of system operating voltages.

PV is to some extent different to other technologies it is commonly compared to in terms of reliability research, such as e.g. paint systems. It is not only important to be reliable, i.e. to avoid failure, but also to maintain a good operational performance close to predicted performance as this is directly linked to the financial outcome of the system. Thus, it is also critical to investigate the durability of any material of the technology.

Research work carried out by DU-REL participants in this arena is described in the following as this describes the starting point of the current work programme.

Work is ongoing on the understanding of the actual stresses being experienced by devices in the field. This is a critical element to avoid over- or under-testing, i.e. setting the bar too high or too low for certification tests. Furthermore, the focus could be on less important failure modes, e.g. indoor testing shows that damp-heat is the most critical test, while field data seems to point at thermal cycling. It is always easy to degrade something, but the question to be answered is if this would be realistic in the field. Too stringent tests drive up the costs of energy. Too lenient testing, on the other hand, will allow devices to enter the market place that are not fit for purpose. This understanding of stress environments is a critical task. The majority of work nowadays is carried out in a GIS framework to identify specific locations. The types of stresses are also expanding. Traditionally humidity and thermo-mechanical cycling were the focus, but in the last years dynamic mechanical loading, UV and combinatory stresses become more relevant. The teams in DU-REL are deeply involved in this mapping effort, which is carried out world-wide. It is expected that a good proportion of deployment will happen e.g. in the MENA states, where stresses such as dust induced mismatch can be more critical than the traditional stresses. Investigating also the stresses and driving forces for Potential Induced Degradation (PID) are important. Thus the overall assessment is also carried out in these regions and for stresses relevant e.g. to the MENA states.

Understanding the relevant stresses allows to develop tests, which ideally are accelerated compared to realistic deployments. This requires also knowledge of the most relevant failure modes as otherwise not insignificant amount of effort could be spend on some irrelevant testing regime. The teams in DU-REL work towards a better understanding of field failures, relevance of failure modes in certain regions of the world as well in novel module technologies, materials. This work is often carried out under the umbrella of the IEA-PVPS programme[1], where specifically task 13 ‘Performance and Reliability of Photovoltaic Systems’ overlaps with the current DU-REL efforts but is not funded and not geared at fundamental research.

It is critical to predict the life-time of devices as without this it is not possible to determine the value and applicability of innovations. Determining the reliability of a product is standard in the majority of industries but in terms of photovoltaics this remains in its infancy. The problem is enhanced by the overall shape of the degradation curve being critically important in terms of the overall energy yield. Thus it is not suitable to just use a test that is ‘harder than reality’ and certify, but one needs to also quantify progression of degradation, as well as the final value. The teams in DU-REL have worked on combinatory testing of different stresses as well as on new, more analytical test approaches.

Durability and reliability of commercial devices is largely determined by the encapsulation and its interaction with the active layers. There is very limited understanding available on this and

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[1] http://iea-pvps.org

all partners are working on this. This also includes finding appropriate test regimes for the materials by themselves and develop appropriate standards for this through the IEC TC82.

Creating the required understanding is not always possible without being able to take the right measurements. There is a lack of metrology currently available for non-destructive testing or at least test methods that do not influence further tests. Moreover, there is a lack of metrology (tools & methods) to pick up 'early warning signals' and physical precursors of degradation, that is before any electrical degradation becomes electrically apparent by IV-testing, which may take sometimes thousands of hours. In order to detect these early warning signals under the 'detection limit' of IV-testing and to be able to pinpoint a specific degradation mechanism, further methods are being developed. A lot of interest of the partners has been on optical measurements (e.g. luminescence, Raman-Spectroscopy, FTIR).

1. Vision

The vision of the Du-Rel SP is to provide the insights and tools required for predicting and guaranteeing life-time energy yield of PV Systems over a 40 year period in all relevant operating environments. This includes understanding stresses, also in relation to the location of the installation, identify relevant failure modes, predictive testing and modelling, life-time prediction, life-time energy yield prediction as well as associated metrology. The work will be contributing to international standards and as such shape the international framework of the industry. Even beyond, it will have implications on how PV projects are evaluated, financed and managed.

A substantial contribution to the value chain for photovoltaics is in the country of operation as installed systems contribute to the local economies. Systems are also often locally funded and owned, which means the financial risks and benefits remain in the country of installation. Benefits of any work on durability and reliability carried out in Europe will thus impact also in the European Community. Understanding and reducing risks will benefit the end-user more than actually the manufacturer as the main economic gain is in the operation and financing of the PV system. Thus impact of durability and reliability work is independent of the country of manufacture.

The system-lifetime plays a significant role to the financial success of any system. Review of the literature indicates that, due to ageing rates reported for fielded modules, 1/3 of the products today will not meet warranty conditions. This does not include any reliability issues such as PID or damaged devices due to cracks, just data reported after several years of operation. This may be an overly negative prediction as the modules deployed today are very different to those deployed e.g. 20 years ago.

Industry has identified an extended lifetime as a key requirement of the future success of the industry because it directly determines the LCOE. The aim is a 40 year life-time of systems, as this is the most efficient way to reduce the overall LCOE. This cannot be guaranteed based on today's knowledge. Not meeting warranty requirements is critical as it not only means that manufacturers may go bankrupt but also the owner and financial people involved, i.e. the economic damage is way more significant than in other industries.

The exchange of single components in a PV system is frustrating, but may be achievable at an acceptable cost. Having to replace the PV modules, on the other hand, is actually critical as a full replacement is very costly, let alone finding the exact same modules to replace the defected ones. Thus it is critical to be able to predict the life-time of the systems with great accuracy and this SP will focus particularly on this issue.

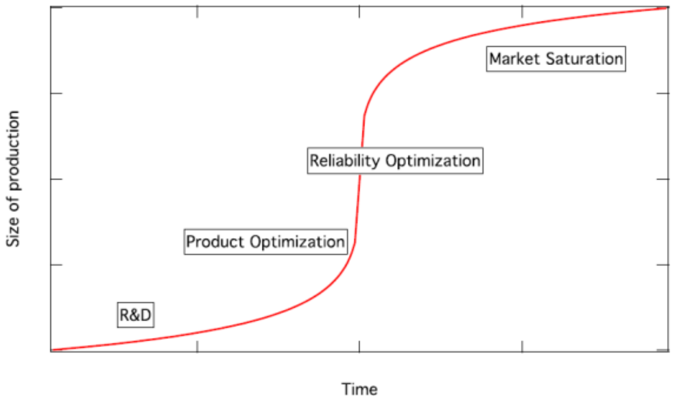

Figure 1: Importance of Durability and Reliability for Industries (Figure taken from a presentation by Sarah Kurtz, NREL)

This assessment of the need for Du-Rel work is shared by others around the world. An example is given in Figure 1, which presents the assessment of NREL. The message of this graph is that wide-spread application and potentially market saturation can only be achieved with reliable (and durable) products.

Beyond the reliability and durability science, there is a fundamental gap in metrology and even in the knowledge of environmental stresses seen, observed failure and degradation rates, how these can be accelerated and what product parameters need to be controlled to ensure this 40 year lifetime. This SP will deliver against these fundamental gaps in knowledge.

This SP will contribute to developing a life-time and life-time energy prediction, identify key production relevant quality assurance parameters, deliver the tools to do this in production relevant measurement times and develop accelerated tests to support the 40 year life-time requirement identified by industry as key requirement for the future.

2. Objectives 2017-2020

The aim is to establish a test framework to ensure a 40 year life-time and predict the energy yield throughout operation. The objectives in the current period are:

1. **Assessment of stress climates being seen by PV modules.** Detailed modelling of micro-climates is required, as it has been shown that the Koeppen-Geiger classifications are not suitable for PV. GIS based mapping software will be developed to enable reliability researchers to extract realistic stress potentials
2. **Fatiguing and life-time models of key failure modes.** Models for e.g. thermomechanical and chemical (humidity and / or UV driven) failures will be developed.
3. **Establish acceleration factors of key certification tests.** Current certification tests are developed on the basis of experience of other industries. Apply PV specific stresses to simulate long term degradation of devices.
4. **Improve understanding of correlation of durability and key material properties.** This will involve different lamination materials and different lamination conditions of the same material to identify durability optimised laminations (as compared to minimum reliability requirements). Similar studies on cell metallization, solder joint and other module materials such as glass, backsheet must also follow.
5. **Model environmental stress dependent life-time energy yield.** This involved integrating the previous objectives into a model that estimates life-time. An assessment of the uncertainties will be done to show where potentially the biggest gains in terms of accuracy can be made.

6. **Accelerated testing routines.** Moving beyond the current state of the art of single stress testing, work will move towards multi-stress testing to ensure that correlations between different stresses are captured with the aim to develop life time tests. Emergence of novel cell interconnection, module assembly technologies require development of adapted testing method based on insight in their failure mode.
7. **Novel non-destructive, module scale metrology to assess state of materials and performance.** The objective is to establish key parameters to observe as well as tools to monitor them.
8. **Life time energy yield model.** Model the life-time energy yield of devices of all technologies.

The detailed work against these objectives is described below in section 3.

3. Research roadmap

The work is structured into work packages where partners integrate national research efforts into a European research framework.

WP1 – Stress Mapping

Task 1: Local micro-climates and stresses.
Meteorological data is normally limited to horizontal irradiance and ambient temperatures. This is not what is actually experienced by installed PV systems. Meteorological data must be translated into the in-plane irradiance and module temperature and humidity loads. These are done for performance purposes (e.g. PV-GIS) but not for stress modelling. It is believed that here the rates of change are important and some stresses cannot be assessed to date. The current work will include e.g. the assessment of UV experienced at the back of the module as this this is much more relevant for durability then the UV dose experienced in the horizontal or the front of the modules (which will largely be absorbed by the front glass) and humidity transfer through the back or edges of the modules

WP2 – Physics of Failure

Task 1: Fatiguing due to thermal cycling
Thermal cycling is a standard certification test, but not yet linked to realistic cycling profiles. It is not clear how realistic changes link to the existing tests. The common assumption is that degradation depends on the absolute degrees travelled, i.e. two cycles over half the thermal range do the same damage as one single cycle over the full range. Based on this assumption, the current tests only cover about a year’s worth of realistic operation. In realistic operation, the effects of thermal cycling have been identified as a key failure mode but this has not been seen in certification, which would somewhat agree with the statement above. Work will be carried out to investigate e.g. the impact of rate-of-change and temperature range on full scale modules. Potential changes in failure modes or patterns will be investigated.

Task 2: Failure mode analysis and thermo-mechanical modelling in low temperature solder alloys
Low temperature and lead-free solder alloys are required for module assembly of silicon heterojunction cell and/or multi-wire interconnection technologies. The solder fatigue behaviour of these materials as well as the altered geometry and process conditions question the relevance of current accelerated tests. Although some of the alloys have been investigated by the micro-electronics industry previously, the considerably different stress experienced by the final product demands an investigation dedicated to PV products. We foresee in this activity the experimental study of failure mechanisms relying on advanced characterization techniques

also developed in WP7 to determine their root-cause. Correlation with thermo-mechanical simulation will be also explored.

WP3 – Certification testing

Task 1: How far can one accelerate?

Industry requires shorter certification times, which in turn requires faster tests. This may or may not be possible as the current testing acceleration is already very aggressive compared to other industries. Currently 6 week-long tests are supposed to certify 20 years life-time. Specific tests, such as increasing acceleration in damp-heat testing will be investigated for their suitability of further acceleration, or indeed the need for deceleration.

Furthermore, new materials such as glass/glass modules with and without edge sealing are entering the market place. These may experience completely different degradation modes and acceleration factors. This will be investigated.

WP4 – Linking material properties to degradation modes.

Task 1: Linking lamination conditions to durability

It is currently assumed that one module with the same bill of materials behaves just like any other. This is not the case as e.g. the thermal regime plays a significant role as well as unreported changes in the actual material being used. The latter may be an EVA from the same supplier, even of the same type, where the added UV absorber may be from a different supplier or quantity. These changes will not be visible to the end user but may change module behaviour fundamentally. We will investigate the longevity of differently laminated samples under different stress regimes. Different stresses will be applied and failure modes investigated and modelled.

WP5 – Life-time energy yield

Task 1: Life-time energy yield

Existing performance models will be modified to include a site- and failure-mode specific ageing to assess long term yield of PV modules. The aim is to map certification tests, or novel combinatory tests as developed in this SP, onto device performance and enable system developers to calculate long term energy yield and its uncertainty boundaries. Especially changes in low-light behaviour and innovative designs (e.g. bifacials) as well as innovative materials (e.g. OPV) could be interesting as well.

Task 2: Reliability modelling linked to E-yield

The current industrial or academic energy yield calculations typically neglect the degradation of the PV modules over time. In some cases they only assume a gradual or linear degradation without any correlation to degradation processes and rates hence neglecting installation and climate specific degradation processes and decay rates. Over the last years, Imec and KU Leuven have built a *physics-based fully parameterized* framework for electrical-thermal-optical E-yield modelling of Si-PV modules with fine-grain temporal and spatial resolutions. Model parameters for the optical, thermal and electrical behavior are determined from experimental data. Combined with the weather data they enable one of the most precise prediction of Eyield among published simulation tools. The model layer by layer resolves the light absorption and heat generation in the PV module, this is a key starting point to provide reliability modelling based on local material conditions. Combined with reliability models developed by partners, and/or published in literature, this could allow to define a bottom reliability model adapted to different technologies, weather and installation conditions

WP6 – Novel test routines

Task 1: Combination testing

Some stresses can enhance or ameliorate each other and thus a combinatory testing will be required for a full assessment of device lifetime. The national funding is currently not sufficient for a proper assessment as it will require an international collaboration on these tasks. Work will focus both on small-area devices that are aged in weatherometers and on UV and humidity loads for full size modules. Transformation models between coupons and full-scale modules and between thermo-mechanical stress and dynamical mechanical stress could reduce testing efforts.

WP7 – Advanced Metrology

Task 1: Spatial Mapping Techniques
Degradation does not happen uniformly over a module and thus one needs to be able to probe different areas separately. This concerns encapsulation as well as active components. Different tools around digital micro-mirror devices will be developed allowing to probe predominantly active components. This includes measurement of I-V characteristics of fully encapsulated cells as well as current mapping across an entire module (six-cell mini module for the prototype application).

WP8 – Developing Reliability Research Community

Task 1: Workshops and events
A number of established workshop series are organised by institutions within this group. These include ISE’s SOPHIA reliability workshops and LU’s Energy Generation of Photovoltaic Systems. A strong link to the SOPHIA-workshop for PV-module reliability, which is networking with similar events in USA and Japan will be established.
There will be links with IEA Task13 workshops (Intersolar).

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 dedicated to reliability and durability research among the SP6 partners upon CHEETAH project completion.

Task 2 Workshops and webinars

A number of established workshop series are currently organised by members of SP6. These include ISE’s SOPHIA reliability workshops and LU’s Energy Generation of Photovoltaic Systems. A strong link to the SOPHIA-workshop for PV-module reliability, which is networking with similar events in USA and Japan will be established. Finally, there will be links with IEA Task13 workshops (Intersolar). Next to workshops, the target is also to assure at least 2-3 webinars per year provided via the EERA-PV platform on the topic of reliability and durability.

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 staff 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 SP6 partners or exchange of the staff.

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

The task is to organize meetings and round robins to come to the development of common protocols and standardization for new reliability and durability testing. Work will focus both on small-area devices that are aged in weatherometers and on reliability testing for full size modules.

<u>Task 5</u> 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 at least one proposal every year by utilizing the roadmap.

5. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M6.1	*At least one funded proposal on reliability and durability improvements with EERA label submitted per year*	*Submitted*	*12,24,36, 48*
M6.2	*At least 2 webinars per year organised on reliability and durability of PV-system related topics*	*Webinar*	*12,24,36, 48*
M6.3	*At least one workshop per year organised on the topic of reliability and durability*	*Workshop*	*12,24,36, 48*

6. Participants

Partner	Country	SP6
AIT	Austria	X
CEA-INES	France	X
CENER	Spain	X
CNRS	France	X
CRES	Greece	X
ECN	Netherlands	X
ENEA	Italy	X
EPFL	Switzerland	X
Fraunhofer ISE	Germany	X
FZ Juelich	Germany	X
IFE	Norway	X
IMEC	Belgium	X
Metu	Turkey	X
NPL	UK	X
Sintef	Norway	X
Tecnalia	Spain	X
Ukerc	UK	X
Utrecht Uni	Netherlands	X

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. Contact Point for the sub-programme on DU-REL

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EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 7: *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: *15-10-2017*

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, for training and mobility of researchers, and for development of new joint research infrastructure and new joint research programs is organized in this sub-program.

We note that the activities within SP7 on sharing research infrastructure, training and mobility of researchers and the setting up of new project proposals have been financed in the past by the EC projects Sophia and Cheetah. Since the Sophia project finished in 2015 and the Cheetah project will end in December 2017, it will be crucial for SP7 to find new sources of financing the activities within SP7 from 2018 onwards.

2. Objectives 2017-2020

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 and systems. This can only be achieved by pooling together scientists and infrastructures, and defining common roadmaps and research programs.

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 within Europe.
- To allow an easier access to infrastructure by developing modes of agreement on the use of partners facilities.
- To train researchers and students in the field of photovoltaics.
- To stimulate the exchange and mobility of students and researchers between the EERA-PV partners
- To stimulate the submission of funded project proposals with so-called EERA label that contribute to the realization of the common EERA-PV research roadmaps.
- To stimulate the definition of new and the updating of existing EERA-PV joint research roadmaps in the research themes covered by SP1 to SP6.

3. Sub-programme activities

Task 1 Infrastructure

In this task, we will manage the access to existing and new PV infrastructure that is made available by the various EERA-PV partners, in order to facilitate and stimulate joint experiments and the joint use of infrastructure between EERA-PV partners. We will use the knowledge exchange portal that was developed within the Sophia and Cheetah funded projects as the main software tool and database for the infrastructure: https://www.cheetah-exchange.eu/. As a first step, we will update and make publicly available the Sophia document entitled “Strategic Vision on PV Research Infrastructure”.

Task 2 **Workshops and webinars**
In this task, we will coordinate the organisation of workshops and webinars across the different subprograms 1 through 6. Webinars will be made publicly available afterwards on the knowledge exchange portal that was developed within the Sophia and Cheetah funded projects, which will create a large body of lectures available to students covering broad topics within the photovoltaic field. Moreover, with the different academic partners within EERA-PV, we will start the creation of so-called MOOCs on the topic of PV, which will also be made available on the knowledge exchange portal.

Task 3 **Networking and mobility**
In this task, we will encourage and manage the exchange of students and researchers between the various EERA-PV partners. Until the end of 2017, this will be done within the framework of the Cheetah IRP project. From 2018 onwards, we will continue the exchange of researchers, but will have to look for other project to fund these exchanges or have the partners use their own internal funding. Moreover, at least one physical meeting of the steering committee of EERA-PV will be organised per year to allow for networking. These steering committee meetings will preferably be organized linked to events such as the EU-PVSEC conference at which most of the partners are present anyway in order to reduce the amount of travelling and travel budget needed.

Task 4 **Roadmap and funding**
In this task, we will coordinate the process for updating the roadmaps of the various subprograms and ensuring funding is obtained. The roadmaps defined by the various subprograms will be updated on a yearly basis by the partners involved in the subprogram under the guidance of the subprogram leader. The role of SP7 in this is to make sure the updates take place in all subprograms in the same way, resulting in an updated description of work of the joint program. Concerning funding, SP7 will stimulate the partners and the different subprograms to apply for funded projects with the EERA-label whenever possible. The EERA label is bestowed on those funded projects which are in line with the roadmaps of EERA-PV, defined in this DoW, and in which at least half of the non-industry partners are members of EERA-PV. Finally, in SP7 we will also actively be looking for funding for the SP7 topics on infrastructure, mobility of researchers, and training.

4. Milestones for 2017-2020

Milestone	Title	Measurable Objectives	Project Month
M7.1	*Updated Sophia PV infrastructure document (entitled "Strategic Vision on PV Research Infrastructure", originally published in 2014) to be made publicly available by end 2017*	*Updated document is published*	*M12*
M7.2	*Ensure that at least 10 webinars per year are made available on the exchange portal*	*Webinars*	*M12,M24, M36,M48*
M7.3	*At least one Joint Program Steering Committee meeting per year organised for networking*	*Meeting*	*M12,M24, M36,M48*
M7.4	*Updated DoW once a year*	*Updated DoW*	*M18, M30, M42*
M7.5	*At least 4 funded project proposals with EERA label each year*	*Submitted proposal*	*M12. M24, M36, M48*

5. Participants and Human Resources

All participants of EERA-PV are active in the Sub-Programme.

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

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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

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[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).

[3] Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation" (C(2015)6317).

[4] Strategic Energy Technology Information System website https://setis.ec.europa.eu/

[5] https://setis.ec.europa.eu/system/files/SET_Plan_Issues_Paper_Photovoltaics.pdf

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

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[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

		BIPV's main applications		
		Roof integration	***Façade-integration***	
			semi-transparent	*opaque*
Additional cost[1] (€ / sq. m)	today (end 2015)	80-120 (roof-integrated modules) 130-200 (tiles, membranes)	150-350	130-250
	2020	50% reduction with regard to end 2015		
	2030	75% reduction with regard to end 2015		

SET-Plan TWP PV Implementation Plan

Final Draft

Approved by TWG members

October 18th, 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 great economic opportunity. PV

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[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).

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 to maintain a leading position in the highly competitive global science and technology arena. This provides a crucial basis for any ambition to preserve 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 and in industrial production and other activities over the full value chain 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

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[4] Photovoltaics Report, Fraunhofer ISE, 12 July 2017

[5] Assessment of Photovoltaics, Final report, April 2017, EUR 27985 EN

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 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;

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[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 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

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[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.

Some of the activities have well identified potential participants; however, this is not an exhaustive list. All activities are open to the participation of other interested entities.

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) and George E. Georghiou (CY – University of Cyprus)
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)

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[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. This requires a multidisciplinary approach and close collaboration between the PV/BIPV and building sectors.

   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.

Summary and next steps

The Temporary Working Group on PV, composed by representatives of interested SET Plan countries and relevant stakeholders, representing industry and academia, has identified the priority research and innovation activities (of both technological and non-technological nature) included in the present Implementation Plan. The work has progressed in the course of 2017.

The priority R&I activities are considered to be essential for achieving the corresponding SET Plan targets contained in the Declaration of Intent on PV. Across the proposed actions, the overall volume of investment to be mobilised has so far been identified in broadly 530 M€, with the main contribution expected from the SET Plan countries involved, then from industry, finally from the Horizon 2020 Framework Programme. Some of the actions are already running.

The emphasis has mainly been put on demonstration activities. Nonetheless, research at lower TRL has also been targeted where appropriate, especially under Activities no. 3 and 6. Non- technological aspects have also been addressed, especially within Activities no. 1, 4 and 6. In particular, deployment of BIPV products and PV plants through market uptake actions has been considered under Activities no. 1 and 4, respectively.

The activities proposed have reached different levels of maturity in terms of concreteness, partnership and financing. There is therefore a significant need for further development of the actions. Also, further investments, funding sources and financial instruments[12] will be needed to fully achieve the DoI targets, especially in connection to demonstration and deployment of technologies. The execution of IPs is supposed to be a continuous process, however. Continued work is expected in the next phase to further define financial planning and full commitment of the intended actors.

With the production of this IP and after its endorsement by the SET Plan Steering Group, the mission of the PV TWG is completed. A new structure needed for the follow up of the effective execution of the IP is expected to be put in place.

The EC intends to facilitate through a Coordination and Support Action (CSA) the coordination activities needed for the execution of the IPs[13]. The proposed consortium should count with the participation of research organisations and/or companies (industry) committed in principle to execute all or some of the R&I activities specified in the corresponding IP as endorsed by the SET Plan Steering Group.

In order to keep the momentum and ensure the delivery of the work so far planned, meetings will be organised as necessary.

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[12] At EU level, instruments such as *InnovFin Energy Demonstration Projects* and the future *Innovation Fund* are obvious potential sources of finance.

[13] See topic "LC-SC3-JA-2-2018: Support to the realization of the Implementation Plans of the SET Plan" of the Horizon 2020 Work Programme 2018-2020 - Secure, clean and efficient energy.

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:	**Monitoring mechanism**:
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.	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, buildings being 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[14]. 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, multidisciplinary BIPV solutions in the built 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, amorphous silicon, 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 built 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 introduce advanced solar building skins, including with flexibility in the production process while recognizing the importance of aesthetics in the activities of the implementation. The interconnection to areas such as e-mobility, Internet of things (in buildings and Cities), circular economy, etc. is important to develop new business models for BIPV within the smart city approach. This underlines the interface with other priority areas of the SET Plan, as well as with the Implementation Plan for

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

Energy Efficiency.

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.

Supporting the development of a European BIPV/PIPV[15] value chain is a top priority from the technical, financial and political points of view. The offer of innovation from the R&D institutions (push) should be matched by actions to support the demand by the end-users (pull) starting with the development of industrial prototyping facilities jointly run by industries and research institutions.

TRL: TRL 3 (experimental proof of concept) to TRL 7 (system prototype demonstration in operational environment) - depending on technology and application[16]

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 national workshops, based on the close collaboration with national stakeholders and industries, as well as with the SET Plan Committee representatives of the various European countries.	3. from 2018 on

Party / Parties *(countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
running activities		
EU ETIP PV BIPV Working Group	workshops	combination of EU and national funding mechanisms
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	Initially 190 PM foreseen (approx. 1.7 mill. €, mostly financed by contributing countries)

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[15] PIPV: Product Integrated PV

[16] Extension into TRL 8 cannot be covered in many countries by the funding agencies with some exceptions.

	field for BIPV products and regular building envelope components, respecting mandatory issues, aesthetic issues, reliability and financial issues	
Germany, Netherlands and other Member States and regions	R&I on national level	> 4 mill. €/y
Netherlands	market oriented demonstration and short term product development[17]	40.3 mill. €/y plus 50 mill. €/y
Solar ERA-Net participants	joint R&I activities between SET Plan countries (projects like “BIPV-pod”, “PVme”)	> 2 mill. €/y
Outlook on planned activities		
France, Germany, Italy, Netherland, Turkey and other Member States and regions: support for industrial organizations and joint projects between industry and research institutes	R&I on national level like French initiative dedicated to light weight and flexible PV modules, Italian Flagship Programme: “Italian BIPV/PIPV value chain” partly based on “Mission Innovation” targets	> 15 mill. €/y
Solar ERA-Net participants	joint R&I activities between SET Plan countries	> 2 mill €/y

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[17] both for NLD - generic for RES

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: 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**
running activities		
Silicon purification - Silicio FerroSolar, Aurinka PV, IES-UPM (Spain)	National funding and industry resources	tbd
Crystallization and wafering: multiple R&D projects in different Member States and Regions, beside others	National funding and industry resources	> 10 mill. €/y
- „Inno-Si": development of innovative silicon crystallization processes (PVA Crystal Growing Systems GmbH, Fraunhofer-Center für Silizium-Photovoltaik CSP) - "EpiPower": epitaxially grown wafers (NexWafe GmbH, Fraunhofer-Center für Solar Energiesysteme ISE, Singulus Technologies AG, centrotherm clean solutions GmbH & Co. KG)	National funding and industry resources	
Cell technologies: multiple R&D projects in different Member States and Regions, beside others		
- AMPERE Project (HJT and bifacial Silicon solar cells, module technology, pilot plant)[18]	national/European funding and industry resources	~ 26.6 mill. € in total
- Italian Flagship Programme: "Innovative Technologies for Modern Utility-Scale PV – part a"	national/European funding and industry resources	t.b.d.[19]
- support for industrial organizations and joint projects between industry and research institutes	National funding and industry resources	> 15.0 mill. €/y
Module technologies: ERC Project: Multi- field and multi-scale Computational Approach to design and durability of Photovoltaic Modules[20]	European funding	€1.5M over 5 years (ends in 2018)
multiple R&D projects in different Member States and Regions, beside others - Dutch TKI Urban Energy program - Spanish and German activities	National funding and industry resources	> 5.0 mill. €/y

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[18] http://cordis.europa.eu/project/rcn/209763_en.html

[19] total funds for Flagship Programme (part a, b & c) ~ 100 mill. € over 5 years based on Mission Innovation targets

[20] http://musam.imtlucca.it/CA2PVM.html

Outlook on planned activities		
France, Germany, Italy, Netherland, Turkey and other Member States and regions: support for industrial organizations and joint projects between industry and research institutes on		
Cell technologies: - Evolutionary development of PERC technologies Development of HJT technologies with economic viability - Development of IBC technologies with economic viability - 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	National funding and industry resources	prospective funding - 18 mill. € - 10 mill. € - 15 mill. €
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) and others	National funding and industry resources.	tbd

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
• Low-cost deposition of GaP on Si mj-cells	• 5 – 10 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 modelling 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	• 2 – 5 years
• Life cycle analysis for whole fabrication route	• 2 – 3 years
• Energy yield in real conditions	• 2 – 5 years

Parties (countries / stakeholders / EU)	**Implementation instruments**	**Indicative financing contribution**
running activities		
Horizon 2020 projects CPV Match[21] - Concentrating Photovoltaic modules using advanced technologies and cells for highest efficiencies CHEOPS[22] - Production technology to achieve low Cost and Highly Efficient phOtovoltaic Perovskite Solar cells	European funding	~ 4.5 mill. € from 2015 to 2019 ~ 5.0 mill. € from 2016 to 2019
France, Germany, Italy, Spain and other Member States and regions: support for industrial organizations and joint projects between industry and research institutes on	National funding and industry resources	> 2.5 million € total
- multi-junction devices on Si	beside others ***Flagship project "PersiST"*:** development of perovskite/silicon tandem solar cells on cell level; improvement of efficiency, stability, eco-compatibility	
- CPV	beside others **Flagship project "CPVMod"**: development along whole value chain and demonstration especially in sunny regions to push acceptability	
Outlook on possible funding topics		
Italian Flagship Programme: "*Innovative Technologies for Modern Utility-Scale PV – part b"* Confirmed partners 3Sun, Enel Green Power, Applied Materials, ENEA, CNR, MIBSolar, CHOSE, multiple Italian universities, ..	national/European funding and industry resources - Tandem solar cells obtained by combining crystalline Silicon with thin film solar cells: Perovskite/Silicon,Wide-gap CIGS/Silicon, GaP/Si tandem cells - Innovative solar cell architectures for high conversion efficiency including back contact schemes and multi-junction cells for high concentration PV systems. - bifacial solar cells - Advanced characterization and modelling for multi-junction cells	tbd (total funds for Flagship Programme (part a, b & c) ~ 100 mill. € over 5 years based on Mission Innovation targets)

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[21] https://cpvmatch.eu/

[22] http://www.cheops-project.eu

multi-junction devices 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, Singulus, EPFL/CSEM	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	tbd
CPV *confirmed partners* - FhG-ISE - IES UPM, BSQ Solar, Solar Added Value, DHV Technologies, Tecnalia, CENER *further possible partners* - Azur Space Solar Power, Orafol Fresnel Optics	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 - Life cycle analysis for whole fabrication route	tbd
All thin film multi-junctions *confirmed partners* EMPA/FLISOM, 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	~ 10 mill.€ in total and 4.5 mill. € funding

Member States and regions: support for industrial organizations and joint projects between industry and research institutes like	National funding and industry resources	
Turkish national support for new generation solar cell systems by means of "1003 - Primary Subjects R&D Funding Program"	Research projects for the high efficiency, low cost, long life new generation solar cell system development would be supported (artificial leaf, perovskite and quantum dot)	tbd
and "1511 - Research & Technology Development and Innovation Program"	Support will be given to production and demonstration of new generation solar cells via two different calls (incl. BIPV)	tbd

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**
Outlook on future topics		
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%
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		tbd
Member States and regions: support for industrial organizations and joint projects between industry and research institutes like	national/European funding and industry resources	
Italian Flagship Programme: “Innovative Technologies for Modern Utility-Scale PV – part c” partners: RSE, ENEA, Eurac, CNR, CHOSE, multiple Italian Universities	• Energy Storage for utility-scale PV plants • Innovative Power and Control Electronics • Technologies for O&M/upgrade/decommissioning of existing utility-scale PV plants • Energy dispatch optimisation	tbd (total funds for Flagship Programme (part a,b &c) ~ 100 mill € over 5 years based on Mission Innovation targets)

	and related issues • PV integration in small and medium grids and management of different energy sources • PV as ancillary service to the grid	

R&I Activity n. 5 - Manufacturing technologies

Manufacturing technologies for silicon and thin-film PV

Targets: 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), von Ardenne (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). Additionally, upstream parts of the silicon value chain are provided by up to 6 research and 14 industry partners including machine manufacturing, producers of Si materials, Si ingots and wafers in Norway. 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,	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.

electronics and storage technologies". Proposed FLAGSHIP: "Pilot lines" (cSi: wafer-cell-module, thin film: integrated) with relevant capacity of 300 MWp/a)		
Running activities		
Member States and regions: support for industrial organizations, joint projects between industry and research institutes and support for R&D infrastructure like		
• Germany The set-up of R&D infrastructure is supported. The infrastructure 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.	National funding	~ 14.2 million euros 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
• Turkey National support for new generation solar cell systems by means of "1511 - Research & Technology Development and Innovation Program"	National funding and industry resources Support will be given to production new generation solar cells via two different calls	tbd
• Italy Project "PIPELINE" - Prototype process line for Si heterojunction solar cells": Low environmental impact and high efficiency production process: (ENEA, RISE Tech, Elettrorava spa)	National Funding and industry resources	~ 1.7 million euros (2017-2019)

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[23]
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[24]		eventually, new instruments on funding research infrastructure have to be developed on an European level

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[23] personal costs are expected to be beard by the home institution

[24] see for example the High Performance Computing (HPC) center at the National Renewable Energy Laboratory, www.hpc.nrel.gov

Annex II – Members of the TWG

Member States (11)

member		alternate
Belgium - Walloon region	Laurence Polain	
Belgium - Flemish region	Lut Bollen	
Cyprus - University of Cyprus	George E. Georghiou	Aris Bonanos
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	
Becquerel Institute	Gaëtan Masson	
SolarWorld AG	Milan Nitschke	
Consultores de Energía Fotovoltica SL	Emiliano Perezagua	
EERA PV (Fraunhofer ISE)	Simon Philipps	Ivan Gordon

member		**alternate**
IMEC	Jef Poortmans	
ECN - **(Co-Chair)**	Wim Sinke	
University of Ljubljana	Marko Topič	
First Solar	Andreas Wade	
Singulus	Peter Wohlfart	
3E	Achim Woyte	