FOTOPLAT

Hoja de ruta para la tecnología fotovoltaica

Contribución española

Promueve

UNEF

Unión Española Fotovoltaica

tecnalia

Financia

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

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1. Introducción

El trabajo de definición de una hoja de ruta para la tecnología fotovoltaica en FOTOPLAT se ha realizado en el seno del Grupo de Trabajo de Tecnologías, a partir de un proceso de puesta en común y discusión sobre qué debería aportar FOTOPLAT en este ámbito, en un contexto en el que hay un buen número de organizaciones internacionales de distinto tipo planteando sus propias hojas de ruta, y se quería evitar realizar un trabajo reiterativo o de impacto reducido.

En este proceso se han dado los siguientes pasos:

-Configuración del grupo de trabajo de Tecnologías

-Reconocimiento del impacto de la tecnología española en el desarrollo global de la energía solar fotovoltaica

-Aportaciones a la hoja de ruta de la European Energy Research Alliance – Joint Program on Photovoltaics.

En las próximas páginas se detallan los resultados de dichos pasos.

2. Configuración del grupo de trabajo de Tecnologías

En primer lugar, se debatió cómo organizar el grupo para que mejor sirviese a sus objetivos: asesorar a administraciones españolas en la priorización de líneas de investigación en el ámbito fotovoltaico, e influir en las líneas de investigación en FV promovidas por organismos y foros internacionales, especialmente europeos. Se establecieron seis subgrupos (mostrados en la figura 1), con intención de cubrir todo el abanico de tecnologías fotovoltaicas y todos los ámbitos, del material al sistema, y se eligieron organizaciones y personas para coordinar los mismos.

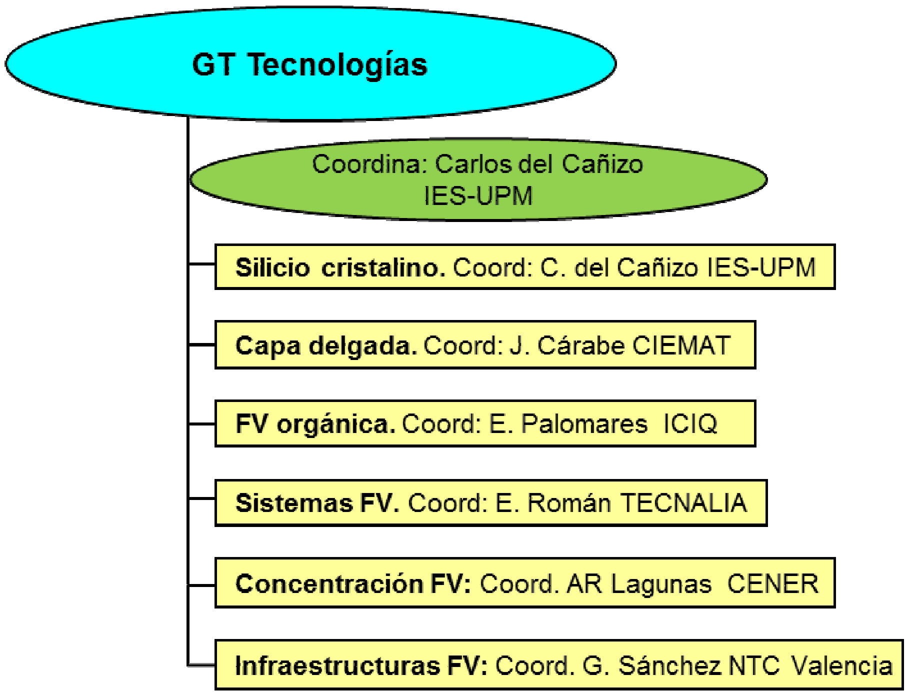


Figura 1. Subgrupos del grupo de trabajo de Tecnologías y coordinadores de los mismos

Se hizo un llamamiento entre las empresas y centros de investigación españoles, y en concreto entre los socios de FOTOPLAT, para que se incorporaran a los subgrupos en los que trabajaran, llegando a sumar unas cincuenta contribuciones de una treintena de instituciones, tal y como recoge la tabla 1. Hay que tener en cuenta que el grupo de Infraestructuras, por su carácter transversal, no se concibió como para que se apuntasen específicamente las instituciones en él, sino que de alguna forma cubre a todos los que participen en alguno de los subgrupos.

SG1: c-Si	IES-UPM
	UPC
	Valencia Nanophotonic Technology Center
	TIM
	CIEMAT
	CENER
	Ferrosolar
	Enertis Solar
	Centro de Tecnología del Silicio Solar. Centesil
SG2: Thin film PV	CIEMAT
	Valencia Nanophotonic Technology Center (Valencia NTC)
	NANO4ENERGY SLNE
	IK4-CIDETEC
	IK4-TECNIKER
	ITMA
	Universidad de Cádiz
	CENER
	Universidat de Barcelona, Departamento de Física Aplicada y Óptica
	UPC- Universidad Politécnica de Cataluña
	Enertis Solar
SG3: Organic PV	ICIQ - Instituto Catalán de Investigación Química
	IK4-CIDETEC
	LEITAT Technological Center
	UPC- Universidad Politécnica de Cataluña
	ICMOL-UVEG Univ. de Valencia, Instituto de Ciencia Molecular
	UAM- Universidad Autónoma de Madrid
	ICMAB- CSIC Instituto de Ciencia de Materiales de Barcelona
	UPO- Universidad Pablo de Olavide de Sevilla
	ICN2 - Instituto Catalan de Nanociencia y Nanotecnología
	URV- Universitat Rovira i Virgili

	CETEMMSA
	ICFO
	UJI- Universitat Jaume I
	NANO4ENERGY SLNE
	ITMA
	Polymat
	CENER
	Universidad de Castilla-La Mancha
SG4: PV Systems	Tecnalia
	IES-UPM
	Universidad de Cádiz
	GRUPO IGFOTON
	CENER
	CIEMAT
	Enertis Solar
	TTA -Trama Tecno Ambiental
SP5: CPV	CENER
	IES-UPM
	Solar MEMS Technologies
	Tekniagroup
	ISFOC
	BSQ
	Valldoreix Greenpower, S.L
	Tecnalia

Tabla 1. Relación de miembros de FOTOPLAT participando en los subgrupos de trabajo de Tecnologías

Se consideran suficientemente representativos dichos subgrupos, pues si algunas empresas y centros de investigación relevantes no han llegado explícitamente a sumarse a los mismos, de las conversaciones mantenidas con ellas se deduce que es simplemente por ritmo excesivo de trabajo, muchas han manifestado su interés en sumarse a los subgrupos, y en cualquier caso se tiene contacto fluido con la mayoría.

La dinámica de trabajo de los subgrupos ha tratado de ser lo más operativa posible, evitando en lo posible reuniones globales y canalizando vía correo electrónico, a través de los coordinadores, las contribuciones al trabajo colectivo.

3. Impacto de la tecnología española

Con idea de tener una visión panorámica actualizada de la contribución de la tecnología española al desarrollo de la fotovoltaica a nivel mundial, se pidió a cada organización participante en el grupo de Tecnologías de FOTOPLAT que resaltara los resultados más importantes de su trabajo en los últimos años en una ficha de "manifestación de interés".

En el Anexo I se presentan las fichas recogidas, que han servido de base para la tarea 4.4, "Situación de la industria y tecnología fotovoltaica españolas", dando lugar al documento que allí se presenta, redactado por los coordinadores de los subgrupos.

Lo que es más importante, el análisis de las fichas pone de manifiesto el papel relevante que juega España en el ámbito mundial de la tecnología fotovoltaica, a través de indicadores como publicaciones en revistas científicas, patentes, transferencias a la industria, etc. Hay, pues, todo un historial de situarse en la "vanguardia" de la tecnología que no se puede perder, un reto al que FOTOPLAT quiere contribuir, entre otras cosas resaltando las aportaciones españolas a las hojas de ruta que se trazan para la tecnología fotovoltaica en distintos ámbitos.

4. Aportaciones españolas a la hoja de ruta de la tecnología fotovoltaica

En el grupo de trabajo de Tecnologías se hizo una reflexión sobre qué hoja de ruta definir en FOTOPLAT. Para ello se tuvieron presentes contribuciones como las realizadas desde la European Photovoltaic Technology Platform, desde la Solar European Initiative, o desde la European Energy Research Association (EERA).

En el caso de esta última, el Joint Program de Fotovoltaica (EERA-PV) ha vivido un proceso de redefinición de los planes de trabajo para los próximos años. Dado que el punto de partida es similar (una visión global del estado de la tecnología, una relectura de las hojas de ruta planteadas recientemente por diversos organismos internacionales y europeos) y que se veía fundamental que las aportaciones desde la tecnología española quedaran reflejadas en dicho plan revisado, se optó porque FOTOPLAT asumiera como propia dicha hoja de ruta europea, y que los esfuerzos se focalizaran en hacer valer las contribuciones españolas en el mismo.

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, y aunque no todos han llegado a su versión definitiva, sí que 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 (en especial, en capa delgada y en orgánica FV –que a propuesta española ha pasado a llamarse FV híbrida, para recoger mejor alguna de las alternativas en las que se trabaja) por otro.

En el anexo 2 se recogen los planes de trabajo de la EERA-FV 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.

ANEXO I – Manifestaciones de interés de empresas y centros de investigación españoles

Las manifestaciones de interés pueden contener información susceptible de ser tratada como confidencial, por lo que no se incluyen en esta versión pública del documento.

Estarán a disposición del MINECO en la memoria técnica justificativa del periodo 2013 y primer semestre 2014

GRUPO DE TECNOLOGÍAS – FOTOPLAT

MANIFESTACIÓN DE INTERÉS PARA APORTAR AL GRUPO

Se ha acordado organizar el trabajo del grupo en los siguientes subgrupos:

- **SG1: c-Si – Carlos del Cañizo (IES-UPM)**
- **SG2: Thin film PV – Julio Cárabe (CIEMAT)**
- **SG3: Organic PV – Emilio Palomares (ICIQ)**
- **SG4: PV Systems (Eduardo Román – Tecnalia)**
- **SG5: CPV – Ana Rosa Lagunas (CENER)**
- **SG6: Education, training and infrastructures -Guillermo Sánchez (Valencia NTC)**

Para cada uno de los subgrupos en los que se desee participar, se pide rellenar la siguiente ficha:

Institución:	
Subgrupo al que se adhiere:	
Persona de contacto:	
Teléfono	
dirección email:	
Descripción de las líneas específicas de trabajo (muy breve, un párrafo o un listado de enunciados)	
Resultados principales en los últimos cinco años (en forma de productos novedosos, resultados científicos, publicaciones, patentes, transferencia,...)	

ANEXO II Plan de trabajo de los SubProjects de la EERA-JP-PV

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

SUB-PROGRAMME 1: Si Technology

DRAFT

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

Description of Work

Version: 3
Last modification date: 06.06.2014

DESCRIPTION OF THE RESEARCH ACTIVITIES

Table of Contents

Summary Research Activity *Silicon Technology*

Wafer-based crystalline silicon (c-Si) technologies accounted for more than 90% of the PV module production power in 2013. This underlines the leading position of c-Si among the commercially available PV technologies. The key factors for this success have been a continuous increase of efficiency in conjunction with a remarkable decrease of production cost. Therefore, Research, Development and Innovation at research facilities and in the industry in Europe have played a major role and are required to proceed on the successful cost reduction path in the future.

Currently, the global photovoltaic industry is strongly affected by a severe production overcapacity, which triggered rapid price erosion and an industry consolidation. Although a growing global PV market and the industry shakeout will eventually lead to a reduction of the overcapacity in the coming years, strong (price) competition will remain. This set-up puts a severe threat on the competitiveness and hence the survival of the EU industry in the field of c-Si PV.

However, Europe's PV sector is set apart to its international competitors by a strong knowledge base and a highly innovative industry supported by a strong research community. Research, development and innovation were and will be the cornerstones in order to stay a step ahead of Europe's competitors in the field of crystalline Silicon PV. Yet, a coordinated effort of all players involved - research institutions, industry as well as political actors - is necessary.

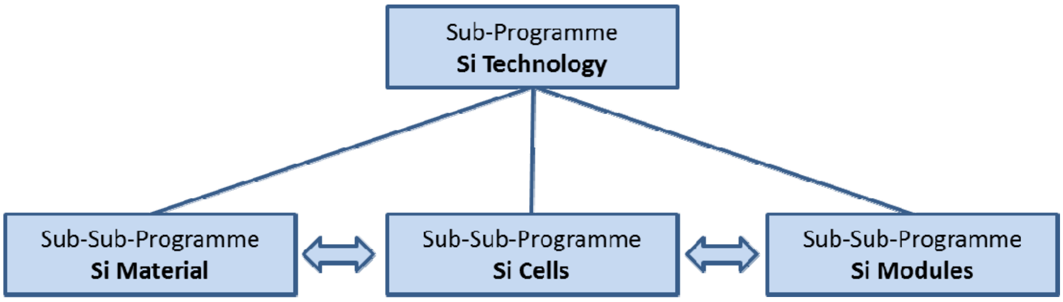
The central aim for this work programme is hence to maintain and secure the competitiveness of the EU industry in the field of crystalline Silicon Photovoltaics through research, development and innovation. In this period a close link with the industry is more important than ever. Therefore, the work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

The main drivers for Silicon technology research are cost reduction, performance enhancement and improvement of lifetime and reliability. To accelerate progress on these drivers, the following five research themes have been identified as focus areas:

- ✓ *Automated Processes*
- ✓ *Improved understanding of the effect of material quality on c-Si solar cell and module efficiency*
- ✓ *Ultra-thin crystalline Silicon cells and modules*
- ✓ *Detection of degradation mechanisms / Reliability*
- ✓ *Ultra-high efficiency c-Si cells*

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

One essential step in this direction was the creation of the sub-programme Silicon Technology in EERA JP PV in 2013. This new sub-programme will become active in the work programme of 2014. In the previous work programme (2010-2013) research related to Silicon 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 Silicon technologies into one sub-programme. Moreover, the essential topic of Silicon cells needed to be included. The new sub-programme on Silicon Technologies brings together important research players along the value chain. The sub-programme is divided into three sub-sub-programmes on Si Material, Si Cells and Si Modules, which will closely work together in order to achieve common objectives on Silicon Photovoltaics.



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

1. Objectives 2014 - 2017

The following overall objectives for the sub-programme Si Technology are defined for the period 2014-2017. These goals are in-line with the SET-Plan. Moreover, they are related to the SEII Implementation Plan as they translate some of the central goals into concrete targets for R&D.

Overall objectives of the sub-programme Si Technology

1) Sustainably reduced manufacturing costs per watt along the value chain from materials via cells to modules.
2) Increased cell and module efficiencies
3) Long term reliability of c-Si technology

The following main objectives for Si Material, Si Cells and Si Modules are directly linked to these overall objectives.

Main objectives of the sub-sub-programme Si Material

a. Low-energy silicon feedstock technologies for reduction of manufacturing costs.
b. Silicon crystal growth techniques for high quality, high throughput and cost-effective consumables. Seeded growth for high-performance mono- and multi-crystalline material.
c. Advanced, automated, kerfless wafering techniques for efficient material utilization and reduction of silicon usage. Wafer-equivalent technologies are included here.

Main objectives of the sub-sub-programme Si Cells

a. High-throughput automated processes for manufacturing, high-efficiency low-cost, cells (like PERC, MWT, Heterojunction and IBC) including advanced process control to reduce efficiency distribution.
b. Development of advanced process technologies and equipment to be implemented in advanced cell concepts (like passivated contacts, multi-functional surface layers, copper metallisation, thin wafer technologies, light management….)
c. Development of future cell generations based on crystalline silicon (like hybrid cells as Perovskites-on-silicon, III-V-on-silicon, …)

Main objectives of the sub-sub-programme Si Modules

a. Development of automated processes for the manufacturing of high efficiency modules

b. Improvement of mechanical and optical modelling to reduce development cycle times
c. Definition of highly accelerated stress tests and execution of outdoor monitoring programs
d. Development of analysis tools for high efficiency modules (e.g. interconnect quality, mechanical properties, adhesion strength of new layers etc)

2. Description of foreseen activities

In order to achieve the objectives listed in the previous section substantial research activities are necessary. The main activities can be grouped into five research themes.

Research Theme 1.1*: Automated Processes*

<u>*Coordinator:*</u> Sean Erik Foss (IFE)

<u>*Background*</u>
Standard crystalline silicon modules are manufactured in six steps: (i) silicon production, (ii) silicon purification, (iii) silicon crystal growth, (iv) wafer slicing, (v) cell fabrication and (vi) module assembly. In a large number of factories worldwide several 10 GWs of these standard c-Si modules are produced each year using highly-automated production lines. Considerable progress has already been made in each step over the last decade and there is still potential for further improvement. However, 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. This is why R&D needs to put a specific focus on automated processes. Moreover, this topic is of high relevance for Europe as the largest share of equipment manufacturing is carried out in Europe.

<u>*Objective*</u>
This research theme focuses on the development of automated, high-throughput manufacturing processes for high performance PV cells and modules, which are essential to be cost competitive in the future. New processes and equipment for novel or improved c-Si cells and modules need to be developed and demonstrated.

<u>*Activities*</u>
Within this research theme the following activities are required:

- Research on silicon production and purification technologies able to reduce cost and maintain quality by increased productivity and reduced energy consumption. New and improved technologies for feedstock production through silane decomposition (mono- and chlorosilane) as well as through the upgraded metallurgical route needs to be developed and has potential for making significant contributions to the objectives stated above.
- Research on high quality and high speed silicon crystal growth techniques, e.g. using continuous Fz and Cz casting, high-performance crucible systems, equipment and processes for scaled block crystallization with low risk profile.
- Improvement of seeded growth for high-performance mono and multi-crystalline silicon material
- Development of advanced, automated, kerfless wafering techniques for efficient material utilization and reduction of silicon usage. This activity includes wafer-equivalent technologies and is closely linked to Research Theme 1.3.
- Research on high-throughput automated processes for manufacturing, advanced, low cost, high-efficiency cells and modules, including process equipment to realize up to 0.4% multicrystalline and 0.5% monocrystalline yearly efficiency increase on module

level. This activity includes automated processes for heterojunction a-Si/c-Si and hybrid IBC cells.

- High-throughput automated processes for manufacturing, high-efficiency low-cost, cells (like PERC, MWT, Heterojunction and IBC) including advanced process control to reduce efficiency distribution as well as technology for thin wafer handling.
- Development of advanced process technologies and equipment to be implemented in advanced cell concepts (like passivated contacts, multi-functional surface layers, copper metallisation, thin wafer technologies, laser processing, light management….)
- Development of automated processes for the manufacturing of high efficiency modules (e.g. conductive adhesives, metallized back sheets for back contact cells).

Partners
ECN, CIEMAT, GUNAM, IES-UPM, IFE, IMEC, ISE, SINTEF, TUBITAK MRC

Milestone	Measurable Objectives	Title	Month
M1.1.1	Report	Report on progress in c-Si material and wafering processes	*M12*
M1.1.2	Report	Report on high-throughput automated processes for high-efficiency, low cost c-Si cells	*M24*
M1.1.3	Report	Report on advanced processes for c-Si modules	*M36*
M1.1.4	Report	Report on advancements in automated processes for c-Si cells and modules	*M48*

Research Theme 1.2*:* Improved understanding of the effect of material quality on c-Si solar cell and module efficiency

Coordinator: N.N.

Background
In order to be able to manufacture a high efficiency module, solar cells with high efficiency are required. The performance of a solar cell is highly dependent on the quality of the wafer. When going from cell to module losses can occur as well, both optically and electrically. For high efficiency solar cells, the electrical losses can be even higher, due to the higher current generated by the cells. Hence, it is necessary to properly characterise the wafer, solar cell and module in order to determine where losses are occurring and how the performance of one affects the other. Proper optical modelling is also needed in order to choose the correct encapsulation and optical coatings to minimise losses.

Objective
To determine the relation between feedstock/wafer characteristics and solar cell efficiency. To set up a model to reduce losses when going from cell to module.

Activities
Within this research theme the following activities are required:

- Standardised measurement of carrier lifetime, metal contamination level, oxygen concentration and surface morphology
- Determination of the effect of carrier lifetime, metal contamination level, oxygen concentration and surface morphology on device performance
- Ultra-thin cell characterisation techniques, e.g. developing measurement techniques that properly take into account the increased importance of surface recombination, as

light trapping becomes more important better methods for quantifying light trapping needs to be developed.

- Development of a comprehensive model for the impact on material quality of impurities and defects during processing
- Development of an optical model for the module, which takes into account all the module components (cells, glass, encapsulant, metal strings and backsheet foil), i.p. to investigate light trapping at module level
- Development of novel strategies to maximize the cell to module gain
- Analysis tool for interconnection losses: contact resistance and resistance loss in current conductor (tab or foil)
- Manufacturing and analysis of a module proto-type, with cell-to-module loss in accordance to loss predicted by model

Partners
CEA-ines (tbc), CENER, CIEMAT, ECN, GUNAM, IES-UPM, IFE, ISE, RWTH-IHT, Sintef (tbc), TUBITAK MRC, UPVLC

Milestone	Measurable Objectives	Title	Month
M1.2.1	Report	Report on required analysis tools	M12
M1.2.2	Analysis tool	Analysis tools available for wafer, cell and module	M24
M1.2.3	Report	Report on comprehensive model for the impact on material quality of impurities and defects during processing	M36
M1.2.4	Report	Report on Improved understanding of the effect of material quality on c-Si solar cell and module efficiency	M48

Research Theme 1.3*: Ultra-thin crystalline Silicon cells and modules*

<u>Coordinator:</u> Ivan Gordon (IMEC)

<u>*Background*</u>
Despite the rapid growth of the bulk silicon market, the costs of the starting silicon material and the fabrication of a wafer by cutting and sawing silicon ingots are still high. Furthermore, despite the cost, only a very thin region of the silicon substrate, the first 40-50 µm, is used in an efficient way. The rest of the material acts mainly as a mechanically conductive carrier. **The classical value chain to produce silicon wafers using ingot crystallization and wire sawing loses more than 70% of the pure feedstock silicon, and consumes about 5-7 grams of silicon per Wp of solar cell power.** Hence, it is important to use less of the expensive silicon material and to develop alternatives to the traditional silicon value chain. Such an alternative is the crystalline silicon thin-film lift-off technology in which epitaxial silicon 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 microns. 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 kerfloss to almost nothing.
However, to integrate such ultra-thin silicon substrates into working devices with high efficiencies, new cell and module processes need to be developed as well as new wafer handling techniques.

Objective

The objective of this research theme is to develop a module manufacturing process suitable for ultra-thin cells (target thickness below 50 µm). The yield of the module manufacturing process must have the potential to match current module production.

Besides the module process itself, the ultra-thin Si substrates will also be developed within this research theme, as well as suitable processing and handling of these thin substrates. The goal is to achieve cells with efficiency above 23% and a usage of less than 2g Si/Wp. The module process itself should yield a cell to module loss of <1% in power output.

Activities

Within this research theme the following activities are required:

- Development of release layers to allow lift-off of the epitaxially grown silicon layers
- Development of high-throughput epitaxial growth of silicon resulting in high-quality material with low defect density
- Demonstration of large-area thin Si wafers and wafer equivalents with high minority carrier diffusion lengths
- Electrical and optical modelling to design the geometric structure of the ultra-thin silicon device
- Design and development of advanced light trapping structures for ultra-thin crystalline silicon solar cells, including module level solutions
- Development of doped layer formation, passivation and metallization processes compatible with ultra-thin crystalline silicon solar cells
- Development of effective handling methods for processing the ultra-thin crystalline silicon substrates with high yield
- Development of a module manufacturing process suitable for ultra-thin crystalline silicon
- Study of different encapsulation materials and interconnection techniques
- Life-cycle analysis and cost of ownership calculations to determine energy payback time, CO2 footprint and environmental impact of resulting module process

Partners

CEA-INES(tbc), CENER, CIEMAT, ECN, EPFL, FZ Juelich, GUNAM, IFE, IMEC, ISE, RWTH-IHT, Sintef (tbc), TUBITAK MRC, Uni Utrecht, UPVLC

Milestone	Measurable Objectives	Title	Month
M1.3.1	Report	Report on the ideal solar cell architecture, defined from numerical modeling (optical and electrical properties) to reach target efficiencies of 23% on thin Silicon substrates (< 50 µm thickness).	M12
M1.3.2	Report	Report on which approach to encapsulate thin wafers will be used	M24
M1.3.3	New prototype	Free-standing wafers below 50 µm thickness with minority carrier diffusion length over 200 µm and size of 156x156 mm2	M36
M1.3.4	New prototype	PV module based in ultra-thin x-Si solar cells, fulfilling common stability criteria with simple, low-cost encapsulation technology and yielding a cell to module loss of <1% in power output	M48

Research Theme 1.4*: Detection of degradation mechanisms / Reliability*

<u>Coordinator:</u> Wilma Eerenstein (ECN)

<u>*Background*</u>
Crucial in the development of new solar concept and processes is that the end product, the module, achieves a service life of at least 25 years. Lower lifetimes are not acceptable. **This means new components, such as ultrathin wafers made by new processing, cell metallisation and module encapsulation and interconnection materials, must all be tested for durability**. These tests are done for the separate components, for combinations of components and for the complete product. In case of early failure, it is very important to be able to detect the failure mode, such that the component or product can be improved. The type of tests and analysis required should focus on:

- Thermo-mechanical stability of the total module, including modelling
- Lifetime of wafer, cell and module components
    - Under high temperature, humidity, UV exposure, temperature cycling and combinations thereof
- Analysis of corrosion, light induced degradation, delamination, degradation of polymer components, instability of the wafer, cracking of cells.

<u>*Objective*</u>
The objective of this research theme is to determine failure modes for new components, and to define the required accelerated stress tests. In order to do so, the development of novel characterisation techniques is required.
For wafers: lifetime of charge carriers and stability of doping profiles in the wafer and surface morphology.
For cells: Stability of metallisation, mechanical stability of the cell inside the module environment.
For modules using these thin cells: delamination, corrosion, insulation properties, degradation of polymer layers
Based on the knowledge of degradation mechanisms, existing accelerated stress tests (IEC61215) will be adapted.
A mechanical model will be set up for the complete module. This model will predict thermo-mechanically induced stress on the cell and interconnection.
The overall aim of this research theme is to support the development of c-Si modules with an extended lifetime of 30 years and more.

<u>*Activities*</u>
Within this research theme the following activities are required:

- Identification of characterisation tools required
- Development of characterisation tool, if not present at EERA partners
- Identification of failure mechanism for individual components
- Development of highly accelerated stress test
- Prolonged outdoor testing
- Setting up thermo-mechanical model
- Calculating thermo-mechanical stability of complete module
- Results of model and stress test will be applied for module re-design if required

<u>*Partners*</u>
AIT, CEA-ines (tbc), CENER, CIEMAT, CREST, ECN, ISE, RWTH-IHT, Uni Utrecht

Milestone	Measurable Objectives	Title	Month
M1.4.1	Report	Report on the identification of required characterisation tools and availability at EERA partners	M12
M1.4.2	Report	Report on stress test and failure mechanism of module components (including cell)	M24
M1.4.3	Report	Thermo-mechanical stress tests performed on module and model verified	M36
M1.4.4	New prototype	PV module with a lifetime of 30 years, passing IEC testing and measured outdoor without degradation for at least one year.	M48

Research Theme 1.5*: Ultra-high efficiency c-Si cells*

Coordinator: Stefan Glunz (ISE)

Background
In the last decades crystalline silicon photovoltaics has dominated the photovoltaic market. The strong decrease of costs for this technology results from cost reduction in production but is also due to the increase of cell efficiency which is a strong lever to reduce the levelized costs of electricity.
In fact, silicon solar cells in lab and production are getting closer to their theoretical efficiency limit of about 29.4%. Therefore, it is important to evaluate concepts for a second generation of silicon-based solar cells which can reach higher efficiencies but are still based on the most mature photovoltaic technology i.e. silicon solar cells. One can distinguish between tandem approaches using a crystalline silicon solar cell as bottom cell and spectrum management like up-conversion to increase the range of useable photons for crystalline silicon solar cells.

Objective
The objective of this research theme is to develop and evaluate technologies with the potential to surpass the theoretical limitation of a single junction crystalline silicon solar cell. Since it is not clear right now which approach has the highest practical potential, a range of approaches will be evaluated.

Activities
Tandem approaches:

- All-silicon tandem cell (based on a silicon quantum dot solar cell and a crystalline silicon solar cell)
- III-V-based top cell on crystalline silicon bottom cell (either via bonding or direct growth)
- Si-based top cell on c-Si bottom cell in 4-terminal tandem
- Perovskite-silicon solar cells
- Organic-inorganic hybride cells i.e. combining organic solar cells on top of crystalline silicon solar cells

Light management approaches:

- Up-conversion of infrared light
- Photonic back reflector

- Spectral splitting

Partners
CENER, CIEMAT, CNRS, ECN, EPFL, FZ Juelich, GUNAM, IFE, IMEC, ISE, RWTH-IHT, TUBITAK MRC, Uni Utrecht, UPVLC

Milestone	Measurable Objectives	Title	Month
M1.5.1	Prototype	Up conversion efficiency of 15% @ 1500 nm	M12
M1.5.2	Prototype	Implied open-circuit voltage of silicon quantum-dot layer > 550 mV	M24
M1.5.3	Prototype	Bonded III-V solar cell on silicon bottom cell with efficiencies >29%	M36
M1.5.4	Report	Final evaluation about the most viable technology	M48

3. Participants and Human Resources

The table below lists the research institutes that participate in the sub-programme Si Technology and its sub-sub-programmes.

Institute	Country	*Participation in:* Coordination	Si Material	Si Cells	Si Modules	Role
AIT	Austria				x	R&D for modules, testing and characterisation.
CENER	Spain		x	x	x	
CIEMAT	Spain			x	x	R&D for module reliability: ageing mechanisms, testing and characterization. Laser crystallization of amorphous silicon. Development of processes for Silicon-heterojunction cells on ultra-thin wafers, passivation, contacts and emitter formation. Improvement of light trapping in ultra-thin cells. Module and cell characterization, modeling and device simulation
CNRS	France		x	x		All-silicon tandem cell (Si-QDs); III-V-based top cell on crystalline silicon bottom cell (InGaN/Si); Perovskite-silicon solar

						cells; Up-conversion of infrared light (Rare earth doped oxides); Spectral splitting (Si-QDs and rare-earth doped oxides)
ECN	Netherlands	x	?	x	x	Coordination of "Silicon modules"
EPFL	Switzerland			x		
FhG-ISE	Germany	x	x	x	x	Coordination of sub-programme and "Silicon cells"; R&D along the value chain from material to modules; Development of new c-Si cells
FZ Juelich	Germany		x	x		Silicon thin-film deposition, characterization and device simulation; Silicon alloy materials (SiC, SiO); Light trapping on thin wafers; Development of c-Si based tandem
Günam	Turkey		x	x	x	High efficiency c-Si cell fabrication; Laser processing for Si materials and Si cells; Implementation of light trapping approaches; Smart modules with integrated micro inverters and battery.
IES-UPM	Spain		x	x		Pilot plant for si purification by chlorosilane route; Impurity impact on solar cell performance and defect engineering approaches; Solar cell development: n-type, B emitters, thin wafers
IFE	Norway		x	x	x	Running of three pilot reactors for silicon feedstock/powder production based on different technologies (free-space, fluidized bed and centrifuge) using mono-silane; Light trapping schemes; Optical modelling (cell/module); Wafer analysis (lifetime, LID); Laser processing (short pulse, surface structuring, ablation); Characterization method development for passivating layer analysis
IHT-RWTH Aachen	Germany		x	x	x	Si material: Material and defect analysis on wafer level, developing of ultra-thin Si/SiO2 multilayer stacks; Si cells: Developing and optimisation of single process steps, cell characterisation and simulation, fundamental research work, all Si tandem cells; Si modules: Modelling and simulation (electrical, thermal and optical) of PV modules and annual energy yields
IMEC	Belgium	x	x	x	x	Coordination of "Silicon material"; Development of ultra-thin kerfless Si wafers and ultra-thin Si cells and modules; Development of new c-Si cell technology
TUBITAK MRC	Turkey			x	x	Wafer surface morphology, light trapping and carrier lifetime schemes, development of ultra-thin Si cells and modules
UPVLC (Uni Valencia)	Spain		x	x	x	Development of advanced light trapping, including modelling and solutions at module level
Utrecht University	Netherlands		x	x	x	Performing LCA analysis to determine CO2 footprint and EPBT

Many of the EERA partners will execute the CHEETAH project. The crystalline silicon R&D part of this project aims to develop high efficiency modules using ultra-thin wafers and solar cells. This project hence contributes to the goals of material and cost reduction. In addition, increased efficiency and improved lifetime of the modules is also a major factor to remain the leading PV technology and to help the EU PV industry remain competitive.

4. Infrastructures

The FP7 project SOPHIA is mapping the research facilities available at the project partners (many also member of EERA), this list is available at the website. Furthermore, a vision document on the research infrastructure (RI) is currently being made. It will contain a description of the current trends in PV RI as well as recommendations for upgrading the capability of new RIs. This document will be aligned with other PV vision documents such as the Strategic Research Agenda from the EU PV technology Platform and should serve as an input for policy makers at national and EU level.
The CHEETAH project will continue this activity by defining how the infrastructure can most effectively be used by European PV R&D parties. This activity is not only relevant for the x-Si sub-program of EERA, but for the entire EERA PV program.

5. Contact Points for the sub-programme on Silicon Technology

Coordinator of Sub-Programme "Si Technologies"
Dr. Simon Philipps
Fraunhofer ISE
Heidenhofstraße 2
D-79110 Freiburg
Germany
Tel: +49 761 4588 5920
E:mail: simon.philipps@ise.fraunhofer.de

Coordinator of Sub-Sub-Programme "Si Material"
Dr. Ivan Gordon
IMEC
Kapeldreef 75
B-3001 Leuven
Belgium
Tel: +32 16 28 82 49
E:mail: Ivan.Gordon@imec.be

Coordinator of Sub-Sub-Programme "Si Cells"
Dr. Stefan Glunz
Fraunhofer ISE
Heidenhofstraße 2
D-79110 Freiburg
Germany
Tel: +49 761 4588 5191
E:mail: stefan.glunz@ise.fraunhofer.de

Coordinator of Sub-Sub-Programme "Si Modules"
Dr. Wilma Eerenstein
ECN
P.O. Box 1
NL-1755 ZG Petten
The Netherlands
Tel: +31 88 515 4435
E:mail: eerenstein@ecn.nl

EERA PV
Status SP 2

Martha Ch. Lux-Steiner
Helmholtz-Zentrum Berlin für Materialien und Energie
Berlin, Gemany

www.eera-set.eu

Organisation of work in projects

- R&D areas
  - Cell & module concepts for **high efficiency**
  - Advanced **transparent conductors**
  - Advanced **module manufacturing**
  - Processes and equipment design for **large-scale production**
  - Analysis and modelling of materials and devices

- Thin film materials
  - amorphous/microcrystalline silicon
  - polycrystalline compound semiconductors such as CdTe, $Cu(In,Ga)(S,Se)_2$ and related materials (**new** Kesterites)

Team

Continuously growing up to:

19 participants

11 countries

11 - 12 py/y

	Status	Total		SP2
Austria	Participant	60		22
France	Participant	58		6
Italy	Participant	120		
Spain	Associate	28		9
Greece	Associate	16		
UK	Associate	24		
Netherlands	Participant	62		6
Switzerland	Associate	5		1
Italy	Participant	120		42
Switzerland	Participant	30		30
Germany	Participant	86		
Czech Republic	Associate	21		21
Germany	Participant	72		48
Turkey	Participant	192		60
Germany	Participant	132		96
Norway	Participant	39		3
Germany	Participant	72		24
Belgium	Participant	60		
UK	Associate	10		
EU	Associate	6		
Portugal	Participant	120		
Spain	Associate	29		20
UK	Participant	39		
Denmark	Participant	38		
Norway	Participant	30		7
Estonia	Participant	5		
Spain	Participant	47		6
Turkey	Associate	9		3
Slovenia	Associate	24		15
Italy	Associate			
Spain	Participant	60		
Finland	Associate	17		
Germany	Participant	60		48
	pm/y	1691		467
	py/y	141		

Milestones Status

Cell & module concepts for high efficiency			
M2.1	▮	Feasibility study: mechanically stacked or monolithic tandem cells based on different types of technology (TF-Si, chalcopyrite and CdTe) incl. simulation	▪ Stacked cells (a-Si/CIGS) were made and characterized; monolithic cells were made but failed at the first attempt. A new set of CIGS-absorbers will be made by HZB in March 2013 and sent to partner FZJ for a-Si deposition. ▪ A solar simulator is being developed by EPFL for the energy yield prediction of multi-junction (monolithic and mechanically stacked) devices of various technologies. Simulator is, for the time being, limited to spectral effects and will be extended to take into account temperature and degradation effects.
M2.2	▮	Workshop in Berlin: design of innovative device structures on the basis of established thin film materials (TF-Si, CIGS and CdTe)	▪ Workshop took place October 2011 in Berlin. ▪ Proposals for research topics for European FP7 programs 2013 were defined during that workshop and sent to EC by the EERA coordinator.

Milestones Status

Advanced transparent conductors			
M2.3		Comparison and exchange: TCO thin film properties prepared at various EERA Institutes.	▪ Database was prepared within SOPHIA project and is available to SOPHIA members at https://www.myndsphere.com/gm/folder-1.11.121731
M2.4		Development of thin films: established transparent conductive oxides exhibiting •high mobility, •n- or p-type doped, •optically adapted to the device requirements. Screening alternatives: TCO materials and carbon-based or ultrathin materials (e.g. thin metals or nano-composites), in particular devoted to flexible devices.	▪ On-going activity at various partners e.g. HZB, FZ Jülich, but no coordinated effort due to lack of funding.

Milestones Status

Advanced module manufacturing			
M2.5		Study of interconnects: appropriate interconnects for modules based on highly structured thin films	▪ This was made a priority in the recent IRP project proposal (CHEETAH). ▪ Progress is also expected from the running EU "Fast Track" project started in March 2012.
M2.6		Screening studies for flexible devices: New encapsulation mats and lamination technologies	▪ On-going activity at various partners e.g. HZB, FZ Jülich, EPFL, but no coordinated effort due to lack of funding (or competition ?).

Processes and equipment design for large-scale production			
M2.x		??	▪ ??

Milestones Status

Analysis and modelling of materials and devices			
M2.7	green	Design of standard procedures: measuring performance and energy yield	▪ Part of work package in SOPHIA project, on-going activity.
M2.8	green	Survey: analysis tools and computer models	▪ A SOPHIA modelling workshop took place on 21-22/02/2013 . It was a forum to exchange and discuss different models, such as: • PV yield simulation tool (ISE) • Artificial Neural Network - ANN (IWES) • Energy Yield Model (ECN) MotherPV & Equivalent Circuit with bulk recombination losses (INES); PV performance prediction & Network based I-V model & Empirical Power Prediction, Site Specific Energy - SSE (CREST); Physical Model & BlackıBox Model (ENEL); ESTI-ENRA Model (JRC).
M.2.9	green	Round robin tests: characterisation tools for solar cells and PV modules	▪ Part of work package in SOPHIA project, on-going activity
M.2.10	green	Optical and electrical simulation: Materials and architecture of devices based on measured input data	▪ Part of work package in SOPHIA project, on-going activity, (see also SOPHIA modelling workshop)
M.2.11	red	Survey: self-assembling processes for highly structured films (eg. quantum dots) with access at EERA	▪ Lack of funds

Indicators

- Five examples for ISI-publications (by 2 partners):

Schmid, M.; Klenk, R.; Lux-Steiner, M.Ch.; Topic, M.; Krc, J.: Modeling plasmonic scattering combined with thin-film optics. Nanotechnology 22 (2011),p. 025204/1-10

Becker, C.; Häberlein, H.; Schöpe, G.; Hüpkes, J.; Rech, B.: Contact resistivity measurements of the buried Si-ZnO:Al interface of polycrystalline silicon thin-film solar cells on ZnO:Al. Thin Solid Films 520 (2011), p. 1268-1273

Zhang, W.; Bunte, E.; Ruske, F.; Köhl, D.; Besmehn, A.; Worbs, J.; Siekmann, H.; Kirchhoff, J.; Gordijn, A.; Hüpkes, J.: As-grown textured zinc oxide films by ion beam treatment and magnetron sputtering. Thin Solid Films 520 (2012), p. 4208-4213

Zhang, W.; Bunte, E.; Luysberg, M.; Spiekermann, P.; Ruske, F.; Hüpkes, J.: Pretreatment of glass substrates by Ar/O2 ion beams for the as-sputtered rough Al doped zinc oxide thin films. Surface and Coatings Technology 205 (2011), p. S223-S228

Wimmer, M.; Bär, M.; Gerlach, D.; Wilks, R.G.; Scherf, S.; Lupulescu, C.; Ruske, F.; Félix, R.; Hüpkes, J.; Gavrila, G.; Gorgoi, M.; Lips, K.; Eberhardt, W.; Rech, B.: Hard x-ray photoelectron spectroscopy study of the buried Si/ZnO thin-film solar cell interface: Direct evidence for the formation of Si-O at the expense of Zn-O bonds. Applied Physics Letters 99 (2011), p. 152104/1-3

- Newly setup research activities

Microconcentrator thin film solar cells

- Commonly used/established infrastructures

Through TNA program of SOPHIA the following were used at HZB: EPR-lab, XPS-lab, PVD for organic solar cells

Planned activities

- Proposed research topics for European FP7 programs 2013

1. Advanced thin film absorber materials for PV applications
2. Low-cost processes for thin film PV materials
3. Reducing absorber thickness and improving light management in thin film solar cells
4. Multifunctional materials in thin film PV
5. Cost effective flexible encapsulants for the long term protection of sensitive thin film devices

(no funding → no joint R&D activities!!)

Planned activities

- Innovation routes by CHEETAH

LESS MATERIAL --- MORE POWER

1. Development of extremely thin planar solar cells with photonic enhanced optical absorption
2. Micro-concentrator solar cells with low and medium concentration enhancement
3. Optoelectronic investigations and modelling of material properties and device performance

Conclusions

Barriers:

- No funding → minimum targeted, coordinated efforts
  (due to lack of manpower)
- Coordination action for each partner (team 2013: 13 + 6) needs funding
  (no part-time job for scientist with other tasks)

Challenges:

- Added value for each partner has to be high and clear
  (because of additional research effort for collaborative work)
- Balance between common goal and competition is challenging

Benefit of EERA has been demonstarted so far in 3 of 5 R&D areas:

- Personal contacts are essential for productive collaboration
  (e.g. local workshops)
- Success will be achieved by projects such as SOPHIA and CHEETAH !!

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

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

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

Description of Work

Version: *HOPV-01*
Last modification date: *20140509*

DESCRIPTION OF THE RESEARCH ACTIVITIES

Table of Contents

Summary Research Activity HOPV

The field of Hybrid and Organic photovoltaics (HOPV) span a range of future photovoltaic technologies including polymer solar cells, small molecule photovoltaics and hybrid solar cells such as Dye-Sensitized Solar Cells (DSSC), Perovskite Solar Cells, and mixture of organics and inorganic nanoparticles. HOPV is the most promising candidate for future ultra-low cost solar cells *and **HOPV has a large 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) medium efficiency and moderate lifetime, and 4) very low energy pay-back time. The research challenge is to lay the scientific foundation for improving lifetime and efficiency to a level where HOPV becomes a viable technology for bulk electricity production while maintaining low production costs. At the same time, HOPV offer a new application horizon where the integration between PV and objects is complete as, for example, in Building Integrated PhotoVoltaics (BIPV). The target is to develop a common platform that allows much easier collaboration between the growing number of groups involved in HOPV research through defining common protocols for materials development, device architecture, and testing. The sub-programme offers a framework for building up the data needed to defining protocols and standards by vivid exchange of information, sample and test devices. The main activities comprise:

- ✓ *Develop and validate protocols for screening of materials - both for active layers and for contact and carrier injection layers – in order to rapidly determine promising candidate materials.*
- ✓ *Advance modelling, theory and advanced characterisation of structural and optical properties. The targets are to define, predict and control optimal nanoscale and molecular scale structure for HOPV and to control interfacial processes, which are critical to HOPV performance. In these cases, also to take into account conditions and restrictions imposed by high speed/large area production.*
- ✓ *Improve the understanding of device physics.*
- ✓ *Facilitate sharing of data and the possibility to reproduce experiments in different laboratories through defining standards for test device architectures for both printed and lab fabricated devices.*
- ✓ *Define common protocols to test lifetime and development of ageing models to predict cell and module lifetimes*
- ✓ *Network on aligning processing methods, knowledge and equipment and defining best practice for test method and to further the development of processes apt for industrialization.*
- ✓ *Network activity on developing a common view on the main assets of HOPV in the broader energy context and planning and aligning large demonstration initiatives.*

The overall objective is to align European activities within HOPV research to lay the scientific foundation for improving lifetime and efficiency to a level where HOPV becomes a viable technology for bulk electricity production. The plans for transnational access to facilities as laid down in the *Sophia* research infrastructure proposal continue to be aligned with the EERA HOPV sub-program. The targets of CHEETAH project are very well matching the objectives of EERA and the activities will be correlated between the two. The workgroup on hybrid photovoltaics will promote specific coordination actions in this field, not accounted in CHEETAH project, which is indeed mainly devoted to polymer solar cells

1. Vision 2020-2050

Organic photovoltaics span a range of future photovoltaic technologies including polymer solar cells, small molecule photovoltaics and hybrid solar cells such as Dye-Sensitized Solar Cells , Perovskite Solar Cells, and mixture of organics and inorganic nanoparticles (such as $Cu(In,Ga)Se_2$:small organic molecules absorber). HOPV is the most promising candidate for future ultra-low cost solar cells *and **HOPV has a large potential for contributing to the 2050 visions of the SET-plan***. With respect to SEII, HOPV will hardly play a significant role in realising the 2020 goals and the incipient HOPV industry has not contributed to SEII. HOPV research is largely pre-competitive though polymer solar cells and DSSC are maturing fast and the first products are marketed. Presently, the HOPV technologies target both low power applications such as power supplies for small electronics as well as building integrated application where control of colour and transparency is of primary importance. No definite measure for when HOPV is ready for bulk electricity production can be set up, but the following characteristics are premises for readiness: 1) ultra low module costs; 2) low capital investment for set-up of mass production facilities; 3) medium efficiency and moderate lifetime 4) control of aesthetical aspect. The research challenge is to lay the scientific foundation for improving lifetime and efficiency to a level where HOPV becomes a viable technology for electricity production in a stand-alone or integrated applications, while maintaining low production costs.

HOPV research covers most aspects of photovoltaic research. There is overlap with the research on crystalline silicon and (inorganic) thin-film PV, but it is characteristic that many HOPV groups have a different background and different competences. Special to HOPV are the materials, the processing methods, and the potential for integration into products. Theoretical understanding of HOPV behaviour and performance has improved much in the last years. No basic physical limitations exist for e.g. polymer solar cells, though materials, structure and processes deviate drastically from other PV technologies. On the other hand, recent developments in hybrid technologies, such as organometal trihalide perovskites, pose new challenges to the theoretical description at both material and device level.

HOPV research will benefit strongly from aligning activities on materials development, characterizing stability and lifetime, develop and understand optimal architectures for solar cells and modules, establishing dedicated test facilities, and improving processing methods. **There exists a need for defining common protocols and establishing standards** in order to facilitate easy data exchange and inter-comparison.

HOPV is mentioned prominently in the Strategic Research Agenda as produced by the EU PV technology platform in 2011 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 and the type and size of funding for the required activities were specified for the next 5 years (http://www.eupvplatform.org/documents/ip.html).
The Solar Europe Industry Initiative (SEII) was subsequently 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 focus. 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 Pillar A.2 Thin film & emerging/novel technologies.

2. Objectives 2014-2017

The overall objective is to align European activities within HOPV research to lay the scientific foundation for improving lifetime and efficiency to a level where HOPV becomes a viable technology for new PV applications as well as for bulk electricity production. The target is to develop a common platform that allows much easier collaboration between the growing number of groups involved in HOPV research through defining common protocols for materials development, device architecture, and testing. The sub-programme offers a framework for building up the data needed to defining protocols and standards by vivid exchange of information, sample and test devices.
The following strategic goals have been identified:

- ✓ Improve speed of materials development and selection through building a comprehensive library of active materials, electrode materials, barrier and carrier injection materials, and light management materials and by defining protocols for fast screening of materials. Materials studied include new low bandgap materials, new dyes for improving efficiency or to enable new applications, “green” perovskites, new inorganic colloidal quantum dots, earth abundant and non-toxic nanoparticles, Cu(In,Ga)Se_2:small organic molecules absorber, “green” solvents, iodine-free electrolytes, materials for multijunction (or tandem) solar cells, and new classes of electron acceptors/donors and molecular and polymeric electron and hole transporting materials.
- ✓ Define, predict and control optimal nanoscale and molecular scale structure for active layers as well as interfaces between electrodes, barriers and active layers both for laboratory test devices and large area devices. Take into account the requirements for high speed production during printing processes, such as temperature, drying time, shear, need for layer adhesion.
- ✓ Improve the understanding of device physics.

- ✓ Improve the possibility to share data and reproduce experiments in different laboratories.
- ✓ Elucidate degradation mechanisms and define common measures of HOPV stability.
- ✓ Develop processes suitable for industrialization including in-line process control as a foresight quality assurance method.
- ✓ Demonstrate the assets of HOPV in the broader energy context and plan and align demonstration initiatives.

3. Description of foreseen activities (including time line)

Task 1 Fundamentals

Materials development, improvement in device architecture and understanding of device physics is the background for the accelerated improvement of HOPV efficiency. The fundamental challenges of combining high efficiency with long stability for large area flexible solar cells printed on flexible substrates (plastics, thin metal foils) at high speed are however far from solved. Similar challenges exist for other HOPV types also on rigid substrates. The challenges comprise materials development, research on morphology and structure of active layers - as well as electrodes, barrier and injection layers – and models and theory for both materials and device physics. This task aims at improving the fundamental materials understanding needed to raise the efficiency and stability of HOPV produced by rapid processing methods.

Development of new materials is a key issue for a number of research groups and an important challenge is to extend the library of active materials, electrode materials, and barrier and carrier injection materials from which researchers produce solar cells. Material classes include new low bandgap materials, new organic/metallorganic/inorganic sensitizers, "green" solvents, iodine-free electrolytes, mesoporous oxides materials for multijunction (or tandem) solar cells, and new classes of electron acceptors/donors and molecular and polymeric electron and hole transporting materials.

Though the development of the materials is NOT the target for the EERA sub program, the structuring, awareness and alignment of efforts ARE. The working task is to define and validate protocols for rapid screening of materials and devices based on new materials. The validation process includes round robin studies of new materials.

Stability of organic hybrid organic/inorganic materials under illumination is critical. Materials yielding high efficiency may very well display vulnerability towards photo-induced degradation due to their chemical structure. At the same time, the requirements for rapid processing put restrictions to the materials – such as solubility for conjugated polymers – which may lead to decreased efficiency and stability. Also mechanical adhesion tends to be an important problem for printed solar cells.

Structure on both the molecular scale and on the nanoscale is of high importance for e.g. bulk heterojunction polymer solar cells. The demonstration of polymer solar cells displaying nearly 100% IPCE at given wavelengths demonstrates that an optimal molecular and nanoscale morphology exists that allows for efficient charge separation and carrier collection at the electrodes. However such morphology is neither characterised nor understood and prediction and control of morphology under conditions used for high speed processing are major research challenges. Similarly, the strong interplay between organic and inorganic parts in hybrid photovoltaics is still an open issue an stabilization activities, needed for industrial exploitation, lack of chemical/physical models.. The coordination of theoretical efforts and materials development is a challenge.

Understanding of device physics and modelling of performance and properties has improved dramatically in the past years. The next challenge is to take the architecture and conditions for high speed production into account in a way that allows for improving the processing methods of HOPV.

Task 1.1 Materials screening

Materials development is central to the rapid progress of HOPV. A common challenge in the HOPV area is to define protocols for screening of materials - both for active layers and for contact and carrier injection layers – in order to rapidly determine promising candidate materials. Such candidate materials encompass low bandgap polymer materials, new dyes for improving efficiency or to enable new applications, "green" perovskites, new inorganic colloidal quantum dots, $Cu(In,Ga)Se_2$:small organic molecules absorber, "green" solvents, iodine-free electrolytes, mesoporous oxides, materials for multilayer structures (i.e. tandem solar cells), molecular and polymeric electron and hole transporting

materials and materials for carrier injection or barrier layers; and electrodes. Advanced characterisation techniques including photo physical studies, transient/frequency optoelectronic device characterisation and chemical and structural characterisation may complement rapid device performance testing. Molecular/atomistic modelling and identification of electronic properties of active materials may also be components of screening protocols.
DoW: Establish the comprehensive data for developing materials screening protocols and to identify both minimal and extended procedures needed to identify given properties through:

- ✓ Fabricating test devices and extend the use of round robin of selected materials classes and test devices furthering the improvement of characterisation and materials screening methods.
- ✓ Classify the set of protocols needed to cover some or all classes of HOPV – small molecule, polymer and hybrid – and to identify where a unified approach is possible.
- ✓ Formulate protocols that allow for easy data exchange and reproduction of data from similar samples across partners laboratories.
- ✓ Establish materials screening protocols

Task 1.2 Structure, theory and models
Define, predict and control optimal nanoscale and molecular scale structure for active layers as well as interfaces between electrodes, barriers and active layers both for laboratory test devices and large area devices. Take into account the restrictions imposed by high speed production regarding temperature, drying time, shear, layer adhesion, roughness and lateral homogeneity.

DoW: Aligning activities and structure characterisation, model and theory building with the activities in task 1.1 in order to use the same sample structures to obtain advanced properties and to test model predictions and enable further theory build-up. A multiscale modelling approach connecting physical description at the nanoscale with device models will be used to analyse experimental data and to optimize cell architecture.

Task 2 Standard solar cell architectures
Regarding dimensions and architecture of active materials and electrodes, no harmonisation exists for HOPV. Versatility is one of the hallmarks of HOPV but comparison of research results and reproduction of research results at different sites will benefit strongly from a standard architecture for testing solar cells and solar cell materials.

DoW: To use information from task 1 and 3 to define standard architectures for test cells – e.g. round robin studies – for both laboratory test devices on glass and flexible substrates.

Task 3 lifetime tests and aging models
Defining common protocols to test lifetime and development of ageing models to predict cell and module lifetimes. Stability is central to advancing HOPV technology and both degradation mechanisms and performance changes – e.g thermal behaviour – are far from well understood. Ongoing work on defining common measures of HOPV stability will be strengthened and improved.

DoW:

- ✓ To establish the data for developing aging models.
- ✓ To develop protocols for lifetime tests and to validate them using round robin of selected materials classes and test devices.

Task 4 Processing
Network activity on aligning processing methods and equipment and defining best practice for test methods. Both flexible (plastic, thin metal foil) and rigid (glass) substrate will be considered

Task 5 Demonstration, applications and main assets of HOPV
Network activity on developing a common view on the main assets of HOPV in the broader energy context and planning and aligning large demonstration initiatives is an important focus. The geographical breadth of the sub-program allow for assessment and demonstration on latitudes spanning Europe in full. Both bulk energy production applications and integrated applications will be considered.

4. Milestones

Milestone	Title	Measurable Objectives	Project Month
M1.1	*Round robin studies of HOPVs*	*Report*	*12*
M1.2	*Rapid screening protocols*	*Draft Report*	*18*
M1.3	*Rapid screening protocols*	*Report*	*36*
M1.4	*Advanced characterisation and model validation*	*Report*	*48*
M1.5	*Workshop on fundamentals*	*Workshop*	*18*
M1.6	*Draft on fundamentals collaboration*	*Draft report*	*12*
M2.1	*Layout of standard test devices*	*Report*	*24*
M3.1	*Processing and demonstration*	*Report*	*48*
M4.1	*Workshop on processing and demonstration*	*Workshop*	*36*
M5.1	*Plan for demonstration project*	*Report*	*36*

5. Participants and Human Resources

Institute	*0. Coordination*	*1.1 Rapid screening*	*1.2 Structure, theory and modelling*	*2. Standard architecture*	*3. Lifetime and aging*	*4. Processing*	*5. Demonstration and applications*	**Total committed per year**
Risø DTU	2	8	7	3	8	8	2	**38**
ECN		3	3	1	3	2	1	**13**
IMEC		2	2	2	2	2	2	**12**
VTT		2		2		3	1	**8**
Imperial College		6	4					**10**
CEA-INES			3		3			**6**
ENEA			2	4	2	2	2	**12**
CIEMAT		4			4		2	**10**
Helmholtz Berlin		12				12		**24**
Fraunhofer ISE		2	0	2	3	2	1	**10**
ZSW		2		3	2	3	2	**12**
LNEG		4		6		2		**12**
UTV	1	6	6	4	5	12	2	**36**
UNIMIB		14		9	5			**28**
FZJ		6			6			**12**
NPL		5	4		5			**14**
Total	**3**	**76**	**31**	**36**	**48**	**48**	**15**	**257**

6. GANT Chart

Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Task 0																
Task 1.1				M1.1		M1.2						M1.3				
Task 1.2				M1.6				W				D				M1.4
Task 2						D		M								
Task 3						D						D				M3.1
Task 4								W								
Task 5								W				M5.1				R

W = workshop
D = draft report
R = report
Mx = milestone nr. X
S = annual status report

7. Infrastructures

The structure for collaboration and using infrastructures has been described in the SOPHIA project proposal which was submitted in the FP7 call INFRA-2010-1.1.22: Research Infrastructures for Solar Energy: Photovoltaic Power. The SOPHIA project has 20 partners and will be finished in Q1 2015. EERA will continue using the infrastructure of SOPHIA partners that are also involved in WP10 of the CHEETAH project (ENERGY.2013.10.1.5: Integrated research programme in the field of photovoltaics, FP7-ENERGY-2013-IRP). CHEETAH project will run until Q1 2018.

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

See section on Governance of the Joint Programme.

9. Risks

Not applicable

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

See section on IPR of the Joint Programme. The output of the work program constitutes the forground knowledge regulated under these conditions. Take an example – materials and devices used to validate protocols for fast screening ARE NOT output of the program, but the protocols ARE.

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

HOPV Sub-Program Leader:

Dr. Suren Gevorgyan
Technical University of Denmark
DTU
Frederiksborgvej 399
DK-4000 Roskilde, Denmark
+45 4677 5482 (fax +45 4677 4791)
surg@dtu.dk

Prof. Frederik C. Krebs
Technical University of Denmark
DTU
Frederiksborgvej 399

DK-4000 Roskilde, Denmark
+45 4677 4799 (fax +45 4677 4791)
frkr@dtu.dk

Leader of Hybrid Photovoltaic Working group

Prof. Aldo Di Carlo
University of Rome "Tor Vergata" (UTV)
Via del Politecnico 1
00133 Rme (Italy)
+39 06 72597456 (fax +390672597939)
aldo.dicarlo@uniroma2.it

EERA

EUROPEAN ENERGY RESEARCH ALLIANCE

A joint Programme on PV Solar Energy

Sub-Programme 5:

Concentrator Photovoltaics (CPV)

A sub-programme within the joint programme on

Photovoltaic Solar Energy

Description of Work

Version 1.0

30th November 2013

Contact Person: Prof. Gabriel Sala

sala@ies-def.upm.es

gabriel.sala@upm.es

DESCRIPTION OF THE RESEARCH ACTIVITIES

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1. Vision 2020-2030

Concentrator photovoltaic technology is the one already demonstrating maxima cell, module and system efficiencies among all PV. In addition, beyond present status, it still promises higher efficiencies at the fastest increase rate, as shown in last decade.

The heart of CPV technology is based on a very high level knowledge on material science, on semiconductor device technology and on complex manufacturing processing. Such characteristics could preserve for long time the current European strategic position in this field, in part due to the difficulties for immediate imitation.

Apart from the preceding singularities, CPV is the technology allowing any future efficient solar cell, no matter what its cost is, having the opportunity to become economically usable for electricity generation.

In other words, this means that CPV is like a short cut to market that should be maintained open and ready for the new achievements.

The progress should consists of developing and standardizing the most advanced and lowest cost solutions for optics and tracking systems that could be use without specific new developments for the ultra high efficiency coming devices.

Europe joints sufficient number of centers and skilled scientist covering all different CPV specialties for reaching the critical mass and for improving the current position.

The scenario for European CPV should share two lines of working: from one side the development of potentially very efficient solar cells, mainly those that will base its performance on the efficient use of the spectrum, and from the other side improving the optics, receivers, cooling, housing and tracking subsystems toward few optimal solutions of proven reliability and manufacturability.

2. Objectives 2014-2018

According the preceding vision of the long term scenario for CPV the research should be addressed in the following directions or objectives:

O1. Development of Ultra-High efficiency solar cells, beyond > 45 %
O2. Optimization of the most proven and successful optics, receivers and module architectures.
O3. Standardization of components and normalization of rating methods for confident and fastest commercialization of any cell improvement.
O4. Manufacturing control for high power yield and guarantied reliability.
O5. Energy forecast and system recycling.
O6. Dissemination, education and communication

2.1 Objective 1: Ultra high efficient solar cells

In the current status of PV, efficiencies beyond 25% can be only obtained on sophisticated devices, like multijunction cells which fabrication is very expensive per unit of area.

Once has been demonstrated that current Multijunction cells mounted on present concentrators could reach the 1€/w field cost level at mature volume manufacturing , any reasonable R&D plan pushing the development of device families promising higher efficiencies and stability options should be highly promoted.

In this moment we envisaged as the most fruitful directing the support to current 4 juntions cells which are providing absolute records in the laboratory and to future 5 junction ones.

Intermediate band solar cells (IBSC) require still a long progressing way for being used in CPV but offer the surplus of combining basic and technological research towards outstanding options, that con go beyond CPV, because the possible development of new bulk PV materials for PV conversion.

High efficiency cells based on photon recycling and hot carriers are still beginners in the run for high efficiency but could require CPV for becoming a realistic way of electricity generation.

2.2 Optimization of most proven optics, receiver, module and tracker architectures

Although very few optical architectures have proven feasibility in real manufacturing, sufficient low costs and enough reliability for commercial competition, still many research proposals, that clearly will provide solutions exceeding the right cost level, are issued everywhere and receiving funds for its development.

Such dispersion of efforts and the only looking for originality are wasting valuable efforts and resources.

Thus, the correct objective should be oriented to optimize the current proven reliable and lowest cost solutions by solving the still remaining and currently well identified problems and limitations.

Super-imaginative and revolutionary solutions for CPV will not be accepted be accepted by the PV market in the near term, while the real need is to reach volume very soon in order to maintain the CPV option alive.

These driving ideas should be applied to:

- Optics of POE an SOE combinations
- Simplification of optics for large gain, beyond 300X

- Optimization of insulation at low thermal drop
- Heat dissipation and heat sinks combined with module housing:
- Water condensation issues
- Tracking accuracy and field management

2.3 Standardization of components and rating methods for CPV.

The number of variables which can adopt CPV systems is surprisingly high. For example, if we decide operate the cells at 500X we can adopt a POE which area can move two orders of magnitude if the cell varies from 1 to 100 mm^2, which are currently found in module prototypes.

The reduced number of MJ cell makers is allowing them some control of the marked, and fortunately have decided limiting the cells size to few standard options.

Such kind of standardization should be driven for other significant components like POE size, wire soldering, cell protection and for several key parameters like secondary gain, minimum breakdown, maximum thermal drop, etc.

Standardization is a way for reduction of components and stock costs.

The second subject of interest is the normalization of components, modules and field system rating. The correct, strict and limited selection of parameters required for checking minimum performance must be published in simple documents for contributing to the confidence of customers in this technology. Maintenance will be positively affected by standardization of components and normalization of control and testing methods.

2.4. Manufacturing control for high power yield and guarantied reliability.

The manufacturing of CPV modules is more complicated than flat panels because alignment of optics on the small cells is critical.

However it can be assumed that once the factory robots are trimmed and operative the costs should be equivalent to conventional PV assembling (with the advantage of less fragile components).

But it is important owning an early and fast control of the manufacturing parameters in order to detect and correct immediately any defective processing.

Equipment on line must check, not only the electrical insulation and power output issues, but also the optics for calculating the power mismatch loses. It becomes a compulsory objective of the control protocol because the loses can be important.

This is still more necessary if we take into account that much manufacturing work for module assembly and field deployment will be local: the control machines must be reliable and easy to install and mount. Europe is present in this sector with experienced companies. The objective is maintaining the leading position with a additional research.

2.5 Energy forecast and recycling of CPV generators

The accurate prediction of the energy to be generated by a CPV system, which power is correctly rated, must be answered for any special technology. This is caused by the specific dependence on spectrum and temperature of cells, and to the variation of optics focal length with temperature and the tracking performance. In the same way the loses due to tracker operation must be known versus position and wind velocity.

The decay rate of the nominal CPV power of a plant is a key parameter for calculate the effective profit of a CPV investment and for maximize the gain taking into account the material recycling. The determinations of such decay rate requires a specific research based on the combination of current experimental know how with the basic theory of degradation and reliability.

Recycling of photovoltaic systems, mainly PV modules, is a common subject in papers of scientific journals and conference presentations. Usually they point out what are the preferred or the easiest material to recover, and less the potential price of recovered material.

Recycling of CPV's could probably be easiest than conventional PV because the shape of the modules and the type of majority materials: Glass, aluminum, plastics, steel. The knowledge of the recoverable capital could be a significant incentive for CPV's commercialization and for this reason should be investigated.

In addition it is not yet known if it will be compulsory removing the whole tracker pedestal, and the expensive mechanisms everywhere and for any tracker model. In the sunny and dry areas, where CPVs are mainly installed, the metallic parts could last operative for more than 30 years. For answering these questions we propose carry out the studies which should provide the economic figures of such radical recycling together with the technical questionnaire, or checking protocol, for reusing acceptance of CPV field infrastructures.

2.6 Dissemination, education and communication

CPV market needs progressing 5 times faster that conventional PV did in the past in order to stay in the market as significant contributor to PV electrification beyond 2020. If the current development is lost it will not probably reappear till 2040, with a new generation of researchers and investors or … never.

For such reason is important devoting important funds for dissemination and information in order to make useful the efforts and expenditure on research and industrialization.

Education of personnel at all levels of specialization is required to follow the expected exponential growth characteristic of PV takeoffs.

3. Description of foreseen activities

Several *Tasks* for each *Objective* are identified. Not all tasks must be really developed for reaching a significant progress of CPVs in Europe. Each partner should joint the task/s for which is most prepared or most interested according its capacity and previous demonstrated results.

3.1. Ultra high efficient solar cells

Task 1.1 - Improvement of current 3MJ structures under spatial chromatic aberration effects. Reductions of vertical and lateral resistance over 1000X. (UPM, FhG-ISE, CEA-INES, Helmholz Berlin)

Task 1.2 - Development of 4MJ and 5 MJ solar cells. (FhG-ISE, CEA-INES, , Helmholz Berlin)

Task 1.3 - MJ cells on Silicon substrates. (UPM, FhG-ISE, CEA-LETI)

Task 1.4 - Intermediate Band Solar cells: demonstration in new material and increase efficiency of IB generation of pairs. (UPM)

Task 1.5 - Assure and increase stability of MJ cells. (UPM, FhG-ISE, CEA-LETI, Helmholz Berlin, CIEMAT-CENER)

3.2. Optimization of most proven optics, receiver and module architectures

Task 2.1 - Reduction of limitations of refractive optics for reaching higher concentration gain. (UPM)

Task 2.2 - Progress and evaluation of one stage reflexive optics potential. Demonstration prototype. (UPM, ENEA)

Task 2.3 - Ultra low cost cell-on-carrier / receivers: insulation without ceramic plates. Reduction of thermal-mechanical stress. (CEA-INES, Tecnalia)

Task 2.4 - Improvement of module architecture and wider angular tolerance. Elimination of water condensation. (CIEMAT-CENER, CESI)

3.3 Standardization of components and rating methods for CPV.

Task 3.1 - Standardization of HESC for CPV modules and assemblies. (CEA-INES, CENER)

Task 3.2 - Standardization of Optical elements: POE and SOE. (UPM, Tecnalia,

Task 3.3 - Standardization of receivers and internal/external connections in modules. (CIEMAT-CENER, CESI)

Task 3.4 - Normative for indoor and field testing. (UPM, FhG-ISE, ENEA, CIEMAT-CENER)

Task 3.5 - Normative for transportation and installation. (Tecnalia, CESI)

Task 3.6 - Normative on trackers. (Tecnalia, CESI, CIEMAT-CENER)

3.4. Manufacturing control for high power yield and guarantied reliability.

Task 4.1 - Online testing of cells, cell-on carrier or receivers. (UPM, FhG-ISE, ENEA, Tecnalia, CIEMAT-CENER)

Task 4.2 - On line testing of receivers with SOE. (UPM, ENEA, Tecnalia, CIEMAT-CENER)

Task 4.3 - Online control of module optics: mismatch loses reduction. (UPM)

Task 4.4 - On line test of CPV modules at C-STC. (UPM, CEA-INES)

Task 4.5 - Equipment for cell/receiver reliability and life-time forecasts.(UPM, CESI)

3.5 Energy forecast and recycling of CPV generators

Task 5.1 - Identification of significant meteorological parameters for CPV: reduced data ser for CPV forecast. (FhG-ISE, CEA-INES)

Task 5.2 - Verification of current available modeling: simplification and standardization of variables: nomenclature. (ENEA)

Task 5.3 - Economic analysis of recycling and reuse: Interaction with initial financing. (Tecnalia, CIEMAT-CENER)

Task 5.4 - Accelerated aging of trackers for evaluating reuse options and residual value. (Tecnalia, CESI)

3.6 Dissemination, education and communication

Task 6.1 - Permanent press and web releases and news presenting real results, comparison with CAPEX and performance vs. other PV technologies, financing, n . local job contribution, etc. (UPM and all)

Task 6.2 - The rest of aspects are presented in EERA sub-programme of Education and Infrastructures.

4. Milestones

Milestone	Title	Measurable objective	Project month
M1.1	Improved MJ cell efficiency 3, 4 or 5 Junctions	45% at factory	42
M1.2	IB solar cells improved current and voltage preservation	15% current increase with Voltage preservation	42
M1.3	MJ cells on Silicon substrate	30% achieved	42
M2.1	CPV with POE only	Gain > 500 X. AA >0.5º	36
M2.2	CPV with mirror POE only	Gain >1000, AA>0.5	24
M2.3Rec	Receiver without ceramic	Cost <0.05 €/W, insulating > 1800 V	24
M2.4	Water condensation in modules	Reduced or eliminated	24
M3.1	Standardization of CPV modules and components	Standard agreements	30
M3.2	Testing indoor and outdoor modules and systems	Standards approved	36
M3.3	Tracker , transportation and installation	Normative written and accepted	42
M4.1	Equipment testing on line	Receiver or/and cells	36
M4.2	Equipment testing on line	Modules and optics	30
M4.3	Forecasts of receiver reliability	Equipment for aging and modeling	36
M4.5	Energy forecast of CPV	Model with only 6 variables	24
M5.1	Recycling and reuse of modules and trackers	Economic modeling and technical questionary.	18

5. Participants and human resources

R&D Centres	**O1**	**O2**	**O3**	**O4**	**O5**	**TOTAL** PxM/ year
UPM	24	7	3	2	0	**36**
Fraunhofer ISE	28	-	3	2	1	**34**
CEA-INES	6	2	2	2	1	**13**
CEA-LET1	8	-	-	-	-	**8**
ENEA	-	6	3	5	2	**16**
CIEMAT-CENER	-	4	3	2	1	**10**
Tecnalia	-	4	4	3	2	**13**
Helmholz Berlin	16	-	-	-	-	**16**
CESI	-	2	3	1	1	**7**
Total per year	**86**	**30**	**22**	**19**	**8**	**153**

6. Infrastructure

The use of infrastructures and facilities, together with Education and Training is addressed to Sub-Programme 5.

8. Contact point for the Sub-programme on Concentrator Photovoltaics (CPV)

Prof. Dr. Gabriel Sala
Instituto de Energía Solar – UPM
ETSI Telecom
Av. Complutense, 30
E-28040 Madrid
Spain
Phone: +3491 544 1060
+3491 336 7231
Fax: +3481 544 6341
e-mail: sala@ies-def.upm.es
gabriel.sala@upm.es

EERA
EUROPEAN ENERGY RESEARCH ALLIANCE

<u>SUB-PROGRAMME 5: *PV Systems*</u>

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

DRAFT

Description of Work

Version: 2.1
Last modification date: 27-5-2014

Prepared by
Christoph Mayr, AIT
Stathis Tselepis, CRES
Marcus Rennhofer, AIT
Karl Berger, AIT
Eduardo Roman, TECNALIA

DESCRIPTION OF THE RESEARCH ACTIVITIES

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1. Introduction

Photovoltaic technology permits the conversion of solar energy directly into electricity. It is a very smart process to generate environmentally-friendly, renewable electrical energy. PV systems can supply electrical energy to a specific consumer or to the electric grid. It has the potential to play an important role in the transition towards a sustainable energy supply system covering a significant share of the electricity needs of Europe. From 0.3% of Europe's electricity needs in 2008, PV with 69 GW of cumulative installed capacity connected to the grid at the end of 2012 ~~27~~ and a yearly production estimated close to 80 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. The potential for PV installations by 2020 is at least twice as high as the levels foreseen in the NREAPs. According to 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 by 2020 [EPIA 2013].
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 the European Photovoltaic Industry Association (EPIA), with support from strategic consulting firm A.T. Kearney and based on an extensive analysis of five E.U. 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 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 ~~technology~~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 have been the cost reduction of the technology, increased lifetime of PV systems, reliability of all components and sustainability of materials and manufacturing processes. 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].

The Implementation Plan of the SEII for the period of 2013-2015 [SEII 2013) addresses the challenges reflecting the changing PV landscape. Europe is resolved to continue to play an important role in the large-scale global manufacturing and deployment of PV that lies ahead of us. This relates to the role of PV in the electricity mix of Europe as well as to the European industry supplying innovative and competitive products and solutions to markets worldwide.

Recognising the rapid development of the market and increased ambition for the contribution of photovoltaics in the near to medium term, evidenced by the adoption of binding 2020 renewable energy targets in Europe and the establishment of the Solar Europe Industry Initiative as part of Europe's Strategic Energy Technology Plan, the 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].

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

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

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

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

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

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

2. Objectives

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

The multifunctional role of the 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 BIPV systems, inherent security mechanisms have to be developed which assure their electrical and other safety. 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. In this sense, the realization of several demonstration projects, focusing on the flexibility of the application (e.g. large/small, different geometries etc), the aesthetics (in new buildings but also in older constructions of historical/heritage value) and the compliance with the building sector standards of innovative BIPV products, will play a particularly important role. Large scale demonstration projects within the concept of "Solar Cities" can be one stepping stone for proving the feasibility of large-scale deployment potentials in urban areas.

3. Description of foreseen activities

Research Theme 5.1: BoS components

- 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 are included here.
- Improved overall performance, efficiency, lifetime and low-cost power electronic devices (i.e. inverter lifetime >20 years of operation). PV optimizers, (micro)-inverters, monitoring systems, security devices, energy management systems. Inverters for PV hybrid systems including storage may also be incorporated here.
- Low-cost, high-accuracy tracking systems/platforms **(**single and double axis) for different applications, including CPV systems.

Research Theme 5.2: Building integration (BIPV)

Summary: Research Activity BIPV

This research theme covers a wide spectrum of disciplines that are often not available at a single research institute. Therefore, collaboration between partners will be essential to realise the ambitious targets. The topics urgently needed in order to strengthen the implementation actions of BIPV on the way to CO_2 neutral and energy-plus buildings, cities and urban regions are wide spread. Some key topics have to be emphasized as they are known to be the bottle-necks for the area-wide and common usage of PV in the context of BIPV. These are e.g. the development of innovative technical solutions, multifunctional BIPV components, system optimization, proper models for energy evaluation or the raise of life time while decreasing manufacturing costs.

One essential step is the exchange of knowledge by experts in the field and by institutions who are able to add essential contributions to the given objectives of the mentioned themes.

The topics of interest are also in accordance with the essential needs as they are given by the EU Photovoltaic Technology Platform [EU PV TP 2011].
The sub-programme BIPV is divided into 11 tasks, which can be grouped into three main areas of interest: technical development, demonstration, and standardization and testing.

Background

Despite the cutbacks in incentive programs for PV installation in Europe, which has been the main market for PV installations in the past few years, the installed capacity of solar power plants per year continues to increase, reaching 35% growth rate in 2011 and 24% in 2012 or 25 GW and 31 GW in absolute terms. In monetary terms, the market has shrunk from €95 billion in 2010 to €75 billion in 2012, but is expected to surpass its previous peak again by 2015. Together with an increasing number of PV installations, the need for accessible free areas continues to grow. In this context, the estimation of the needed installation capacity per country is tremendously higher [Henning12] in order to meet the energy needs. Free accessible areas suitable for PV installations (green land, woods, etc.) are limited, and 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]. As an example, 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]

Objectives 2014 – 2017

The following overall objectives for the sub-programme BIPV are defined for the period 2014-2017. These goals are in-line with the SET-Plan. Moreover, they are related to the SEII Implementation Plan as they translate some of the central goals into concrete targets for R&D.

Overall objectives of the sub-programme BIPV

1) Technical innovation in order to make the technology competitive and useful
2) Demonstration of system design aspects, refurbishment methods and large scalability
3) Development of testing methods, evaluation tools and harmonization of standards

Main objectives of the sub-programme BIPV are

1. *Technical development*
    (a) Development of innovative technical solutions
    (b) Low-cost manufacturing process and BIPV-product optimization
2. *Demonstrators*
    (c) New PV system design approaches
    (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

In the following, objectives of the sub-programme BIPV are given in more detail:

(a) Development of innovative technical solutions (combination of ICT and electronic devices) to increase the self-consumption ratio of PV electricity in residential and tertiary buildings (commercial /industrial), and generally speaking, to enhance the integration of systems in the built environment in order to reduce the overall costs and the environmental impact. Further, linking PV systems to grid communication systems (e.g. IEC 61850-7-420 — Communications systems for Distributed Energy Resources (DER)) for energy management and building automation mechanisms.

(b) Industrial automated low-cost manufacturing process and control methods, including development of new flexible equipment for different production lots with different geometries (e.g. small or large production lots, flexible compounds, different substrates). One essential step within this frame of work is the optimization of BIPV product performance, long term higher energy output and improved optical appearance at reduced costs (Euro/m) together with inherent security mechanisms with design & electronic devices. Methods for refurbishment with multi-usable BIPV-technologies (e.g. usable for refurbishment and new buildings). The aim is to decrease manufacturing costs for the elements and address a bigger market by mass production or pre-fabrication.

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

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

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

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

Activities

Within this research theme the following activities are required:

- Studies of the state of the art
- Inventory of completed or ongoing relevant projects

- Summary of results of projects and studies of the partners
- Workshops for knowledge transfer
- Forming peer groups for joint projects and studies
- Exchange and interaction with standardization committees
- Exchange and interaction with stakeholders and pressure groups

Coordinator: Marcus Rennhofer (AIT)

Partners
Austrian Institute of Technology – Photovoltaic Systems (AIT - PVS), XXx

Milestone	Measurable Objectives	Title	Month
M5.2.1	Report	Report on analysis on development of innovative technical solutions.	
M5.2.2	Report / prototype	Report on Low-cost manufacturing process and BIPV-product optimization *and examples for refurbishing with BIPV components which may also be used in new buildings*	
M5.2.3	Report / demonstration	Report on new system designs using innovative system components or topologies	
M5.2.4	Report / demonstration	Report on demonstrator of innovative BIPV components or report of results of a joint activity (project)	
M5.2.5	Standardization proposal	Report on joint paper on new test methods or standardization harmonization potentials (e.g. between countries).	
M5.2.6	New tool / model	Report or demonstration of new methods to do fast/reliable/exact/forecasting energy rating of BIPV.	

Human resources

Institute	**Country**	***Participation in:***				**Role**
		Coordination	**Technical Development**	**Demonstrators**	**Standardisation**	
AIT	Austria	x	x	x	x	Coordination, inventory, studies, offering results of ongoing projects

Many of the EERA partners join the SOPHIA project. ….

Infrastructure

The FP7 project SOPHIA is mapping the research facilities available at the project partners (many also member of EERA), this list is available at the website. Furthermore, a vision document on the research infrastructure (RI) was made. It contains a description of the current trends in PV RI as well as recommendations for upgrading the capability of new RIs. This document is aligned with other PV vision documents such as the Strategic Research Agenda from the EU PV technology Platform and should serve as an input for policy makers at national and EU level.
The CHEETAH project continues this activity by defining how the infrastructure can most effectively be used by European PV R&D parties. This activity is not only relevant for the BIPV sub-sub-program of EERA, but for the entire EERA PV program.

Contact Points for the sub-programme on BIPV

Coordinator of Sub-Programme "BIPV"

MARCUS RENNHOFER
Energy Department
Photovoltaic Systems
AIT Austrian Institute of Technology GmbH
Giefinggasse 2 | 1210 Vienna | Austria
T +43(0) 50550-6348 | M +43(0) 664 210 37 34 | F +43(0) 50550-6390
marcus.rennhofer@ait.ac.at | http://www.ait.ac.at

Coordinator of theme "Technical development"

Coordinator of theme "Demonstrators"

Coordinator of theme "Standardization"

Research Theme 5.3: Standards, Quality assurance, long term reliability and sustainability

Summary: Research Activity Standards, Quality & Reliability

In comparison to other mature industries, e.g. automotive, there is room for more elaborated quality management and assurance measures in the PV industry. The Quality management system shall span from the suppliers of materials to the PV manufacturers, their processes as well as transportation, erection and plant commissioning, monitoring and maintenance of PV installations and finally the recycling processes of the products after decommissioning.
The existing standards for PV modules as well as BOS components are a good instrument to detect infant failures because of manufacturing problems and material incompatibilities, but are not well suited to give a good estimation of the products degradation rates and lifetime under varying operating conditions. This requires the development of new accelerated test

methods, as well as modelling of micro-climates at / in components depending on real outdoor data of a variety of climates (e.g. northern Europe, alpine and the Mediterranean) .

(g) Improvement and/or application of in-line EU-harmonized low-energy processes and production control techniques and procedures and in general introduce the concept of Total Quality Management (e.g. statistical process control, failure testing). The necessary software development for performing the quality control is included here, together with analytical tools for rapid onsite quality control of cells~~,~~ modules, ~~and~~ inverters and other components.

(h) Improvement of guidelines for optimum transportation, installation, configuration, fulfilment of safety requirements (including fire safety) and monitoring / evaluation for enhancing the energy yield and overall performance at the system level.

(i) Development and application of system design techniques for achieving high outdoor long term system performance >25 years at 90% of the initial Performance Ratio (PR) at low cost and potential reduction of the use of materials. This includes joint efforts to gain understanding of ageing mechanisms and the development of dedicated accelerated test procedures. Issues like thermal management, natural cooling, optimum orientation etc. are also included here.

(j) Standards for energy rating of different PV technologies regarding climates and regional weather conditions (micro climates).

(k) In the focus of module design: Overall design optimization of PV-modules in order to minimize costs: Single optimization of components like frame (geometry optimization), cell interconnects and bus bars (e.g. reflecting), soldering (e.g. gluing instead), lamination (e.g. gluing instead), embedding material and encapsulation materials (e.g. new materials, optimized ranges of spectral transmittance).

(l) New low-cost, long-lifetime material alternatives (e.g. encapsulation materials, glass, antireflective layers, etc.) and module designs that will lead to longer-term reliable PV systems and reduction of degradation effects (e.g. potential-induced degradation (PID)). This includes joint efforts to gain understanding of ageing mechanisms and the development of dedicated accelerated test procedures and infrastructures.

(m) Improved life-cycle assessment (e.g. carbon footprint and EPBT, etc.) of all PV technologies and BoS under detailed guidelines and feedback of the results to the industry.

(n) Development of design criteria facilitating low-cost efficient recycling processes according to relevant EU standards and directives for new designs for all PV technologies and BoS components. PV product designs that will facilitate the dismantling and recovery of materials and components (recycling) are also included here.

Activities

Within this research theme the following activities are required:

- Studies of existing PV-technologies and their degradation and failure rates, see e.g. [Jordan 2012].
- Investigation and modelling of the effects of different module installation types (e.g. field mounted vs. roof integrated) in terms of micro-climatic conditions, temperature and humidity ingress
- Adapting of existing, and developing of new recommendations and standards for degradation and life-time assessment, including statistical methods

- Development of low cost & high performance techniques in module manufacturing, using materials with low environmental impact (e.g. lead free cell interconnects)

Coordinator:

Partners
Austrian Institute of Technology – Photovoltaic Systems (AIT - PVS), XXx

Milestone	**Measurable Objectives**	**Title**	**Month**
M5.3.1	Report	Report on micro-climatic conditions of PV-modules in different climates and installation variants	
M5.3.2	New tool / model	Report on modelling micro-climatic stress conditions of PV-modules based on climatic conditions, and installation variants	
M5.3.3	New tool / model	Report or demonstration of new methods to calculate service lifetime using accelerated test results and outdoor climate data	
M5.3.4	Standardization proposal	Partizipation in European (CENELEC) and international (IEC) standardization committees, (New work item Proposal for service lifetime investigation)	
M5.3.5	Report	Report on existing quality assurance measures in the PV in comparison to other industries	
M5.3.6	Report / prototype	Report on available and future low-cost but highly reliable manufacturing processes	
M5.3.7	Report	Report on existing and future requirements based on EU directives about waste, recycling and use of hazardous materials	

Many of the EERA partners are also among the SOPHIA project, where within the joint research activity JRA01 extended and advanced module tests are performed.

Human resources

Institute	**Country**	***Participation in:***				**Role**
		Coordination	**Technical Development**	**Demonstrators**	**Standardisation**	
AIT	Austria	x	x	x	x	Coordination, inventory, studies, offering results of ongoing projects

Research Theme 5.4: PV system monitoring and simulation tools

- European "PV Monitoring Centre", aimed at gathering and disseminating a variety of monitoring data (including information on failure modes) and information for benchmarking, including technology, industry, market and policy aspects (mainly carried out by SETIS, the Information System for the European Strategic Energy Technology Plan (SET-Plan)).
- Development of simulation and monitoring tools (early fault detection, weather and PV energy production forecasting, modelling and simulation of ancillary services or scenarios with electrical storage integration, etc.). These tools should rely on open communication protocols and ensure compatibility of PV generation with distribution management systems (considering regulation proposed by ENTSOE - European network of transmission system operators for electricity), state estimators for distribution and transmission, protocols related to power market operations and balancing and data collection from regulatory or public agencies and asset management systems.
- Assessment of performance parameters of PV installations by the means of monitoring
- Further development of the field methods of infra-red thermography (of modules) allowing for better documentation of degradation issues, quantitative loss analysis, and modelling.

Research Theme 5.5: Social and business acceptance

- Identify and quantify the non-technical (i.e. societal, political, economic and environmental, PESTEL analysis) costs, barriers and benefits of PV systems
- Address regulatory requirements and barriers to the use of PV on a large scale deployment.
- Address regulatory requirements, barriers and business opportunities to the use of PV in urban areas, especially for multi-family homes, rental apartments and building project organizers.
- Establish the skills base that will be required by the PV and associated industries in the short and medium term and develop a plan for its provision
- Address the administrative and public relations aspects of a cost-effective and workable infrastructure for reuse and recycling of PV components
- Develop schemes and dissemination / training material for improved awareness in the general public and targeted commercial sectors

4. Description of Work for 2014-2015

During the EERA Solar PV Joint Program Steering Committee (JPSC) meeting on February 7th 2014, in Amsterdam, it was proposed to work on the 1st deliverable titled **Deliverable 5.1:**

"Overview of the state of the art in BIPV" with a tentative deadline one year from now. As it was remarked during the JPSC meeting, the integration of PV systems in buildings may help to maintain the PV supply chain in Europe and to promote the recovery of the PV industry in Europe. The aim of this deliverable is to collect the state of the art information of the ongoing activities. Through the information collection of RTD activities, the state of the art overview would identify the gaps and the needs. The first step would be to make a call to all EERA PV JPSC for their participation and contribution to deliverable 5.1.

The activities that have to be addressed for the organization of the first deliverable 5.1 are:

- ⇨ Leader, participants,
- ⇨ Expected outcomes and benefits
- ⇨ State of the art
- ⇨ workshop organization
- ⇨ Interested stakeholders
- ⇨ Contacts and information collection from running and older BIPV projects
- ⇨ Links to other JPs (e.g JP Smart Cities)

5. Milestones

Milestone	Measurable Objectives	Title	Project Month
M5.1	*Workshop*	Workshop on BIPV system technology and building code requirements in collaboration with BIPV projects	*9* *(A workshop during the 29th EUPVSEC could be envisaged)*
M5.2	*Report*	BIPV system technology and building code requirements	*12*
M5.3	*Workshop*	*Workshop on BoS component development and testing*	
M5.4	*Workshop*	*Workshop on Standards, Quality assurance, long term reliability and sustainability of PV systems*	
M5.5	*Workshop*	*Workshop on PV system monitoring and simulation tools*	
M5.6	*Workshop*	*Workshop on Social and business acceptance*	
M5.7	*Report*	*BoS component development and testing*	
M5.8	*Report*	*Standards, Quality assurance, long term reliability and sustainability of PV systems*	
M5.9	*Report*	*PV system monitoring and simulation tools*	
M5.10	*Report*	*Social and business acceptance*	

6. Participants and Human Resources

The table below lists the research institutes and the effort in **person months** per year.

Institute	*Coordination*	*BoS components*	*Building integration*	*Standards, Quality assurance, long term reliability and sustainability*	*PV system monitoring and simulation tools*	*Social and business acceptance*	**Total committed (person months per year)**
CRES	1	6	6	5	4	2	**24**
AIT							
TECNALIA							**20**
Utrecht University							

7. Infrastructures

The use of infrastructures and facilities, together with Education and Training, is addressed in sub-programme 6.

8. Contact Points for the sub-programme on PV Systems

Christoph Mayr
Head of Business Unit Photovoltaic Systems
Energy Department

AIT Austrian Institute of Technology
Giefinggasse 2 | 1210 Vienna | Austria
T +43(0) 50550-6633 | F +43(0) 50550-6311
christoph.mayr@ait.ac.at | http://www.ait.ac.at

Dr. Stathis Tselepis,
Head of PV Systems and Distributed Generation Department
19th km Marathonos Ave., 19009, Pikermi, Athens, Greece.
Tel. +30 210 6603370
e-mail: stselep@cres.gr

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