# UPDATING THE EUROPEAN STRATEGIC RESEARCH AGENDA

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ABSTRACT: The Strategic Research Agenda of the European Photovoltaic Technology Platform has been updated to include new cost and performance targets, together with revised research priorities. This reflects the progress in the PV market, advances in PV R&D and the increased ambitions for PV contribution to Europe's electricity supply since the publication of the first SRA four years ago. This paper discusses the approach taken and summarises the main differences between the new and old versions. It highlights the research priorities across the range of PV device technologies and at PV system level.
Keywords: Research; PV Cell Technologies; PV Systems

## 1 INTRODUCTION

The continuing growth of the PV market and the fulfillment of the potential of PV to make a major contribution to electricity generation around the world require a strong R&D activity to deliver the technical advances that drive product development.

In 2007, the European Photovoltaic Technology Platform published a Strategic Research Agenda (SRA) for photovoltaic technology in Europe [1]. The overall cost and performance targets used in this document were referenced to the 2005 report "A Vision for Photovoltaic Technology" prepared by the Photovoltaic Technology Research Advisory Council [2]. The SRA formed the basis of the Platform's input to the European Commission on the content of the Seventh Framework Programme in relation to photovoltaics research and has also been used by Member States in the definition of their national research programmes. The Platform followed up the SRA in 2009 by publishing an Implementation Plan, which addressed the methods by which the required R&D could be accomplished [3].

Although it is only four years since the first edition of the SRA was launched, there has been rapid progress in the photovoltaic market and in the ambition in relation to the contribution of renewable energy technologies to our energy needs. Despite the general economic downturn around the world, annual global PV shipments increased to over 17 GW in 2010 [4]. In the policy area, the period since 2007 has seen the adoption of mandatory renewable energy targets for 2020 within Europe [5], the development of the Strategic Energy Technology (SET) Plan and the launch of the Solar Europe Industry Initiative (SEII) [6]. Of course, there have also been significant research advances in this period.

Therefore, the European Photovoltaic Technology Platform took the decision to update the SRA to acknowledge the progress since 2007 and to support the latest policy initiatives, particularly the SEII. This paper summarises the approach to the SRA update, the topics covered and the main differences between the first and second editions. The new SRA is expected to fulfill a similar function to the previous document, in assisting the European Commission, the governments of Member States and the PV community in general to define the priorities for research and development over the next few years.

## 2 PREPARING THE SRA

The SRA has been developed by Working Group 3, Science, Technology and Applications, of the European Photovoltaic Technology Platform. The membership of WG3 is drawn from European experts in a wide range of photovoltaic technologies. Calls for new members are issued regularly (approximately every two years) via the Platform web site. Details of the current membership can be found in the Acknowledgements section at the end of this paper.

The first stage in the updating of the SRA was to review the technology categories used in the first document for their current relevance. The main change in category was the transfer of organic devices from the Novel Technologies section to the Thin-Film Technologies section, to reflect the move of these types of devices towards commercial production.

Sub-groups were set up to consider each of the technical sections, as follows:

- Wafer based crystalline silicon
- Thin-film PV technologies
- Concentrator photovoltaics (CPV)
- Novel PV technologies
- PV components and systems: integration with the electricity grid and buildings
- Standards, quality assurance, safety and environmental aspects
- Socio-economic aspects and enabling research

In determining the research priorities and detailed research themes for each section, the sub-groups considered the advances that have been made since the publication of the first edition of the SRA. After completion of the sections by the specialist sub-groups, the document was reviewed by the full WG3 membership and was available for public comment via the Platform web site.

## 3 GOVERNING PRINCIPLES OF THE SRA

The governing principles for the second edition largely follow those in the original document, but also reflect the current market and policy position. The principles are summarised below.

Short term research should be dedicated to EU industry competitiveness. In particular, the SRA supports the objectives of the Solar Europe Industry Initiative, which has been established to promote the short-term R&D required to reach the 2020 implementation targets. The SRA also addresses the need for medium and long-term research for continued progress beyond 2020.

Regarding PV technologies, the SRA is not selective but considers what would be necessary to allow all device approaches to make a significant contribution. Historically, it is clear that different technologies are suited to different applications and that the market includes a variety of product. There is no reason to assume that this will change in the near future.

Therefore, as in the previous document, the SRA adopts cost targets that are independent of the PV technology assumed (see the next section for further information on the cost targets). Then, the research priorities for each technology consider the specific progress required to address those targets in each case.

Whilst the balance between public and private funding will differ substantially across topic areas, the SRA considers that it is necessary that public money continues to fund short, medium and long-term research across the whole PV value chain. That includes not only the device technologies, but research at system level, in regard to integration into the electricity system and relating to environmental and socio-economic issues.

The SRA considers new concepts and approaches in each technology, but also recognises the importance of promoting the incremental development of manufacturing processes and implementation schemes and makes recommendations in these areas as well. Both "revolution" and "evolution" are needed to balance risk and ensure that advances can be developed from the basic R&D through to manufacture and implementation on a large scale.

## 4 RESEARCH TARGETS IN THE SRA

Whilst research progress is often measured in terms of increased efficiency or lifetime, the commercial viability of photovoltaics as perceived by the user is based on the resultant energy cost (or, sometimes, cost of the service provided in the case of a stand alone system). Therefore, whilst the detailed research objectives are expressed in terms of specific changes in device performance, material usage etc., overall R&D targets for the SRA are defined in terms of typical installed system price, typical electricity generation cost per kWh and typical energy system payback time. These overall targets are defined for 2020, 2030 and the long term potential and are shown in Table 1.

It is acknowledged that system prices and energy generation costs cover a wide range today in Europe, depending on the details of the system, the market status and the solar resource at the location, and will continue to do so as a result of the range of applications for which PV systems can be used. The range in system prices reflects the fact that component prices and installation costs vary and also depends on the type of application (residential, commercial, industrial and utility-scale). Differences in irradiation levels, operating conditions and financial aspects for different locations will also result in a different electricity generation cost for the same system capital cost.

For clarity, however, a single set of figures for a specific reference system has been used to define the targets, that of a 100 kW commercial roof system in Italy. In practice, additional targets could be set for PV systems designed for specific applications or specific locations. The selected reference system is one of five defined by the Solar Europe Industry Initiative in regard to determining key performance indicators and the current and 2020 values given in the table are consistent with the SEII values.

The following assumptions are made to derive the energy cost for the reference system:

- An average performance ratio of 80% resulting in an annual output of 1440 kWh/kW in the southern European location.
- On average, 1% of the system price is expended each year on operation and maintenance.
- An economic system lifetime of 25 years.
- A discount rate of 6.5%

For values in 2030 and beyond, longer system lifetimes and improvements in performance ratio are assumed.

The reference case assumes a fixed flat plate PV system. For systems using concentration of sunlight or those which incorporate solar tracking, a different output will be obtained under the same global irradiation conditions in comparison to the reference system. Hence, in this case, the overall generation cost should be taken as the target, knowing that this will be achieved at a different system price to the reference case.

Table 1. Targets for PV development used as the basis for the research objectives (see text for the summary of the assumptions used in deriving the cost targets).

| | Today | 2020 | 2030 | Long term potential |
|---|---|---|---|---|
| Typical turn-key price for 100kW system (2011 €/W, excl. VAT) | 2.5 | 1.5 | 1 | 0.5 |
| Typical electricity generation costs, Southern Europe (2011 €/kWh) | 0.19 | 0.10 | 0.06 | 0.03 |
| Typical system energy payback time, Southern Europe (years) | 0.5-1.5 | <0.5 | <0.5 | 0.25 |

## 5 SIMILARITIES AND DIFFERENCES

The second edition of the SRA maintains the approach and format of the first version. Also, many of the medium and long-term research topics remain applicable since they have not yet been fully addressed in the interim period between the two editions. Nevertheless, many research advances have been made and all the R&D objectives have been reviewed and updated where necessary. This section summarises the main differences between the first and second edition, on a section by section basis.

The timescales now considered are:

- Short-term: 2011-2016
- Medium-term: 2016-2025
- Long-term: 2025 – 2035 and beyond

As in the first version, these timescales refer to the time at which the results are expected to be used in a commercial product, not when they would be in widespread use or when the work is expected to be carried out. All research topics should be addressed as early as possible.

Because of the change of timescales, some medium and long-term topics in the first SRA now automatically fall into short and medium-term respectively. However, other topics have been brought forward as a direct result of developments in the last four years, allowing us to expect adoption at an earlier stage.

### 5.1 Wafer-based crystalline silicon

Crystalline silicon technology still accounts for the majority of the PV market and continues to make R&D advances. The SRA notes that, since 2007, strong developments in crystalline silicon have been observed, with the efficiency of both mono- and multi-crystalline silicon cells having increased by about 1% absolute, cell thickness having reduced to around 180 μm and six companies now having production capacities of > 1 GW/year. Important progress has also been achieved in cells with epitaxially grown silicon layers, with efficiencies reaching 17-19% depending on the approach adopted. Many of these trends were predicted in the first edition of the SRA.

The three main routes to cost saving – reduction in material consumption, increase in device efficiency and advanced, high-throughput manufacturing – remain the most important topics. The requirement for continued research on embedded energy content, lifecycle environmental impacts and product standards is also recognised.

In regard to materials, the availability of polycrystalline silicon feedstock has been a critical issue in the past few years and this has triggered innovation in wafer production and cell manufacturing. This has led to a reduction in silicon usage from typically 10 g/W in 2007 to around 7 g/W today. Although the feedstock price has now reduced, minimisation of silicon usage by achieving higher efficiencies and using thinner wafers remains a priority.

An increased emphasis is placed on three aspects in comparison with the first SRA. These are:

- Manufacturing development, including minimum wafer handling, process integration automation, process control, reduction and recycling of process wastes
- Encapsulation and module durability to extend the lifetime to beyond 35 years and to accommodate new cell and module designs
- Sustainability in terms of the materials used, including the investigation of alternative contact materials (e.g. studies of the stability of copper contacts as a potential replacement for silver).

Within the detailed research priorities for silicon materials, medium term and long term targets for feedstock cost and wafer thickness have been reduced, in the latter case to <50 μm in the long term. Targets have also been defined for Si utilization and Si-foil and ribbon thickness. The reduction of glass thickness has been included as a short term priority and material development for up- and down-conversion layers as a medium to long term priority. Revised targets have also been set for module efficiency in the short and medium term, exceeding 21% for mono-crystalline silicon in the latter case. The introduction of high-efficiency concepts, such as up- and down-conversion and quantum dots, has been included in the basic research activities.

Finally, whilst it is acknowledged that manufacturing processes have been improved significantly in recent years, the SRA emphasises the need for continuing development in this area. It is noted that high efficiency cell concepts will require specifically designed equipment and new or adapted module structures. The increasing size of manufacturing facilities also requires improved process control and quality assurance procedures.

### 5.2 Thin-film PV technologies

The technologies covered in this section include the main categories of inorganic thin films (thin film silicon, copper indium gallium diselenide/disulphide and cadmium telluride) and, since they are now commercially available albeit at small volume, dye-sensitised and organic cells are also included. This is in contrast to the previous SRA, where organic cells were included in the novel materials section.

Since 2007, production capacities have increased strongly, especially for CdTe, and the development of production equipment has become a much higher priority leading to major reductions in module costs. The efficiency of CIGS cells has advanced so that the maximum laboratory value of 20.3% is now comparable to the best polycrystalline silicon cells and important gains have also been made at module level. Dye-sensitized cells have shown continuous improvement in efficiency and stability and are currently in the pilot production phase.

There are a number of research topics that are common to all thin film technologies, including material development, transparent electrodes, high productivity deposition techniques, encapsulation processes and quality control techniques, and these remain priorities. Within the materials area, topics on modeling of heterostructures (including substrates and encapsulation) and finding alternatives to scarce or critical materials have been added. Closed material cycles are required to minimise waste and allow high-value metals to be recovered. The need for development of accelerated ageing tests for new thin-film modules is also noted, along with further development of procedures for determining energy yield. Finally, as a long-term topic, the transfer of novel high efficiency concepts is included.

Thin film silicon modules have seen a small increase in efficiency, but important challenges remain to achieve laboratory-scale performance from production modules and to master the production of multijunction devices. At the materials level, new absorber layers, low-cost high-quality deposition methods, back reflector materials, transparent conducting oxide layers for flexible substrates and improved understanding of interfaces are among the highlighted topics. Several of the efficiency targets and all the cost targets have been strengthened, giving a long-term target of >16% and ≤0.3 €/W at 1 GW/annum production levels.

For copper indium gallium diselenide/disulphide (CIGSS) and related compounds, the main challenge is identified as reducing the difference between the laboratory efficiencies reached and those achieved in large scale production. This includes addressing the production processes, such as the deposition of the absorber layer, the use of non-glass substrates and low-cost encapsulation. Most of the detailed research topics remain as in the first SRA, but all the efficiency targets are strengthened (long term of 18-21%) and cost targets are reduced as for other thin film technologies. There is more emphasis on the reduction in material usage, the replacement and/or recycling of critical materials and high efficiency concepts such as light trapping and spectrum conversion.

The production of cadmium telluride modules has increased dramatically in recent years and the manufacturing cost is the lowest of all current PV technologies. Nevertheless, there is still the necessity for further understanding of the fundamental physical properties of the material, improvement of the electrical back contact and development of alternative transparent substrates. As with the other organic thin film technologies, efficiency targets have been increased and cost targets reduced in comparison with the previous SRA. New efficiency targets (14% in the long term) have been introduced for flexible substrates and cells with very thin absorber layers.

Due to the advances made in organic devices, the SRA now presents a full table of research priorities for both dye-sensitised and full organic cells. In both cases, the short-term targets are 5% efficiency at <1 €/W for consumer and outdoor recreational uses and the long term targets are >10% at 0.3 €/W for the power market. Processing, encapsulation and reliability, energy yield assessment and characterisation tools and procedures are identified as the main R&D topics in relation to manufacturing. These are complemented by activities in modeling, fundamental studies of materials and degradation, material development with different spectral sensitivity and photon management.

5.3 Concentrator photovoltaics (CPV)

Of all the PV device technologies, concentrator cells have probably seen the most rapid development over the last few years, already surpassing the short-term targets set in the first edition of the SRA. III-V multijunction cells have exceeded 40% efficiency under concentration levels of several hundred, CPV modules have reached 29% and AC operating efficiencies of 25% at system level have been achieved.

In addition, whilst the CPV market still lags that of the flat plate market by several years, there has been a significant growth in production and installed capacity. This is reflected in the increased priority given to R&D topics relating to volume manufacture and to system implementation in the new SRA. CPV has moved from a prototype development phase into manufacturing in the last four years.

The main R&D themes for CPV remain the same:

- Concentrator solar cell manufacturing
- Optical systems
- Module assembly and fabrication methods of concentrator modules and systems
- System aspects: tracking, inverter and installation issues

The whole system is addressed in relation to CPV, in contrast to the crystalline silicon and thin film technologies discussed so far, since interfaces between components are crucial to optimisation of the complete system.

In the detailed tables of R&D priorities, cell efficiency targets have been increased (for example, to 45% at 500 suns for III-V multijunction cells in the short term) and cost targets have been reduced for cells, modules, optical systems and at the system level, across short, medium and long term categories. Cell concepts for efficiencies above 50% have been brought forward into the short-term category.

New topics have been introduced, covering optical developments such as spectrum splitting and anti-soiling layers, bonding technologies for new cell concepts, development of in-line quality control for manufacturing and an increased emphasis on the development of standards and reliability testing to reduce perceived investor risk.

5.4 Novel PV technologies

This section of the SRA considers potentially disruptive technologies aiming for high efficiency (beyond the Shockley-Queisser limit), but where it is not yet clear what the practically achievable costs or efficiencies would be. A distinction is made between approaches that modify the properties of the active layer so as to match better to the solar spectrum and approaches that modify the incoming solar spectrum to match better the properties of the active layer. It is noted that the developments discussed in this section are likely to be adopted first in concentrator PV, with application to 1-sun technologies at a later stage.

In relation to the modification of active layers, this section summarises research on quantum wells, quantum wires and quantum dots, noting the recent application of quantum wells in single junction III-V concentrator cells. The use of quantum dots in II-VI cells is also now discussed. In relation to spectrum modification, the progress in up and down-conversion is summarised, along with an extended section covering photonic structures on the front or rear surface of the cell.

For the detailed research topics, multiple exciton generation has been added to the investigation of novel active layers. Across the different approaches, more emphasis is given to modeling, both of materials and the opto-electronic system. The long-term cost targets for the inclusion of these measures has been strengthened to achieve module costs of <0.3 €/W, implying a target for applying the spectrum modification layers of <0.05 €/W.

5.5 PV components and systems

The rapid growth of the PV market and the increased ambition for the use of PV across Europe has had a significant impact on the R&D priorities at the system level since it brings forward the time at which high penetration levels will be achieved in the electricity distribution system. Therefore, the revised SRA puts more emphasis on strategies and research topics that will enable that widespread PV penetration, in terms of integration both into the electricity grid and into the built environment.

The key aims of reducing cost, extending lifetime and improving efficiency, both at the component and system level, remain but have been supplemented by the implementation of system approaches that broaden the hosting capacity of the grid and enlargement of the options for building integration. This includes new sub-sections on both these topics.

In regard to the interaction of PV systems with the electricity grid, it is noted that one of the biggest challenges is the daily and seasonal variation in output. The SRA identifies the use of smart grids, smart meters, smart inverters, together with electricity storage, electric vehicles and coordination with other renewable electricity generation, as requiring short and medium-term research effort. Neither R&D on new storage technologies nor the overall development of the smart grid are topics that can be covered directly by the PV SRA, but they are important topics for the overall uptake of the technology. The integration of PV into the grid is part of a continuing dialogue between the PV Technology Platform and the European Technology Platform for Electricity Networks of the Future.

The SRA identifies a number of important research fields in relation to grid integration, including:

- Voltage control, including inverters with reactive power control
- Temporary voltage drop immunity, focusing on the correct compromise between safety, protection device sensitivity and grid connection solidity
- Frequency-dependent power control
- Step-wise power reduction through remote control, including standards for communication systems and power electronics control
- Storage
- Smart appliances, including links to smart inverters
- PV production forecasting.

The European Energy Performance of Buildings Directive [7] requires all new buildings to be “nearly zero energy” by 2020. This promotes both energy efficiency and on-site generation of energy, where one of the most elegant solutions is to incorporate PV into the building structure. The revised SRA includes a strengthened discussion of the R&D required for building integration of PV, identifying important topics in

- BIPV performance, including energy yields and ease of installation
- Effects of BIPV on relevant building functions
- Standards and regulations, including testing for compliance with building codes, multifunctional aspects and new materials
- BIPV economics, including determination of added value for multifunction
- The Smart Building, including combining PV with ICT and other technologies.

### 5.6 Standards, quality assurance, safety and environmental aspects

This section deals with issues that are applicable to all technologies and so the establishment of performance and safety standards, the determination of environmental impact and the development of quality assurance procedures are ongoing requirements to complement the technical research described in the previous sections. Thus, there are only a few modifications required in this section compared to the previous version.

There is a specific reference to safety standards and best practice guidelines in relation to system design and installation, so as to minimize the risk of electric shock in both normal operation and under extreme conditions (e.g. in the case of fire). In terms of harmonisation, specific reference is made to smart grids given that photovoltaic systems will be components of such grids.

### 5.7 Socio-economic aspects and enabling research

This section of the SRA deals with non-technical aspects of PV that are, nevertheless, vital to the successful uptake of the technology. These aspects include public and political awareness, customer acceptance, regulatory issues and workforce training. The major topics in this section are essentially unchanged in nature. However, since the first edition, the PV market has grown rapidly and the expected date of cost parity with delivered electricity has been brought forward. Thus, the focus now needs to be on the widespread use of PV and how to cope with the transition to cost parity conditions, especially in terms of an effective public dialogue on costs, benefits and risks of the technology.

With the growing volume of modules in the market, more emphasis has been placed on the development of the administrative procedures for collection and recycling or reuse of modules and other PV system components. There is also a continuing requirement to address the requirements for trained personnel in such a rapidly growing industry and to develop plans for the delivery of training as an ongoing activity to meet changing needs.

## 6 R&D PRIORITIES

There are some issues that apply across all technologies and underpin the R&D approach taken in the SRA. These are:

- Advances in efficiency, energy yield, stability and lifetime
- High productivity manufacturing, including in-process monitoring and control
- Environmental sustainability, including minimisation of material and energy requirements as well as recycling
- Increasing applicability, including issues of standardisation, ease of installation and use.

The research priorities for each section are provided below. Further information on each aspect can be found in seventeen detailed tables in the SRA, covering the split between short, medium and long term research and considering topics relating from fundamental studies to industry manufacturing issues.

6.1 Wafer-based crystalline silicon technology

- Reducing the specific consumption of silicon and materials in the final module
- New and improved silicon feedstock and wafer (or wafer equivalent) manufacturing technologies that are cost-effective and ensure high quality devices
- Increasing the efficiency through the optimisation of existing concepts for cells and modules as well as through new and integrated concepts in the long term
- New and improved materials for all parts of the manufacturing chain, including encapsulation and metallisation
- Integrated processes for cell and module manufacturing, thereby combining features of Si and thin-film PV technology
- High-throughput, high-yield, integrated industrial equipment, processing and quality assurance
- Finding safe processing techniques with lower environmental impact, including waste reduction

6.2 Thin-film PV technologies

Common aspects for thin-film technologies
- Reliable, cost-effective production equipment
- Low-cost packaging solutions for both rigid and flexible modules
- More reliable modules through better quality assurance procedures (advanced module testing and improved assessment of module performance)
- Recycling of materials and modules that have reached the end of their lives
- Alternatives for scarce chemical elements such as indium, gallium, tellurium

Thin-film silicon (TFSi)
- Processes and equipment for low-cost, large-area plasma deposition of micro/nanocrystalline silicon solar cells
- Development of high-quality, low-cost transparent conducting oxide layers suitable for large-area, high-performance (>12% efficiency) modules
- Demonstration of higher efficiency TFSi devices (above 15% on laboratory scale), improved understanding of interface and material properties, light trapping and the fundamental limits faced by TFSi-based materials and devices

Copper indium gallium diselenide (and related materials
- Improvement of throughput, yield and degree of standardisation for processes and production equipment
- Module efficiency >16% (or >20% at prototype scale) through improved TCO/heterojunctions, absorber quality, contact passivation and deeper understanding of the fundamental physics of these devices
- Alternative/modified material combinations and processing (roll-to-roll coating, combined or non-vacuum deposition methods), highly reliable and low-cost packaging to reduce material costs
- Device concepts for high efficiency

Cadmium telluride
- Activation / annealing treatments to control the electronic properties of the CdTe layer
- Improved and simplified back-contacting for enhanced yield and throughput
- Enhanced fundamental knowledge of materials and interfaces for advanced devices with high efficiencies (up to 20% on laboratory scale)
- Device concepts for reduction of CdTe layer thickness
- Device concepts for high efficiency

Organic photovoltaics
- Fundamental understanding of the physics of dye and full-organic solar cells including the effect of nanomorphology and order on electrical transport and exciton transport and dissociation
- Improvement of stability, including low-cost encapsulation layers
- Extrinsic doping of organic materials
- Behaviour and time evolution of contact-organic semiconductor interface
- Development of new materials (sensitisers, donor and acceptor materials) and *ab initio* modeling of properties
- Materials and processes for multiple band gap approaches
- Optical optimization in thin layers taking into account interference effects
- Development of high-throughput processing equipment

6.3 Concentrator photovoltaics

Materials and components
- Optical systems: find reliable, long-term stable and low-cost plane and concave mirrors, lenses and Fresnel lenses as well as secondary concentrators
- Module assembly: develop materials and mounting techniques for assembling concentrator cells and optical elements into highly precise, long-term stable modules using low-cost, fully automated methods
- Tracking: find constructions that are optimised for size, load capacity, stability, stiffness and material consumption

Devices and efficiency
- Develop materials and industrial production technologies for very high efficiency concentrator solar cells:
  - Si cells with efficiencies of 26%
  - Multijunction III-V compound cells with efficiencies above 45% (48% in the laboratory)
- Identify the optimum concentration factor for each approach

Manufacturing and installation
- Find optimised design, production and testing routines for the integration of all system components

- Scale up production with fully automated production lines for high volumes
- Optimise methods for installing, outdoor testing and evaluating the cost of CPV systems

6.4 Novel PV technologies

- Demonstration of new conversion principles and basic operation of new device concepts
- *Ab initio* material modeling
- Opto-electrical modeling and simulations
- Nanoparticle synthesis
- Stability of boosting layer material for up-down converters and photonic structures
- Investigation of deposition techniques

6.5 PV components and systems: integration with the electricity grid and buildings

PV components
- Increasing inverter lifetime and reliability
- New storage technologies for small and large applications and the management and control systems required for their efficient and reliable operation
- Harmonising components, including lifetimes, dimensions and options for modularity to decrease site specific costs at installation and replacement costs during system life
- Assessing and optimising the added value of PV systems for different system configurations
- Innovative BIPV components that enhance multifunctionality
- Components and system design for island PV and PV-hybrid systems

PV systems
- Grid codes with appropriate requirements on distributed generation devices in terms of reactive and active power control, fault-ride-through capabilities etc.
- Local consumption of electrical energy at the point of generation in order to reduce grid overload
- Implementation of smart-metering concepts in order to gain more transparency in energy generation and consumption
- In order to increase the utilisation of PV, storage by local batteries, including consideration of the capabilities of electric vehicles, has to be taken into account

6.6 Standards, quality assurance, safety and environmental aspects

- Further develop performance, energy rating and safety standards for PV modules, PV building elements and PV inverters and AC modules
- Harmonise conditions for grid connections across Europe, including in relation to smart grids
- Develop quality assurance guidelines for the whole manufacturing chain
- Develop recycling processes for thin-film modules and BoS components
- Conduct life cycle analyses on thin-film and CPV module and BoS components and, in the longer term, on novel cell/module technologies

6.7 Socio-economic aspects and enabling research

- Identify and quantify the non-technical (i.e. societal, economic and environmental) costs and benefits of PV
- Address regulatory requirements and barriers to the use of PV on a large scale
- 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 for improved awareness in the general public and targeted commercial sectors

## 7 SUMMARY

The Strategic Research Agenda of the European Photovoltaic Technology Platform has been updated to include new cost and performance targets, together with revised research priorities. This reflects the progress in the PV market in recent years, advances in PV R&D and the increased ambitions for PV contribution to Europe's electricity supply since the publication of the first SRA four years ago.

This paper has discussed the approach taken and summarised the main differences between the new and old versions. It has highlighted the research priorities across the range of PV device technologies and at PV system level. The full version of the Strategic Research Agenda for Photovoltaic Solar Energy can be downloaded from the Platform web site at www.eupvplatform.org.

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The current membership of WG3 is as follows:

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