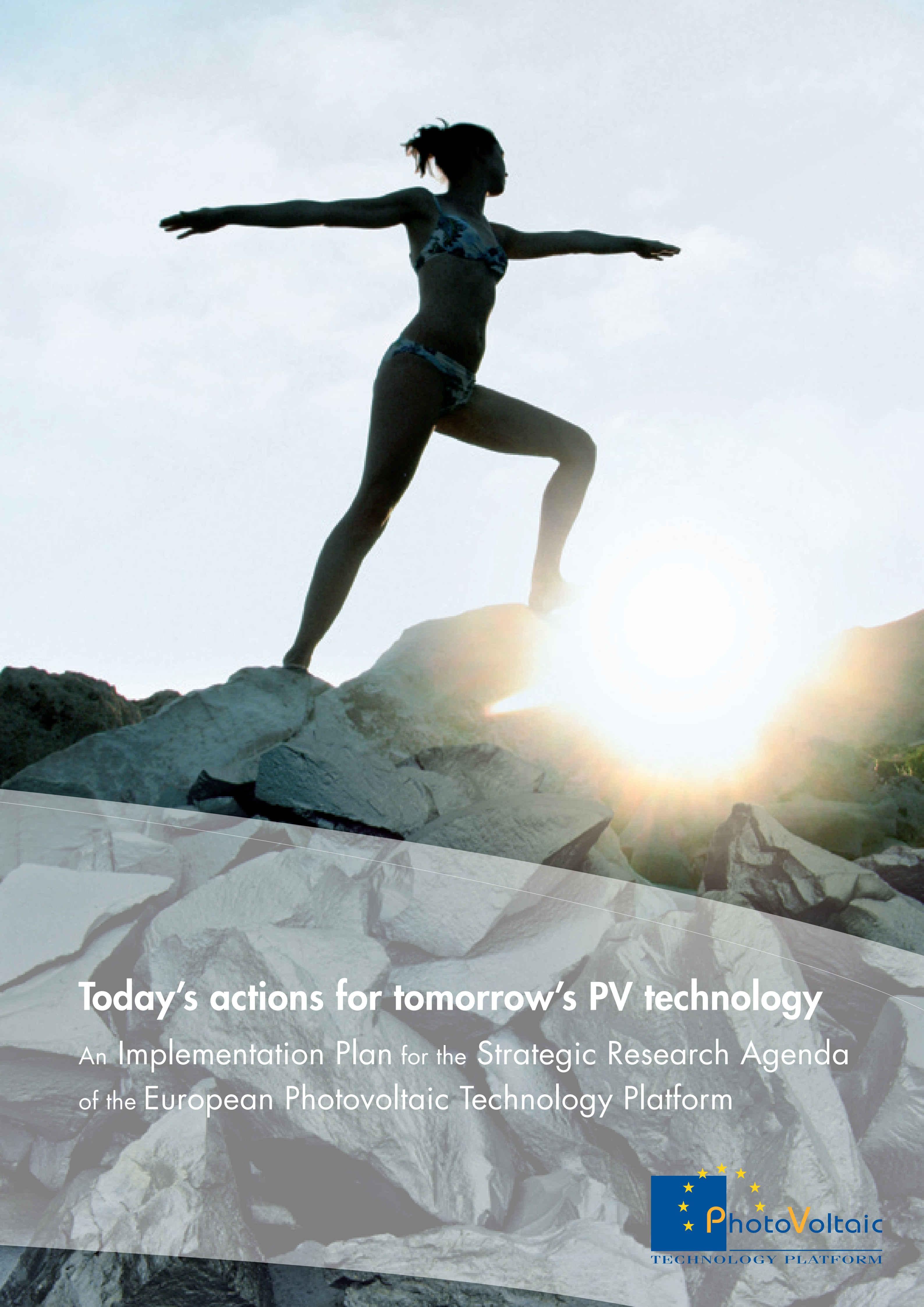

Today's actions for tomorrow's PV technology

An Implementation Plan for the Strategic Research Agenda of the European Photovoltaic Technology Platform

PhotoVoltaic
TECHNOLOGY PLATFORM

SIXTH FRAMEWORK PROGRAMME

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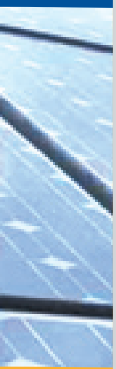

1 Preface

The European Photovoltaic Technology Platform published its Strategic Research Agenda for Photovoltaic Solar Energy Technology (SRA) in 2007 [SRA 2007]. It describes what R&D work the EU and its Member States should fund to make PV a very widely used technology generating significant economic returns for Europe. This Implementation Plan follows on from the SRA, describing how to put into practice the SRA's findings and recommendations.

Like the SRA, the Implementation Plan has been developed to serve as a reference document for individuals and organisations involved in PV R&D. The contents of this Plan reflect the outcome of detailed discussions and analyses by the members of the Working Group on Science, Technology & Applications of the Platform, as well as the feedback received in a public consultation. Both documents are available on the Platform's website, www.eupvplatform.org. The page where an electronic version of this document, and links to supporting information, can be found is www.eupvplatform.org/documents/ip.html.

On behalf of the Working Group,

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August 2009

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2 Summary

The European Photovoltaic Technology Platform published its Strategic Research Agenda for Photovoltaic Solar Energy Technology (SRA) in 2007 [SRA 2007]. It describes the development targets of the European PV sector and the research & development (R&D) needed to achieve those targets. The SRA was developed to serve as a reference document for PV R&D programming by the EC and the EU member states, thus increasing the efficiency and effectiveness of the joint European efforts in this area. This Implementation Plan complements the SRA by quantifying the R&D needs, by recommending adequate instruments for R&D funding, by describing interactions with other technology sectors that may help to accelerate innovations in the PV sector and by making recommendations for attracting people to work in the industry.

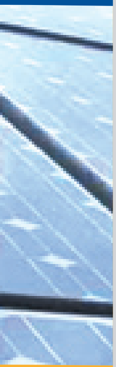
The main conclusions and recommendations from this Implementation Plan are:

- The basic principle of the SRA, 'creating a PV revolution through accelerated evolution' still stands. To reach the energy policy targets that the EC and the Member States set in 2007 (amongst which, a 20% share of renewable energy in final energy consumption) will need additional acceleration. In other words, it is important to develop PV technologies that will come to market in the short, medium and long term to sustain the sector's robust and continuous growth. The coming decade, when global competition will intensify, prices will fall, and large-scale deployment may really take off, is a crucial one for the European PV sector. But it is also essential to have a strategy for the longer term and to explore the potential of technologies that could be highly competitive after 2020.

- The priorities set in the SRA have been fully adopted in this Implementation Plan, but they have been grouped according to the drivers of technology development:
  - Enhancing performance
  - Improving manufacturability
  - Promoting sustainability
  - Addressing applicability

  These drivers are derived from the overall target of achieving low-cost, sustainable generation of electricity using PV. Each research category consists of a number of topics (which can be thought of as 'projects' or 'programmes'), classified according to the amount of time needed before their results will be exploited in commercial products ('short-term', 'medium-term' and 'long-term'). A 'topic type' is assigned to each topic, indicating the nature of the research project (basic, applied, industrial), so is an estimate of the total budget required over the period 2009-2013 and of the relative sizes of public and private contributions to this budget. When defining the budgets needed, the ambitious technology development and deployment targets defined by the European Photovoltaic Industry Association (EPIA) in 'SET for 2020' have been taken as a reference [SET 2009]. By summing budgets per topic, estimates of total budgets have been obtained.

- The total spending on R&D required over the next 5 years is 6.6 bn EUR (billion euros). This implies a substantial increase compared to the budgets seen in the past 5 years. This is a consequence of the adoption of the ambitious technology development and deployment targets outlined in 'SET for 2020' and is consistent with rapid growth of the global and the European PV sector. Of the



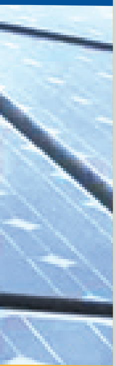
Novel solar module based on rear-contact solar cells © ECN total amount, 55% will have to be contributed by the private sector, while 45% consists of public contributions. The total budget for short-term R&D is 3.5 bn EUR, for medium-term 2.2 bn EUR and long-term 0.9 bn EUR.

- Instruments for research funding need to evolve with the PV sector. To be able to face the great challenges in the period to 2020 (and beyond) it is necessary to introduce new instruments while keeping successful existing instruments and best practices. New instruments need to fit the needs of a rapidly innovating industry operating in a global setting and to access further the research potential of Europe. Flexibility, rapid response and cross-border cooperation of funding agencies and research organisations are some of the features of these new instruments.

- The PV sector may benefit substantially from intensified communication and cooperation with other industrial sectors. Solutions to specific challenges might be found outside the PV sector. The large-scale deployment of PV depends on, amongst other things, successfully integrating PV in buildings, integrating PV in the grid at high penetrations and finding better materials for PV products, requiring a concerted exchange with the construction and electricity sectors and the chemical industry.

- Realising PV's full potential relies on awareness of the technology increasing and on greater numbers of people having in-depth knowledge of it. Therefore education and training are indispensable parts of the Implementation Plan. Through its work on the R&D topics identified in the Plan, the industry will be afforded an excellent opportunity to educate and train the personnel it requires to take the R&D results through to commercial exploitation and to educate and train other professionals needed by a growing PV sector.

- This Implementation Plan has been prepared by the members of Working Group 3 of the EU PV Technology Platform, who are a group of experts from public and private organisations, with backgrounds in different technologies. The Implementation Plan describes the consensus that was reached within the group and includes many of the comments that were made during a public consultation.



3 Introduction

Photovoltaic solar energy (referred to as 'PV' throughout this document) is a versatile, sustainable technology with a huge potential. PV systems can be connected to the grid in systems with peak outputs ranging from few hundred watts to tens of megawatts or more. They can also meet the needs of those who demand electricity, but who have no access to the grid, whether companies, communities or individuals. The pace at which scientific and technical understanding of PV has progressed over the past three decades is impressive and has resulted in dramatic cost reduction. Today, several kinds of PV technology are available commercially. Many more, at earlier stages of development, are to be found in the laboratory and in pilot production.

The price of PV systems is low enough for PV electricity to undercut the price of peak power in many grid-connected applications and the cost of electricity from diesel-generators in off-grid applications, but it is not less than the prices paid by large or small consumers of grid electricity. A substantial further reduction in the prices of turn-key systems is therefore needed and fortunately possible. 'A Vision for Photovoltaic Technology' [VIS 2005], published in 2005 by PV TRAC (the PV Technology Research Advisory Council, which was the forerunner of the EU PV Technology Platform) demonstrated this (Fig. 1). Two years later, the Platform developed a 'Strategic Research Agenda for Photovoltaic Solar Energy Technology' (SRA – Fig. 2), which indicated that the generation cost of PV electricity can soon fall below the retail price of electricity[1]. This situation is generally referred to as the attainment of 'grid parity', expected within five years in some southern European countries and in most of Europe by 2020. PV technology will be much more widely deployed after 2020 taking generation costs to parity with the prices paid by bulk electricity consumers and then taking them even lower. Increases in the cost of electricity (for example as a result of internalising the societal cost of carbon emissions, or of rises in the cost of fuel for the plant) will make PV competitive sooner.

1. 'Cost' and 'price' have specific meanings in this context. The owner of (or investor in) a PV system is initially confronted with the (turn-key) price of that system. The owner also has the alternative of paying retail prices for electricity purchased from the grid. When a PV system is feeding electricity into the grid, the system price translates to generation costs. 'Grid parity' refers to the point where generation costs equal retail prices. Generation costs will have to fall below retail prices for system owners to make enough margin for the market for PV technology to be self-sustaining.

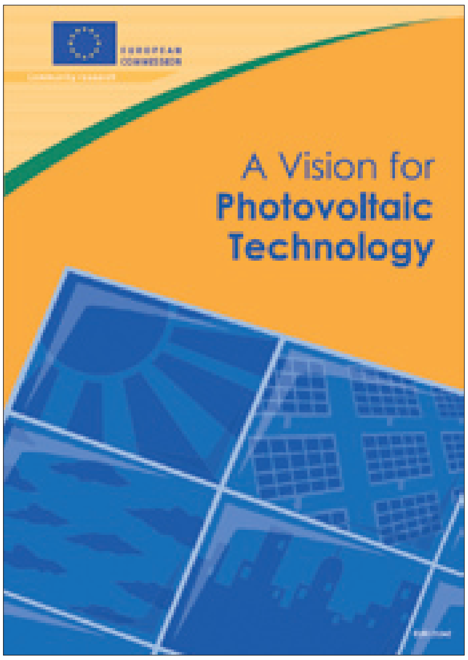


Figure 1: A Vision for Photovoltaic Technology (2005) [VIS 2005]

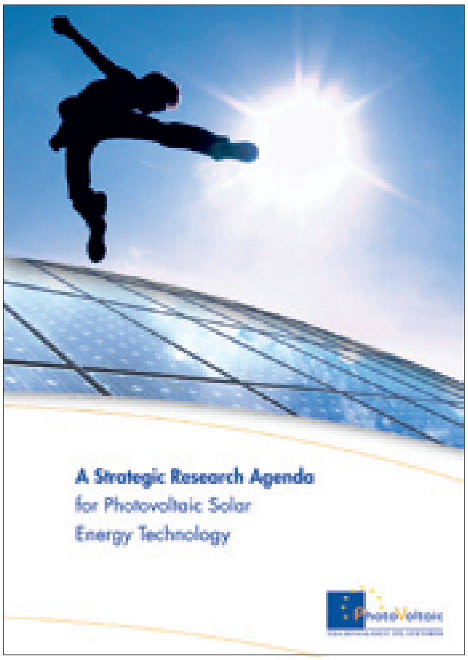


Figure 2: A Strategic Research Agenda for Photovoltaic Solar Energy Technology (2007) [SRA 2007]

3.1 Recent developments: the Solar Europe Industry Initiative

Since the publication of the SRA in 2007, the PV industry represented by the European Photovoltaic Industry Association (EPIA) has prepared a roadmap for ambitious PV deployment in Europe: 'SET for 2020'. Implementation of the roadmap targets is supported by the 'Solar Europe Industry Initiative' (SEII) that has been developed in close cooperation with the EU PV Technology Platform. 'SET for 2020' and the SEII are key elements of the EU PV sector's response to the challenge of meeting Europe's 2020 energy policy targets (which include the goal of a 20% contribution of renewable energy in total final energy consumption). The two initiatives aim to make "PV a mainstream source of clean and competitively-priced electricity within the next decade". The temporary continuation of ambitious market support programmes in those EU Member States that currently have them is a necessary condition for further growth, as is the establishment of such schemes in Member States that do not yet have them. 'SET for 2020' and the SEII, however, aim to make PV independent of such programmes as soon as possible. 'SET for 2020' sets out three different scenarios:

- A **Baseline Scenario** with a **4% contribution to the total EU electricity demand by 2020**. It requires full cooperation from the whole industry to achieve price reductions in solar modules and balance-of-system (BoS) components. It does not require changes to the existing electricity system.

- An **Accelerated Growth Scenario** with a **6% contribution by 2020**. In addition to the conditions outlined for the Baseline scenario, it requires minor changes to the existing electricity system, for the industry to optimise its supply chain and to cooperate with the utilities on infrastructure changes.

- A SEII-enabled **Paradigm Shift Scenario** with a **12% contribution by 2020**. It requires the adoption of technologies to store PV electricity and 'smart grid' technology to manage the dispatch of loads at times when the supply of PV electricity is plentiful, together with an optimised strategy for cost reduction, supply chain management, and operations and marketing.

Three strategic objectives are at the heart of the Paradigm Shift Scenario:

- To bring the PV industry steadily towards to full **cost competitiveness**[2] in all market segments (residential, commercial, and industrial) by 2020;
- To establish conditions that allow the **integration** of distributed PV electricity within the European grid at high penetration;
- To carry out large scale **demonstration and deployment** projects. The Scenario holds research and technology development to be necessary but insufficient ingredients for success. It is research and technology development that this Implementation Plan is concerned with, not demonstration and deployment projects.

2. There is not yet a straightforward definition of 'competitiveness' in relation to grid-connected PV capacity. 'Competitiveness' depends on where the boundary is drawn around the system, and on how cost savings realised from the presence of PV on the grid are allocated between the PV technology and the rest of the generation and distribution infrastructure connected to grid.

3.2 The Strategic Research Agenda and the Implementation Plan

The SRA set targets for the performance of PV technology by 2020 and 2030. The 2020 targets have been tightened to meet the aims of the SEII (Table 1).

Table 1: Milestones for PV technology as described in [SRA 2007], updated to include the targets of the Solar Europe Industry Initiative. The lower end of the range for "typical turn-key system price" corresponds to prices that could be reached for large ground-mounted systems, while the upper end is for small building-mounted systems. There will be variation, too, between the Member States for installations with the same characteristics.

ROUNDED, INDICATIVE FIGURES*	1980	1995	2009	2020	2030	Long term potential
Typical turn-key system price	> 30	10	3 - 4.5**	1.5 - 2.3	< 1	0.5
Typical electricity generation costs @ 1300 kWh/kW$_p$·year***	> 2	0.7	0.20 – 0.30	0.10 – 0.15	< 0.07	0.03
Commercial flat-plate module efficiencies	up to 8%	up to 12%	up to 20%	up to 23%	up to 25%	up to 40%
Commercial concentrator module efficiencies	(~10%)	up to 20%	up to 30%	up to 35%	up to 40%	up to 60%
System energy pay-back time @ 1300 kWh/kW$_p$·year (years)	> 10	> 5	< 2	< 1	0.5	0.25

* *Monetary quantities are expressed in EUR at 2009 values.*
** *The range covers power plants (at the lower end of the price range), large systems on buildings (middle of the range) and small systems on buildings (upper end of the range).*
*** *Calculated using the PV TP's 'NPV/FiT' model [NPVTP] with the parameters of amortisation over 25 years, 6% cost of capital, 1% O&M & insurance costs*

If PV meets the milestones in Table I, it will become a major component of Europe's and the world's energy supply system. To get the technology to that point, European countries are supporting PV with incentive schemes and R&D programmes. The SRA itemised the R&D work that needs to be done. This Implementation Plan describes how to undertake it as an appropriately-funded, co-ordinated, joint effort between industry and research centres. As part of its analysis, it discusses the instruments that are used to fund European-level research, the benefits of approaching other fields of technology to find answers to the technological challenges faced by PV, and the sector's requirement for human resources. The policies and instruments related to PV market development are beyond the scope of the Implementation Plan.

The structure of the document is outlined here:

- Chapter 4 sets out the main features of the **global PV research landscape**. It compares Europe's R&D policies with those of other parts of the world.

- Chapter 5 **quantifies the R&D needs** associated with the research areas defined in the SRA, taking account of the need to meet the SEII's Paradigm Shift targets. It provides data on the money that must be spent now on research for the short, medium and long term, and on the relative roles of the public and private sectors in funding this research.

- Chapter 6 offers guidelines for **efficiently funding R&D**. It describes best practice and the lessons learned from European as well as Member State programmes, and where and how new approaches to funding research could be useful.

- Chapter 7 looks at **other sectors** that link or could link to the PV sector, either because they are part of the same offering to the end-consumer (in the case of building-integrated PV), or because there are synergies to be exploited further upstream. The chapter describes where and how closer interaction may be beneficial.

- Chapter 8, deals with **education and training**. The rapidly growing PV sector requires an ever increasing number of well educated and trained workers at all parts of the value chain: from scientists, process engineers and plant managers to system installers, business developers and financial specialists.

4 R&D strategies for PV: Europe compared to the rest of the world

4.1 Different countries – different strategies

The PV industry of today looks very different to the industry of five years ago. Production has increased fivefold and new producers like China and Taiwan have taken major shares of the production market. Meanwhile, an increasing number of emerging players like India, Korea, Singapore and Malaysia are strengthening their R&D base in PV to support the growth of their own PV industry. This state of affairs calls for a re-evaluation by those countries/regions of the world with longer-standing positions in manufacturing (e.g. Europe, the USA and Japan) of the relative importance of international competition and cooperation, and of policies on licensing intellectual property, technology transfer, and other issues arising from the rapidly changing global situation. On the one hand, the availability of low-cost, high-quality PV technology, wherever it is produced, is a prerequisite for any ambitious deployment scenario. On the other hand, the European PV sector has the responsibility and the ambition to maintain a strong position on the global market and to derive economic benefit for the EU taxpayer, who has nursed PV technology through the expensive, initial stages of its development.

It is interesting to note that Europe's competitors are approaching these topics quite differently. The focus of national attention varies from pure industry policy to promote the build-up of capacity and utilisation of economics of scale in order to improve manufacturing advantages to a focus on research to develop the technology further.

4.2 Europe

The Member States of the European Union administer their own programmes for research, development, demonstration and deployment, but have also indirectly funded research and demonstration projects in PV on an EU-level since 1980 through the contributions that they pay to the budget of the European Commission. The European Commission re-distributes this money as grants using an instrument known as the Framework Programme for Research, Development and Technical Demonstration ('Framework Programme' for short). The Framework Programme's budget accounts for roughly 6% of total spending on PV R&D, according to figures that are soon to be published by the Institute for Prospective Technological Studies in the European Commission's Joint Research Centre. 35% of total spending is by the Member States directly (although this share could be higher because it does not include institutional funding for research centres for every Member State), and 59% comes from the private sector. Germany leads in Member State spending, followed by France, Italy, the Netherlands and the UK. These proportions were calculated on the basis of 2007 figures. The picture could have changed substantially since then.

Europe has a strong and prolific workforce of PV researchers. The Framework Programme plays an important role in maintaining a 'European Photovoltaic Research Area', i.e. in connecting groups of these researchers in different countries and guiding the R&D strategy of a number of Member States. A large number of research institutions – from small university groups to large research centres, covering everything from basic materials research to the optimisation of industrial processes – are involved and contribute to the progress of PV. The focus of this work is to reduce cost.

4.3 India

India's first National Action Plan to tackle climate change was published in 2008, identifying eight 'National Missions' to develop and use new technologies. In April 2009, the National Solar Mission was finalised. The actions it calls for for PV are R&D collaboration, technology transfer and capacity building. The overall mission is to make India a global leader in solar energy (PV and solar thermal power plants) and to install a solar generation capacity of 20 GW by 2020 (probably 10 GW of each technology), 100 GW by 2030 and 200 GW by 2050.

So far, R&D has aimed at the development of materials for solar cells and modules, different types of device structures, module designs and components, and systems and sub-systems, with the overall aim of reducing the costs and improving system efficiency. Production-oriented research is financed by the emerging PV industry rather than publicly.

India has an excellent research base in materials science and semiconductors. As a White Paper published in 2009 by the PV group of the Indian branch of SEMI showed, with proper publicly- and privately-funded R&D programmes for focused, collaborative, goal-driven R&D, India could develop a substantial PV industry [SEM 2009]. Investing in production capacity alone, it seems, would not enable India to achieve its full potential.

4.4 Japan

Japan's 'New Energy Development Organisation' (NEDO) is responsible for devising and executing that country's R&D strategy [NED 2007], which is a combination of support for R&D and 'industrial policy'. In R&D, cost reduction is, not unexpectedly, the prime concern. There are programmes on future technology (in and outside NEDO) where participation of Japanese institutes or companies is by invitation only. Non-Japanese partners can participate in 'future development projects' and the NEDO Joint Research Programme, which mainly deals with fundamental R&D.

Examples of the kind of the research and demonstration that receives public funding are 'Field Test Projects', 'Verification of Grid Stabilisation with Large-scale PV Power Generation Systems', 'Research and Development of Next-generation PV System Technologies', 'Research and Development on Innovative Solar Cells' and 'Research and Development of Common Fundamental Technologies for Photovoltaic Generation Systems'. More details about the running projects and the programmes that fund them can be found in the annual JRC Photovoltaic Status Report [JRC].

Like Europe, Japan explores many different technology options in parallel without picking winners and losers (Fig. 3). The country's 'industrial policy' aims at creating viable, independent and sustainable businesses along the whole length of the PV value chain, from raw material production to cell, module and BoS component manufacturing.

As part of an agenda to export its technology, Japan is keen to participate in committees setting international technical standards.

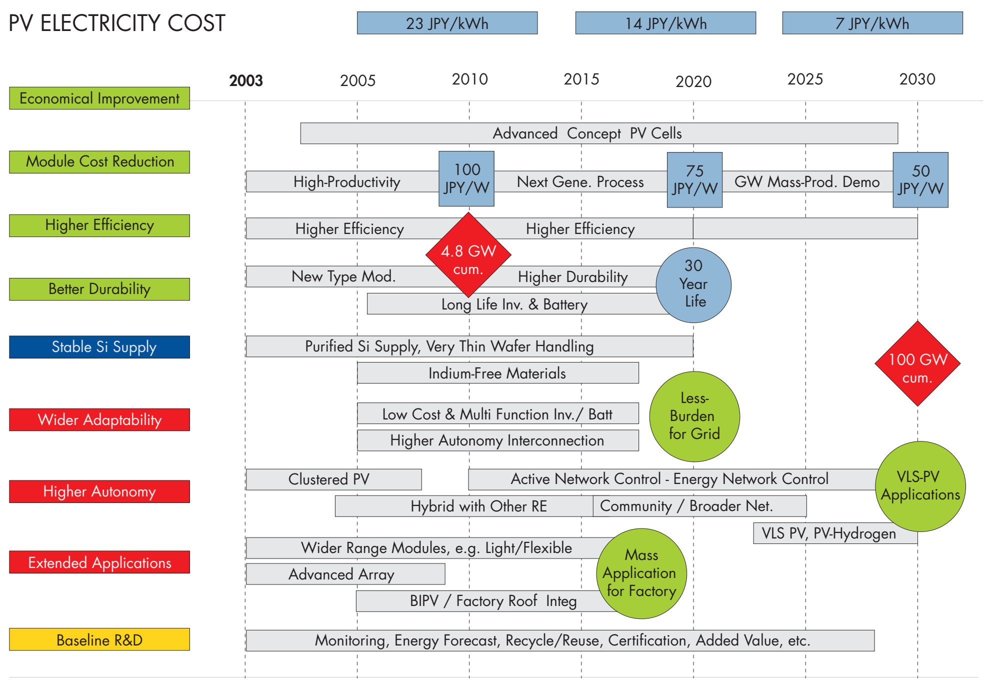


Figure 3: Diagram summarising Japan's 'PV Roadmap towards 2030' [PVR 2004]. Notice the deployment targets alongside the research themes. At the time of printing 1 EUR = 134 JPY.

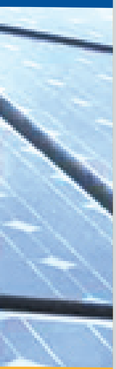
4.5 People's Repulic of China

The National Outlines for Medium- and Long-term Planning for Scientific and Technological Development (2006-2020) and the National Medium- and Long-Term Renewable Energy Development Plan describe solar energy development and utilisation as a priority [NDRC].

Within the National Basic Research Programme of China, the so-called '973 Programme', there is support for research into 'large-area, low-cost and long-life solar cells' [NBRB].

With the support of national ministries and commissions, China has reached a PV cell efficiency of 21% in the laboratory. Commercial PV components (modules) and normal commercialised cells have respective efficiencies of 10 – 13% and 14 – 15%. The price of Chinese cells has gradually fallen from 40 RMB/W_p (4.40 EUR/W_p)[3] in 2000 to 33 RMB/W_p (3.62 EUR/W_p) in 2003 and 27 RMB/W_p (2.57 EUR/W_p)[4] in 2004, which is not only crucial to the growth and maturity of China's domestic solar energy market but also significant in connection with the international PV market. It is estimated that by 2010, the electricity generation cost with solar PV systems will decline to some 1 RMB/kWh (0.089 EUR/kWh)[5], reaching or approaching the price of power on electricity markets.

3. Exchange rate 2003: 1 RMB = 0.11
4. Exchange rate 2004: 1 RMB = 0.095
5. Exchange rate 2008: 1 RMB = 0.089



4.6 South Korea

In January 2009, the Korean government announced its third national renewable energy plan, under which renewable energy sources will steadily increase their share of the energy mix to 4.3% in 2015, 6.1% in 2020 and 11% in 2030. The plan covers such areas as investment, infrastructure, technology development and programs to promote renewable energy.

The Korea Institute of Energy and Resources Technology Evaluation and Planning' (KETEP) manages energy R&D. The focus of R&D has recently shifted away from development work on interconnections, electrical standards, mounting systems and other know-how related to PV installations and towards improving manufacturing technology. This research ranges from cost reduction and efficiency improvement in c-Si cells to novel thin-film solar cells and high-efficiency concentrating cells. A parallel adjustment has been made in power generation system research, away from the pursuit of high performance and towards the pursuit of cost effectiveness.

4.7 Taiwan

To promote its solar energy industry (PV and low-temperature solar thermal), the Taiwanese government has decided to subsidise manufacturers engaging in R&D and will offer incentives to consumers to use PV electricity. About a dozen manufacturers have expressed an intention to manufacture thin-film PV modules and eight of them will set up their own plants to process the products. Moreover, the Industrial Technology Research Institute (ITRI), a government-backed research organisation, is going to import advanced foreign technology for local manufacturers.

ITRI has drawn up an R&D strategy for Taiwan with the aim of lowering module costs to around 1 USD/ W_p between 2015 and 2020. The strategy includes a doubling of Taiwan's annual spend on PV R&D within the next four years. The research will span increasing the efficiency of various wafer-based and thin-film cells, concentrator concepts and novel devices. Despite the push for R&D, Taiwan's focus is on helping its industry increase production and improve its manufacturing technologies.

4.8 USA

PV research in the US is funded under the U.S. Department of Energy's (DOE) Solar Energy Technologies Programme [DOE SETP]. The main components of this programme are the Solar America Initiative (SAI) and the National Centre for Photovoltaics at the National Renewable Energy Laboratory.

The Solar America Initiative is an effort to make solar electricity (PV and concentrating solar power) cost-competitive with conventional forms of electricity by 2015. The goal is to bring down the cost of electricity from grid-connected PV systems from 0.25 USD/kWh in 2005 to 0.09 USD/kWh in 2015 (at 2005 dollar values). The SAI's strategy on PV is to accompany the expected increase in deployment of this technology with R&D on cost reduction.

The SAI is organised as a multi-tiered, multi-phased programme addressing near-, medium-, and long-term technological advances for improved performance, lower cost, and improved reliability of PV system components (Fig. 4).

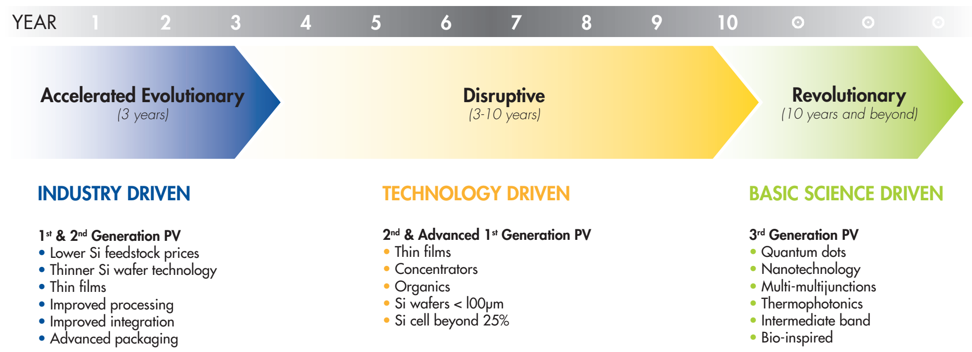


Figure 4: Multi-tiered approach of the Solar America Initiative. Source: EERE, Solar America Initiative, 2007

To support the SAI, ten PV technology roadmaps were developed in 2007 by NREL, Sandia National Laboratories, DOE, and experts from universities and private industry [SAI 2007]. They summarise the current status and future goals of specific technologies. The roadmaps for intermediate band PV, multiple-exciton-generation PV and nano-architecture PV are still drafts.

5 PV research topics: who should do what with how much?

5.1 Introduction

The SRA presented research areas categorised according to device technology and system-level technology. This chapter, by contrast, groups the work identified by the SRA into four broad themes (see bulleted list below), then for each one indicates the nature of the research projects or programmes to be carried out, the total resources that need to be committed to them and how this commitment might be shared between private and public budgets.

As discussed in the SRA, a range of cell and module technologies can be found in commercial production and in the laboratory. Rather than attempt to identify a 'winner' within these technologies, the SRA adopted the approach of identifying the technical advances needed in each in order to meet general performance and cost targets (Table 1, page 11). The Implementation Plan follows the same approach. Whilst it is possible that some technologies will ultimately fail, it is not possible now to identify which ones those are. The most likely scenario for the period up to 2030 is that the market will see a changing mix of technologies, each with specific advantages for particular applications.

'Zornitza', Bulgaria's first large grid-connected PV system (200 kW) near the town of Sandanski © CLSENES

The four themes used in this Implementation Plan are as follows:

- **Enhancing Performance** – research that leads to higher device outputs and improved system performance
- **Improving Manufacturability** – research that addresses the ease and cost of component manufacturing and of system operation
- **Promoting Sustainability** – research that aims to bolster PV's green credentials
- **Addressing Applicability** – research that develops products and technology to meet specific market needs

The main barrier to widespread implementation of PV technology is acknowledged to be cost, which can be addressed by a combination of improved performance and lower manufacturing costs, so it is not surprising that most research topics come under the first two of these themes. In some cases, topics in different themes are interlinked.

5.2 A summary of our findings

In practice, the real budget required for each of the topics mentioned in the tables that follow will be worked out case-by-case as projects are put forward to cover them, as will the contributions of public and private funding to the projects. Our approach has been to give a range for the likely overall cost of accomplishing the research work for each individual topic. Based on the assumption that when aggregated, the values corresponding to the middle of these ranges for topics within a particular category represent the overall spend for the category, the total budget for the research proposed here is around 6.6 billion EUR up to 2013.

5.2.1 Funding by technology segment

Just over three quarters of R&D funds are allocated at the cell and module level, with the remainder going to all aspects of PV system development, from components and system design to grid integration, environmental assessment and standards. Within cell and module development, the highest allocations are made to crystalline silicon (30%) and thin-film (29%) technologies. Concentrator and emerging and novel technologies follow with 10% and 6% respectively (rightmost column, Fig. 5). This order reflects the expected order in market share between different cell/module technologies in 2020. Future market shares cannot be inferred from these figures, but thin films might capture up to 30% of the market by this date, with concentrator technologies increasing their market share and perhaps reaching 10%. Emerging and novel technologies are not expected to claim more than 1% of the market in the next decade, but it is important to dedicate resources to them to assess their long-term potential. The budget levels assigned to each sector are not a statement of their relative importance, but a statement of their current needs.

The allocation of a high percentage of funds to the crystalline silicon and thin-film sectors reflects the fact that many of the actions with the highest budgetary requirements involve the development of advanced production equipment for those technologies. This work is funded to a high degree by industry, has a short- to medium-term impact and tends to be at a higher funding level than basic research projects. The distribution of funds looks different if it is broken down into work with short-, medium- and long-term impact (Fig. 6).

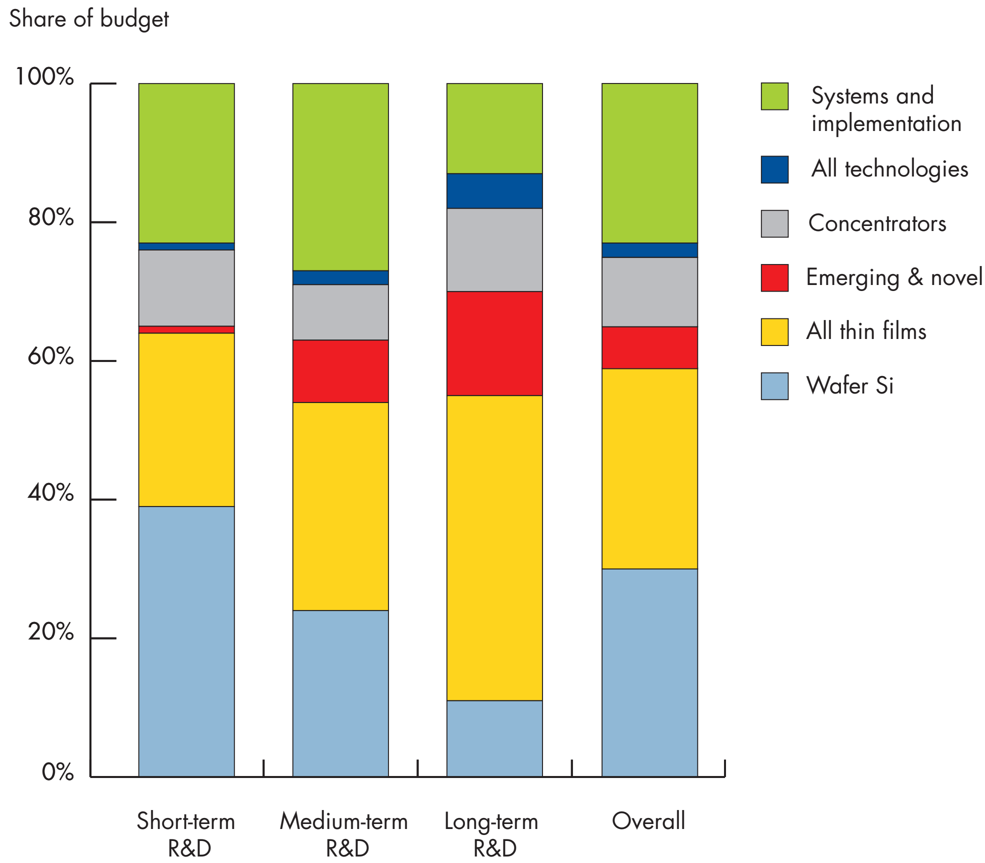


Figure 5: Budget distributions for R&D with short-, medium- and long-term impact and overall across all timescales for exploitation

N.B.

- *The Systems and implementation segment includes not only BoS components, but also system design and operational issues, together with grid integration, environmental, socio-economic and standardisation aspects*
- *All technologies refers to actions that, if carried out, would benefit all PV technologies.*
- *The PV Technology Platform believes all the research mentioned in this Implementation Plan must be funded before 2013. 'Short', 'medium' and 'long' refer to 'exploitation timescales', i.e. the length of time that will likely elapse between the research being funded and its results being taken up in commercially-available PV products.*

Crystalline silicon research, together with that for system-related issues, will mainly have a short- and medium-term commercial impact, whereas thin-film technology will have an impact in the longer term. The relative share of funding for concentrator and emerging technologies is largest for research with long-term commercial impact. The smaller share of funding for concentrator technologies for research with medium-term impact compared to its share for short-term research in fact corresponds to a funding requirement that is larger in absolute terms.

5.2.1 Funding by source and theme

Around 55% of the funding is expected to come from the private sector and around 45% from public funds, but this varies depending on the timescale by when the results of the research are intended to be applied commercially (Fig. 6).

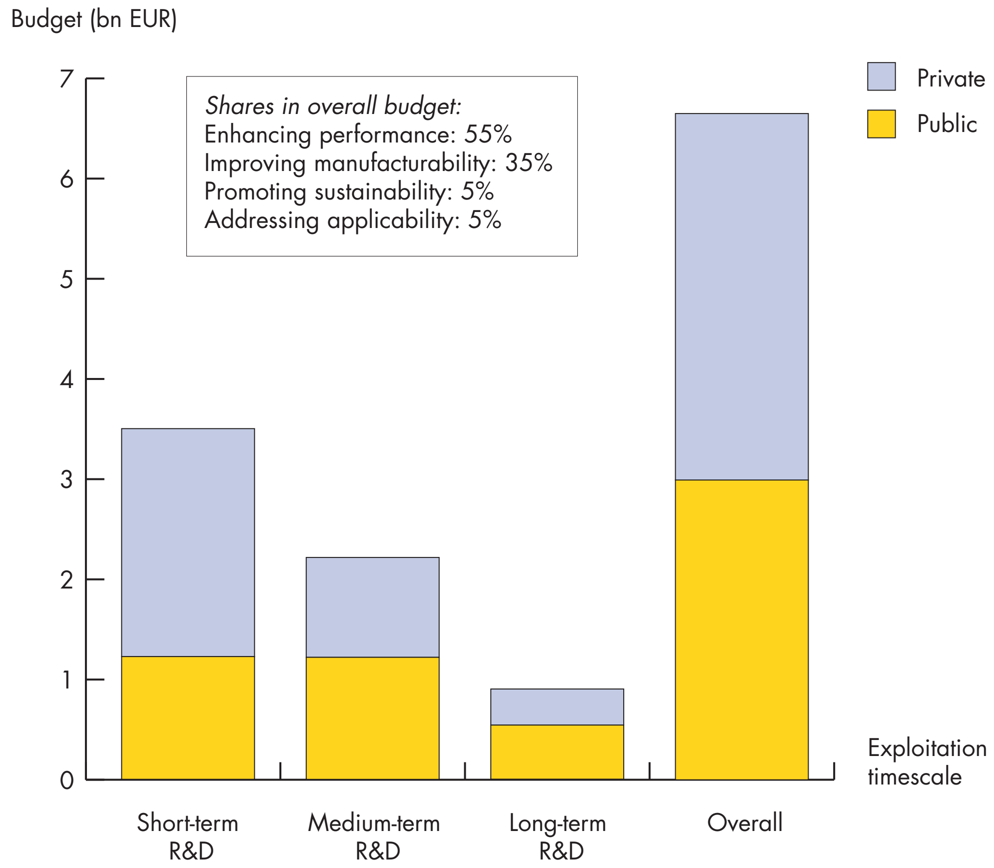
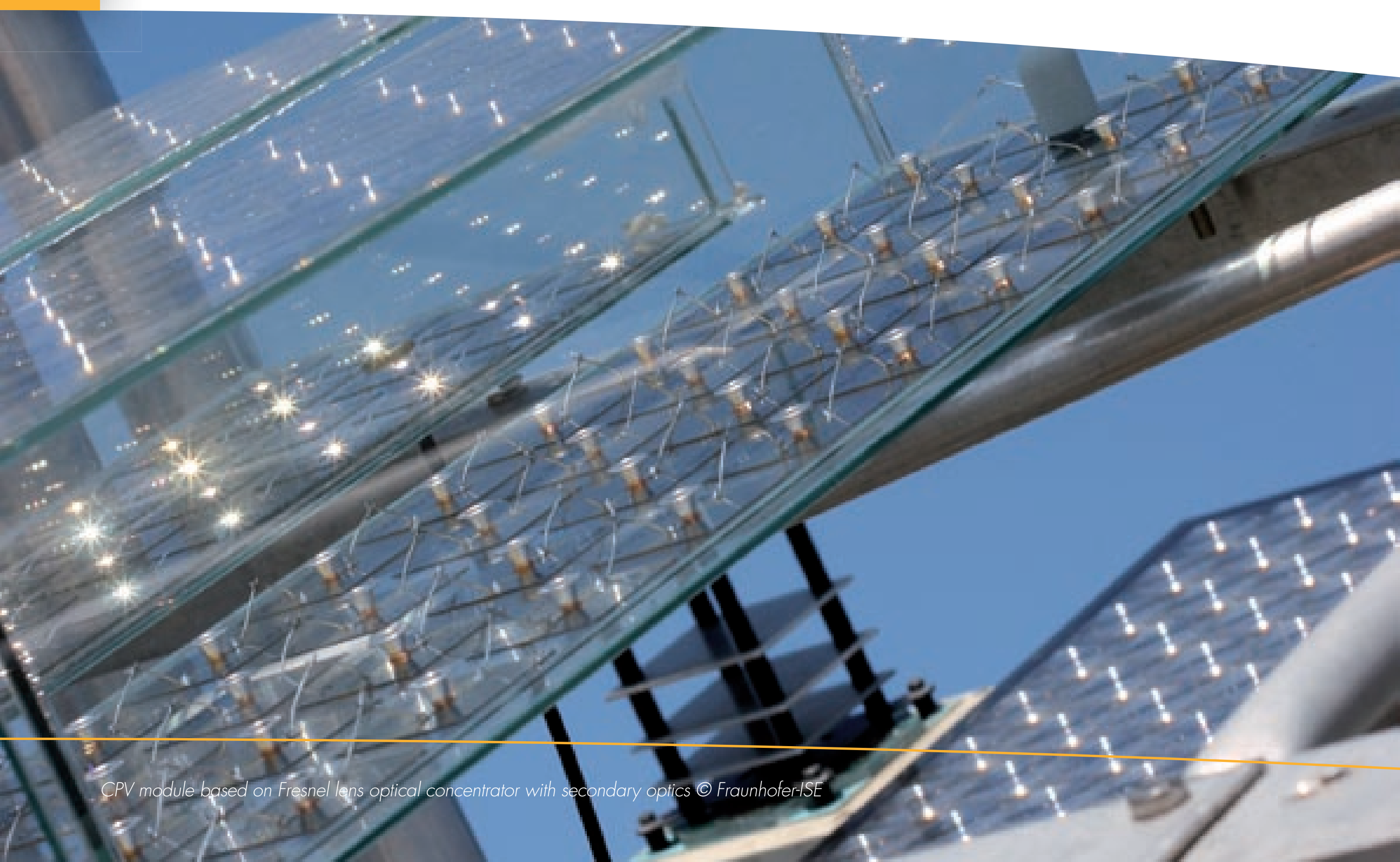


Figure 6: PV R&D funding requirements by timescale for exploitation

The majority of the budget (around 55%) is allocated to the first theme, *Enhancing Performance*, as might be expected. As well as fundamental research to identify and overcome any performance losses in PV devices (40% of the budget for research with a long-term impact), this category includes novel production equipment to translate advances in performance achieved in the laboratory into commercial production (almost two thirds of the overall budget for research with a short-term impact).

The theme *Improving Manufacturability* receives around 35% of the budget for each of the three exploitation timescales, reflecting the need of all cell technologies to address these issues in current and future products. *Promoting Sustainability* also has a similar share for each exploitation timescale (of around 5%), which is explained by the fact that it is necessary to address the issues of lifecycle assessment and recycling across all PV technologies as developments occur. Finally, *Addressing Applicability* receives around 5% of the budget on average, but with an increasing allocation to research for the longer term as new applications are developed.

Whilst this section has considered the overall budget for the development of PV technology in line with the performance and cost targets outlined previously in the SRA, some consideration has also been given to the enhancement of the sector in line with the current targets for renewable energy utilisation and the imperatives of the climate change agenda. In particular, the objectives of the Strategic Energy Technology Plan of the European Union ('SET Plan') [ECS 2007] have been taken into account in arriving at the indicative budget levels. The proposals of EPIA in regard to the SEII are a necessary part of the R&D required, but this document covers a wider range of projects and identifies a budget that is also consistent with the ambitious targets that the PV sector must reach in the coming years.



CPV module based on Fresnel lens optical concentrator with secondary optics © Fraunhofer-ISE

5.3 Research themes

5.3.1 Guide

In the tables that follow, research topics first presented in the SRA have been grouped by theme, then by sub-themes within each theme.

The second column of each table contains a research topic or reformulation of a set of research topics taken from the SRA. A more detailed description of the research work implied by the entries in this column, including the purpose of the work, can be found in the SRA. The four columns that come after it contain the following information:

- Topic type: the projects are allocated to Basic, Applied or Industrial research and development according to their nature.

Basic	Applied	Industrial

- Public/private funding split: depending on the nature of the project, it is expected that the funds required will be provided from a combination of sources, both public (European Commission, national or regional government) and private (industry, other private funding). One of five indicative combinations of public and private funding were assigned to each research topic.

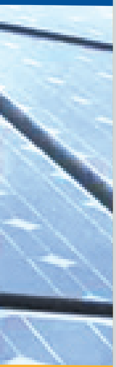
Public	100	75	50	25	12.5
Private	0	25	50	75	87.5

  The category of 12.5/87.5 includes many research projects that might be funded with 0% public money and 100% private money. Such work is included in this category because it is possible, too, that there are projects in the category that receive as much as 25% public funding. It is difficult to generalise about the public co-funding of industry-led projects, so 12.5/87.5 is our best guess of an average funding level.

- Funding level: the indicative funding level is given, using the following categories:
  €: up to 20 M EUR
  €€: 20-50 M EUR
  €€€: 50-100 M EUR
  €€€€: 100-200 M EUR
  €€€€€: over 200 M EUR

- An indication is given of the timescale by when the results of research that is funded now can be exploited in commercially-viable products, and the rows are ordered by this category.

Short: the result will be implemented in commercial products before 2013	Medium: implementation before 2020	Long: implementation after 2020



5.3.2 Tables classified by research theme

5.3.2.1 Enhancing performance

Research in PV devices over the last few years has seen major advances in efficiency, reliability and reproducibility, but it is clear that there is potential for further progress, both in device structure and in device topology. Key to these advances is an understanding of material properties and fabrication processes. These are the subject of the first two tables. Subsequent tables present the research required for specific aspects of device design and fabrication, and consider the new production equipment required for the fabrication processes. Devices themselves are considered in a table addressing advanced device concepts and in another addressing long-term stability.

In parallel, advances in system architecture and operation will allow the increases in cell efficiency to be reflected in the energy output of the system, as detailed in the table on system concepts.

This section concludes with research topics on standards and guidelines, which are essential for maintaining the quality of devices and systems; and on non-technical aspects, which include topics on the provision of skilled personnel, education of the public, user interfaces and the quantification of the benefits of PV.

⚠ **Acronyms and abbreviations used in the tables are defined in a glossary on the inside back cover.**

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC / PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
UNDERSTANDING MATERIALS AND DEVICES					
All thin films	■ Defect characterisation and control			€€€	
c-Si	■ Material physics and chemistry: optoelectronic properties, impurities, interfaces			€€€	
Concentrators	■ Material physics and defect control ■ Characterisation techniques for cells and modules			€€€	
c-Si	■ Defect control and engineering			€	
All thin films	■ Defect chemistry, process engineering and control			€€	
Concentrators	■ Characterisation techniques ■ Defect control			€€	
Emerging and novel technologies	■ Control of surface, phase and grain boundary effects			€€	
All technologies	■ Novel materials and devices			€€	

1. *Solar water villas in Mayersloot, Holland © ECN*
2. *1071 GeneCIS Solar Modules in the façade of the new World Jewellery Center in Milan, Italy © Würth Solar*

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
DEPOSITION TECHNOLOGY AND DEVICE PROCESSING					
c-Si	■ Process and production technology enhancing device quality (e.g. laser processing, new vacuum deposition technologies, advanced cell processing including lab/ pilot line demonstration)			€€€€€	
All thin films	■ Process engineering, alternative substrates and materials			€€	
All thin films	■ Advanced deposition techniques (fast, large area, material usage process control)			€€	
c-Si	■ Novel production/device technology (e.g. ultra-fine line metallisation, completely novel ARC and surface passivation process, new highest efficiency cell architectures, device simulation)			€€€€	
Emerging and novel technologies	■ Deposition techniques (large area, process control) ■ Morphology of organic solar cells			€€	
All thin films	■ Process and material engineering enhancing device qualities			€€	
All thin films	■ Industrial process engineering enhancing productivity (yield, control, deposition speed, energy)			€€€	

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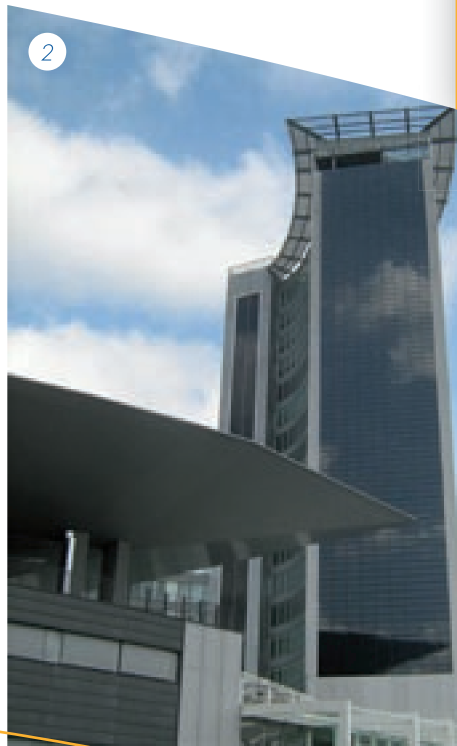
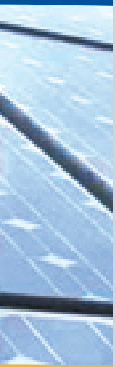




TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
ADVANCED MATERIALS					
c-Si	■ UMG and other novel technologies			€€€	
All thin films	■ TCO/semiconductor interfaces ■ Low cost TCO/substrate combinations for light trapping			€€	
All thin films	■ Improvement of the performance and stability of TCO layers			€€	
All thin films	■ Material screening and synthesis (reduction of/ alternatives for expensive materials)			€	
Concentrators	■ Novel materials (e.g. GaInNAs) ■ Low cost optical materials with high performance			€€	
c-Si	■ UMG and other novel technologies			€€	
All thin films	■ Alternative materials and deposition techniques			€€	
All thin films	■ Material screening and synthesis (reduction of/ alternatives for expensive materials)			€€	
Emerging and novel technologies	■ Dyes and polymers with extended coverage of the solar spectrum ■ Highly efficient selective emitters and IR-reflecting materials for TPV			€	
Concentrators	■ New III-V semiconductor materials (e.g. GaInN) ■ Growth of III-V semiconductors on Si			€	
All thin films	■ Material alternatives for improved performance			€€	
Emerging and novel technologies	■ Alternative II-VI semiconductors ■ Synthesis of materials for quantum confinement and proof of concept			€€	
Concentrators	■ New materials and combinations for cells, concentrating optics and modules			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
ADVANCED DEVICE CONCEPTS					
c-Si	■ Back-contact cell structures ■ Heterojunctions for emitters and passivation ■ Low recombination contacts ■ New device structures			€€€€€	
All thin films	■ Implementation of advanced optical concepts and device structures into industrial processes ■ Novel contact patterns ■ Novel series connection schemes and (laser) patterning methods ■ Patterning for BIPV applications			€€€	
Concentrators	■ Metamorphic triple cells ■ Optical concepts for very high concentration, increased acceptance angle			€€	
c-Si	■ Low recombination contacts ■ New device structures			€€€	
All thin films	■ Modeling, simulation and development of improved optical and electronic properties of heterostructures and devices ■ New cell concepts on existing and materials and novel structures			€€	
Emerging and novel technologies	■ Contacts with improved catalytic action in dye-sensitised solar cells ■ Solid electrolytes in dye-sensitised solar cells ■ Multijunction approaches for dye-sensitised and full organic solar cells ■ Superstrate configuration for poly-Si cells ■ Low bandgap TPV receiver cells			€€	
Concentrators	■ Cells with > 3 junctions ■ Cells, optics and thermal management for ultra-high concentration > 2500 suns ■ Systems for hybrid applications (thermal and electrical)			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
All thin films	■ Up/down converters and other novel concepts for very high efficiency	$\beta = f(x)/\sqrt{3}$		€€	
c-Si	■ Device concepts for organic/ inorganic hybrids and multijunctions, nanomaterials, quantum effects	$\beta = f(x)/\sqrt{3}$		€€€	
Emerging and novel technologies	■ Synthesis of bulk-type intermediate band materials + demonstration in PV-device ■ Introduction of up- and down-converters in existing PV-devices ■ Inclusion of plasmonic effects to boost efficiency	$\beta = f(x)/\sqrt{3}$		€€	
Concentrator cells	■ Novel cell concepts for efficiencies > 50 %	$\beta = f(x)/\sqrt{3}$		€	
Concentrator optics	■ Optics with high acceptance angle at high concentration level ■ Advanced optical systems for reducing tracking requirements	$\beta = f(x)/\sqrt{3}$		€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
LONG-TERM STABILITY OF CELLS AND MODULES					
c-Si	■ New long-term stable encapsulants ■ Hot spot issues			€	
All thin films	■ Quantitative ageing models and understanding of long-term stabilities	$\beta = f(x)/\sqrt{3}$		€	
All thin films	■ Outdoor performance ■ Sealing concepts, advanced lifetime			€€	
Concentrator Module	■ New sealing techniques for stable long-term field performance ■ Investigation of interaction between the materials used for module fabrication			€€	
Emerging and novel technologies	■ Building of failure models for dye-sensitised and organic PV cells	$\beta = f(x)/\sqrt{3}$		€	
All technologies	■ Accelerated and long-term testing of new concepts	$\beta = f(x)/\sqrt{3}$		€	

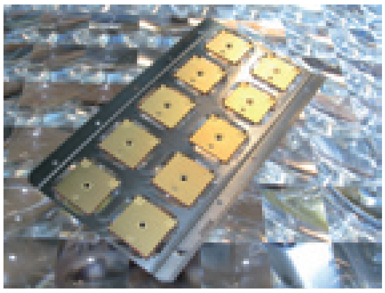
TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING AMOUNT	TIMESCALE FOR EXPLOITATION
SYSTEM LEVEL RESEARCH AND BALANCE-OF-SYSTEM COMPONENTS					
Power conditioning	■ Increased inverter reliability and lifetime to achieve > 20 years of full operation ■ Highly efficient inverters with new semiconductor materials (SiC, GaN) ■ New inverter topologies ■ inverters optimised for different PV module technologies			€€€€€	
Structure and mounting	■ Simplified module mounting structures (e.g. pre-fabrication of solar generators)			€	
Tracker	■ General purpose tracking platforms for all kinds of high efficiency modules ■ Combined inverter and tracker electronics, combined maximum power point and tracking algorithms ■ Smart tracking control ■ Increased tracking accuracy ■ Rapid detection of tracker failure ■ Solution for wind load effects ■ New tracker drivers			€€	
Storage technologies	■ Battery management systems for new generations of batteries ■ Battery ageing models specific to PV applications			€€	
Monitoring and prediction	■ Low cost control and monitoring of system output and measurement protocols ■ Output prediction and validation of prediction algorithms over short and long periods ■ Tools for early fault detection ■ Long-term average local radiation potentialss			€€	
Grid connection and supply aspects	■ Assessment of the value of PV electricity, including peak demand and UPS applications ■ Grid control and ICT for high penetration			€€	
High voltage systems	■ Technology development for systems > 1000V			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING AMOUNT	TIMESCALE FOR EXPLOITATION
Module development	■ Component development for minimisation of system losses (e.g. module with tolerance to partial shading, modules for operation at system voltage > 1000V)			€	
Power conditioning	■ Increased inverter reliability and lifetime to achieve > 30 years of full operation			€€	
Power conditioning	■ Multifunctional PV systems			€€	
Tracker	■ New tracker design concepts ■ Alternatives for steel in tracker construction ■ Sensorless tracking methods ■ Advanced control algorithms for grid stabilisation			€€	
Storage technologies	■ Innovative storage technologies for small PV systems (up to 50 kWh)			€€	
Monitoring and prediction	■ Strategies for centralised system monitoring (e.g. web based) ■ Fault detection tools for advanced system designs			€	
Grid connection and supply aspects	■ Interaction of PV with other decentralised generation ■ Development of power electronics and grid control strategies for improving the quality of grid electricity at high PV penetrations ■ Management of island microgrids with high share of PV capacity ■ New concepts for stability and control of electrical grids at high PV penetrations			€€€	
Tracker	■ Control algorithms for distributed inverter based grids			€	
Storage technologies	■ Module with integrated storage, providing extended service lifetimes (target of 40 years) ■ Technologies for high capacity storage (> 1 MWh) ■ Alternative storage technologies			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING AMOUNT	TIMESCALE FOR EXPLOITATION
PREPARATORY RESEARCH FOR STANDARDS AND GUIDELINES					
All module technologies and system types	■ Performance, energy rating, qualification and safety standards for PV modules, PV building elements, concentrator systems including trackers and PV inverters/AC modules ■ Guidelines for specifications and quality assurance of materials, wafers and cells, modules (including sizes and mounting techniques), components for concentrator systems and BoS components ■ Quality label for PV modules ■ Harmonise conditions for grid connection ■ Guidelines for design, installation and system test, monitoring/evaluation			€€€	
All module technologies and system types	■ Improve certification schemes, in particular for systems ■ Harmonise standards and guidelines applied to components			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING AMOUNT	TIMESCALE FOR EXPLOITATION
NON-TECHNICAL ASPECTS					
Information transfer	■ Industry training needs for the short and medium term ■ Optimisation of technology transfer to construction and electricity supply sectors ■ User interaction – optimisation of the user interface ■ Public awareness and information dissemination schemes relating to large scale deployment of PV technology			€€	
Cost/benefit analysis	■ Identification and quantification of non-technical costs and benefits of PV technology			€	
Market analysis	■ Development of scenarios for high PV penetration ■ Financing models and operating schemes for sustainable rural electrification			€€	
International collaboration and capacity building	■ R&D co-operation for emerging markets ■ Socio-economic and educational joint ventures with developing countries			€	

5.3.2.2 Improving Manufacturability

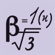
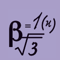


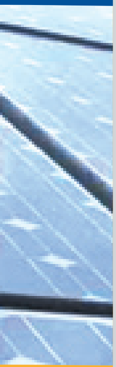
The research topics in this theme aim to reduce the cost of manufacturing whilst maintaining the performance of PV technology. As before, the research topics are split into sub-themes, each addressing an important aspect of the manufacturing process and its development.

The first set of tables considers the manufacture of cells and modules, looking first at advanced manufacturing processes and improving productivity. Subsequent tables focus on important elements of the manufacturing process, including raw material supply, TCOs and substrates, as well as module design, packaging and encapsulation. Finally, research on standards for manufacture are discussed as well as advanced pilot line concepts, successful pilot production runs of technology being crucial to the transfer of technology from the research laboratory into large-scale manufacturing. Concentrator systems have certain specific requirements so two tables are devoted to research on the manufacture of the related optics and tracking system. Finally, BoS components and system level research are considered.

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
ADVANCED MANUFACTURING PROCESSES					
c-Si	■ New Si feedstock technologies < 25 EUR/kg ■ Advanced wafering technologies (wafer thickness < 150 µm), low kerf losses, fracture mechanics ■ Improved crystal growth ■ Reusable crucibles with low impurity levels ■ Wafer equivalent technologies ■ Metal pastes suited for thin wafers ■ Contacting and surface passivation techniques ■ In-line high-yield processing ■ Roll-to-roll/automatic module manufacturing ■ Equipment development for novel manufacturing processes			€€€€	
All thin films	■ Deposition speed and yield ■ Alternative deposition methods ■ Novel interconnect structures ■ In-line quality control techniques and tools			€€€	
Concentrators	■ Improved cell designs for all concentration levels ■ Improved MOVPE growth processes ■ Establish stable industrial-level manufacturing processes for Si and III-V concentrator cells			€€€	

Illustration: Solar cell assemblies equipped with GaInP/GaInAs/Ge triple-junction solar cells and bypass diodes on top of a Fresnel lens plate, as they are used in FLATCON® concentrator modules © Fraunhofer-ISE

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
c-Si	■ New silicon feedstock technologies 20 EUR/kg ■ Novel wafering technologies (wafer thickness < 120 µm) ■ Low defect (high electronic quality) silicon wafers ■ Wafer equivalent technologies ■ New electrode technologies ■ High speed cell and module processes ■ Equipment development for novel manufacturing processes			€€€	
All thin films	■ Large area and fast deposition: alternatives to current deposition methods ■ Large area control methods ■ Modified device structures ■ Alternative TCOs and processes thereof, light confinement	 		€€€€	
Emerging and novel technologies	■ Advanced contacting and metallisation schemes (printed TCOs, printed metallisation fired at low temperatures, nano-inks) ■ Advanced application technologies (e.g. spraying) for active layers ■ Roll-to-roll manufacturing of cells and modules on flexible substrates ■ High-temperature substrates for thin-film poly-Si cells ■ High-throughput Si deposition for thin-film poly-Si cells			€€€	
Concentrators	■ Advanced manufacturing processes for III-V multijunction solar cells ■ Low cost design concepts and manufacturing processes for silicon cells for moderate concentration and moderate climates			€€	
c-Si	■ New Si feedstock < 15 EUR/kg ■ Novel wafering technologies (wafer thickness < 100 µm) ■ Low defect (high electronic quality) silicon wafers ■ Wafer equivalent technologies ■ Integrated cell and module processes ■ Equipment development for novel manufacturing processes			€€	

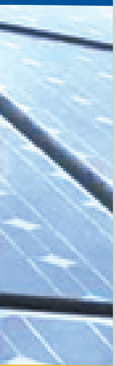


TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
All thin film	■ Novel very high speed deposition methods			€€	
Emerging and novel Technologies	■ Roll-to-roll manufacturing of cells and modules on flexible substrates			€	
Concentrators	■ Fully automated, high-throughput processes for large scale ■ Manufacturing concepts for 4- to 6- junction cells			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
PRODUCTIVITY IMPROVEMENT					
c-Si	■ Productivity and cost optimisation in production			€€€€	
All thin films	■ Very high deposition rates			€€	
All thin films	■ Productivity and cost optimisation in production ■ Equipment standardisation			€€€€	
Emerging and novel technologies	■ High-throughput epitaxial Si deposition for thin-film poly-Si cells ■ Advanced application technologies (e.g. spraying) for active layers			€	
c-Si	■ Productivity and cost optimisation in production			€€€	
All thin films	■ Large-area module equipment ■ High-throughput, high-yield equipment, requiring low material and energy inputs			€€€	
All thin films	■ Ultra-high-throughput processes and equipment ■ Manufacturing challenges specific to very large production units			€€	
Emerging and novel technologies	■ Reproducible production of quantum-confined materials (size, shape) ■ Reproducible production of metallic nanoparticles in sufficient quantity and quality (size, shape)			€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
MODULE DESIGN, INCLUDING PATTERNING					
c-Si	■ Low cost framing/mounting ■ Standardisation of cells and modules			€	
All thin films	■ Standardise products and production equipment between the TF-/CIGSS industries			€€	
c-Si	■ Frameless structures ■ Integrated cell and module designs and processes			€€	
All thin films	■ Alternative cell structures, interconnects and methods			€€	
Thermo-photovoltaics	■ Development of module concepts for TPV systems (including monolithic approaches)			€	
All thin films	■ Transfer of R&D to large-volume manufacturing			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
PACKAGING AND ENCAPSULATION					
c-Si	■ New low-cost, high-quality encapsulants			€€	
All thin films	■ Low-cost and application-adapted packaging processes and equipment			€€	
Emerging and novel technologies	■ Low-cost sealing methods for dye-sensitised and full organic solar cells			€	
Concentrators	■ Approaches for high-throughput assembly			€€	
c-Si cells	■ Conductive adhesives or other solder free solutions for module interconnection			€	
All thin films	■ Alternative sealing solutions			€€	
Concentrators	■ Concepts for automated pre-mounting of modules			€	
c-Si cells	■ Processes and designs for module efficiency > 25%			€	
All thin films	■ Transfer of new solutions to high-volume production			€€	

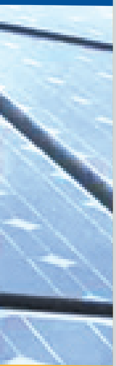


TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
Emerging and novel Technologies	Adapted encapsulation methods for novel cell concepts (e.g. including nanoparticles)			€	
Concentrators	Concepts for GW_p range module production			€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
ADVANCED PILOT LINE CONCEPTS					
All thin films	High-rate deposition on large-area			€€€€	
Emerging and novel technologies	Advanced and adapted test/control methods in production Transfer and qualification of new concepts in industrial pilot			€	
All thin films	Proofs of concept of modified/new deposition methods, process and material variations in pilot scale			€€	
Emerging and novel technologies	Advanced and adapted test/control methods in production Transfer and qualification of new concepts etc. in industrial pilot			€	
c-SI	Qualification of advanced technologies for large-volume manufacturing (pilot)			€	
All thin films	Qualification of advanced technologies for large-volume manufacturing (pilot)			€€€	
All thin films	Advanced and adapted test/control methods in production Transfer and qualification of new concepts in industrial pilot			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
OPTICS MANUFACTURING PROCESSES					
Concentrators	■ Primary- and secondary-optics for medium and high concentration with wider acceptance angle ■ Technologies for improved alignment of optical parts and cell assembly			€€	
Concentrators	■ System design using materials for 85% optical efficiency in mass production			€	
Concentrators	■ New technologies for large area coatings (ARC, mirrors)			€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
SYSTEM LEVEL RESEARCH AND BALANCE-OF-SYSTEM COMPONENTS					
Systems	■ Reliable electronic components, new design structures, new semiconductor devices			€€	
Systems	■ Standardising system components to facilitate economies of scale in manufacture and simplify replacement			€	
Systems	■ Low cost support structures, cabling and electrical connections for domestic and large ground based PV systems ■ Prefabricated ready-to-install units, particularly for large grid-connected systems			€€	
Systems	■ Introduction of new storage technologies in pilot units for large field trials and assessment of lifetime and cost			€	
Trackers	■ Production technology for trackers with accuracy < 0.2°			€	
Systems	■ Low cost AC modules with integrated inverters ■ Development of low cost installation techniques for complex terrains			€€	
Systems	■ System integration for TPV applications			€	
Trackers	■ Concepts for automated mass production of trackers			€	



5.3.2.3 Promoting Sustainability

An attractive feature of PV is its environmental benefits, principally electricity with very low lifecycle greenhouse gas emissions. But the sector must strive to reduce its negative environmental impacts further. PV technology must be manufactured in a way that minimises the use of hazardous materials and their release into the environment. The lifetime of PV technology must be extended to minimise resource requirements. Recycling or reuse schemes must be developed and implemented.

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
LOW ENVIRONMENTAL IMPACT MATERIALS AND PROCESSES					
All technologies	■ LCAs on modules (especially thin-film and concentrator modules) ■ LCAs on BoS components ■ Environmental impact assessment at system level for all applications			€€	
All thin films	■ Reduce material thickness, purity for reduced costs			€	
c-Si	■ Avoidance of hazardous materials ■ Replacement of scarce materials ■ Low environmental impact manufacturing			€	
All thin films	■ Minimisation of energy in production ■ Avoidance of hazardous materials ■ Reduction of material consumption (device, deposition, recycling)			€€	
Emerging and novel technologies	■ Development of In-free active layers and Cd-free window layers for CIS-based cells (new concepts) ■ Development of processes for dye-sensitised and full organic cells avoiding harmful solvents ■ LCAs on emerging cell/ module technologies			€	
Concentrators	■ Optimisation of material utilisation (lightweight construction)			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
c-Si	■ Reduced silicon consumption, low energy content solar-grade silicon compatible with an energy pay back time < 6 months			€	
All thin films	■ Waste and energy management in production ■ Reduction/replacement of expensive raw materials			€	
Emerging and novel technologies	■ LCAs on novel cell/module technologies			€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
EXTENDED LIFETIME					
c-Si	■ Materials and concepts for lifetimes > 35 years			€	
Concentrators	■ Increase stability of optical systems ■ Guaranteed module lifetime: > 25 years			€€	
All thin films	■ Enhanced life times > 35 years			€	
Emerging and novel technologies	■ Improved stability for dye-sensitised and fully organic cells			€	
BoS components	■ Bringing the lifetimes of different components into line with each other > 25 years ■ Understanding and managing the influence of the climate on system and component lifetimes			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
RECYCLING					
c-Si and all thin films	■ Develop and implement recycling processed for all current products			€	
All technologies	■ Recycling processes for all new products ■ Economic and logistical aspects of PV module and component reuse and recycling			€€	

5.3.2.4 Addressing Applicability

The fact that PV can be used in different kinds of application sometimes requires the development of products to address the specific needs of each. The tables below consider this aspect of the technology. The first table considers aesthetics and suitability, particularly in relation to building integration, where the challenges relate to both the appearance and functionality of the module and its support structure. The second table considers system design for a specific purpose (e.g. stand-alone systems) and the final table considers some non-technical issues relating to markets and finance.

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
AESTHETICS AND SUITABILITY					
c-Si	■ New frames and support structures			€	
BIPV modules	■ Advanced modules for BIPV applications that are multifunctional, self-cleaning and serve as construction elements			€€€	
BIPV systems	■ System optimisation for low energy buildings ■ Active (energy producing and regulating) façades ■ Integration into home control systems ■ Characterisation of performance ■ Interdisciplinary architectural research			€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITATION
SYSTEM DESIGN					
Concentrators	■ Design optimisation for easy transportation and installation for utility applications ■ Power plant engineering and grid connection			€€	
Stand-alone systems	■ Highly reliable, low maintenance components for stand alone systems for development applications			€€	

Illustration: DESIGNline PV system with GeneCIS modules © Würth Solar

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITA-TION
Systems	Trackers for larger systems (maintenance-free, low energy consumption, high reliability and stability) Inverters that actively stabilise the grid and improve grid power quality Procedures for easy mounting and replacement Integration of short-term storage			€€	
Concentrators	Combined use CPV and thermal solar energy			€	
Systems	Inverter-based grids Standardised village grids Hybrid systems for rural applications Integration of long-term storage			€€€	

TECHNOLOGY AREA	ACTION	TOPIC TYPE	FUNDING PUBLIC/ PRIVATE	FUNDING LEVEL	TIMESCALE FOR EXPLOITA-TION
NON-TECHNICAL ASPECTS					
Market development	Market development research, including efficiency of financial schemes for promoting PV in different markets Regulatory aspects of market development – insurance, contracts, planning issues			€	
Financial control	Managing incentive schemes for PV efficiently Billing and metering schemes for off grid PV systems			€	

5.4 Reasonable figures?

Is 3½ bn EUR a reasonable figure to ask industry to spend on R&D in Europe before the end of 2013? The question is not, of course, easy to answer, particularly given the uncertain economic situation. Doubt over the future of incentive schemes and the financial crisis might mean difficulties on the demand side, and in sustaining growth. The correct reaction of companies to this uncertainty should be to accelerate product development in order to meet cost and performance targets sooner rather than later, spending R&D money all along the value chain.

This level of spending would probably be necessary if the industry is to follow the accelerated scenarios of 'SET for 2020' and to keep a substantial share of the global market. We recognise however that it does imply an acceleration of spending from only a few percent nowadays to possibly more than 5% of total European PV turnover. The good news is that there is some evidence that spending on R&D might increase in 2009 or 2010 as companies use the lull in demand to maintain their equipment and perform R&D.

PV, in both its manufacture and deployment, impacts on other industrial sectors and can benefit from the knowledge of those sectors (see chapter 7, 'Assimilate knowledge from beyond the PV sector'). There has been no attempt to quantify what proportion of the research budget could reasonably be expected to be sourced from beyond the PV industry (e.g. in relation to electricity storage systems) or from public sources allocated to programmes not specifically targeted to energy production. However, it is clear that some cross-fertilisation is both possible and advantageous.

20kW PV installation on an AGIP petrol station, Italy © Centro Ricerche Eni – Istituto Guido Donegani

6 Guidelines for using public money efficiently on PV research projects

In the SRA and in this Implementation Plan, we called on governments to make top-down decisions on how to allocate money to research with medium- and long-term prospects for commercialisation. Such research is generally high-risk and there is no natural 'market pull' for it. The preceding chapters in this Implementation Plan have shown both where public sector money can help and where the private sector is the most suitable source of R&D funding.

Here we discuss the process by which research should be funded to use this money effectively. Our observations and recommendations pertain mainly to EU-level research.

6.1 What participants in (part-) publicly-funded R&D programmes want

6.1.1 Good administration

It is no surprise that researchers want their lives to be made as simple as possible. They want straightforward, easy-to-understand procedures for applying for grants. Their proposals must be handled swiftly. The costs they incur in carrying out their projects must be refunded promptly.

The smooth-running of a project consortium is highly dependent on the partners in the project. Project leaders should have the freedom to work with the best partners for their task, irrespective of any artificial, administrative barriers that might happen to come between them, like borders (see section 3.2). Conversely, the participation of partners from other countries in research consortia should not be forced.

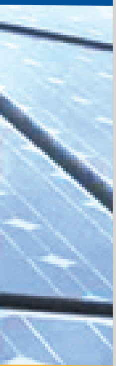
There should be no directly competing industrial partners in the project unless the project is designed such that they would collaborate in solving a problem that they both need a solution to (in this case, they would most likely participate as the users or validators of a project's results).

There are considerable inefficiencies associated with restarting research in a particular area after a period when it has not been funded (researchers have to be re-recruited, equipment re-purchased, leases on facilities re-negotiated). Rather than funding research in this 'stop-and-go' manner, it is better gradually and/or steadily to scale up or scale back research in a particular area, and better still if this intention is announced well in advance[6]. This Implementation Plan, indicates the need, exceptionally, for a rapid and large increase in funding for PV. It is more important to achieve this increase and accept some transient inefficiencies than to delay it for the sake of achieving the increase more elegantly.

Finally, critical evaluations of the impact of research projects and programmes must be carried out as a matter of routine.

Some of these ideas are among the lessons learned from 'CrystalClear' (a 16 partner project funded by the European Commission that lasted 5½ years with a total budget of 28 M EUR) – see box on next page.

6. For example, it is known that the annual budget of FP7 for collaborative research will be roughly 75% greater in the final year of FP7 (2013) than in the first (2007).



6.1.2 A pragmatic approach to managing intellectual property

The agendas of private companies and public research centres on the management of intellectual property are different. As the German Government pointed out in its position paper on an intellectual property charter, circulated to other European governments when it held the Presidency of the EU in 2007, "Whereas research institutions tend to be mainly interested in the publication of the research results, industry is interested in preventing disclosure and in filing and exploiting protective rights." [BMBF 2007]

The different interests of research institutions and industry can be reconciled within a project, or by designing funding instruments that cater for the specific interests of each class of participant.

Reconciliation

Each side can move a long way towards accommodating the other's interests within a project. Indeed, many, if not most, of Europe's leading research centres in PV receive a part of their income from participating in projects co-funded by industry. The principle that the higher the ratio of public to private funding, the greater control the research institution has over the dissemination of knowledge created in the project ('foreground') is widely accepted.

The ownership of foreground is handled pragmatically. Industry understands that its ownership of foreground restricts the ability of research institutions to push forward the frontier of knowledge outside of the project, and is hard to justify if it has been acquired with public funds. Research institutions understand that industry must see an opportunity to gain a competitive advantage from participating in the project. The solution is increasingly to give the industry partner(s) in a project the exclusive right to exploit the knowledge commercially for a fixed period before it is licensed to third parties. This is a standard condition placed, for example, on the projects funded within Germany's 'Spitzencluster Solarvalley Mitteldeutschland' (see box below).

CRYSTALCLEAR – LESSONS LEARNED

- defining, explaining/translating and communicating overall targets is key to building a project team (corporate spirit), Putting the target into a broader perspective, e.g. reaching grid parity, can be very motivating;
- "integration" activities may be small in size, but are big in effect;
- finding the balance between partner interests and consortium interests is difficult, but essential for success;
- long duration (including annual re-planning) allows for implementation of practical lessons learned within the project and gradual focusing of R&D, this has been another key to success;
- combining skills in the field of science & technology with complex project management & administration is crucial to manage projects of this size and complexity;

SPITZENCLUSTER SOLARVALLEY MITTELDEUTSCHLAND

Each SVM project is governed by a consortium agreement setting out how IP is to be handled. In general, foreground is owned by the organisation that created the foreground. All partners in the R&D project get a free licence to use the foreground. The foreground can also be sold to an entity outside the project, such as one of the partners' competitors, for a fair price, but before this can happen, the partners in the project must be given a chance to buy exclusive rights to the foreground, again at a fair price.

Segregation

'Segregation' is a simply a label for the idea of instruments designed to meet the specific wants of industry and research institutions. Section 6.2 outlines two such instruments suitable for funding PV R&D at European and national level.

6.2 New approaches for funding R&D in PV

6.2.1 An instrument for industry: publicly-supported 'open innovation'

'Open innovation' is a model for European companies to acquire intellectual property by sharing the costs and benefits associated with generating the knowledge by jointly contracting work to one or more R&D centres. Such programmes go by various other names, including 'collective R&D' and 'early and shared insight'. An example from Germany, the 'Forschungsvereinigung' is described in the box below. 'Open innovation' is attractive for companies that want to have access to the latest science in their field, but that need a way to contain the costs associated with pursuing a multiplying number of possible lines of enquiry. The disadvantage to them is that because they have commissioned the research with other companies, they share an entitlement to exploit the knowledge with their competitors.

In the microelectronics business, where R&D costs have grown faster than revenues for over a decade, many companies have found the advantages to outweigh the disadvantages. With downward pressure on the price of PV technology because of cuts to incentive schemes, and with a need to increase process complexity in order to reach higher cell efficiencies, new technologies have to be brought to the market faster and at lower overall cost. One research centre, IMEC (in Belgium), has decided the time has come to apply 'open innovation' to PV (box on next page).

FORSCHUNGSVEREINIGUNGEN

Germany's FV model is entirely about large groups of companies – often SMEs – that manufacture a particular kind of product clubbing together to contract research work to research centres. They each pay a small amount of money to an association set up for this purpose, the 'Forschungsvereinigung'. This financial contribution buys them access to all the research work privately funded by the association. Public money can co-fund a project, but where this happens, the results are put in the public domain.

A mechanism operates inside the association to allow all members to propose a project for funding by the association. The progress of the projects is monitored by the association by committees of people with relevant experience.

Forschungsvereinigungen have existed in some sectors of the German manufacturing industry for decades. A typical FV project in mechanical engineering would last 2 or 3 years, cost about 300-350 k EUR and tie up the time of one junior researcher and a supervisor.

The European Commission research funding programme, FP7, provides two instruments for making available one-off grants to either SMEs collectively contracting research, or SME associations contracting the work on their behalf. FVs, meanwhile, are supported by a public funding agency that expects to be providing funding year after year.

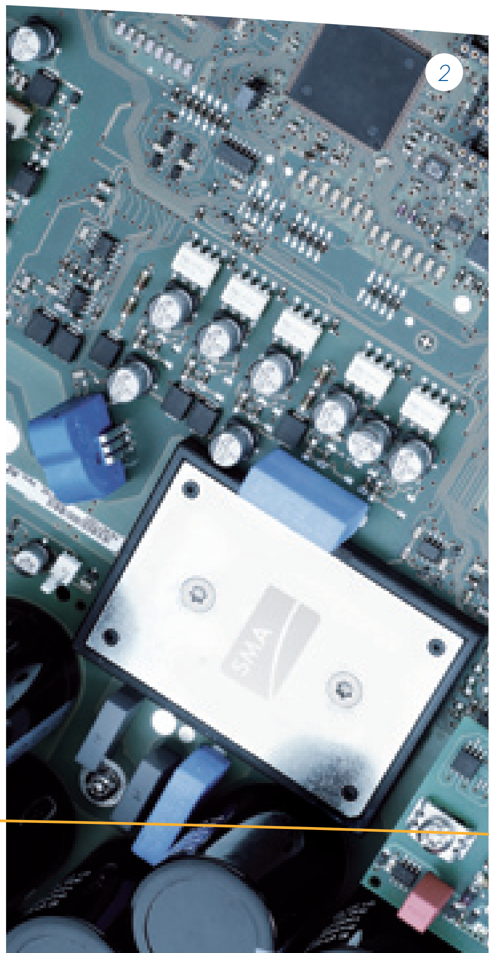
'Open innovation' in PV would apply to research in process technology development yielding 'generic' results, i.e. with potential for adoption by a large number of the companies co-funding the research (device/system manufacturers, material and equipment suppliers). Assuming the research is successful, the results would need to hold out the potential for the companies to develop proprietary intellectual property from them, which would result in their implementation in industrial-scale production lines in 3 to 10 years. The SRA, which describes what research needs to be done and by when, and this Implementation Plan, which identifies the resources that will need to be committed to specific areas and the party that should commit them, are together a good basis on which to build consensus with the industry on the areas that 'open innovation' should address.

IMEC'S 'OPEN INNOVATION' PLATFORM

In June 2009, Schott Solar entered into a 3-year agreement with IMEC that will enable their researchers to work closely with IMEC's to build up knowledge in wafer-based bulk silicon solar cells and epitaxial thin-film (< 20μm) silicon solar cells on low cost silicon carrier.

Other silicon solar cell manufacturers, equipment and material suppliers are invited to join the programme. They will share intellectual property, risk and cost with each other. [IMEC 2009]

Industry-funded R&D in PV will continue very largely to be done in-house including, increasingly, on purpose-built experimental lines. 'Open innovation', at least in its early years, will account for a very small percentage of industry's total R&D budget (currently 5% in micro-electronics). Although it should be in the self-interest of companies to fund such schemes from the outset without public subsidy, at least initially, some inducement will be needed to overcome their conservatism. This inducement could be the promise to equip the research centre(s) willing to participate in 'open innovation' with the latest research apparatus.



1. New 4 GW plant manufacturing Sunny Boy PV inverters © SMA

2. Printed circuit board of a modern PV inverter with customised power electronics module © SMA

6.2.2 An instrument for research centres

'Open innovation' puts industry in the driving seat for defining and funding research areas with short- to medium-term prospects for yielding commercially-applicable results. But research with medium- to long-term prospects for commercialisation needs to be defined by a set of actors more attuned to the potential offered by a new technology long before it reaches the market. These actors are to be found in the academic community: researchers in universities and publicly-funded research organisations.

Below, we sketch out the features of a funding instrument that could help these actors work effectively on such topics. Projects funded with the instrument could be called 'flagship innovation projects', or, at European level, they could be what Framework Programme-funded PV research naturally evolves into once the SEII becomes operational.

Flagship innovation projects would carry more risk than current FP7 projects typically carry and would aim to discover or invent something with the potential to disrupt or transform the evolution of PV technology. To achieve such breakthroughs will require persistence. These projects will need a long-term funding plan. Research centres would lead them and they would tend to involve a small number of partners (typically 4 or 5).

6.2.3 Equipment Development Projects

Much R&D requires access to the manufacturing equipment that will be used when the technology under investigation reaches full-scale production. This is obviously the case for microelectronics (where researchers need access to tools allowing processes on 300 and, in future, 450 mm diameter wafers, which are, or are soon to be, standard in the microelectronics industry) but is also relevant for PV. Procurement of such systems is often beyond the budget of R&D-institutes, but with a small incentive, it should be possible to convince equipment manufacturers to make available an alpha- or beta- version of their tool to one or more research centres for a much reduced price. In return, the research centre shares the results of tests on the tool with the manufacturer, and provides the manufacturer with a full understanding of the effects of parameter variation on its performance.

6.3 Greater co-ordination between public funding agencies

6.3.1 European countries should stay informed of the breadth and depth of other countries' research programmes

A country can only gain from knowing and understanding the research policy of other countries. The governments of the EU acknowledge this in their conclusions on the SET Plan [ECS 2007], where they support the EC's idea to "establish an open access European energy technology and knowledge management system". In PV, a good recent example of such a system is the database of nationally supported projects and programmes compiled for the 'PV-ERA-NET' project (www.pv-era.net). Funding must be found to improve and update such databases continually.

6.3.2 Countries should implement their R&D policy coherently

PV research progresses faster the larger the pool of expertise that can be called upon to solve a particular question. Enlarging the pool of expertise is partly a human resources challenge (more scientists and engineers needed – see chapter 8, 'Education and Training'), but it also about using the talent of those people who already work in PV research more effectively.

Administrative barriers to international collaboration between research institutions in research projects should be dismantled. Initiatives that aim to do this must be sensitive to a country's reluctance to tamper with a system that it put in place and that it finds works effectively. Every step that a country takes towards greater transnational co-operation must be taken in its national self-interest.

The kinds of measures that facilitate transnational collaborative research are:

- Allowing the participation of foreign partners in a nationally-funded research project
- Allowing the combination of national funding and EC funding within a project
- Calls for proposals on the same topic with the same deadline in each country
- A standard proposal evaluation procedure
- A standard application procedure

The PV ERA NET project identified two distinct areas, complementary to national and EU-funded research, where joint projects between different national programmes have good prospects:

- Increasing collaboration in pre-commercial research fields (early in the PV value chain): exchange of experience and support for research teams that are small or isolated and that could perform better given the chance to make connections with teams in other countries

  Achieving a critical mass in a specific field can be the objective of such joint activities. For interdisciplinary subjects (for example, polymer and organic solar cells), connecting small teams specialised in particular areas in a single project can have a big impact. Sometimes it is enough to bring these teams together by networking rather than with a research project, especially in the case where one research team has access to a specific tool that another one needs.

- Supporting system integration and standardisation (towards the end of the PV value chain):

  Quality and reliability of PV systems are general objectives which most countries define as their goals. Typically, this concerns component and system related topics beyond the competitive domain of individual technologies. If countries plan and fund research work aiming at defining a new standard together, a standard can be found that complies with as many of their regulations as possible. Work on standards is particularly relevant to system-level research (BoS components, grid-connection, stand-alone functionality, integration of local electricity storage technology).

Countries have yet to decide how much they want to force transnational collaboration. Should national funding agencies call for proposals where one (or more) foreign partners is required in order for a proposal to be eligible (the feature of PV-ERA-NET's 'Polymol' call)? Some initial forcing may mean that a natural instinct to collaborate internationally emerges sooner among research institutions. The pragmatic approach might be to reward proposals that include foreign partners with higher financing rates rather than make their inclusion an eligibility criterion.

Development of 100 kVA multi-functional PV-Inverter © ISET e.V./Fraunhofer-IWES

ERA AND EERA

The European Research Area (ERA) and European Energy Research Alliance (EERA) both attempt to enhance collaboration between the R&D funding agencies of different Member States and between the research centres of different Member States and to align their work with the European Commission's strategy. In the ERA model, this happens through groups of Member States' funding agencies jointly launching calls for research projects and exchanging information on the R&D projects that they run.

The EERA model addresses the Member States' research centres directly and invites them to agree to commit a certain amount of financial, human or infrastructural resources to a particular area of research in order to follow a strategy agreed among themselves.

Both ERA and EERA are best suited to medium- and long-term research topics.

There is some evidence that research institutions might not need much persuading to create joint work programmes with foreign counterparts. The European Energy Research Alliance [EERA], conjured into being by the SET Plan, is a network of research centres that want to explore whether they can press ahead with this mission without waiting for their ministries or funding agencies to spur them (box on left).

The High Level Steering Group of the SET Plan is a forum where decisions on the co-ordination of research policy can be made at a high level: where countries could agree, for example, to commit to focusing on researching a particular area described in the SRA. Unlike the FP7's Programme Committees and Member States' delegates in the Council of Ministers, it has no formal role in deciding how Framework Programme money is spent.

6.4 Make optimal use of research infrastructure in Member States

Another aim of the EERA is to develop policies for helping research centres access each others' experimental apparatus. In PV research, an expensive but sought-after piece of equipment is the experimental production line, or 'platform'. In Annex A, five such facilities and the uses that they are put to are described (PVcomB, PV-TEC, RESTAURE and facilities at ECN and IMEC). Our recommendation is that access to these lines should not come to be governed by a 'sellers' market'. Lines must be upgraded and expanded and new lines must be built to keep pace with demand.

7 Assimilate knowledge from beyond the PV sector

7.1 Introduction

PV is related to many other sectors of research and industry. On the one hand, the use of PV requires direct interaction with other areas of technology, e.g. the building sector, electricity networks or advanced power storage devices. On the other, areas of research and technology that are not directly linked to PV can contribute significantly to improving the efficiency of cells, and to finding new materials and production methods to enhance their productivity and sustainability.

In this chapter, some ideas are put forward on how knowledge from sectors outside of PV technology can help in implementing the targets of the SRA.

Part 7.2 focuses on knowledge from other technology sectors. Ideas for specific Technology Platforms for the PV community to link to are listed in Part 7.3. Part 7.4 provides some ideas of knowledge from non-technology areas that could also support the attainment of the SRA targets.

7.2 Knowledge from other technological sectors

The chapter 'PV research topics: who should do what with how much' identified R&D topics, several of which require interaction with or support from sectors beyond the immediate realm of PV. The following table is structured according to the type of knowledge that must be brought in from other sectors. The rows follow roughly the order of the PV value chain.

A new type of fully automatic, high-throughput, small-footprint in-line equipment for mass producing c-Si cells © Singulus

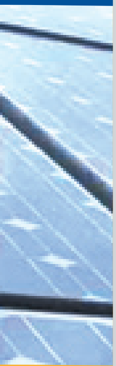
Such external knowledge can concern standards and norms applicable in fields related to PV like electrical grids or buildings. It can have its origin in R&D activities and technologies related to PV by the manner in which they are manufactured or used or in other Technology Platforms that are likely to interact with PV.

EXTERNAL KNOWLEDGE	TYPE OF SOURCE	INTERACTING PV TECHNOLOGY	POSSIBLE CONTRIBUTORS	WAYS TO INTERACT	EXAMPLES
Photonics & plasmonics	R&D, industry	Nanomaterials, Cells, Modules, Optical systems for concentration	Data transmission systems industry, R&D-groups working around nanoparticle synthesis and photonic IC's (including photonic crystals)	Application of the know-how to increase efficiency of cells or systems	Nanomaterials to enhance photon absorption
Micro & nano technology	R&D, industry	Materials, Cells, Modules	Physics and chemistry of interfaces, tailoring of surfaces; MEMS	Finding new ways to tailor surfaces and interfaces to increase cell and system efficiencies.	Advanced texturing, lateral structures for new cell concepts
Material modelling	R&D	Materials, Cells, Modules	R&D-groups; prediction of optical and electrical properties of novel materials	Application of material simulation tools to obtain optical and electrical information on promising materials and material system	Absorbers, functional layers, up-/down converters and others
Opto-electronic processing & manufacturing	R&D, industry	Cells, Modules	For CPV-technology: Equipment manufacturers (die placing, thick and thin wire bonding, encapsulation)	Adaptation of existing equipment, transfer of existing processing technologies (e.g. LED, laser)	Thermal management of high power devices; encapsulation used as secondary optics (LED as an example)
Chemical processes	R&D, industry	Cells	Semiconductor industry, ETP sustainable chemistry	Improvement of existing cell production processes and adaptation of ideas to improve efficiency and cost of ownership	Galvanics for metal grids of higher purity, less material usage in chemical processes, recycling
Printing technology	Industry, R&D	Cells	Printing industry, R&D groups	Common industry activities and R&D schemes to find cost efficient methods for structured surface coatings	Front grids, other structures, deposition processes for organic cells
Organic electronics	R&D, industry	Cells	Industry and R&D groups related to OLED, RF-ID etc; material suppliers	Adaptation of methods and materials from other organic electronics applications for organic solar cells	Stable organic electron donors and acceptors, graphenes as TCOs, materials for 2-photon absorption

EXTERNAL KNOWLEDGE	TYPE OF SOURCE	INTERACTING PV TECHNOLOGY	POSSIBLE CONTRIBUTORS	WAYS TO INTERACT	EXAMPLES
Vacuum & thin-film deposition processes	R&D, industry	Cells, Modules	Equipment and component manufacturers, R&D groups, semiconductor, display, glass, optical industries, plasma experts (e.g. INPLAS)	Industry and R&D collaborations regarding modelling of deposition rates and distribution; more efficient and alternative sources, materials and methods, improved cleaning and uptime, alternative production processes → improvement of efficiency and cost of ownership	Improved ARC, metal, absorber layers, TCOs, etching, diffusion barriers
Automation know-how	Industry, standards	Cells, Modules	Equipment manufacturers, institutes, ETP future manufacturing technology, semiconductor industry, SEMI/ Fraunhofer work group	Adaptation of existing ideas and standards, common R&D and industry activities → improvement of transport and automation systems in cell and module production lines, thus in uptime and productivity	Design of more efficient production lines, less interfaces and complexity, safer handling, easier operation, well defined machine standards and interfaces, in-line quality control and feedback loops for a higher degree of automation
Micro-electronic processing equipment	R&D, industry	Cells, Modules	Adaptation of systems used in microelectronics for novel processes for high-efficiency solar cells (mainly Si)	Cooperation with equipment manufacturers	Silicon cell production equipment like 'pick-and-place' machines for in-line production of concentrator modules
Laser applications	Industry, R&D	Cells, Modules	Laser and laser device producers, R&D groups	Cooperation with equipment manufacturers and research institutes to improve structuring and cleaning processes	Structuring and edge-cleaning, drilling for EWT/ MWT cells, local doping, tool cleaning
Test equipment specifications	Best practices, industry, R&D	Cells, Modules	Test equipment manufacturers, optical and electrical equipment suppliers, users, research groups	Establishing a group of institutes, cell producers and test equipment suppliers to define measuring standards, e.g. via round-robin-tests	Testers for input material quality, carrier lifetime, wafer breakage, I-V-testers
Glass production technology	Industry, R&D	Cells, Modules	Glass industry, R&D groups	Know-how transfer for thin-film or concentrator applications by joint R&D programs or industry cooperation	Glass treatment, cleaning, stability, optical properties, mounting, focusing, lenses

EXTERNAL KNOWLEDGE	TYPE OF SOURCE	INTERACTING PV TECHNOLOGY	POSSIBLE CONTRIBUTORS	WAYS TO INTERACT	EXAMPLES
Polymer industry	Industry, R&D	Modules	Materials for framing and front covering of modules	Industry cooperation or common R&D schemes to find or apply new materials	New disposable materials replacing aluminium frames and front glass
Mechanical engineering for trackers	R&D, industry	Systems, BoS	Industry and R&D groups related to light-weight construction, astronomy tracking, tracking control; material suppliers	Cooperation with manufacturers, adaptation of methods and materials applicable for tracking systems	Astronomy needs high precision tracker, crane construction is robust ➔ merge both approaches
Electrotechnology	Standards	Systems, BoS	ISO/DIN working groups, ETP on smart grids	Adaptation of existing norms, standards and best practices to PV related applications	Electrical grid standards, specifications for inverters, energy storage practices, battery specifications, power electronics standards
Informatics	Industry, R&D	Systems, BoS	Companies specialised in installing of PV systems and/or PV system maintenance and administration or specialised companies like Meteocontrol	Grid monitoring, data transfer and acquisition, remote global supervision and control of PV systems	
Meteorology	Meteo stations, R&D programs and consortia, space institutions	Systems, BoS	Satellite weather (irradiation), long-term forecasts	Use of know-how to optimise design, installation and operation of PV systems	
Building & architecture	Standards, best practices	Systems, BoS	Building related standards, ECTP, EEB PPP (see later)	Branch or industry wide exchange of ideas for systematic integration of modules on roofs or in building façades; special designs	

EXTERNAL KNOWLEDGE	TYPE OF SOURCE	INTERACTING PV TECHNOLOGY	POSSIBLE CONTRIBUTORS	WAYS TO INTERACT	EXAMPLES
Batteries	Industry, R&D	Systems, BoS	EUROBAT	Combined industrial approach (e.g. EPIA and EUROBAT), comprehensive research programs	Development of solutions for on-grid (local short-term storage) and off-grid applications (autonomy)



EXTERNAL KNOWLEDGE	TYPE OF SOURCE	INTERACTING PV TECHNOLOGY	POSSIBLE CONTRIBUTORS	WAYS TO INTERACT	EXAMPLES
Recycling	Best practices	all	Electronics producers, recycling standards, REACH, abatement system suppliers	Coordination of public and industrial initiatives to adapt existing recycling routines for production materials and products in the PV sector	Recycling and improved usage of silicon, precursors, fluorinated gases, toxic substances, cells, modules etc., product take-back strategy
Other EU TPs	EU TPs	different	ETPs on sustainable chemistry, engineering, materials, smart systems integration, future manufacturing technology, smart grids, construction, photonics21, ESA, nanoelectronics	Joint activities, e.g. establishing cooperation structures or expressing common targets in common statements	See part 7.3

7.3 Contributions from other Technology Platforms

Several Technology Platforms (TPs) are acting in technical fields related to or helpful for the further development of PV.

European Technology Platforms (ETPs) provide a framework for stakeholders, led by industry, to define research and development priorities and action plans on a number of strategically important issues. They play a key role in ensuring an adequate focus of research funding in areas with a high degree of industrial relevance. A number of them may be synergetic with the European Photovoltaic Technology Platform (EU PV TP).

The benefit of interaction and cooperation between ETPs active in related areas has been recognised (for example, in the Third status report on European Technology Platforms, box right).

Besides ETPs, there are many other Technology Platforms or industry associations on global, European, national or regional level that can contribute with knowledge to the PV sector. The synergies with the PV sector are revealed in their action plans.

The interaction between these groupings could be started with joint workshops to identify common targets that could be addressed in each Platform's agenda. In addition, representatives of the PV sector can directly address suggestions to those other groupings to integrate advantageous external knowledge into the PV sector.

CROSS-TECHNOLOGY PLATFORM INTERACTIONS

The Third Status Report on European Technology Platforms [ECR 2007] says, "The development of ETPs has also brought to light the benefits of interaction and networking between platforms, especially for those active in related areas. A clear trend exists whereby ETPs interact within clusters of related technological areas, establishing cooperation structures (e.g. EPISTEP for the IT field) or memorandums of understanding (e.g. EuMaT for materials)." In practice, not all ETPs have reached this level of interaction.

Each mounting carries a 5.75 kW high-concentration PV system. Livestock graze on the land between the systems
© ISFOC and Concentrix Solar

With regard to the rapid speed of innovation necessary to meet the ambitious targets of 'SET for 2020', it is necessary to coordinate to a certain degree the interactions between the PV sector and other sectors.

EU PV TP is a grouping that has the capability to evaluate the benefit of cooperation within these networks, to initiate and to coordinate interaction between the PV sector and other sectors, to define common targets and to act as a mediator between research and industry.

In the list that follows, some prominent examples are given of other Technology Platforms and their possible input to PV. A more extensive list of groupings is given in Annex B.

7.3.1 Smart Grids (www.smartgrids.eu)

The ETP 'Smart Grids' looks to the future of the European electrical grid. Smart Grids has published its SRA and a Strategic Deployment Document.

Areas relevant for PV are

- Networks of the future – a system engineering approach to study the operational integration of distributed generation and active customers
- Innovative energy management strategies for large distributed generation penetration, storage and demand response
- Distribution networks of the future – customer driven markets
- Ancillary services, sustainable operations and low level dispatching
- Customer interface technologies and standards
- Regulatory incentives and barriers

Specific suggestions from the PV sector to Smart Grids could be

- Development of strategies to deal with significant amounts of PV electricity produced in locally distributed systems
- How to optimise the integration of PV energy together with other power generation sources (flexible generation mix)
- Priority access of renewable sources to the grid
- Actively managed distribution grids to cope with complex local imbalances
- Ensure that demonstration projects launched by the Smart Grids community are relevant to PV

7.3.2 Sustainable Chemistry (www.suschem.org)

Energy is one of the eight priority topics of the TP and PV is one of the first of the 'key activities' of interest to the Platform. Its Implementation Plan [SUS 2006] notes, "Synergies between several other Technology Platforms such as Photovoltaics, Hydrogen & Fuel Cells, Biofuels, and SusChem are expected and will be exploited."

Areas indicated for development are:

Energy:

- More efficient usage and conservation of energy is possible, for example, by using organic LEDs for lighting or novel nanofoams for insulation
- Portable technologies require novel materials for the storage of energy, such as supercapacitors or new batteries
- The 'Smart Energy Home' as a 'visionary project' developed with other Technology Platforms

PV:

- Development of new routes for the production of crystalline silicon
- Development of amorphous silicon hybrid materials that could result in enhanced efficiencies
- Further development of thin layer technology
- Concerted efforts for cheaper and more stable dyes
- Improving the efficiency of dye-sensitised cells
- Process development to deliver enhanced device performances, ensure sustainability and reduce production costs on an industrial scale

The PV sector could describe to SusChem its need for

- Durable sealants
- Precursors for enhanced film deposition methods
- Agents for sustainable etching and cleaning processes
- Alternatives for scarce or hazardous materials used in current PV devices

7.3.3 Future Manufacturing Technologies (www.manufuture.org)

The 'Manufuture' Technology Platform aims to help Europe's manufacturing industry transition to a knowledge-based sector capable of competing successfully in the globalised market place.

Among its objectives are to help European manufacturers discover:

- New, high- added-value products and services
- New business models
- New manufacturing engineering technology
- Results from scientific research that can be put to use in manufacturing

Manufuture's interest in, for example, ICT-based production systems and 'Nanosciences, Nanotechnologies, Materials and new Production Technologies' (an FP7 research theme) makes it relevant to PV.

On 11 March 2009, MANUFUTURE entered into a public-private partnership with the European Commission called 'Factories of the Future', establishing an industry association (the European Factories of the Future Research Association, 'EFFRA') to act the Commission's legal partner.

Manufuture and EFFRA are interested in a dialogue with PVTP, which could take the form of representatives from the Platform participating in the Manufuture High Level Group meetings or in the annual General Assembly.

Specific suggestions from the PV sector to Manufuture or EFFRA could be

- To help us ensure that Europe remains an attractive place to manufacture PV
- To give us ideas for adding value to European PV production in global competition
- To help us optimise in-line quality control and gain a higher level of automation in manufacturing, and thereby achieving higher yield and throughput

7.3.4 European Construction Technology Platform (ECTP) (www.ectp.org) and the Energy Efficient Buildings Public-Private Partnership

ECTP's Implementation Plan, under 'Priority C: New Technologies, Concepts and High-tech Materials for Efficient and Clean Buildings', addresses energy efficiency of buildings without specifically addressing the integration of PV [ECTP 2007]. However it also says, "As a consequence, contacts and links have been established with all these other sector oriented European Platforms (such as Sustainable Chemistry, Steel, Forestry, PV, Hydrogen…) dedicated to the development of technologies and/or materials that the construction sector, as the assembling stakeholder, will have to implement to carry out its goal". The ECTP is linked to the Energy-Efficient Buildings Public-Private Partnership (see Annex B, 9.2.6).

An injection of ideas and suggestions from PVTP into ECTP and the EEB PPP could accelerate the development of building integrated PV. EPIA has links with both already.

Specific suggestions from the PV sector to ECTP could be

- Actively to address the challenges and opportunities of building-integrated PV (BIPV)

A third grouping relating to saving energy in buildings that the PVTP should maintain contact with is the Renewable Heating and Cooling Technology Platform – currently being formed by the biomass, geothermal and low-temperature solar thermal associations – to identify complementarities between BIPV and active heating and cooling technology (one of the Platform's four panels will handle 'cross-cutting' issues including the use of hybrid systems).

7.4 Knowledge from non-technological sectors

As both technological progress and the expansion of the market are closely interrelated, knowledge of various non-technological factors which may affect the PV market is of great importance. A good example here is the 'feed-in tariff' policy and the role which it has played and still plays in Germany and many other countries. Information on the financial support available to investors in PV, and the facilitation of access to this information for small investors is of high importance.

Information that could help the PV sector develop further could be found in the following sectors:

7.4.1 Finance

- Information on how to access low-rate credit (often related to the return on investment of a project and the likelihood that the project will deliver the return – see 'Law', below)
  Sources: banks, financial institutions

7.4.2 Law

- Information on incentives like feed-in tariffs, green certificates, the possibility of co-funding investments, taxes and customs tariffs (PV products may sometimes be subject to special treatment by tax law as pro-environmental goods), merchant law, in some cases labour law.
  Sources: ecological foundations, pro-environmental organisations, energy agencies, relevant ministries (e.g. Ministry of Environmental Protection or Ministry of Labour) etc.

7.4.3 Higher education

- Knowledge of the structure of higher education in a particular area and the plans of local education authorities for expanding or cutting back the provision of courses relevant to PV may influence where a company chooses to locate its manufacturing plant.
- In addition, highly-educated specialists are required in large numbers by the PV production industry, (e.g. chemists, material science engineers, electronics and informatics engineers). The availability of these highly skilled experts has to be maintained.
- Access to knowledge about the rules for creating of spin-off companies especially based on agreement with public bodies like universities or high schools can drive PV development if coupled with a climate that fosters entrepreneurial spirit.
  Sources: Ministries of Education, regional authorities, non-profit national or regional organisations like PV associations, technological parks etc.

7.4.4 Consumer incentives

- The acceptance of, and demand for, PV energy must eventually come from the consumer. The success of PV will therefore depend on consumer incentives not only for the acceptance of, but also the demand for PV energy.
- The major consumer incentives are price and the quality of delivered electrical power, whether that be through the grid or from stand-alone, dedicated sources for special purposes. The ease with which consumers can deliver PV energy to the grid will also be an incentive for domestic PV installations.
- It is likely that during the time horizon of this report, consumers in industrialised countries will be increasingly inclined to demand high quality sustainable energy sources at a competitive price. Understanding consumer attitudes is crucial for the PV industry.
  Sources: retailers of PV products, market research organisations

8 Education and training

8.1 Introduction

Realisation of the full potential of PV as an important and integral part of our energy supply requires a wide range of actors to have relevant knowledge, from those that develop the technology to those that use it. There is thus an imperative to facilitate and promote 'education' on PV in its widest sense. Directive 2009/28/EC of the European Parliament and Council on the promotion of the use of energy from renewable sources recognises this (box below). This chapter considers the role of research and development in that education.

DIRECTIVE 2009/28/EC – ARTICLE 14 [ECD 2009]

§1: "Member States shall ensure that information on support measures is made available to all relevant actors, such as consumers, builders, installers, architects, and suppliers of heating, cooling and electricity equipment and systems and of vehicles compatible with the use of energy from renewable sources."

§3: "Member States shall ensure that certification schemes or equivalent qualification schemes become or are available by 31 December 2012 for installers of [...] solar photovoltaic [...] systems [...]. Those schemes may take into account existing schemes and structures as appropriate [...]. Each Member State shall recognise certification awarded by other Member States [...]"

In a rapidly growing industrial sector, human resources are needed, not just financial or material resources. "Assuming continued accelerating growth in demand for PV products," the PV-Employment study states, "the PV sector could create around 1.4 million sustainable jobs by 2020 and 2.2 million by 2030" [PVE 2009]. Because PV impacts on several other sectors and the lives of the general public, the education needs to extend beyond the immediate demands of the industry and include the development of suitable skills in associated industries and the transfer of knowledge to a widespread audience. [PVE 2009] also showed that considerable retraining of the workforce will be needed because jobs will be "lost due to reduced conventional electricity production and reduced general consumption as a result of increased electricity costs." Thus, education is an essential part of the Implementation Plan for the PV sector.

The PV sector employs people with a wide range of skills, but of particular importance in the context of this Implementation Plan are those personnel responsible for innovations in cell and module fabrication, system design and system usage and those who subsequently turn these innovations into marketable products. This document has described the implementation of the SRA in terms of the technical areas and budgets required. The research portfolio also provides the opportunity to train of the personnel that the industry will require to take the results through to commercial exploitation and to realise the innovations that will make PV a major contributor to energy supply across Europe in the years up to and beyond 2020.

A strong and vibrant research and development portfolio provides the opportunity for in-depth training of staff, not just in the technical aspects of PV but also in general investigative skills, objective assessment and project management. Many of today's leaders in the PV industry started their career in the sector in research before adapting their skills to production or company management. Opportunities for engagement with the research activities, whether in industry or academia, also provide valuable experience as a bridge between undergraduate training and employment in the sector (e.g. by providing placement opportunities for students on Master's courses).

There is a long list of groups that should be considered in the overall education needs related to the development of PV as a widespread energy source, including (those that are directly impacted by the research agenda are shown in italics):

- Students at primary and secondary school – to educate them in regard to energy sources, usage and efficiency and understanding of their role as energy users in society
- *Students at undergraduate and post-graduate levels in different target fields – this relates to engineering courses of all disciplines, but also to students in construction, architecture, planning, environmental management etc.*
- *Researchers (including post doctoral) – personnel directly involved in innovation and technology development as a career*
- Craftsmen (electricians, construction etc.) – personnel directly involved in the installation and maintenance of PV systems and energy systems in general
- *Engineers (lifelong education for engineers) – continuing professional development for relevant personnel in the PV and associated industries to ensure as rapid a diffusion as possible of current knowledge*
- Managers – so that R&D, manufacturing and investment decisions can be made on a sound technical basis
- Market and financial professionals, bankers – so that informed financial decisions can be made on a sound technical basis
- Private and institutional investors – so that informed financial decisions, including when and what to purchase, can be made on a sound technical basis
- Community, regional and national officials (political and non-political) – to allow the optimum implementation of PV in society, with appropriate support schemes when necessary
- Clubs, associations and societies – to promote community level actions
- Society as a whole on all levels – to achieve the maximum benefit from the implementation of PV for all members of society

The overall goal is to achieve a society with an awareness of the energy challenge and an informed view of where PV can contribute. EU PV TP is addressing education and awareness-raising in relation to the wider community through its Working Group on Market Deployment. Below, we concentrate on professional training and the role of research and development in equipping professionals with the range and level of skill required for meeting the performance targets of EU PV TP and the deployment targets of EPIA.

8.2 PV professionals

The growing PV industry requires an increasing supply of trained personnel with sufficient background knowledge to enable rapid integration into companies. Whilst on-the-job training is important to ensure that the company specific requirements are met, being able to minimise the period of initial training allows maximum growth rates. Research and development projects have a key role to play in this process, over and above the technical results of the research itself. These can be summarised as

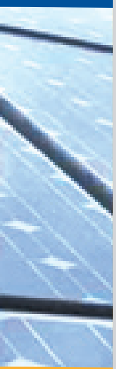
- Specific technical skills – direct involvement in research projects imparts specific technical skills, whether at the cell or system level, that are comparable with and in many cases in advance of those existing in the industry; researchers can use those skills directly within the industrial sector and can adapt them to meet the demands of technical development in those specific areas.
- General technical and analytical skills – the undertaking of research requires an analytical approach, backed up by technical skills, which can then be applied to a range of technical developments in industry, even where these are not specifically related to the research project originally undertaken.
- Ability to review options critically – in a rapidly growing sector with a choice of different technologies, research training in critical analysis can assist in the informed comparison of options.
- Linking research to education – the inclusion of up-to-date research results and the interaction of researchers with postgraduate and undergraduate students adds relevance and context to degree courses.
- Linking research to industry – the direct inclusion of industry in the training of researchers adds relevance and makes the researcher more aware of the needs of the industry.

Whilst the training of new researchers takes place most often in academic or research institutions, ongoing training takes place in industry via internal R&D and collaborative projects.

8.3 Other professional education

Elsewhere in this document, the prospects for cross-cutting research and the use of innovation in sectors outside PV have been discussed. Many of the projects outlined in chapter 5, PV Research Topics are also interdisciplinary and will involve interaction with sectors such as construction, electrical networks and the electronics industry. These research activities provide the opportunity for education in all participating sectors.

In some areas, there is a need for additional targeted educational activities to complement the training available from direct participation in the research projects. Perhaps the most obvious requirement is for increased and sustained dialogue with the construction sector, so that everyone from the architects and design engineers to those responsible for the realisation of the buildings and those who make the planning and development decisions have an appropriate understanding of PV in the built environment. A further important sector is the electrical supply industry as a whole, since PV must be successfully integrated into the electricity distribution network alongside other renewable technologies.



Since the successful implementation of PV depends on a range of professional sectors, it is important that appropriate education of professionals in these sectors is also addressed. This is generally done at degree level and then in some form of Continuing Professional Development (CPD). In formal educational training, the interaction of researchers and students again brings context and relevance and can stimulate the student to consider approaches of which (s)he would otherwise not have been aware. The incorporation of research results and experiences into CPD courses is more challenging. The research must be at an appropriate stage to warrant inclusion in such courses, which are often conducted by organisations not themselves directly involved in research. It is also important to ensure a balanced view, especially where research results are not yet commercially applied or proven. Nevertheless, it is essential to consider ways in which research results might be brought more rapidly and in a more comprehensive manner to the professionals working in related sectors.

The successful implementation of PV and the achievement of its potential for contribution to our energy needs are crucially dependent on the decision makers and regulators who can push forward the take-up of different technologies. This is true of both systems contributing to existing energy provision or to rural electrification for development purposes.

8.4 Educating society

Since the public are the ultimate users of PV technology, the rapid expansion of the market will depend on awareness and acceptance across all sectors of society (see 7.4.4). The provision of sound and reasoned information about research developments to a non-specialist, non-technical audience, and often by routes that are themselves non-technical in regard to presentation (e.g. popular media), is a challenge in any subject area, but particularly so in the energy field where there are different technologies and many different players. It is also important to fire the imagination of young people, throughout their schooling, to encourage them to choose science and engineering as a career and to demonstrate the rewarding opportunities in the PV sector.

It is important to reflect the exciting and dynamic developments that are being, and will be, made in PV, without giving false impressions of performance or commercial readiness and raising expectations unrealistically. Again, a balanced view is required between competing technologies and, for this reason, the clustering of projects with respect to dissemination of results to the general public may be appropriate.

Specific activities with respect to dissemination of results and issue awareness need to be included as part of the technical research projects but perhaps more importantly in regard to the socio-economic studies that consider benefits and acceptability of the widespread use of PV. This might include user workshops and consultations to feed back experience into the research process.

1. Assembly line for Sunny Boy PV inverters © SMA
2. Glove box for lab preparation of hybrid polymer solar cells © Centro Ricerche Eni – Istituto Guido Donegani

8.5 Educational initiatives

A number of new education initiatives have been proposed and/or implemented within Europe recently, including the European Institute of Innovation and Technology and its call for the establishment of Knowledge and Innovation Communities (KICs). One of the areas eligible for its first call is 'sustainable energy'. The KICs are intended to promote collaboration between a grouping of public research centres, universities and industry, and to offer Master's and doctoral courses within its activities. In the PV sector, however, such collaborations are already being formalised in projects such as Germany's Spitzencluster Solarvalley Mitteldeutschland (box below). There are also a number of existing Master's courses, mainly centred on the theme of renewable energy, that assign a significant portion of the curriculum to PV. Courses have been created that offer students the chance to move between universities

The industry partners in the German network 'Spitzencluster Solarvalley Mitteldeutschland' want to expand the availability of Bachelor or Master courses in disciplines relevant to PV technology in several Länder and make existing courses more attractive. Following negotiations between them and Länder governments, which have responsibility for education funding, new courses have recently started.

University of Applied Sciences, Anhalt:

In October 2008, 'Hochschule Anhalt' welcomed the first 18 students on its new programme 'Solartechnik' (solar technology) a 6-semester course ending with a Bachelor of Engineering degree. To join the course, students need to have completed their schooling and, unusually, have a applied for and received an employment contract with either Fraunhofer-CSP (Fraunhofer Centre for Silicon PV) or Q-Cells. In return, the students receive a grant from Q-Cells while they study so they can concentrate on their work, which is also unusual. 20% of their time is spent either at Fraunhofer-CSP or Q-Cells. During the course, students can choose to specialise in one of two areas: 'Technology' or 'Plant technology'. They can choose to extend their studies to earn a 'Master of Science' degree.

University of Halle-Wittenberg:

Q-Cells is endowing a professorship in PV-related studies from 2009.

University of Applied Sciences Jena:

Fachhochschule Jena has set up a Bachelor course in 'PV and semiconductor technology', which also started in October 2008 with the companies Schott Solar, Wacker Schott Solar and Ersol and the Institute for Photonic Technologies (IPhT) Jena.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during their studies to take advantage of the particular strengths of each. A prime example is the EUREC Agency Master in renewable energy, which enables students to spend 4 months of the 16-month course studying PV exclusively [EUM].

Clearly, in order to meet the growing need for skilled personnel in the PV sector, these courses must be expanded and new courses developed. As has previously been discussed, participation in research projects provides direct and relevant training and fosters skills related to innovation. Whilst doctoral training has been an integral part of research projects for many years, especially in relation to academic institutions, it may be beneficial to include specific support for the placement of Master's students with industry partners within publicly funded research projects to meet training needs. Even though the placements are only for a few months and so may not add significantly to the research output, the contribution to education can be important.

8.6 Summary

The specific inclusion of educational initiatives in the research agenda allows us to address the PV sector's needs for trained personnel, as well as the improvement of information transfer to other related professions and to society as a whole. Appropriate dissemination of the results and of the issues raised by the research can contribute significantly to the general public's understanding and acceptance. In order to meet the training needs of the industry, it is imperative to have a strong and vibrant research agenda in which suitable technical and analytical skills are fostered. Educational initiatives should be embedded in the research projects and actions taken to facilitate the transfer of information to the relevant target groups.

Testing of PV inverters © SMA

9 Annexes

9.1 Annex A – PV Research infrastructure

9.1.1 PV-TEC (Fraunhofer-ISE, Freiburg, Germany)

Inaugurated in 2006, PV-TEC ('PV Technology Evaluation Centre') is the largest not-for-profit laboratory for c-Si solar cell pilot production and technology evaluation. State-of-the art processing equipment with mostly automated wafer handling and processing is available, with throughput of 300-1200 wafers/hour. PV-TEC's equipment allows for the processing of standard screen-printed as well as highly efficient solar cells. PV-TEC began with 30 employees. More than 100 scientists, technicians and students now work there.

About 40 companies used the PV-TEC line in 2008 (most of the European cell manufacturers, equipment manufacturers and materials manufacturers). Experiments were mostly run in parallel because few experiments required the entire facility. Some projects are expected to last for two or three years - others were over in half a day.

Fraunhofer staff run the line on behalf of industry clients. On the few occasions when the whole line is rented, the client needs to supply very well trained people to operate it. The Fraunhofer workers have "explored the parameter-space" of their equipment, giving them a thorough knowledge of what works best. Some potential clients see the fact that this knowledge can't be 'unlearned' after an experiment as a disincentive to make use of the line, others as useful way to get the result they want faster.

The line used to be somewhat over-subscribed. 10-15% of clients had to be turned away because PV-TEC could not do the work within their deadline. But with the expansion of personnel and technical infrastructure in 2008 this shortage has been overcome. The kind of projects that industry uses PV-TEC for has also changed in over the 3 years that the facility has existed, from work to duplicate state-of-the-art technology very quickly (satisfying demand from new entrants into the PV business) to work on novel technology and cell structures, such as very thin c-Si cells at 20% efficiency.

9.1.2 ECN's line

Since 1999 ECN has had a line for the development and piloting of new processes, new manufacturing equipment and new cell and module concepts. The line can be quickly reconfigured (within half an hour) to accommodate a wide range of experimental runs. Running different experiments on the line concurrently is possible.

At present, companies have access to the pilot line when they participate in joint research projects. Even with this policy, the line is in constant use. ECN is exploring the option of adding an evening and night shift to the line, allowing companies to use it for trial production runs suiting their own purposes. Also, ECN is exploring possibilities to expand the pilot line for larger scale production runs to qualify processes for full-scale production.

9.1.3 CEA-INES's platform RESTAURE

Although it has existed since 2004, RESTAURE, the CEA's platform for the industrial development of PV technologies, expanded hugely when it moved from Grenoble to Chambéry in the first quarter of 2008. Equipped with tools and manufacturing equipment found on complete commercial production lines, its silicon wafer technology platform is geared towards optimising process parameters for the use of UMG silicon to achieve acceptable efficiencies with this substrate, the use of thinner substrates, and the use of N-type silicon substrates.

Technology based on amorphous silicon heterojunctions might improve efficiencies by as much as 5% compared to c-Si technology. RESTAURES's role here is to take work beyond the scale reached in the laboratory and assist in devising a protocol for industrial-scale manufacture on full-sized wafers.

RESTAURE also aims to deliver a proof of concept for nanostructured junctions in Si-based devices containing nano-wires and nano-particles, which could offer efficiencies that are higher than a-Si heterojunctions. It will aim to develop a proof of concept, then to assist in turning the proof concept into a commercial process.

Further expansion of the platform into thin-film technologies should be complete before early 2010.

It is mainly French companies that are making use of the platform, with about 8 companies, including equipment manufacturers, using it for projects lasting about a couple of years (one area being the manufacture of machines capable of building a-Si-based heterojunctions and nanostructures). RESTAURE is also available for short-term ad hoc work on silicon wafer technology (processing and characterisation).

By far the most common way that the platform is used is by CEA researchers executing projects on behalf of clients, perhaps with staff from the client present at the facility. CEA retains ownership of the project's foreground. The right to exploit this knowledge is negotiated case by case. Where CEA provides little or no co-funding for the research project, exclusive rights can be granted.

9.1.4 PVcomB – Competence Centre Thin-Film- and Nanotechnology for Photovoltaics Berlin

PVcomB's main goal is to support thin-film PV technologies and products by providing a platform on which researchers from industry and academia can collaborate. The founding partners of PVcomB are HZB – Helmholtz-Zentrum Berlin für Materialien und Energie GmbH and TUB – Technische Universität Berlin, with additional research partners joining later in 2009.

PVcomB operates two dedicated pilot-lines for intermediate size (30 cm x 30 cm) PV modules, based on both a-Si/µc-Si and CIS technologies. In parallel to the pilot lines, alternative processes will be developed and tested for each process and analytical step, from substrate through absorber layer deposition to encapsulation. The great variety of analytical tools available ensures that changes in the product's performance can be understood in terms of fundamental material or process properties. The typical projects running at PVcomB are:

- Ramp-up support
- Continuous development of industrial processes
- Development of promising high-risk concepts

- Upscaling of successful basic research results to module size of 30 cm x 30 cm
- Use of PVcomB reference production lines as a benchmark for PV suppliers: new materials, analytical tools or alternative process steps

9.1.5 IMEC's solar cell facilities

IMEC in Leuven (Belgium) has been involved in PV research since it was founded in 1984. In 1992, it was one of the first European PV laboratories to build a c-Si solar cell process pilot-line, the 'Z-line', capable of processing cells at a throughput between laboratory-scale and manufacturing-scale. The combination of the 'Z-line' with advanced facilities for high-efficiency Si cell processing, backed up by competence in microelectronics and analysis, has built up IMEC's reputation in PV.

A second pilot-line now also operates at IMEC, for organic solar cells. IMEC expects that the presence of both organic solar cell activities and organic electronics expertise under one roof will put it ahead of the game in this novel technology.

9.2 ANNEX B - More examples of Technology Platforms with knowledge to contribute to the PV sector

9.2.1 Advanced Engineering Materials and Technologies (EuMaT) (www.eumat.org)

EuMaT covers all elements of the lifecycle of advanced engineering materials and technologies: design, development & qualification of advanced materials.

- Advanced production, processing and manufacturing
- Material and component testing
- Material selection and optimisation
- Advanced modelling on all scales
- Databases and supporting analytical tools
- Lifecycle considerations, including impacts, decommissioning, reliability, hazards, risks and recyclability

Interaction with PV:
- New materials
- Basic material processes
- Recycling

EuMaT intends to link with other Technology Platforms through the High Level Board, which senior representatives of other ETPs are expected to join. Its interest in PV is announced in its SRA [EUT 2006].

Specific suggestions from the PV sector to EuMat could be
- Selection of low-hazardous production and cleaning processes
- Materials and technologies for multifunctional PV-modules
- Improvement in lifecycle analysis and recycling of PV modules

9.2.2 ETP on Smart Systems Integration (EPoSS) (www.smart-systems-integration.org/public)

Smart systems integration addresses the trend towards miniaturised multifunctional devices and specialised connected and interacting solutions. Multidisciplinary approaches featuring simple devices for complex solutions and making use of shared resources are among the targets
There is no specific reference to PV, but its objective is to develop materials, e.g. Si, SiC, SiGe, non-Si semiconductors, ceramics, polymers, glasses, textiles. Although not explicitly mentioned, sensor and networking technologies hold potential for PV installations

Specific suggestions from the PV sector to EPoSS could be

- Integration of concentrator cell systems
- Integration of sensors in PV panels

9.2.3 Photonics21 (www.photonics21.org)

Photonics21 undertakes to establish Europe as a leader in the development and deployment of photonics in five industrial areas (information and communication, lighting and displays, manufacturing, life science and security) as well as in the sectors education and training. A possible cooperation with PVTP is mentioned in the SRA of Photonics21 [PHO 2006].

Activities relevant for PV:
WG2 – Industrial Production/Manufacturing Quality ➔ possible interaction with PV production and quality procedures
WG4 – Lighting and Displays ➔ possible interaction with organic PV and thin-film PV
WG6 – Design and Manufacturing of Photonic Components and Systems ➔ possible interaction with materials research and application for new cells

Specific suggestions from the PV sector to Photonics21 could be

- Development of photonic structures to enhance cell and module efficiencies
- Further exploring the synergies between thin-film PV (organic and inorganic) and lighting & display technologies in terms of materials, device designs, manufacturing processes, qualification, etc.

9.2.4 European Space Agency (www.esa.int)

Although PV space applications face different constraints than ground ones (cost is about 1000 EUR/W_p as compared to terrestrial 2 EUR/W_p), radiation resistance is a major issue as well as mass, which drives research towards high efficiency, multijunction cells.

9.2.5 European Technology Platform Nanoelectronics (www.eniac.eu)

Another ETP of interest to PV is the ETP Nanoelectronics, which could contribute to new cell designs and materials research relevant for PV.

9.2.6 Energy-efficient Buildings Public-Private Partnership (www.e2b-ei.eu)

With more than 100 members, the 'Energy Efficient Buildings Association' is the industrial interlocutor of the European Commission (DG RTD, TREN, INFSO) in the EeB PPP.
An 'Ad-hoc Industrial Advisory Group', drawn from the membership of EEBA, spent a month and a

half in the second quarter of 2009 writing a Draft Multiannual Roadmap presenting a preliminary list of research priorities. Some of research priorities were taken up in the 2010 FP7 Work Programme in a special call for proposals co-ordinated between DGs RTD, TREN and INFSO in the service of the PPP. The draft Roadmap makes explicit mention of the SRA as a source of information, saying that it and the Implementation Plans and relevant position papers of 37 groupings like European Technology Platforms and Joint Technology Initiatives were analysed in depth to arrive at a taxonomy "which maps the European R&D priorities landscape". The Multiannual Roadmap will be finalised for the end of 2009, and contain proposals for research that the Commission could co-fund with up to 505 M EUR of money from FP7 until 2013. EPIA, as a member of EEBA, is ensuring that all the topics relevant for the development of PV in buildings are taken into account in the Roadmap.

9.2.7 Verband Deutscher Maschinen- und Anlagenbau (VDMA) - German Engineering Federation (www.vdma.org)

The Federation operates mainly at national level, but also internationally.
Interaction with PV:

- Productronics Association
- Solar Engineering Portal
- Involvement in Micro-and Nanomanufacturing ETP
- Organic Electronics Association OE-A (www.oe-a.org)
- Large Area Organic and Printed Electronics Convention (LOPE-C)

9.2.8 Kompetenznetze Deutschland - Innovation Network Germany (www.kompetenznetze.de)

Kompetenznetze Deutschland, run by the German Federal Ministry of Economics and Technology, gathers together Germany's best performing innovation networks. The initiative currently involves 107 members, clustered in 9 topics and in 8 regions.
Topics relevant to PV:

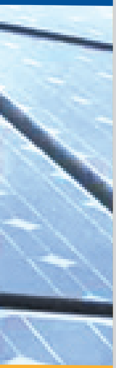
- New Materials and Chemistry
- Production and Engineering
- Energy and Environment
- Microsystems/Nanotechnology/Optical Technologies

One example for a network within Kompetenznetze Deuthschland that interacts with PV is INPLAS (www.inplas.de), the Industrial Network of Plasma and Surface Technology. Its objective is the development and application of plasma technology for layer deposition and surface treatment.

9.2.9 Internationaler Fachverband Mikrotechnik (IVAM) (www.ivam.de)

IVAM is an international association of companies and institutes in the field of microtechnology, nanotechnology and advanced materials.
Possible interaction with PV:

- Use of lasers in manufacturing
- Surface technologies
- Functional materials



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11 Glossary of acronyms

Technical terms

ARC	Antireflection coating
BIPV	Building integrated photovoltaics
BoS	Balance-of-system (all components of a PV system except the PV array)
EWT	Emitter wrap through
ICT	Information and communication technolog(y/ies)
LCA	Lifecycle analysis
MEMS	Micro-electro-mechanical systems
MWT	Metal wrap through
MOVPE	Metalorganic vapour phase epitaxy
TCO	Transparent conducting oxide
TPV	Thermophotovoltaic(s)
UMG	Upgraded metallurgical grade
UPS	Uninterruptible power supply

Non-technical terms

DG INFSO	Information Society and Media Directorate General of the European Commission
DG RTD	Research Directorate-General of the European Commission
DG TREN	The Directorate General for Energy and Transport of the European Commission
EPIA	European Photovoltaic Industry Association
ETP	European Technology Platform
EU PV TP	European Photovoltaic Technology Platform
EUROBAT	Association of European Storage Battery Manufacturers
FP7	The Seventh Framework Programme for Research, Development and Technical Demonstration, running from 2007 to 2013 – the European Commission's main instrument for directly funding research
FV	Forschungsvereinigung – German association existing for the purpose of contracting research on behalf of its members
SEII	Solar Europe Industry Initiative, a strategy prepared by EPIA "to bring the PV industry to full cost competitiveness in all market segments (residential, commercial, and industrial) by 2020" SEII will aim to establish the conditions that will allow PV to be integrated into the grid at high penetrations. It will put forward a number of large scale demonstration and deployment projects to achieve these aims.
'SET for 2020'	A set of scenarios for the development of the European PV industry, the most ambitious of which, 'Paradigm Shift', envisages a 12% contribution of PV to electricity supply in 2020.
SET Plan	'Strategic Energy Technology Plan' – Communication COM(2007) 723 of the European Commission, see [ECS 2007]
SRA	Strategic Research Agenda for Photovoltaic Solar Energy Technology, published by EU PV TP in 2007
SVM	Spitzenclsuter Solarvalley Mitteldeutschland – region of Germany awarded funding to integrate research centre and industry R&D efforts

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