PHOTOVOLTAIC SOLAR ENERGY

Development and current research

European Commission

A great deal of additional information on the European Union is available on the Internet. It can be accessed through the Europa server (http://europa.eu).

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Union, 2009

ISBN 978-92-79-10644-6
doi: 10.2768/38305

Printed in Belgium

PRINTED ON WHITE CHLORINE-FREE PAPER

Foreword

It is with great pleasure that we present this synopsis – – *Photovoltaic solar energy: development and current research* – illustrating the results of various projects carried out under the European Union (EU) Framework Programmes for Research, Technological Development and Demonstration Activities.

The impressive progress of the photovoltaic sector in recent years is a clear justification for this publication.

The European Strategic Energy Technology (SET) Plan – proposed by the European Commission in order to accelerate the availability of low-carbon energy technologies – has already established the European Solar Initiative, as one of the industrial initiatives in the six energy sectors most relevant for Europe.

It is essential that solar energy and renewable energy sources are increasingly used as a part of the EU's strategy to improve the security of the energy supplies and reduce the impact of energy production and consumption.

Renewable technologies are a clear opportunity for Europe to establish and reinforce a competitive edge in a highly innovative industrial sector. It is currently in a position to lead the worldwide effort to reduce harmful emissions from energy systems and strengthen its industrial basis, thus also creating new skilled jobs.

In this context, photovoltaics offers a key solution due to its unique features. Photovoltaic technology is safe, clean, robust and proven to be efficient and highly scalable. Photovoltaics is easy to introduce and implement all over the world, in both developed and developing countries.

In addition, photovoltaics is already associated with a fast-growing and dynamic industry. This success story has been driven both by national support schemes and first-class research and demonstration. The European Commission strongly supports the development of the photovoltaic sector in its policy measures, and also in its research and demonstration activities.

Photovoltaic electricity costs are becoming more and more competitive. A stronger effort towards further development and technological innovation will make the sector more productive and competitive, and accelerate its evolution. As a result, the whole community will benefit from the increasing possibility that photovoltaic energy will be able to contribute substantially to EU electricity generation by 2020.

Andris Piebalgs
European Commissioner for Energy

Janez Potočnik
European Commissioner for Research

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Introduction

Over the last decade, European photovoltaic companies have achieved an average annual production growth rate of over 40 %. Currently the turnover of the photovoltaic industry amounts to some EUR 10 billion. The European market is characterised by a dominant German market while other European countries – like Spain, Italy, France and Greece – have recently boosted their share. For the whole European Union (EU), approximately 70 000 people are employed by the photovoltaic sector. Although productivity in the photovoltaic industry progresses with automated production and reduced unit and system costs, the rapid market growth will create new jobs in Europe.

Support for the research, development and demonstration of new energy technologies is available through the EU Framework Programme (FP) for research. Through a series of research FPs, the European Commission has maintained long-term support for research, development and demonstration in the photovoltaic sector, providing a framework within which researchers and industry can work together to develop photovoltaic technology and applications. Within the **6th Framework Programme** (FP6, 2003-06), the European Commission committed EUR 105.6 million for supporting photovoltaic research, development and demonstration (RD&D) thus continuing co-financing the development of solar electricity in Europe.

This synopsis describes the projects funded under FP6, in the research, development and demonstration domain, their aims and the achieved results. In addition, it outlines four photovoltaic projects funded under the first **Intelligent Energy – Europe** programme (IEE-I, 2003-06) which tackles the 'softer', non-technological factors and ran in parallel with FP6.

The impact of EU programmes on the development of photovoltaics can be examined on several levels. The announcement of champion cell efficiencies achieved in EU projects is an obvious indicator. Indeed one key impact, which arguably only really began to manifest itself within the current environment of dynamic market growth, is the creation of know-how, resulting in start-up companies. For example, many of the European companies producing thin-film photovoltaics have their origins in EU projects. There is also significant anecdotal evidence that start-up companies receiving support from EU RD&D projects can successfully attract investment from larger companies that are looking to broaden their technology portfolio. FP6 coincided with a remarkable period of sustained high growth of photovoltaics. As a result of such growth, the role and objectives of European RD&D have been re-examined, with the aim of maximising the effect of available public funds, including national and regional funds. Two initiatives – the European Photovoltaic Technology Platform and PV-ERA-NET – which began during FP6, have been active in recent years in improving the overall coordination of the photovoltaic sector at European level.

The budget for the **7th Framework Programme** (FP7, 2007-13) has significantly risen compared with the previous programme, and will run for seven years. Calls for proposals based on topics identified in the ***work programme*** are launched on an annual basis.

FP7 has begun with less emphasis on the development of traditional wafer-based silicon for photovoltaic solar cells – the focus of increasing R&D investment by companies and national programmes. Material development for longer-term applications, concentration photovoltaic and manufacturing process development have attracted most European funding. Furthermore, significant funding is expected to be made available for thin-film technology in future years.

The potential of solar electricity and its contribution to the EU's electricity generation for 2020 has recently been reassessed by the photovoltaic industry. This ambition needs now to be made concrete in a realistic ***European Solar Initiative*** to make the sector realise its full potential.

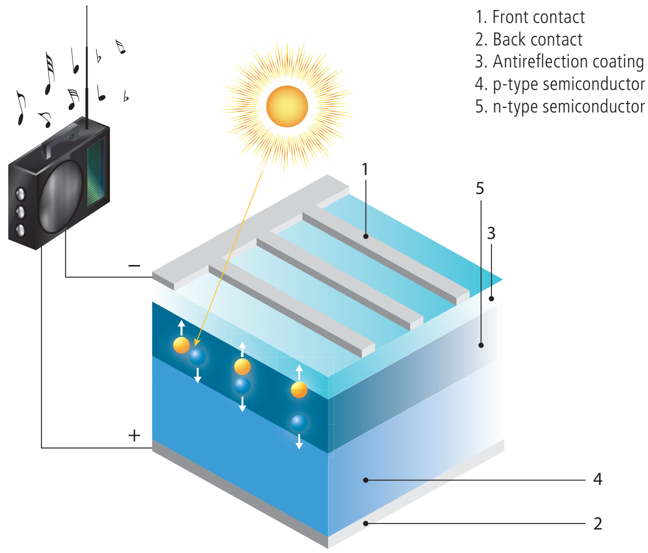
Variable electricity generation (as with solar photovoltaic), at high penetration level, will bring additional challenges to power systems. Furthermore, quality and longevity of photovoltaic devices and systems, and profitable lifecycle features of whole photovoltaic systems, will become increasingly important in such a highly competitive world market. These are parts of the RD&D needs which future activities should address.

Photovoltaic technology

Photovoltaics is the field of technology and research related to the devices which directly convert sunlight into electricity. The solar cell is the elementary building block of the photovoltaic technology. Solar cells are made of semiconductor materials, such as silicon. One of the properties of semiconductors that makes them most useful is that their conductivity may easily be modified by introducing impurities into their crystal lattice.

For instance, in the fabrication of a photovoltaic solar cell, silicon, which has four valence electrons, is treated to increase its conductivity. On one side of the cell, the impurities, which are phosphorus atoms with five valence electrons (n-donor), donate weakly bound valence electrons to the silicon material, creating excess negative charge carriers. On the other side, atoms of boron with three valence electrons (p-donor) create a greater affinity than silicon to attract electrons. Because the p-type silicon is in intimate contact with the n-type silicon a p-n junction is established and a diffusion of electrons occurs from the region of high electron concentration (the n-type side) into the region of low electron concentration (p-type side). When the electrons diffuse across the p-n ***junction***, they recombine with holes on the p-type side. However, the diffusion of carriers does not occur indefinitely, because the imbalance of charge immediately on either sides of the junction originates an electric field. This electric field forms a diode that promotes current to flow in only one direction. Ohmic metal-semiconductor contacts are made to both the n-type and p-type sides of the solar cell, and the electrodes are ready to be connected to an external load.

When photons of light fall on the cell, they transfer their energy to the charge carriers. The electric field across the junction separates photo-generated positive charge carriers (holes) from their negative counterpart (electrons). In this way an electrical current is extracted once the circuit is closed on an external load.



Solar Cell

There are several types of solar cells. However, more than 90 % of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Wafer-based silicon solar cells are approximately 200 µm thick. Another important family of solar cells is based on thin-films, which are approximately 1-2 µm thick and therefore require significantly less active, semiconducting material. Thin-film solar cells can be manufactured at lower cost in large production quantities; hence their market share will likely increase in the future. However, they indicate lower efficiencies than wafer-based silicon solar cells, which means that more exposure surface and material for the installation is required for a similar performance.

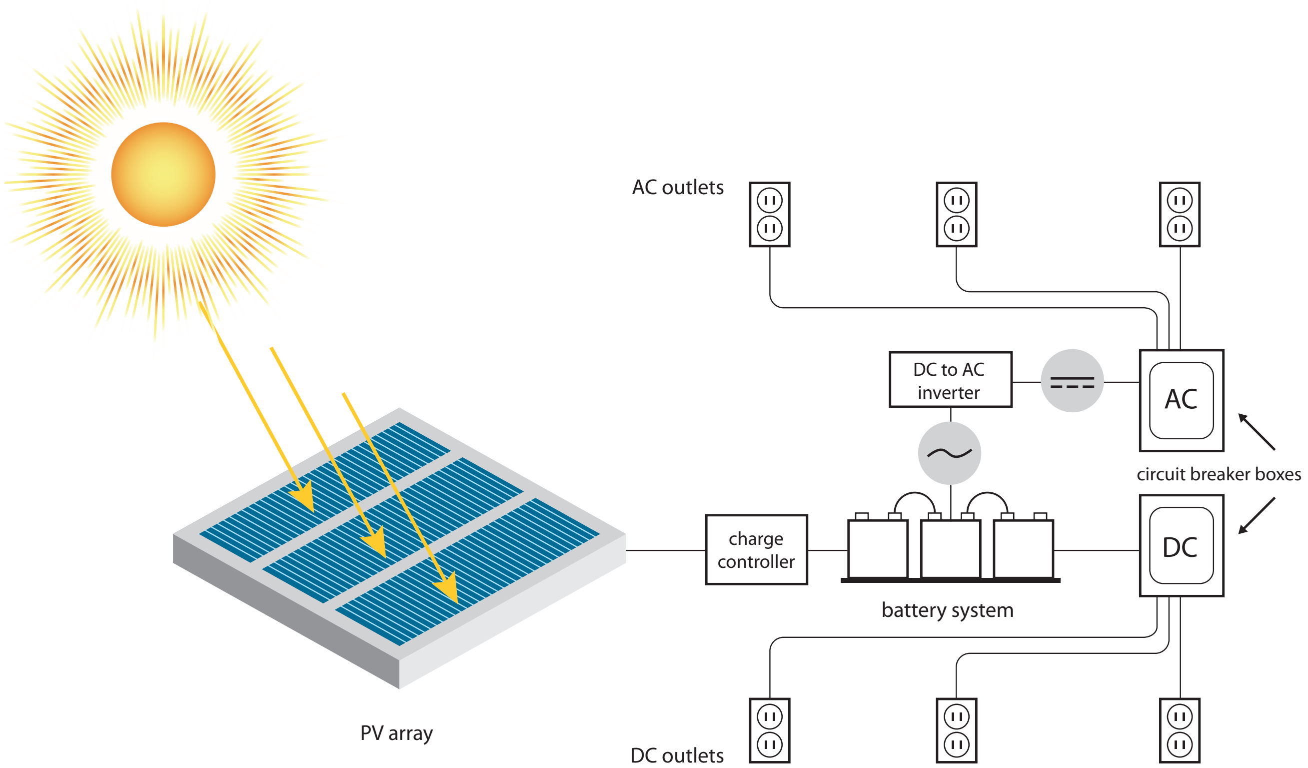
A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module.

Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

There are two main types of photovoltaic system. Grid-connected systems (on-grid systems) are connected to the grid and inject the electricity into the grid. For this reason, the direct current produced by the solar modules is converted into a grid-compatible alternating current. However, solar power plants can also be operated without the grid and are then called autonomous systems (off-grid systems).

More than 90 % of photovoltaic systems worldwide are currently implemented as grid-connected systems. The power conditioning unit also monitors the functioning of the system and the grid and switches off the system in case of faults.

Photovoltaic Installation



Photovoltaic market development

The current levels of dependence on fossil fuels, the need of reducing the carbon emissions associated with energy use and the prospects of developing a new and extremely innovative technology sector, make photovoltaics increasingly attractive. In the last years the photovoltaic market expanded extensively, especially in Germany, followed by Spain and Italy. In addition, Greece is due to be the next fast-growing market. Several incentives have stimulated the expansion, rendering the photovoltaics industry ready to expand. However, the high production cost of electricity, due to the significant capital investment cost, is the main barrier to large-scale deployment of photovoltaics systems.

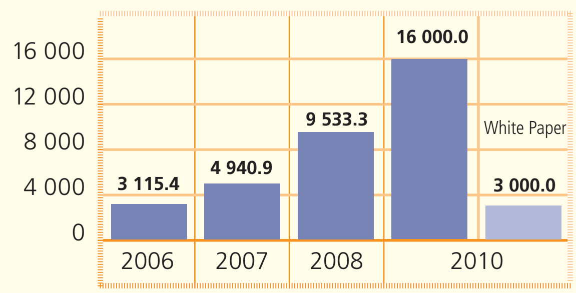


Figure 1: Comparison of the recent photovoltaic growth (in MW) in the EU with the White Paper objectives
Source: EurObserv'ER, 2009.

Competition is increasing. New technologies are being developed. Solar photovoltaic systems today are more than 60 % cheaper than they were in the 1990s. The focus lies now on cost reduction and lowest cost per rated watt in order to reach competitiveness with all sources of electricity in the medium term. In the 1997 White Paper (1), the European Commission set a target of 3 000 MW of photovoltaic capacity to be installed in Europe by 2010. Figure 1 demonstrates the current growth. The White Paper target, already exceeded in 2006, has been more than tripled in 2008, marking the success of the European sector. In 2010 the total cumulative capacity installed in the European Union could be as much as 16 000 MW.

The European photovoltaic industry currently has an important role in photovoltaic technology development, capturing about 30 % of the world market of photovoltaic modules.

In 2008, the photovoltaic capacity installed in the EU was about 4 600 MW, with a total cumulative capacity of more than 9 500 MW achieved. This illustrates an increase of 200 % with respect to 2006. Within the EU market, practically the whole of the newly installed capacity is focused on grid-connected power plants. More than 56 % of the EU-27 photovoltaic installations are located in Germany.

(1) White Paper for a Community Strategy and Action Plan. Energy for the Future: Renewable sources of energy. COM(97)599 final. 26.11.1997. Figures relate to the EU-15.

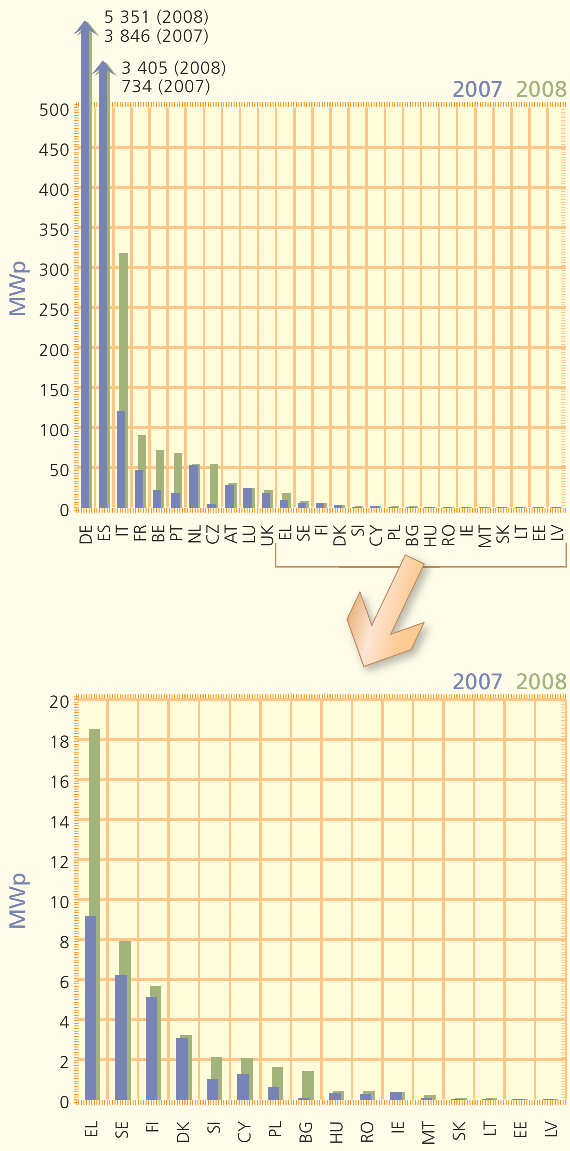


Figure 2: Cumulative installed photovoltaic capacity (in MW) in the EU in 2007 and 2008 (figures for 2008 are estimates). Source: EurObserv'ER 2009.

The leading role in photovoltaic installation is played by Germany, after the renewable energy law came into effect in 2004. Revenues from photovoltaics have climbed more than 10 times since 2003. The market stagnated somewhat in 2006 with installed capacity of 830 MW compared with 866 MW in 2005. Nonetheless, it still accounts for over 56 % of the total EU installed capacity. There are more than 80 companies involved in production of thin-layer technology in Germany.

Attractive framework needed

In order to boost the adoption of photovoltaics and to increase its competitiveness in all EU Member States, it is necessary to create an attractive framework. In the first place it entails financial support, which encourages growth of the industry even where the cost of photovoltaics is above grid parity. Another crucial aspect is the reduction of administrative hurdles and grid barriers. However, most Member States do not place importance on adequate support to its development. National electricity markets and efficiency of support schemes still vary significantly. Therefore cooperation between countries and optimisation of the support schemes seem indispensable.

TABLE 1: Support schemes

Feed-in tariffs	Bulgaria, Czech Republic, Germany, Estonia, Greece, Spain, France, Italy, Cyprus, Latvia, Luxembourg, Hungary, Netherlands, Austria, Portugal, Slovenia, Slovakia
Investment support	Belgium, Austria, Finland
Tax deductible	France, Estonia
Reduced VAT	Estonia, Poland, UK
Grants	Greece, Cyprus, Malta
Green Certificates	Belgium, Romania, Sweden

Every Member State chooses its support scheme itself. The possibilities are wide, ranging from investment support (capital grants, tax exemptions or reductions on the purchase of goods) to operating support (price subsidies, green certificates, tender schemes and tax exemptions or reduction on the production of electricity). They are often used in combination. The development of support schemes still undergoes a transitional phase. Directive 2001/77/EC provides an important framework for national support schemes.

Quota obligations and tax measures give little incentive for investments in photovoltaic technology. The most efficient and effective practice for stimulating the photovoltaic market growth in most of the Member States constitutes well-adapted feed-in tariffs. They provide fixed prices determined by public authorities for a certain period, mostly 20 years, which is to be paid per kilowatt-hour by electricity companies to producers of green electricity.

Only in those countries in which the tariff has been high enough to recuperate the investment cost in a reasonable time, and the cap has been set sufficiently realistically, have photovoltaic installations increased and competition in production and trade developed substantially.

Green certificates are used like a proof that the electricity was generated from a renewable energy resource and can be traded as green. In addition to feed-in tariffs, some countries offer incentives for building-integrated photovoltaics.

Job motor

Apart from incentives, the development of photovoltaics requires the transfer of knowledge of research institutes. Innovative thin-layer cells have to be developed so that they could be more effective than the most used mono- and polycrystalline cells. The photovoltaic sector does not imply only investment in research and technological innovation – it generates employment. Its decentralised structure leads to jobs in the less industrialised areas, with the majority encompassing high-quality jobs in aircraft enterprises and industry.

DEMONSTRATION PROJECTS

BiThink

Bifacial thin industrial multi-crystalline silicon solar cells

In order for photovoltaic to be implemented on a significant scale, the cost of solar electricity needs to be substantially reduced. This cost essentially derives from the raw material employed in the manufacturing of solar cells, the high purity crystalline silicon, and the low density of energy obtained from photovoltaic collectors. Using thinner silicon wafers and higher conversion efficiencies is the clearest path for reaching photovoltaic competitiveness – an idea widely accepted by the photovoltaic community.

Approach

The objective of the BiThink project was to develop and demonstrate, at industrial scale, a technology able to exert direct influence on the cost of photovoltaic systems.

BiThink focused on three key aspects:

- the use of bifacial cells and albedo modules as a simple way to increase the amount of energy collected;
- the increase in the number of wafers obtained from the slicing of silicon ingots;
- the use of a simple and efficient manufacturing process, able to combine high mechanical yields with reasonable cell efficiency.

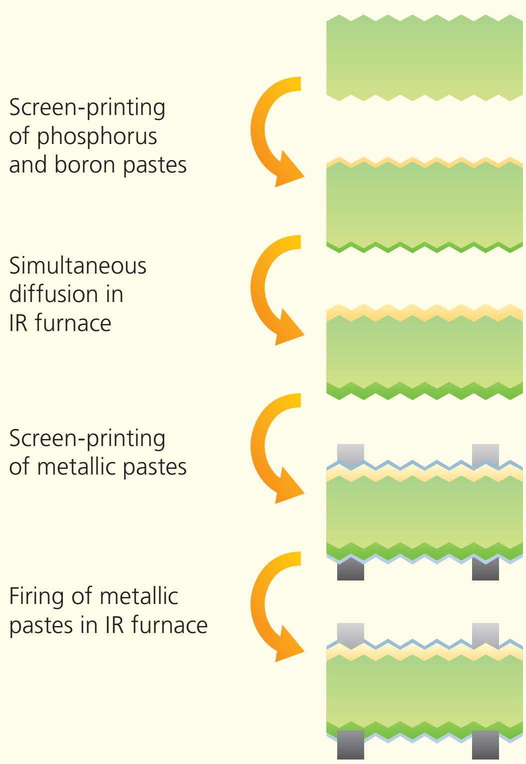
Albedo modules are photovoltaic modules that include bifacial cells in a similar manner to standard flat modules but using a transparent back cover. Because bifacial cells are capable of using the light that falls on any or both of its sides, albedo modules can produce from 30 % to 50 % more electricity than conventional ones, only by placing them close to a wall or a floor painted white. The BiThink project focused on demonstrating the industrial viability of albedo modules based on very thin crystalline silicon wafers.

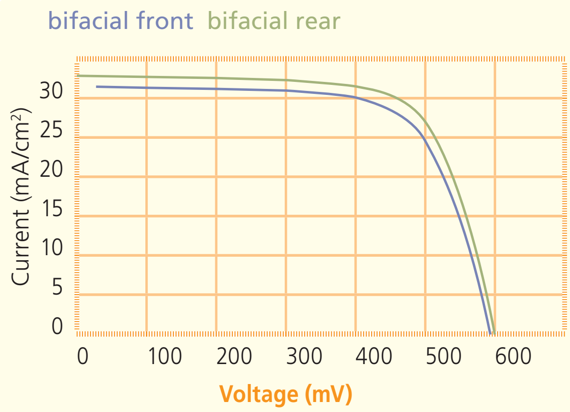
Results to date

The 1 800 wafers per linear metre of silicon ingot obtained at the beginning of the project rose to the final target of 3 500 wafers. This represents a cost reduction of 50 % in raw material, which currently accounts for more than 70 % of the final cost of solar modules. The Swiss company HCT Shaping Systems is developing the new slicing techniques. The wafer thickness has been decreased down to 90 µm and the wire diameter has been reduced from the standard 160 µm to 120 µm. The final target of 3 500 wafers per metre has been fulfilled on multi-crystalline wafers of 156 mm x 156 mm.

Solar cell technology must be simple and efficient, being able to be used in standard industrial lines with minor modifications. Technology developed in BiThink is based on an integral screen printing process. TiM-EHU in Spain and Fraunhofer-ISE in Germany have developed the new manufacturing process for thin bifacial cells. This process produces back surface field (BSF) bifacial cells with phosphorus and boron emitters diffused from screen printed pastes. Contacting the boron emitter with low contact resistance and without short circuiting the p-type emitter was a challenge solved by the formulation of a new silver paste. Ferro-Holland has developed this new paste, among other pastes used for the n- and p-type emitter formation.

Main steps of the new manufacturing process developed for preparing bifacial cells.





Electrical characteristics (I-V curve) of the solar cell, measured on both sides

Interconnection of thin solar cell requires new technology. Thus Isofoton worked on this task within BiThink. Lastly, to reach high yield values in industrial manufacturing of ultra-thin solar cells requires a better understanding of the mechanical behaviour of thin silicon wafers, apart from the optimisation of existing handling procedures. CENER from Spain and NPC-Europe from Germany are working on these topics. Finally the University of South Florida (USA) has proven a new technique to detect wafer cracks on an industrial line.

BiThink results show impressive figures in terms of the consumption of silicon, rising to only 3.9 g/W using conservative yield values. In addition, extensive new technology has been developed in the project, in the areas of ingot slicing, wafer un-sticking, screen printing diffusion, mechanical handling, crack detection or inter-connection of thin solar cells, technologies which will be used for the next advances on thin silicon solar cells.

INFORMATION

Project acronym	BiThink
Project full title	Bifacial thin industrial multi-crystalline silicon solar cells
Proposal/ contract no.	503105
Coordinator	Universidad del País Vasco/ Euskal Herriko Unibertsitatea, Spain (Contact: Prof. Juan Carlos Gimeno)
Total eligible cost	EUR 4 930 000
EU contribution	EUR 1 999 000
Start date	September 2004
Finish date	September 2007
Partners	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Npc Europe GmbH, Germany
	Ferro (Holland) B.V., Netherlands
	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain
	Isofoton S.A., Spain
	Hct Shaping Systems, Switzerland
	University of South Florida, United States
Website	http://cordis.europa.eu

highSol

High-volume manufacturing of photovoltaic products

highSol aims to transform innovative manufacturing concepts on a laboratory scale into the full industrial scale, in order to demonstrate technologies that will enable the mass manufacturing of photovoltaic products with a significant reduction in manufacturing costs.

The objectives are to:

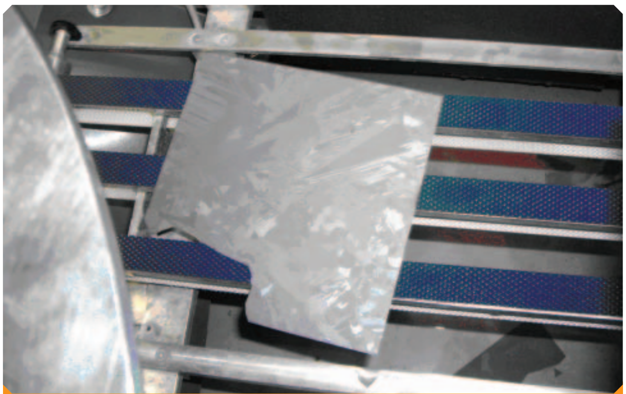
- demonstrate the automated manufacturing of photovoltaic products based on thin wafers with a thickness of 150 μm and thinner;
- increase and maintain the overall yield with the implementation of in-process quality control and feedback systems;
- illustrate manufacturing integration with the implementation of interfaces which will serve for future standards.

Approach

The objectives will be reached by the following approach:

- Saving feedstock, by enabling manufacturing of 150 μm wafers with a wafer size of 156 mm x 156 mm, will enable a high direct-cost reduction.
- For high automation manufacturing, fast and reliable methods of wafer and cell handling will be demonstrated. These are the stress-free handling, feeding, flipping, aligning and transporting of thin wafers. These methods will be made available for the integration into process equipment as well as for the manufacturing interfaces.
- Processing thin wafers of 150 μm has to meet current and future quality standards. This can only be realised by implementing advanced methods of in-line process control. The solutions of advanced process control from other industries like semi-conductor sector will be transformed and adapted for the photovoltaic industry.

The work and expected results will have a significant impact in the short and medium term. It will help save feedstock, allowing a guaranteed lifetime of photovoltaic products of 35 years and will enable the building up of a large manufacturing facility based on standardised high automation.



Broken wafer during thin wafer test run

Results to date

Within highSol, thin wafers (thickness: from 140 μm to 150 μm, size: 156 mm x 156 mm) were tested with state-of-the-art equipment and processes to find the handling, automation and process challenges of the different production steps. Out of this thin wafer test run, several handling and transport steps were identified as the principal stumbling blocks for thin wafer inline and batch production. As a result, three prototype demonstrators were designed to test new handling strategies and find the physical barriers in a first step at laboratory scale.

The first advanced methods of in-line process control were developed and implemented in a test bed with real production data at the manufacturing partners.

Therefore different data loops were obligatory:

- feedback loop: optimise the same process step for the next run;
- feed forward loop: adjust subsequent process steps for same run;
- feed backward loop: modify previous process steps for the next run;
- online loop: adjust the process during processing based on in-situ measurement.

To gather and exchange production data of all processes and equipments, a standardised equipment interface was required. With support of the project, the PV Equipment Interface Specification taskforce was formed in September 2007. Looking at other industries, such as semiconductor manufacturing, suitable IT interfaces for production equipment have proven to be essential to run factories efficiently and effectively. Data sent and received through these interfaces is not only the prerequisite for line monitoring and control, but also for the implementation of sophisticated quality assurance, traceability and advanced process control strategies.

Initially, the taskforce installed two working groups to assess the requirements of the photovoltaic industry, and review existing IT equipment integration standards and best practices from other industries and the photovoltaic industry. The evaluation process based on the working groups' results led to the IT integration standard framework developed within the semi-conductor industry. To facilitate the use of these standards within the photovoltaic industry, the taskforce devised the ***Guide for PV equipment communication interfaces*** that describes how to integrate process, automation and metrology equipment in the photovoltaic manufacturing environment. It contains a number of restrictions and clarifications that should simplify the application of SECS/GEM compared with the original version used in semi-conductor manufacturing. The document has been submitted for balloting and is expected to be available as an approved SEMI standard in 2009. As the next step, the taskforce plans to initiate a new activity to extend the capabilities of the PVECI guide in terms of material tracking.

Future prospects

During highSol, stress-free, faster and reliable handling and transport of the increasingly thinner and fragile wafers will be demonstrated and analysed. As such, the experiences and results at mass-production scale could be implemented by the manufacturing partners. Besides the automation aspect, an IT framework for the advanced process control will be developed and integrated, for a cost-effective mass manufacturing of solar cells.

INFORMATION

Project acronym	highSol
Project full title	High-volume manufacturing of photovoltaic products
Proposal/ contract no.	038519
Coordinator	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany Contact: Christian Fischmann
Total eligible cost	EUR 2 730 000
EU contribution	EUR 1 120 000
Start date	September 2007
Finish date	August 2010
Partners	Isofoton, S.A., Spain
	Schott Solar GmbH, Germany
	De Clercq Engineering Bvba, Belgium
	Baccini S.P.A., Italy
	Semco Engineering S.A., France
	Camline Datensysteme für die Mikroelektronik GmbH, Germany
	Bernhard Brain GmbH & Co. KG, Germany
Website	www.highsol.eu/

HIGHSPEEDCIGS

Development of a low-cost and high-speed pilot production line for CIGS manufacturing

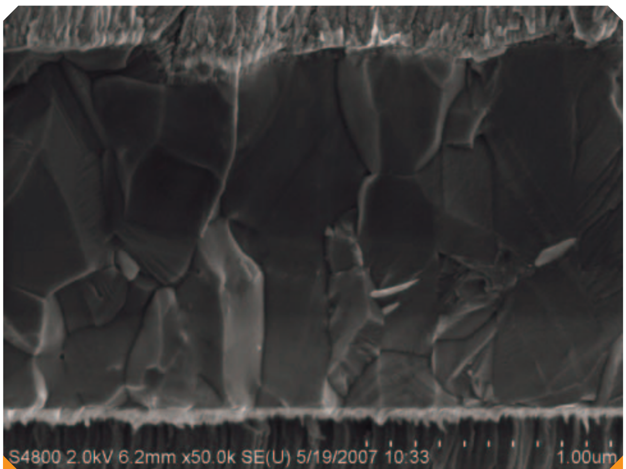
There are two main strategies in the production of solar cells based on copper-indium-gallium-selenium (CIGS) compounds: evaporation and selenisation. The main drawback of both approaches is that the deposition process is slow, leading to low productivity. The only way forward to increase the productivity has been to gradually augment the size of each module.

However, this approach leads to very expensive production equipment and it is difficult to keep the cell performance on these large substrates. The handling of large-area glass substrates, especially for temperatures above 400°C, is highly complex with substrate bending causing yield problems. Maintenance in the large deposition chambers is also difficult, causing a decline in uptime. HIGHSPEEDCIGS explores a different path to high productivity CIGS production.

Using the expertise in high-speed production of optical discs from Midsummer AB, the project coordinator, and the expertise in producing high-speed sputtering equipment from FHR Anlagenbau GmbH, the consortium will demonstrate an all-vacuum, all-sputtering pilot production line showing the potential of a 10 s cycle time in production. This can be achieved by keeping the substrate small (similar size to crystalline silicon cells) and only utilising dry processes for all process steps.

Approach

The overall approach of the pilot production line is to have no manual handling of the substrates from cleaning and until the top contact is deposited onto the finished solar cell. Gee Kaye Ltd has developed an in-cassette cleaning of the 150 mm substrates and the same cassettes can be used when loading the substrates into the first sputtering station in the pilot production line. The barrier layer and back contact is sputtered in two stand-alone metallisers before the substrate is transported by a robot into the main production tool. In the main production tool, all deposition and post-treatment of the cell from CIGS deposition until the top contact deposition takes place in continuous vacuum. The pilot production line does not use any wet processes.



Micrograph of the CIGS solar cell layers (cross section)

In the project, different substrate types have been evaluated to find the best material for both performance and productivity. After the consortium decided on stainless steel as the most suitable carrier substrate, different barrier layers to avoid iron diffusion have been evaluated. Various approaches to CIGS sputtering deposition have also been investigated, using different compound materials and both RF and DC magnetron sputtering.

In addition, the consortium has evaluated different cadmium-free sputtered buffer layers to find the most suitable material that can be sputtered minimising the detrimental effect on the absorber layer.

Results to date

During the project, the consortium decided on stainless steel as the most suitable material for the solar cell carrier. Based on Midsummer's market research, solar grade stainless steel carriers are 2-3 times cheaper than equivalent soda lime substrates. From a cost perspective, it is a great advantage if stainless steel substrates – instead of soda lime glass – can be used as carrier. There are also many advantages in handling and automation with stainless steel. Soda lime glass is difficult to handle at high temperatures and is easily deformed. With Midsummer's all-vacuum process, glass substrates that easily break would influence the uptime negatively.

Midsummer has evaluated four barrier layers to avoid iron diffusion. The best performance was obtained with tungsten titanium- and tantalum nitride-barriers. With these barrier layers, similar short circuit current density and fill factor could be obtained as those on soda lime glass, even though the open circuit voltage was still lower, most probably due to the lack of sodium diffusion from the soda lime glass. The next step will be to add sodium doping to the CIGS layer to improve the open voltage.

In the original EU application, the consortium planned to use a wet cadmium sulphide process for the buffer deposition. However, as the project evolved and the design of the pilot line took shape, the members realised that it would be almost impossible to integrate a chemical bath in the production line and still maintain high productivity. Therefore, the development of a cadmium-free buffer layer was added. This work has been successful and a buffer layer deposition in vacuum is now included in the pilot line.

Future prospects

The project coordinator, Midsummer AB, plans to start pilot production on a slightly modified production line after the project end. Midsummer is also in the process of securing financing for an order-made all-vacuum production tool with a design that will reach the 10 s cycle-time goal of the EU project. Thanks to the support from the European Union, a novel approach to high-speed, low-cost solar production will be transferred from idea to full-scale production.

INFORMATION

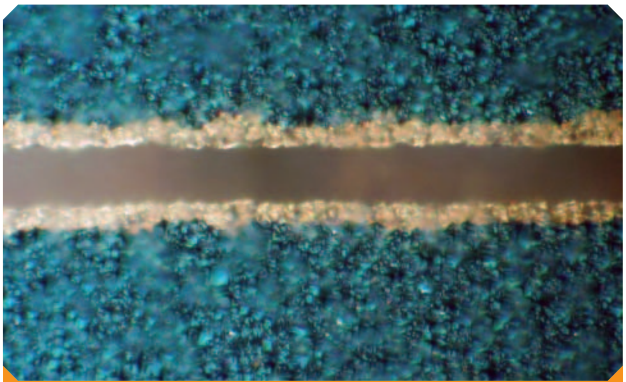
Project acronym	HIGHSPEEDCIGS
Project full title	Development of a low-cost and high-speed pilot production line for CIGS manufacturing
Proposal/ contract no.	020008
Coordinator	Midsummer AB, Sweden Contact: Eric Jalemalm
Total eligible cost	EUR 3 057 800
EU contribution	EUR 1 124 258
Start date	January 2006
Finish date	January 2009
Partners	VTT, Valtion Teknillinen Tutkimuskeskus, Finland
	FHR Anlagenbau GmbH, Germany
	Gee Kaye Linder Limited, Gibraltar
Website	http://cordis.europa.eu/

Lab2Line

From the laboratory to the production line

There is a wide gap between the best solar cell efficiencies that are being obtained in research laboratories and those offered commercially by manufacturers.

Specifically, almost 25 % efficiency has been obtained in the laboratory for small-area mono-crystalline silicon solar cells and just over 20 % for multi-crystalline silicon solar cells while production mono-crystalline cells are typically from 16 % to 17 % efficient and multi-crystalline cells up to 15.5 %. The challenge is to apply the high-efficiency processes in such a way that they be carried out on full-size silicon wafers and in high-throughput facilities to achieve effectiveness. High solar cell efficiencies are beneficial in reducing overall system cost and in lessening the embedded energy content in photovoltaic modules.



Optical microscopy image of a standard groove top

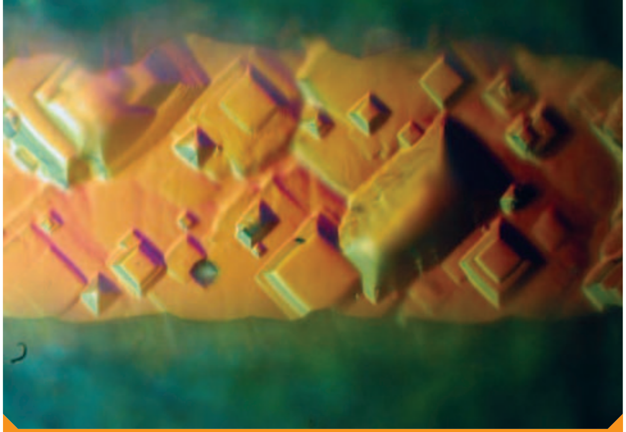
Approach

With a wide range of experimental techniques available, the approach was narrowed to two prospective paths. For multi-crystalline material the decision was taken to demonstrate 17 % efficiency on n-type silicon. N-type was chosen as this has a higher lifetime than p-type material and should not show the small light-induced degradation in efficiency that p-type material experiences. The partners not only are well equipped to process n-type material but also have considerable expertise in gettering techniques to improve the electronic quality of the silicon wafer, paving the way to higher efficiency. To avoid the known difficulties with boron diffusion in multi-crystalline silicon, a rear emitter structure with aluminium doping was pursued.

A different route has been followed for p-type mono-crystalline material. Screen printing of the contacts is the dominant manufacturing technology globally but has the disadvantage of high surface shading and the requirement to have a more heavily doped emitter than is desirable for a solar cell. However, the laser grooved buried contact solar cell has demonstrated high efficiencies with potential to reach 20 % efficiency but is a complex process and has achieved limited commercial success. This project aims to combine the two techniques to produce a screen printed contact in a laser groove to unite the low-cost advantages of screen printing with the high-efficiency potential of buried contacts.

To ensure that the processes developed in the project are environmentally beneficial, a full environmental impact and lifecycle assessment will be carried out together with a full cost analysis of the improved processes projected for high-volume production.

Optical microscopy image of a modified groove top



Optical microscopy image of a modified groove bottom

Results to date

A website www.virtualfab.eu has been set up to publish the results obtained in the project to date. The n-type multi-crystalline solar cell development is showing good progress. At the start of the project, the aluminium rear surface emitter cell was giving a best efficiency of 11.3 %. With optimisation of the processing parameter particularly for the printing of the aluminium, the efficiency was raised to 15.0 % in the latest trials. Modelling of the device showed that high minority carrier lifetime (τ) is critical to the achievement of high efficiency while the available material had rather low lifetime. To demonstrate this, the same process was applied to mono-crystalline n-type material and an efficiency of 17.7 % was achieved.

Higher lifetime material is being sourced but good progress has been made in applying gettering techniques to n-type multi-crystalline silicon. It was found that the average wafer lifetime was being dominated by regions of low lifetime material. High and low lifetime areas were identified and subjected to a variety of phosphorus gettering, hydrogen passivation and annealing. Good material could be increased from an average lifetime of 69 μs to 900 μs while the poor material increased from 40 μs to 440 μs. Moreover, these lifetimes are comparable with the best float zone lifetimes.

For the p-type mono-crystalline silicon cell, the main difficulties have been in aligning the screen print pattern with the laser grooving and in getting good silver paste transfer into the groove. A cleaved-edge datum solved the alignment problem while the groove profile had to be modified to allow good screen printing. Initial cells were very poor but 15.2 % efficiency has now been demonstrated.

Future prospects

It is anticipated that by the end of the project both n-type multi-crystalline and p-type mono-crystalline processes will demonstrate extended processing runs average efficiencies of 17 % on 100 cm^2 wafers and that these processes will be cost effective. This will provide solar cell manufacturers with tools to further reduce the cost of photovoltaic modules and systems.

INFORMATION

Project acronym	Lab2Line
Project full title	From the laboratory to the production line
Proposal/ contract no.	019902
Coordinator	NaREC, New and Renewable Energy Centre, United Kingdom Contact: Alexander Cole
Total eligible cost	EUR 2 824 392
EU contribution	EUR 1 269 675
Start date	January 2007
Finish date	December 2009
Partners	Ente per le Nuove Tecnologie, L'Energia e L'Ambiente, Italy
	Interuniversitair Micro-Electronica Centrum Vzw, Belgium
	Soltech NV, Belgium
	Institut für Solarenergieforschung GmbH; Hameln/Emmerthal, Germany
Website	www.virtualfab.eu

PV-EMPLOYMENT

The role of the European photovoltaic industry for Europe's jobs and education today and tomorrow

The future employment opportunities offered by a fairly young European industry are crucial aspects in order to receive support for the implementation of the technology and the industry within European society and economy.

The annual growth rates within the European photovoltaic industry keep an average level above 35 % for more than five consecutive years. And there are great expectations for the years to come. To establish photovoltaics not only as a future-oriented technology but also as a European industry with tremendous opportunities for the future, it will be essential to gain realistic numbers in terms of jobs offered by the European photovoltaics industry in the future.

Approach

The two main objectives of the PV-EMPLOYMENT project are to quantify the amount of net jobs that will be created and replaced by the expanding European photovoltaic industry and to determine the qualification profiles of employees needed in the future to allow the ongoing expansion of the European photovoltaic industry. Based on the results, the consortium will address recommendations to the higher education sector, and especially to the higher technical schools and universities.

In detail this means: how many net jobs will be created by the expanding European photovoltaic industry in terms of:

- direct and indirect jobs created;
- direct and indirect jobs replaced;
- jobs lost.

The difference between the positive effects (newly created jobs) and negative effects (replaced jobs) of the expanding European photovoltaic industry will result in the net amount of jobs created/replaced by the European photovoltaic industry.

There are two different kinds of models that have been developed in this project. The focus lies on a detailed input-output model of the European photovoltaic industry developed by the University of Flensburg. This model allows the net job creation to be determined by breaking the whole process within the European photovoltaic industry into approximately 20 individual steps and stages.

The final model allows different scenarios to be run for the European photovoltaic industry depending on different market developments, technological developments in the future and consequences of import-export activities.

A general equilibrium model has been developed as well by the National Technical University of Athens. It represents the theoretical background work that puts the whole empirical analysis into a broader economic context, e.g. by considering price effects.

The combination of the results of both models leads to a non-biased and realistic evaluation of today's net amount of jobs linked to European photovoltaic industry and its forecast up to 2030 and beyond.

To ensure that the outcomes of PV-Employment have an impact beyond the project duration and beyond the project partners, several measures are being taken. A workshop/seminar will be organised at the end of the project to present the results in terms of net job creation and the required job profiles and the recommendations to the higher education sector. The results will be disseminated to the photovoltaic industry sector during the European Photovoltaic Industry Association (EPIA) activities and through the EPIA newsletter. The European Trade Union Confederation will also circulate the results among its members. A brochure and dedicated website (www.pvemployment.org) will be published, presenting the context of the project, methodology, final results and recommendations of the consortium.

Results to date

All data has been collected though questionnaires and interviews of relevant companies in the EU photovoltaic sector and fed into the models. The partners are making final adjustments on assumptions and scenarios on both models in order to obtain final results.

The consortium has developed three photovoltaic development scenarios up to 2050. The pessimistic scenario assumes a minimum implementation of photovoltaics with an installed capacity that remains at its actual level. The average scenario assumes a photovoltaic installed capacity of 500 GW in 2050. The optimistic scenario assumes that photovoltaic would cover 12 % of EU final electricity demand by 2020 and 25 % by 2050.

Future prospects

The initial results show that price reduction for photovoltaic systems will be crucial to obtain a ***net*** job creation compared with a business-as-usual scenario and that a volume market is needed to achieve it.

INFORMATION

Project acronym	PV-EMPLOYMENT
Project full title	The role of the European photovoltaic industry for Europe's jobs and education today and tomorrow
Proposal/ contract no.	020063
Coordinator	European Photovoltaic Industry Association, Belgium Contact: Eleni Despotou
Total eligible cost	EUR 380 485
EU contribution	EUR 380 485
Start date	January 2006
Finish date	January 2009
Partners	Social Development Agency Asbl, Belgium
	University of Flensburg, Germany
	Wirtschaft und Infrastruktur & Co. Planungs KG, Germany
	Institute of Communication and Computer Systems of the National Technical University of Athens, Greece
Website	www.pvemployment.org

PV-MIPS

Photovoltaic module with integrated power conversion and interconnection system

A photovoltaic system achieves the highest output when every solar module is continuously operated at its maximum power point. This can be reached by using module-integrated inverters, since every solar module has its own controller. Module-integrated inverters lead to higher yields especially with solar modules that are partially shaded or aligned with different angles.

Other advantages are that the design of the photovoltaic system is more flexible and that the system can easily be expanded. In addition, costs for direct-current wiring do not apply. Within PV-MIPS, solar modules with integrated inverters are being developed that can feed solar electricity directly into the grid. The challenge is to reduce the total costs of a photovoltaic system. At the same time, lifetime and reliability of the integrated solar power inverter shall be increased considerably.

There is a growing interest in module-integrated converter concepts but the market share of inverters for module integration remains small. The currently available alternative current (AC) module inverters are intended for use in conjunction with common photovoltaic modules. No integrated AC modules are commercially available to date. The inverter manufacturer and the photovoltaic module manufacturer are indeed two separate entities, each delivering a product that is optimised and manufactured independently.

The most relevant factors which have prevented a wide spread of AC modules are:

- high failure rate and limited lifetime;
- high specific costs (from EUR 1/W to EUR 2.5/W), compared with central or string inverter topologies;
- labour-intensive installation;
- low efficiency (less than 93 %).

The actual figures regarding price and efficiency must be improved by the new developments within the PV-MIPS project. The real inverter costs shall be lower than EUR 0.3/W and the targeted European efficiency is 95 % (maximum efficiency 97 %). If these aims are met, the new inverter will be strongly positioned against the state-of-the-art devices and can compete with system topologies based on string inverters.

Approach

New layouts and concepts for the photovoltaic module (e.g. large area, high-voltage module) will be designed and selected in order to optimise the match between direct current output from the module and inverter input. Newly developed semi-conductor power modules will be utilised in the photovoltaic inverter. In addition, electric connection and mechanical mounting of the modules will be considered, to complete the optimisation of the whole system.

This project gathers essential knowledge, technology, as well as production and market experience from different European countries. The project consortium incorporates module and inverter manufacturers, utilities and research institutes in the field of photovoltaics and power electronics.

The development and demonstration of module-integrated inverters within the project are related to different photovoltaic module technologies. In total three module inverters and AC module systems respectively will be demonstrated within PV-MIPS.

Due to the high market share of crystalline solar cells, a module inverter will be developed for this technology based on a multi-stage topology with isolation and a DC range that matches most photovoltaic module specifications.

In contrast, the share of thin-film modules is expected to increase. Thus, based on photovoltaic modules in CIS technology, two alternative solutions are under development. An AC module system developed by the industrial partners consists of optimised CIS modules with a maximum power point voltage of 80 V and an adapted inverter.

Compared with crystalline photovoltaic modules, one significant advantage of CIS is the capability to design modules with a high DC level of several hundred volts. This property is exploited in a third development line using an inverter, which takes advantage of a high input voltage.

Results to date

Within PV-MIPS, a transformerless three-phase inverter for the integration into high voltage CIS modules has been developed. The chosen topology – a PWM Current Source Inverter – features a single-stage power conversion system that feeds directly into the grid. This topology has been used for the first time in a low-power application such as the 250 W photovoltaic module.

Due to the three-phase grid connection to the DC link, energy storage can be significantly reduced. No electrolytic capacitors are necessary which are generally highly temperature-sensitive and thus have a short lifetime. A highly efficient laboratory prototype of a compact low-power (250 W) inverter has been implemented and tested. A maximum conversion efficiency of more than 97 % has been achieved. High efficiency is not only a selling point, but it also contributes to improved reliability of inverters as the thermal stress is reduced. In order to show the features of AC module systems and module inverters, several demonstration plants have been set up, which will be extended in the future.

INFORMATION

Project acronym	PV-MIPS
Project full title	Photovoltaic module with integrated power conversion and interconnection system
Proposal/ contract no.	503123
Coordinator	ISET, Institut für Solare Energieversorgungstechnik E.V., Germany Contact: Dr Norbert Henze
Total eligible cost	EUR 10 451 952
EU contribution	EUR 4 399 813
Start date	November 2004
Finish date	October 2009
Partners	Infineon Technologies AG, Germany
	Österreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H., Austria
	MVV Energie AG, Germany
	Würth Solar GmbH und Co. KG, Germany
	Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Germany
	Heliodomi S.A., Greece
	Ecofys B.V., Netherlands
	Energieonderzoek Centrum Nederland, Netherlands
	Lafarge Roofing Benelux, Netherlands
	Netherlands Organisation for Applied Scientific Research, Netherlands
	Philips Lighting B.V., Netherlands
	Steca GmbH, Germany
	Delta, Germany
Website	www.pvmips.org

SELFLEX

Demonstration of SELF-formation based FLEXible solar cells manufacturing technology

The SELFLEX project aims to demonstrate at industrial scale cost-effective manufacturing technology for crystalline silicon (c-Si) solar cells based on self-formation, a highly innovative manufacturing concept. Self-formation has proven itself proposing industrially feasible technological solutions for c-Si solar cells with complicated spatial structure. The fundamental principle of self-formation is an increase in complexity through structured object and chaotic media interaction.

To become competitive with conventional energy sources, new improved solar cell concepts must be developed to facilitate further growth of the photovoltaic sector. Silicon technology represents some 90 % of the world's photovoltaic market. Using self-formation manufacturing concept enables optimisation of manufacturing processes in a cost-effective way. This concept is based on the selected groups of planar bottom-up processes ('self-formation processes') able to form the structure of objects. Therefore, a group of processes has to be chosen, defining new and particular structures.

Approach

The *SELFLEX* project addresses the common issues among all different cell technologies, which are related to manufacturing and scaling up:

- *Equipment:* the SELFLEX proposed approach is flexible and adaptable to any technological infrastructure used for crystalline solar cells manufacturing.
- *Patterning:* by applying self-formation, crystalline solar cell structures with efficiency from 16 % to 24 % could be manufactured with patterning processes reduced to two or even one. Therefore, significant decreases in manufacturing costs for solar cell can be expected.
- *Quality control:* the quality management system for performance of qualifying tests of novel manufacturing technology will be integrated for unprejudiced evaluation and proof of this solution.

Application of self-formation manufacturing concept enables twofold manufacturing cost reductions:

- *Direct reductions in manufacturing costs:* by applying a self-formation manufacturing concept, crystalline solar cell structures with efficiency ranging from 16 % to 24 % could be manufactured, while the number of most costly patterning (top-down) processes can be reduced to two (or even one) and the optimised (in costs approach) manufacturing route based on bottom-up techniques is developed.
- *Reductions in costs associated with implementation of new PV manufacturing technology:* the project's approach ensures that a low rate of investments is needed for technological transfer to novel manufacturing technologies and allowing the time and cost reduction of 'research-development-prototyping-manufacturing' cycle needed for the introduction of the new product.

Results to date

During the time of project implementation, new developments in solar cell technology state of the art emerged. Thus, the SELFLEX consortium has adopted recent achievements in the area of the technology under development. Such novel solutions are for example the development of single step selective emitters using self-formation processes, and recent laser techniques for patterning processes. They were adopted in SELFLEX technology for ensuring that most recent developments will be covered by the project activities.

Taking into account results obtained in the project so far (based on 12-month project results), possibilities to introduce into industry proposed modified technology were evaluated positively and decisions regarding launching projects for photovoltaic production plant were made. The first stage of the project was dedicated to introducing a pilot line of 2 MW for which application to national ERDF funding schemes was submitted and successfully evaluated.

The next stage of the project foresees two 25 MW production lines development with private capital participation placing Lithuania back on the photovoltaic producers' map.

Future prospects

Technology developed under the SELFLEX project is expected to go into production at the end of 2009, starting from capacities up to 2 MW per year and increasing capacities up to 50 MW per year within 2-3 years.

Bringing SELFLEX results to the European photovoltaic industry projects can help to reduce costs in existing and newly launched photovoltaic plants and contribute to increase the profitability of photovoltaic sector.

INFORMATION

Project acronym	SELFLEX
Project full title	Demonstration of SELF-formation based FLEXible solar cells manufacturing technology
Proposal/ contract no.	038681
Coordinator	Applied Research Institute for Prospective Technologies Contact: Juras Ulbikas
Total eligible cost	EUR 1 439 415
EU contribution	EUR 700 000
Start date	April 2007
Finish date	March 2010
Partners	Ente per le Nuove Tecnologie, l'Energia e l'Ambiente, Italy
	UAB Saules Energija, Lithuania
	UAB Telebaltikos Importas Ir Eksportas, Lithuania
	Vsi 'Perspektyviniu Technologiju Taikomuju Tyrimu Institutas', Lithuania
	Dutchsolar B.V., Netherlands
Website	http://selflex.protechnology.lt/

SOLAR PLOTS

Multiple ownership grid connected PV solar-plots with optimised tracking and low concentration reflectors

Photovoltaics still cost more than conventional energy. The cost could be reduced by reducing the need of module surface, being modules – the most significant cost component. This can be achieved by adopting the concentrating photovoltaics appproach.

Concentrating photovoltaics comprises substituting the solar cells – the most expensive element in the photovoltaic system – for optical systems (called 'concentrators') which lead the radiation received on a cell or a surface of cells. In this way, the area of photovoltaic cells is reduced by boosting the optical concentration. However, there are some disadvantages, such as the necessity to track the sun in its movement.

Approach

To analyse the performance of conventional photovoltaic modules (used in installations without concentration) when they are subjected to low concentration, a tracker which includes three layouts of modules and mirrors has been built. The tracking is undertaken in a single axis (azimutal tracking) and the tracker is made of three series each with eight modules, connected individually to other inverters. Each series comprises eight modules distributed into two columns. On either side of the modules of the first series, mirrors are placed with a slope of approximately 60˚. In the second series, the mirrors are placed only on one side of each module, while the last series are mounted without mirrors. The total space used by the device is similar to the traditional trackers of 5 kW.

Both the modules and mirrors are installed on a structure composed of profiles of welded steel. This structure is based on a vertical mast anchored to the floor through a mechanism of intermediate rotation which enables tracking of the sun using an azimuth angle.

Results to date

The analysis undertaken brings to light several problems which significantly affect the concentrator efficiency as well as the working temperature of these devices:

- *Mirror efficiency:* the mirror used in the prototype has a nominal efficiency higher than 83 % and thus approximately 16 % of the radiation is not reflected. A mirror's reflectivity depends mainly on the incident radiation wavelength and is highly reduced for shorter wavelengths. The solar spectrum moves towards shorter wavelengths as the solar height increases (when irradiance is high), causing a strong reduction in the optical gain. This problem can be minimised by using higher-quality mirrors with more suitable characteristics for photovoltaic concentration.
- *Temperature:* the increase in temperature of modules occurs due to the increase in incident radiation, meaning a loss in their efficiency, which will be higher as the concentration factor is increased. The temperature is also affected by wind speed.

- *Diffuse radiation:* on days when radiation is scarce due to clouds or fog, the diffuse radiation, with an optical concentration closer to the unity in the centre of the panel, becomes important comparing it with the direct radiation, producing a strong decrease in the global optical concentration.
- *String resistance:* the cells present an internal resistance called 'string resistance' in most part due to the metal net, contacts and the resistance of the semiconductor material. There is a threshold irradiance above which the losses in string resistance increase. As a result of this irradiance, the efficiency of the cells will be maximal.
  In particular the modules used in the prototype present a maximum efficiency for an irradiance value of 600 W/m^2. Thus, when working with concentration, the efficiency of the modules is reduced. In this case the gain loss is approximately 13 % in the string with the geometric concentration 2x and some 4.6 % in the string with the geometric concentration 1.5x.
  However, the temperature increase experienced by the modules brings about one more problem. The highest temperature guaranteed to maintain the integrity of the module is 85°C. This would be achieved for the string with the geometric concentration 2x for an outside temperature of 30°C; as such, the integrity of the modules will be seriously at risk during the summer months.

The project found that the technical feasibility for concentration ratios of 2.5x or higher, with the current standard photovoltaic module technologies is questionable. The module temperatures reached at this sun concentration will very probably lead to deterioration in the module properties. Even for lower concentration ratios, the situation remains problematic. The photovoltaic module suppliers are not prepared to provide the usual guarantees (for instance lifetime guarantees) for module performance, if the modules are used for concentration systems. Even with modules especially manufactured for concentration, guarantees will not be provided.

After analysing the full economic viability, also in view of the results obtained on prototype systems, the consortium concluded that the foreseen concept of a photovoltaic system tracking technology with low concentration ratio using standard modules does not lead to the expected reduction in electricity generation costs.

INFORMATION

Project acronym	SOLAR-PLOTS
Project full title	Multiple ownership grid connected PV solar-plots with optimised tracking and low concentration reflectors
Proposal/ contract no.	503172
Coordinator	Acciona Solar SA, Spain Contact: Miguel Arraras
Total eligible cost	EUR 4 824 274
EU contribution	EUR 1 800 000
Start date	June 2004
Finish date	June 2006
Partners	Tenesol SA, France
	João Nuno Serra, Sociedade Unipessoal Lda, Portugal
	Elektro Primorska Javno Podjetje Za Distribucijo Elektricne Energije, D.D., Slovenia
	Commissariat à l'énergie atomique, France
	CIEMAT, Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain
	Cener, Centro Nacional de Energías Renovables – Fundación Cener, Spain
Website	http://cordis.europa.eu/

Solsilc Demonstrator

Validation of a direct route for production of solar-grade silicon feedstock for crystalline wafers and cells

Scenarios show that solar energy will be, in the long term, the most important energy source, provided that the cost of photovoltaic modules is substantially decreased.

Low feedstock availability (priced from 35 EUR/kg to 100 EUR/kg) is currently jeopardising the decreasing of module costs. Currently 17 % of module costs relate to feedstock. Even though cells will be thinner and more efficient, demand for solar grade silicon will grow from the current available capacity of 15 000 t/year to approximately 50 000 t/year in 2010. A low-cost dedicated solar grade silicon feedstock source is needed in Europe or growth of the total photovoltaic industry could be compromised.

Fesil Sunergy's upgraded metallurgical-grade Si test plant in Lilleby

Approach

The main goal of the Solsilc Demonstrator project is to validate at pilot scale the techno-economic feasibility of the 'SOLSILC' route – a direct metallurgical route to produce solar grade silicon. The project will provide the detailed knowledge to prepare for production at industrial scale of solar grade silicon.

H29 furnace for upgraded metallurgical-grade Si

The techno-economic feasibility can be divided into two sub-objectives for the project:

- making photovoltaic module costs of 1 EUR/W possible by providing an intrinsic low-cost feedstock route for solar grade silicon, a necessity for reaching the European goals for the photovoltaic industry;
- creating new business options in producing solar grade silicon feedstock in a sustainable way and with sufficient return on investment and thereby reinforcing competitiveness of the SMEs of the Solsilc Demonstrator consortium.

In preceding EU projects, a process was successfully developed based on direct carbothermic reduction of quartz with silicon carbide as an intermediate product, followed by limited refining steps.

Results to date

The challenges per topic are listed below, based on the current status of relevant know-how within and outside Solsilc Demonstrator:

- *Raw materials and siliconcarbide (SiC):* in the R&D runs, among others, a high-purity test batch of Saint-Gobain SiC was used, which appeared to react optimally in terms of physical strength and reactivity. In the R&D phase, supplier assessments have been made and strong relations were built up with suppliers. Sintef and ScanArc conducted extensive work on intermediate scale for SiC production. In Solsilc Demonstrator this experience will be used for optimisation of the raw materials supply.
- *Process silicon metal (Si-Metal):* pelletising different compositions of SiC, Carbon Black and quartz have been optimised in the R&D phase. The carbothermic reduction of quartz with SiC is a complex high-temperature (2 000°C in reaction zone) process, never operated at industrial scale. In the Solsilc Demonstrator, it is necessary to learn the operating parameters to optimise yield and stability, of the new high-efficiency Si-Metal process for carbothermic reduction.
- *Process silicon refining (Si-Refining):* the basic principle of SOLSILC's refining process is to precipitate excess carbon from the reduction furnace by controlled cooling rates to temperatures just above solidification temperatures, allow for some dwelling time and separate the silicon with about 30 ppm dissolved carbon from SiC by decanting/filtration.
- *Product quality of ingots, wafers and cells:* one of the partners (ECN) operates a baseline industrial cell process which results in commercial good-quality p-type multi-crystalline silicon wafers, in efficiencies higher than 16 %. Cell processing will be conducted by ECN.

Future prospects

Large investments in production facilities are only opportune when sufficient insight is generated in the process parameters at larger scale and in optimal compositions. Led by SMEs, the consortium includes major European institutes with expertise in silicon production and refining, and solar cell processing. The project is organised into eight work packages, which follow the value chain. Several integral runs from raw materials to cells will be executed to prove reproducibility and quality of the results. A successful completion of the project results in the preparation of a production plant. The expected solar grade silicon cost price is below 15 EUR/kg, making photovoltaic module costs of 1 EUR/W feasible and the growth of photovoltaic sector sustainable.

INFORMATION

Project acronym	Solsilc Demonstrator
Project full title	Validation of a direct route for production of solar-grade silicon feedstock for crystalline wafers and cells
Proposal/ contract no.	038373
Coordinator	Sunergy Investco B.V., Netherlands Contact: Boukje Ehlen
Total eligible cost	EUR 4 755 200
EU contribution	EUR 1 499 920
Start date	April 2007
Finish date	March 2009
Partners	Energieonderzoek Centrum Nederland, Netherlands
	Fesil, Norway
	Sintef, Norway
	Scanarc Plasma Technologies AB, Sweden
Website	http://cordis.europa.eu/

SUNRISE

Strengthening the European photovoltaic sector by cooperation with important stakeholders

The main objective of SUNRISE is to accelerate and facilitate the integration of photovoltaic systems in buildings and the electricity network to reduce the cost of photovoltaic systems and become competitive with conventional energy production in the future liberalised energy market. To achieve those targets, the project is working to foster new alliances and initiate intense dialogue between the photovoltaic industry and the construction sector, architects, equipment suppliers, electrical installers and the European utilities.

Challenges

Building integrated photovoltaic

Considering the potential market of building integrated photovoltaic (BIPV), the construction sector may play an important role in the sector's development. The success of the photovoltaic penetration in the Japanese market lies with the fact that photovoltaic was considered a building component and integrated since the beginning in the construction. Photovoltaic systems can be seen integrated in Japan prefabricated houses. This chance has not yet been seized in Europe and the construction sector hardly considers the photovoltaic technology as a potential market. As such, SUNRISE aims at changing this situation and improving the cooperation with building sector architects. The main tasks will be the identification of barriers, collaboration in developing new products, awareness-raising and standardisation.

Photovoltaic networks integration

The SUNRISE project is working to initiate a dialogue between the photovoltaic industry and utilities. Under discussion will be the integration of photovoltaic in the network and finding a balance between centralised and decentralised electricity generation, keeping in mind grid stability and system control. In this context the contribution of solar electricity to the peak power supply will be analysed. Within a taskforce of participants from utilities and the photovoltaic industry, proposals for a unified European standard for photovoltaic grid connection will be elaborated.

Standardisation

Standards and specifications also strongly support the objective to reduce costs. Standards contribute to the harmonisation and simplification of processes, leading to reduced costs. Supply contracts between manufacturers can be simplified by referring to adequate and accepted standards. Finally, standards also lead to more competition between the suppliers of standardised products, which in turn results in declining prices. The discussion results will be communicated via drafting proposals to national and international standardisation committees.

Approach

Having started on 1 May 2007, SUNRISE will last for 30 months until 1 November 2009. The project is being carried out by a consortium of five partners which represent the relevant sectors as the photovoltaic industry, construction sector, architects and electrical installers. Furthermore, Electricité de France (EDF) has been subcontracted in order to facilitate the dialogue with European utilities.

The project is coordinated by the European Photovoltaic Industry Association (EPIA) with the support of Wirtschaft und Infrastruktur GmbH & Co Planungs KG.

The SUNRISE project is organised into three work packages:

- WP1: Photovoltaic diffusion in the building sector;
- WP2: Photovoltaic networks integration;
- WP3: Dissemination activities.

Exploitation plan

To ensure that the outcomes of SUNRISE have an impact beyond the project duration and beyond the project partners, several measures are being taken. EPIA, the project coordinator, as multiplier, will incorporate the outcomes of the project into its short-term strategy. This means that new ideas or initiatives that emerge from the project will be followed up after the project end. The work items proposed within this project are already part of its action plan for the next four years. In addition, EPIA will continue dialogue with the photovoltaic sector stakeholders and maintain the contacts established.

Moreover, the other associations involved in this project will ensure a wide dissemination. The European Construction Industry Federation (FIEC) and the International Union of Architects (UIA) through the ARES – Int. WP will distribute the relevant project outcomes in the building sector. The target group containing utilities and electrical installers will be covered by the European Association of Electrical Contractors (AIE), which is composed of 21 national associations representing 175 500 electrical installation contractors.

Results to date

A number of results have been achieved during the first year of the project. The most concrete results are:

- the BIPV brochure targeting architects and builders provides an overview of the various possible applications for the integration of photovoltaic systems in buildings, analyses the cost competitiveness of photovoltaic modules with other materials and offers a valuable list of related literature (available at www.pvsunrise.eu/documents/BIPV_web.pdf);
- a report on identified barriers (administrative, market, technological and barriers of perception) for photovoltaic in the building sector which offers a set of recommendations to overcome them;
- creation of the project website www.pvsunrise.eu

In addition to all these results, the main achievement of this first year of the project is the set-up of frequent dialogue channels between the photovoltaic sector and other relevant sectors such as architects, planners, representatives of the construction sector, installers and utilities. Conferences and workshops have been and are being organised in order to disseminate results and offer forums for discussion between the related sectors.

INFORMATION

Project acronym	SUNRISE
Project full title	Strengthening the European photovoltaic sector by cooperation with important stakeholders
Proposal/ contract no.	038589
Coordinator	European Photovoltaic Industry Association, Belgium Contact: Eleni Despotou
Total eligible cost	EUR 933 480
EU contribution	EUR 650 000
Start date	January 2007
Finish date	June 2009
Partners	Fédération de l'industrie européenne de la construction, Belgium
	Association européenne de l'installation électrique, France
	International Union of Architects, France
	Wirtschaft und Infrastruktur & Co Planungs KG, Germany
Website	www.pvsunrise.eu

UPP-Sol

Urban photovoltaics: polygeneration with solar energy

The cost of the electricity produced by photovoltaic technology is higher than that from conventional fuels. This is a major obstacle for sustained long-term growth of solar technologies, and currently requires massive governmental support to create artificial markets for solar electricity. Two reasons contribute to this high cost: the need to use large amounts of expensive semiconductor material, and the low conversion efficiency.

A combination of two innovative approaches can achieve a synergy that addresses both the abovementioned issues: ***Concentrating Photovoltaics*** (CPV) and ***Cogeneration***. The concentration reduces the area of expensive cells. Cogeneration collects the thermal energy generated in the cells in addition to the electrical energy, resulting in overall efficiency that can reach 75 %. The combination of both approaches is a CPV/Thermal (CPVT) solar collector system. Such unique collectors will be demonstrated for the first time in a commercial scale installation.

An important requirement for CPVT systems is the location of the solar collectors as collectors have to be close to the end-user. The Di.S.P. and SHAP collectors are small enough to integrate into an urban environment, for example on a building rooftop.


A CPVT solar collector

CPVT systems are suitable for a wide range of thermal applications, including absorption cooling and air-conditioning, steam production, desalination, and industrial process heat. Such systems can satisfy the energy needs of many users in the urban areas of sunbelt countries, greatly reducing the peak load of the electrical grid during summer, and displacing large amounts of conventional fuels.

Another advantage is the fact that the solar energy replaces conventional energy bought at retail cost, which is much higher than the production cost to the utility. Therefore, the same solar technology may be non-competitive at the utility's power station, but competitive at the end-user site. If the end-user enjoys government incentives given to renewable energy systems, the system will be even more competitive, accelerating the pace of public adoption of renewable energy.

Approach

Project participants have developed CPVT collector technology for urban applications under national and bilateral programmes. The collectors are small to permit easy integration and installation in buildings. Concentration is by a factor of a few hundred. Triple-junction cells with nominal efficiency of 35 % are used, to obtain the highest possible electrical conversion efficiency, and also since this type of cell is capable of operating under higher temperatures relative to silicon cells. Two collector versions with different geometries have been developed for applications in various types of building – a roof-integrated stationary collector, and a freestanding tracking parabolic dish collector.

In UPP-Sol, the innovative CPVT collector technology will be integrated for the first time into a fully functional system at a commercial scale. Two complete demonstration systems will be built and operated, in typical buildings located at Colleferro (Italy) and Valladolid (Spain). The two plants will include conversion of the thermal energy into air conditioning by absorption chillers to demonstrate the use of the thermal energy throughout the year, for cooling and heating as needed. Plant integration and control including all auxiliary equipment for the electrical and thermal parts, is developed by project partners. The project will also include testing of triple junction cells with comparison with current state of the art cells manufactured in the USA.

Results to date

Work has been conducted on improvement of collector technology, resulting in enhanced collector design that is easier and less expensive to manufacture, while improving performance relative to the prototype versions. The design and optimisation of the complete plants is under way. Simulation and optimisation software was developed in order to predict and analyse the plant's performance, and to serve as a design tool for future commercial projects.

Future prospects

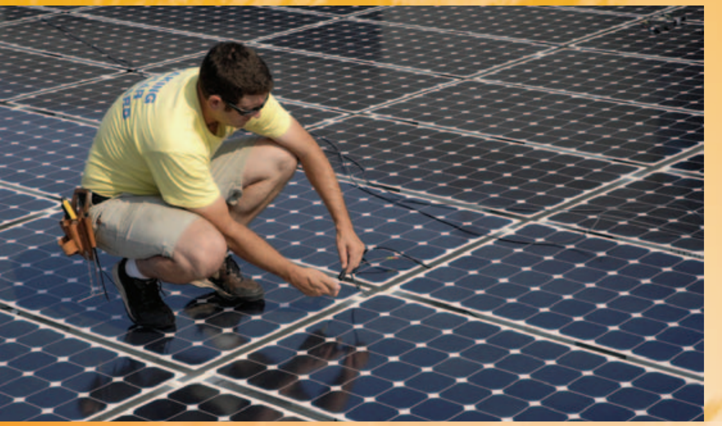
The project expects to deliver a first demonstration of a full CPVT plant operating under realistic field conditions, showing the capability of producing simultaneously electricity, air conditioning and heat. Such a demonstration will allow the assessment of this new technology and the validation of its benefits, from both the economics and energy efficiency point of view.

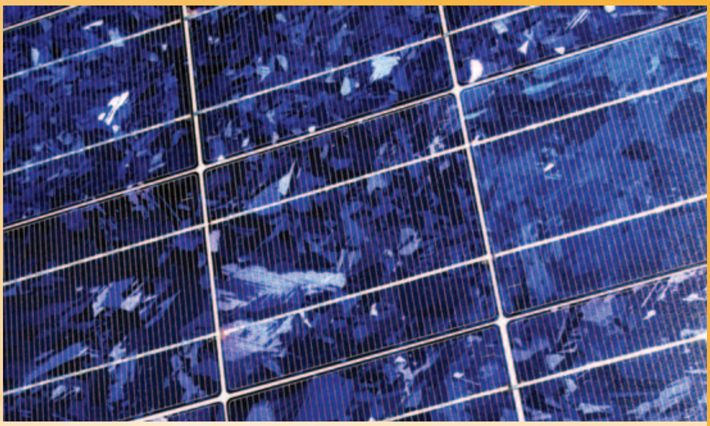
Following a successful demonstration and operation of the two demonstration plants, the project partners will be able to widely disseminate and implement the CPVT technology. Italy and Spain are two relevant markets for CPVT systems and offer a wide range of possible applications and market niches where such technology can offer superior benefits relative to other solar technologies, and even compete against conventional energy supplies. Following the home markets, the CPVT systems can also be exported and implemented in many other sunbelt countries.

INFORMATION

Project acronym	UPP-Sol
Project full title	Urban photovoltaics: polygeneration with solar energy
Proposal/ contract no.	038386
Coordinator	Consorzio Roma Ricerche, Italy Contact: Manuela Bistolfi
Total eligible cost	EUR 3 384 322
EU contribution	EUR 1 747 881
Start date	April 2007
Finish date	March 2010
Partners	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Di.S.P. Distributed Solar Power Ltd., Israel
	Tel Aviv University, Israel
	Comune di Colleferro, Italy
	Shap S.P.A. Solar Heat and Power, Italy
	Università di Firenze – Centro Ricerche Energie Alternative e Rinnovabili, Italy
	Besel, S.A., Spain
Website	www.uppsol.eu/

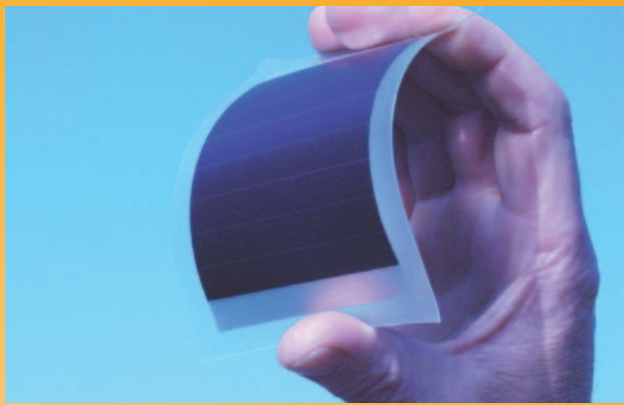
RESEARCH PROJECTS





Thin-film technologies

Thin-film solar modules are produced by depositing thin films directly onto large-area substrates, such as large glass panels (larger than 1 m^2) or long foils. With film thicknesses of around 1 µm, thin-film modules are inherently low cost because their manufacture requires only a small amount of active materials and is suited to fully integrated processing and high throughputs. Although conversion efficiencies of thin-film materials are currently lower than those of crystalline silicon, thin-film technology offers the lowest cost per watt and the shortest energy pay-back time among commercial solar products. Thin-film photovoltaics is growing rapidly, and the availability of large-area deposition equipment and process technology, and the expertise of the architectural glass and the flat panel display industries, offer significant opportunities for high-volume and even lower-cost manufacturing.



ATHLET

Advanced thin-film technologies for cost effective photovoltaics

The project aims to accelerate the decrease in the cost/efficiency ratio for thin-film photovoltaic modules. It focuses on technologies based on amorphous, micro- and polycrystalline silicon as well as on I-III-VI_2-chalcopyrite compound semi-conductors. The work centres on large-area chalcopyrite modules with improved efficiencies and on the up-scaling of silicon-based tandem solar cells. This is complemented by a range of activities from the demonstration of lab scale cells with higher efficiencies to the work on module aspects relevant to all thin-film solar cells.

Approach

For the first time, research in amorphous, micro- and polycrystalline silicon as well as in chalcopyrite technologies is being undertaken within a single project. The research activities range from fundamental research to industrial implementation. This features short feedback loops and benefit from the synergies between partners with specific expertise. A unique facility is the virtual lab for device analysis and modelling.

Results to date

In the field of flexible solar cells a first copper indium gallium diselenide (CIGS) cell has been prepared on polyimide with a world record efficiency of 14.1 %. Cu(In,Ga) Se_2 cells on titanium cells were further developed and exhibit now up to 16 % on small area.

For compound buffer layers, two different chemical bath deposition (CBD) processes for zinc sulphide, oxide (Zn(S,O)) have reached a high status of development, demonstrated by manufacturing of 30 x 30 cm² Cu(In,Ga) $(Se,S)_2$ modules exceeding 12 % aperture area efficiency. New buffer layer deposition techniques based on spray techniques have been improved to best cell efficiencies of 12.4 % for USP-indium selenide buffers and 15.3 % for ILGAR-zinc sulphide/indium sulphide buffers, both deposited on Cu(In,Ga)$(Se,S)_2$ absorbers. With ILGAR-In_2S_3 buffers, 10 x 10 cm² mini-modules have been processed with a best aperture area efficiency of 12.4 % and proved to have comparable damp-heat stability to cadmium sulphide-buffered references.

Two routes are followed in the investigation of thin-film polycrystalline silicon solar cells: the intermediate temperature route (up to 650 °C) and the high temperature route (700-1 200 °C). In the latter approach, seed layers were prepared on glass-ceramic substrates with grains up to 16 μm. The current density of these polysilicon cells on alumina was increased from around 17 mA cm^{-2} to around 20 mA/cm^{-2}. This led to an efficiency increase from 5.9 % to 7 %.

INFORMATION

Project acronym	ATHLET
Project full title	Advanced thin-film technologies for cost effective photovoltaics
Proposal/ contract no.	SES6-019670
Coordinator	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (previously Hahn-Meitner-Institut Berlin GmbH) Germany
Contact person	Thomas Riedle +49 3080622462
Total eligible cost	EUR 20 834 030
EU contribution	EUR 10 999 735
Start date	January 2006
Finish date	December 2009
Partners	Interuniversitair Micro-Electronica Centrum Vzw, Belgium
	Universiteit Gent, Belgium
	Fyzikalni Ustav Av Cr, Czech Rep.
	Centre national de la recherche scientifique, France
	Saint Gobain Recherche SA, France
	Applied Films GmbH & Co. KG, Germany
	Forschungszentrum Jülich GmbH, Germany
	Freie Universität Berlin, Germany
	IZT Institut für Zukunftsstudien und Technologiebewertung GmbH, Germany
	Schott Solar GmbH, Germany
	Shell Solar GmbH, Germany
	Solarion GmbH, Germany
	Sulfurcell Solartechnik GmbH, Germany
	Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Germany
	University of Patras, Greece
	Energieonderzoek Centrum Nederland, Netherlands
	Univerza V Ljubljani, Slovenia
	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain
	Eidgenössische Technische Hochschule Zürich, Switzerland
	Unaxis Balzers AG, Switzerland
Website	www.ip-athlet.eu/index.html

Concerning microcrystalline silicon single-junction cells, the current has been increased by reducing the optical losses in the transparent conductors layers due to improved zinc oxide with lower free carrier concentration. Titanium oxide anti-reflective layers are also being developed to further reduce primary reflection. Record μc-Si:H cells were achieved with an efficiency of 10 %. Cells with short circuit current density values close to 26 mA/cm², but with lower efficiencies, have also been obtained.

On the industrial side, processes optimised on intermediate sizes (30 x 30 cm² – 40 x 50 cm²) were transferred to full size 1.4 m² micromorph modules with aperture initial efficiency up to 9,6 % were fabricated.

BIPV-CIS

Improved building integration of photovoltaic by using thin film modules in CIS technology

Building integration of photovoltaic systems leads in most cases to a 'high-tech' and 'modern' appearance of the building, caused by the typical window-like surface of most conventional photovoltaic modules.

In many existing building-integrated photovoltaic systems, the modules do not harmonise with the building and its surroundings. Based on experiences like this, conflicts with urban planners are not unlikely. Furthermore the market for refurbishing and modernisation of old buildings is much larger than the market for new buildings. Therefore it is not only an aesthetic but also an important economic issue to open up this market.

Approach

The project idea was to modify the surface and colour of photovoltaic copper indium selenium (CIS) based-thin-film modules technology so that building integration of photovoltaic into the ventilated building skin as well as into the insulated building skin or into the roof is more accepted. Special methods to influence the colour impression of a photovoltaic module were to be developed. In parallel, legal and administrative items regarding BIPV in European countries was to be taken into consideration. Furthermore the electrical wiring should be as unobtrusive as possible.

Results obtained so far

- Studies concerning legal and administrative aspects of BIPV in European building regulations.
- Coloured CIS module and large-size CIS module arrays were demonstrated.
- A detailed overview on market needs.
- A transom mullion façade and a structural sealant façade with prefabricated elements containing CIS modules in double-glazing units as well as a mock-up of a façade element with more than 2 m² could be realised. The small generators are in the range of approximately 1 kW.
- A cost- and size-optimised junction box especially suited for thin-film modules. In the meantime, it is available as an industrial product.
- A solution for the invisible connection for modules integrated in the insulated building skin.
- A photovoltaic tile for roof integration based on a CIS module with an injection moulded frame was developed. A European market survey on roof tiles and solar roof tiles was carried out. Material compatibility tests were done.

Future prospects

- Module colour and surface can be varied in a surprisingly wide range.
- The project results allow an improved and widened use of CIS photovoltaic modules in building integration of photovoltaic.

INFORMATION

Project acronym	BIPV-CIS
Project full title	Improved building integration of photovoltaic by using thin film modules in CIS technology
Proposal/ contract no.	SES6-CT-2003-503777
Coordinator	Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Germany
Contact person	Dieter Geyer
Total eligible cost	EUR 4 229 595
EU contribution	EUR 2 300 000
Start date	January 2004
Finish date	December 2007
Partners	European Commission – Directorate-General Joint Research Centre, EC JRC
	Saint Gobain Recherche SA, France
	Shell Solar GmbH, Germany
	Technische Universität Dresden, Germany
	Würth Solar GmbH und Co. KG, Germany
	Permasteelisa S.P.A., Italy
	Politechnika Warszawska, Poland
	Politechnika Wroclawska, Poland
	Solar Engineering Decker & Mack GmbH, Sweden
	Swiss Sustainable Systems AG, Switzerland
	Ove Arup & Partners Limited, United Kingdom
	Tyco Electronics UK Ltd, United Kingdom
Website	http://bipv-cis.info/

FLEXCELLENCE

Roll-to-roll technology for the production of high-efficiency low-cost thin-film silicon photovoltaic modules

Thin-film silicon solar modules have high potential in the current booming photovoltaic market. They can be produced by means of chemical vapour deposition (CVD) processes which have high potential for low production costs per watt, and require comparatively low quantities of raw materials and energy. Flexible substrates and roll-to-roll processes go a step further towards higher production capacities and unbeatable prices. The challenge is to develop equipments and processes for cost-effective roll-to-roll production of high-efficiency thin-film modules, involving microcrystalline (μc-Si:H) and amorphous silicon (a-Si:H).

Approach

The consortium focuses on the demonstration of new substrate concepts, new technologies for interconnection and encapsulation, high efficiency and reliable single a-Si:H and tandem μc-Si:H/a-Si:H solar cells and modules. The three most promising CVD technologies (microwave and very high frequency plasma assisted CVD, hot wire CVD) are being investigated to produce high-rate and high-quality photovoltaic material and the innovative results and concepts are directly implemented in production and in the final blueprint of multi-megawatt production lines.

Results to date

A back reflector system with high-reflecting and scattering optical properties was developed, produced by roll-to-roll on plastic and metal foils and implemented into solar cells and modules. In the pilot production line at VHF-Technologies, initial efficiencies up to 6.8 % could be reported for single a-Si:H cells and the first proof of concept for tandem μc-Si:H/a-Si:H cells and modules was successful.

In addition, new insight into cost-effective monolithic series interconnection with low dead area losses was gained for flexible PV modules; a complete encapsulation process was developed and validated with the certification of large area BIPV products, and cost modelling results have shown that the target cost of EUR 0.5/W is reasonably achievable as medium-term target (5-10 years).

Future prospects

The industrial exploitation of the results has been partly achieved with many developments already implemented in production, especially a large-width electrode which is now used for the up-scaling of the production plant at VHF-Technologies.

Further improvements could also be made towards higher efficiency, lower costs, lower environmental imprint and a fair comparison of the different processes.

INFORMATION

Project acronym	FLEXCELLENCE
Project full title	Roll-to-roll technology for the production of high-efficiency low cost thin film silicon photovoltaic modules
Proposal/ contract no.	SES6-019948
Coordinator	Université de Neuchâtel, Switzerland
Contact person	Prof. Christophe Ballif and Vanessa Terrazzoni vanessa.terrazzoni@unine.ch +47 93059428
Total eligible cost	EUR 4 691 951
EU contribution	EUR 3 095 319
Start date	October 2005
Finish date	September 2008
Partners	Carl Baasel Lasertechnik GmbH & Co. KG, Germany
	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Roth und Rau AG, Germany
	Energieonderzoek Centrum Nederland, Netherlands
	Univerza V Ljubljani, Slovenia
	Universitat de Barcelona, Spain
	VHF-Technologies SA, Switzerland
	Exitech Ltd, United Kingdom
Website	www2.unine.ch/flex/

LARCIS

Large-area CIS-based thin-film modules for highly productive manufacturing

Many established companies as well as photovoltaic newcomers have made decisions in favour of the copper indium selenium (CIS) based-technology, although for the commercial production of large copper indium gallium diselenide and disulphide $Cu(In,Ga)(Se,S)_2$ (CIS) modules on the multi-megawatt scale, most processes remain to be optimised with respect to economical and ecological aspects.

The LARCIS project aims at supporting the upcoming CIS-type solar cell both on the materials and production levels. Thus, high efficiency and high process yield at reduced costs are overall goals which ultimately should make the young CIS technology more competitive.

Approach

Two CIS approaches are supported which affect the optimisation procedures of the non-CIS layers: coevaporation and electrodeposition. Novel cost-effective multilayer back contacts are developed in order to enhance conductivity for the electrodeposition approach and to increase the reflectivity – e.g. by titanium nitride and/or zirconium nitride layers. The second approach is a zinc sulphide/zinc magnesium oxide $ZnS/Zn_{1-x}Mg_xO$ based buffer consisting of a sputtered $Zn_{1-x}Mg_xO$ and a ZnS layer deposited in a chemical bath.

Results to date

An efficiency close to 14 % (without anti-reflecting coating) has been demonstrated both with a ZrN and TiN back contact covered by a thin molybdenum layer. The thin Mo layer (few nm) is necessary to form good ohmic contact. A certified record efficiency of 15.2 % (without ARC) was obtained with an evaporated In_2S_3 buffer on an area of 0.528 cm^2. The best cell with ZnS buffer and ARC reached 16.6 %, whereas the best monolithically integrated mini-module on 10 x 10 cm has an efficiency of 15.8 % (with ARC). With the modified inline CIS evaporation method, a certified efficiency of 17.8 % (with ARC) was obtained on a small area. The scalability and good homogeneity of the electrodeposition CIS process on 30 x 30cm could be demonstrated by optimised bath composition, Mo resistivity, electrolyser geometry and the monitoring of film composition. Both the Micro-Raman analysis and the laser light scattering have shown to be very powerful tools for the control of the electrodeposition and the evaporated absorber growth, respectively.

Future prospects

The project intends to further improve these encouraging results. In addition, promising processes will be tested and/or transferred to the production lines of our manufacturing project partners.

INFORMATION

Project acronym	LARCIS
Project full title	Large-area CIS based solar modules for highly productive manufacturing
Proposal/ contract no.	SES6-019757
Coordinator	Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Germany
Contact person	Dr Friedrich Kessler Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW) Industriestrasse 6 70565 Stuttgart +49 711 7870 201

Total eligible cost	EUR 7 205 501
EU contribution	EUR 4 193 500
Start date	November 2005
Finish date	October 2008
Partners	Centre national de la recherche scientifique, France Electricité de France, France Saint Gobain Recherche SA, France Hahn-Meitner-Institut Berlin GmbH., Germany Würth Solar GmbH und Co. KG, Germany Universitat de Barcelona, Spain Solibro AB, Sweden Uppsala Universitet, Sweden Eidgenössische Technische
Website	http://cordis.europa.eu

LPAMS

Production process for industrial fabrication of low-price amorphous-microcrystalline silicon solar cells

LPAMS aims for a drastic price reduction of film-silicon photovoltaic produced by solar cells split. This will be accomplished by enhancing the photovoltaic module efficiency, while keeping the manufacturing costs per m^2 at a low level.

Approach

To significantly improve photovoltaic module efficiency and long-term efficiency stability, it was found necessary to change the concept from single junction thin-film silicon towards tandem cells, using amorphous, nanocrystalline and/or microcrystalline film-silicon layers. In LPAMS, existing and new deposition methods for transparent conductive oxides, and for doped and intrinsic thin-film silicon have been optimised towards industrialisation by solar cells split. Thin-film silicon was deposited using radio frequency-plasma enhanced chemical vapour deposition (RF-PECVD) and, alternatively, by MicroWave (MW)-PECVD.

Results to date

Excellent material properties have been obtained in 'as-grown' amorphous and nanocrystalline film silicon, deposited by RF-PECVD (Urbach edge as low as 38 meV, defect density 3 x 10^{15} cm^{-3}).

Using the optimised deposition processes, modules with amorphous silicon/amorphous silicon and nano silicon/amorphous silicon a-Si/a-Si and nano-Si/a-Si tandem configuration were fabricated at solar cells in split.

The stabilised efficiency of tandem cell modules was higher than the efficiency of single cell modules. Furthermore, the relative efficiency decrease of the amorphous-crystalline tandem cells was slightly better compared to the amorphous-amorphous tandem and the single cells.

The crystalline tandem cells show better stabilised efficiency (5.7 ± 0.5 %) than the single cells from current production (≈ 4 %) while the production costs are only slightly higher due to longer deposition times of the extra film-silicon layer. The costs per watt drop from EUR 2/W to EUR 1.3/W.

Future prospects

Solar cells split will use the new procedure for deposition of nanocrystalline silicon layers in the production of tandem film-silicon solar cells. Since the extra silicon layer requires significantly longer deposition times, further improvements in production costs can be expected by reducing the deposition time of this crystalline layer, for instance by implementing MW-PECVD in the process line.

INFORMATION

Project acronym	LPAMS
Project full title	Production process for industrial fabrication of low price amorphous-microcrystalline silicon solar cells
Proposal/ contract no.	509178
Coordinator	Energieonderzoek Centrum Nederland, Netherlands
Contact person	Dr. Wim Soppe and Astrid Sander
Total eligible cost	EUR 1 056 000
EU contribution	EUR 609 000
Start date	October 2004
Finish date	September 2007
Partners	Institute for Physics, Croatia
	Rudjer Boskovic Institute, Zagreb, Croatia
	Solar Cells Ltd, Croatia
	Fyzikalni Ustav Av Cr, Czech Republic
	Research Center for Energy, Informatics and Materials, Macedonian Academy of Science and Arts, FYROM
	Roth und Rau AG, Germany
Website	http://cordis.europa.eu

SE-PowerFoil

Roll-to-roll manufacturing technology for high-efficient multi-junction thin-film silicon flexible photovoltaic modules

Compared with wafer-based photovoltaic panels, photovoltaic systems based on thin-film photovoltaic panels already are the lowest cost, despite their (still) lower efficiencies.

Thin-film silicon-based flexible photovoltaic technologies have strong potential. Amorphous silicon based on flexible photovoltaic laminates with aluminium as the superstrate with moderate efficiencies of 5-6 % energy efficiency will be capable of resulting in competitive turnkey system prices. However, with tandem amorphous microcrystalline silicon (a-Si: Hμc-Si:H), tandem devices record R&D cells on glass panels have efficiencies of 13 %, so that this technology has the potential of reaching at least 11-12 % in production. Achieving this target for flexible photovoltaic laminates leads to the possibility of turnkey photovoltaic system prices, but issues such as transfer from batch glass process to roll-to-roll foil process and up-scaling have to be overcome.

Approach

SE-PowerFoil aims to develop deposition technology together with analysis methods. This approach seeks to lead towards high-efficiency long-lifetime photovoltaic laminate in intimate interaction with pilot fabrication. The core project activities are the integration of optimised components for a high-efficiency flexible module into the processes at the pilot-line production on 0.35 m wide foil.

Results to date

Considerable progress has been achieved for flexible tandem solar modules. Tandem a-Si:H/μc-Si:H laminates of 60 cm^2 aperture with initial efficiency of 9.4 % (active area 10 %) and stabilised efficiency of 7.8 % have been made – a world record for this type of flexible photovoltaic product. Mini-modules based on the same layer configuration on glass superstrates show stabilised efficiencies of 10.1 %.

Furthermore the development of photovoltaic-diagnostics has increased knowledge about optical and electrical performance and the current limitations. In parallel the up-scaling of the silicon deposition has been demonstrated.

Future prospects

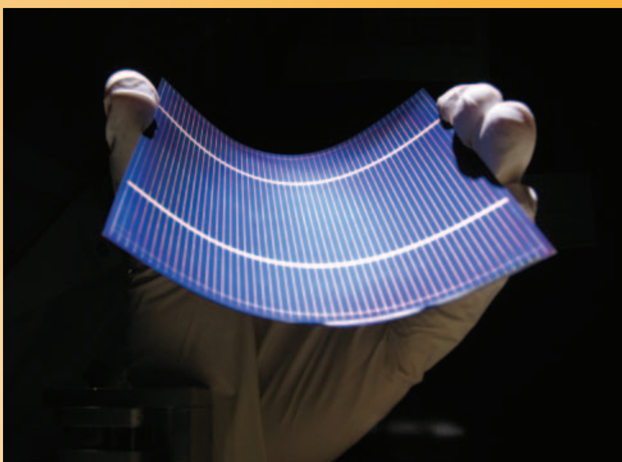
Improving roll-to-roll photovoltaic-technology based on tandem a-Si:H/μc-Si:H laminates is not limited to improving the individual materials or processes. With a combined effort, the project continues to integrate these improved materials and processes into modules and to transfer them into the roll-to-roll production line, leading to world-class lifetime and efficiency.

INFORMATION

Project acronym	SEPOWERFOIL
Project full title	Roll-to-roll manufacturing technology for high efficient multi-junction thin film silicon flexible photovoltaic modules
Proposal/ contract no.	SES6-038885
Coordinator	Helianthos B.V., Netherlands
Contact person	Edward Hamers +31 263661617
Total eligible cost	EUR 3 658 670
EU contribution	EUR 2 200 000
Start date	October 2006
Finish date	September 2009
Partners	Fyzikalni Ustav Av Cr, Czech Republic Centre national de la recherche scientifique, France Forschungszentrum Jülich GmbH, Germany Uniresearch B.V., Netherlands Universiteit Utrecht, Netherlands Cvd Technologies Ltd, United Kingdom University of Salford, United Kingdom
Website	www.se-powerfoil.eu/

Wafer-based crystalline silicon

Solar modules made from wafers of crystalline silicon have been the dominant technology in terrestrial photovoltaics for the last 30 years, in part due to the massive resources and expertise available from the micro-electronics industry. In addition, crystalline silicon has a track record of excellent reliability and consistent cost reduction. Purified silicon is the basic ingredient of crystalline-silicon solar cells. Although silicon is an extremely abundant raw material, the processing required to achieve the necessary purity is inherently energy-intensive (and therefore cost-intensive). Significant effort has been invested into reducing silicon consumption and developing new, less energy-intensive techniques for silicon feedstock preparation. Cell manufacturing also leads to the loss of 50 % or more of the starting material during the manufacturing process, even after recycling. To improve casting and wafering, it is necessary to reduce waste during polysilicon crystallisation, recycle saw dust and other silicon off-cuts, and improve material handling in the production process through automation.



CrystalClear

Low-cost, high-efficiency and reliable solar modules

Solar energy is an essential building block for our future global sustainable energy system. Its potential is practically unlimited and it can be applied in sunbelt regions as well as in countries with less favourable conditions, including all of Europe. Within the family of solar energy technologies, photovoltaic conversion takes a special position because it is really versatile. It can be used from MW to GW scale, for consumer products and solar home systems for rural use up to building integrated systems and large-scale power plants.

WAFER-BASED CRYSTALLINE SILICON

The major barrier towards very large-scale use is the current cost of electricity generation with photovoltaic. The heart of any photovoltaic system – the solar module – comes in different forms. The market is currently dominated by wafer-based crystalline-silicon technology, which has the highest performance of all (non-concentrating) technologies and still has large potential for cost reduction. CrystalClear aims to further increase the module efficiency and reduce the manufacturing cost to EUR 1/W of module power.

Approach

The typical manufacturing cost breakdown of silicon solar modules at the project start is shown in the figure, with major cost components relating to silicon material, solar cell processing and module assembly. CrystalClear aims to cover the entire value chain from silicon feedstock up to the completed solar module. Key topics are the use of low-cost, 'solar-grade' silicon, very thin (0.1 mm) silicon wafers, high-efficiency (17-18 %) cells and novel approaches to interconnection of cells and encapsulation.

Results to date

The project has developed a set of technologies which potentially comply with the cost target. Wafer thickness has been successfully reduced from 0.2 mm to 0.1 mm, while efficiency is well on its way to the target values. A novel, integrated cell and module technology based on rear-side contacting and conductive adhesives has been demonstrated. The consortium has undertaken crucial research on the (so far missing) specifications for solar-grade silicon.

Future prospects

The consortium is confident that it can reach the overall project targets and demonstrate solar modules that can be produced at EUR 1/W. Using such modules it will be possible to build photovoltaic systems that can compete with electricity from the grid at retail level.

INFORMATION

Project acronym	CRYSTAL CLEAR
Project full title	Crystalline silicon PV: low-cost, highly efficient and reliable modules
Proposal/ contract no.	SES6-CT-2003-502583
Coordinator	Energieonderzoek Centrum Nederland, Netherlands
Contact person	Wim Sinke/Wijnand van Hooff. +31 224564539. pmo@ipcrystalclear.info
Total eligible cost	EUR 28 140 140
EU contribution	EUR 16 000 000
Start date	January 2004
Finish date	December 2008

Partners	Interuniversitair Micro-Electronica Centrum Vzw, Belgium
	Centre national de la recherche scientifique, France
	Photowatt International SA, France
	Deutsche Cell GmbH, Germany
	Deutsche Solar AG, Germany
	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Schott Solar GmbH, Germany
	Shell Solar GmbH, Germany
	Universität Konstanz, Germany
	Universiteit Utrecht, Netherlands
	Renewable Energy Corporation As, Norway
	Scanwafer Asa, Norway
	BP Solar Espana SA, Spain
	Isofoton S.A., Spain
	Universidad Politecnica de Madrid, Spain
Website	www.ipcrystalclear.info/default.aspx

FoXy

Development of solar-grade silicon feedstock for crystalline wafers and cells by purification and crystallisation

FoXy aims at developing refining and crystallisation processes for metallurgical solar-grade silicon (SoG-Si) feedstock, optimise associated cell and module processes, and set parameters for these types of feedstock.

Under the realistic assumption that silicon-wafer-based photovoltaic modules will dominate the market in the coming decade, the FoXy partnership will answer the need of the photovoltaic market for low-price and high-quality SoG-Si feedstock by:

- further developing and optimising refining, purification and crystallisation processes for metallurgical SoG-Si feedstock, as well as for recycled n-type electronic grade silicon;
- optimising associated cell and module processes;
- setting input criteria for metallurgical and electronic n-type silicon to be used as raw materials for SoG-Si feedstock;
- transferring the technology from laboratory to industrial pilot tests.

Approach

The objectives are to:

- achieve a significant cost reduction (down to EUR 15/kg) through more efficient cleaning processes for raw materials;
- secure high-volume production of SoG-Si;
- develop recycling techniques for end-of-life products;
- shorten energy payback time to six months;
- manufacture wafers on a large-scale industrial production line 150 x 150 mm^2 aiming at 16-17 % cell efficiency with increased yield.

The work has been divided into following tasks:

- feedstock via direct route;
- refining of highly doped feedstock and production of n-type ingots;
- electrochemical refining of metallurgical feedstock;
- material characterisation;
- cell process optimisation;
- modules and recycling 'end of life';
- integration and exploitation.

Results to date

Record solar cells efficiencies:

p-type SoG-Si:

16.7 % average (best 17.1 %) on textured 125 x 125 mm^2 SoG-Si cells (ref. ISC Konstanz)

16.1 % average (best 16.5 %) on textured 156 x 156 mm^2 SoG-Si cells (ref. ISC Konstanz)

n-type reference:

16.4 % on textured 125 x 125 mm^2 mc-Si (ref. ECN)

18.3 % on textured 125 x 125 mm^2 Cz-Si (ref. ECN)

Module characterisation

The module operating temperature of bifacial open-rear cells was compared with that of monofacial with opaque aluminium-back surface field. The dominant heat dissipation mechanism in free back photovoltaic modules is air convection and not radiation. This explains why the operating temperature is not lower in the bifacial module. The low-stress stringing technology based on conductive adhesives was tested on 180 µm cells of 156 x 156 mm^2 area.

INFORMATION

Project acronym	FoXy
Project full title	Development of solar-grade silicon feedstock for crystalline wafers and cells, by purification and crystallisation
Proposal/ contract no.	SES6-019811
Coordinator	Sintef, Norway
Contact person	Aud Waernes – Marisa Di Sabatino
Total eligible cost	EUR 4 448 000
EU contribution	EUR 2 700 000

Start date	January 2006
Finish date	December 2008
Partners	Deutsche Solar AG, Germany
	Universität Konstanz, Germany
	Università degli Studi di Milano – Bicocca, Italy
	Energieonderzoek Centrum Nederland, Netherlands
	Sunergy Investco B.V., Netherlands
	Fesil, Norway
	Norges Teknisk – Naturvitenskapelige Universitet, Norway
	Isofoton S.A., Spain
	Scanarc Plasma Technologies AB, Sweden
	Joint Stock Company Pillar, Ukraine
Website	www.sintef.no/Projectweb/FoXy/

Novel and emerging concepts

In parallel to the efforts to decrease the price per watt of present-day solar modules, more fundamental research is being carried out with the aim of developing radically lower-cost or higher-efficiency modules for the longer term. Furthest from the market are the novel concepts, often incorporating enabling technologies such as nanotechnology, which aim to i) modify the active layer to better match the solar spectrum, or ii) to preferentially modify the incoming solar radiation before it impinges on the active layer. Closer to the market are the 'emerging technologies', principally organic solar cells (including both dye sensitised solar cells and bulk heterojunctions). Concentrator photovoltaics are probably closest to commercialisation, with significant advances in the laboratory and in production having been made in recent years. By concentrating direct sunlight onto smaller but higher-efficiency cells, concentrator photovoltaics have the possibility to reach system efficiencies of over 30 %, which cannot be achieved by non-concentrating technologies.

FULLSPECTRUM

A new PV wave making more efficient use of the solar spectrum

FULLSPECTRUM aims to make use of the FULL solar SPECTRUM to produce electricity. Present commercial solar cells used for terrestrial applications are based on single gap semi-conductor solar cells. These cells can by no means make use of the energy of below band gap energy photons since these simply cannot be absorbed by the material.

Approach

FULLSPECTRUM's innovation is the creation of a multi-junction solar cell that makes better use of the entire solar spectrum. The technology uses solar cells made of different materials (including gallium, phosphorus, indium and germanium) with different band gaps stacked on top of each other. Tests have shown that these cells can convert as much as 37.6 % of the sun's energy into electricity.

However, these cells are very expensive, although their cost may be significantly reduced by arranging them in special panels which include lenses that cast a large amount of solar energy on the cells. Because the cells are much more efficient, fewer photovoltaic panels are required to achieve the same power output, thereby offering a major advantage over conventional silicon cells. Since these cells are very expensive they must be used in concentrators at very high concentration (between 500 and 1 500 times the natural solar power flux). The adequate concentrators have also been the object of the FULLSPECTRUM research. Concentrator modules and trackers have also been the object of the FULLSPECTRUM research.

Results to date

Triple junction solar cells with 39.7 % efficiency at 293x (x is times the natural solar flux) have been demonstrated. An efficiency of 37.6 % at 1 700x has also been obtained, which is a world efficiency record at this high concentration.

A world record efficiency for dual junction solar cells of 32.6 % has been achieved. These cells are also able to operate at very high concentration and also constitute a step for obtaining good higher efficiency triple junction solar cells in the future. This technology is now being tested on industrial scale at the recently opened Institute of Concentration Photovoltaic Systems (ISFOC).

In another FULLSPECTRUM achievement, the project partners provided the first-ever evidence of the intermediate band effect. This refers to the absorption of photons at three different energy levels, corresponding to three different band gaps. In practical terms, this enables the system to capture low energy photons that would otherwise pass through a conventional solar cell and be lost. In the long term, intermediate band cells might substitute the complex high efficiency multi-junction cells used today.

The consortium reached at the same time a new world record of 7.1 % efficiency of electricity conversion in so-called luminescent solar concentrators (LSC). These concentrators are able to trap and convert the sun rays wherever they come from without additional collectors. The advantage for LSC are their low production cost and that they can be employed nearly everywhere as for example also in transparent windows.

INFORMATION

Project acronym	FULLSPECTRUM
Contract no.	SES6-CT-2003-502620
Project title	A new PV wave making more efficient use of the solar spectrum
Coordinator	Universidad Politécnica de Madrid, Spain
Contact person	Prof. Dr. Antonio Luque +34 913367229 a.luque@upm.es
Total eligible cost	EUR 14 716 209
EU contribution	EUR 8 339 993
Start date	November 2003
Finish date	October 2008
Website	www.fullspectrum-eu.org/

Partners	
	University of Cyprus, Cyprus
	European Commission – Directorate-General Joint Research Centre, EC JRC
	Commissariat à l'énergie atomique, France
	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Philipps University Marburg, Germany
	Projektgesellschaft Solare Energiesysteme mbH, Germany
	RWE Space Solar Power GmbH, Germany
	Energieonderzoek Centrum Nederland, Netherlands
	Universiteit Utrecht, Netherlands
	Ioffe Physico-Technical Institute, Russia
	Consejo Superior de Investigaciones Cientificas, Spain
	Inspira, Spain
	Isofoton S.A., Spain
	Paul Scherrer Institut, Switzerland
	Solaronix S.A., Switzerland
	Imperial College of Science, Technology and Medicine, United Kingdom
	University of Glasgow, United Kingdom

HiconPV

High concentration photovoltaic power system

HiconPV aims to develop, set up and test a new high-concentration 1 000 times photovoltaic system for a large-area III-V-receiver. The objectives are directed towards high-efficient concentrating photovoltaic to reach the system cost goal of EUR 1/W by 2015.

Approach

The development of the high-concentration system integrates two technology fields: the high concentration of the sunlight is obtained using technologies used in solar thermal systems, parabolic dishes and tower systems. The high concentration photovoltaic receiver is based on the III-V solar cell technology. With the current knowledge on solar concentrator technologies, it has been possible to design and build a solar concentrator tailored to specifications such as incident solar power (maximum, mean and median values) and best flux distribution to achieve the best system annual performance.

The most challenging technical development of the project is the receiver. To deal with the high concentration, monolithic integrated modules have been developed with III-V materials and assembled to compact concentrator modules. The heat generated in the receiver at high-flux density levels on the technical limit is rejected with coupled heat exchanger plates. Careful design of the heat exchanger including flow pattern has to prevent overheating of the modules.

Each compact concentrator module comprises a module power of around 2 kW from a module area of about 100 cm² on frameless water- or air-cooled heat sinks. The modules are designed such that their assembly to larger panels for large area concentrators is possible. Inverters suitable for this kind of solar system have been developed for the use in grid connection, with the option for remote operation mode.

Simulation tools have been adapted to perform annual power output and cost calculations for high-concentrating photovoltaic power systems with the parameters determined from the analysis of the components.

The models include site-specific data like solar or water resources, and grid connection cost. A study estimated the installation potential in European and non-European countries. The costs for different production numbers and system sizes as well as cost reduction potentials were evaluated.

Results

The innovative result of this project is a compact concentrator photovoltaic module for the application in concentrating solar power systems at 1 000 times concentration. Each compact concentrator module comprises a module power of around 2 kW – from a module area of about 100 cm² on frameless water- or air-cooled heat sinks. Single-junction solar cells made of gallium arsenide (GaAs) are considered for this new technology and efficiencies of 20 % are reached. The adaptation of the concentrator technology and of the inverters has been finished.

Future prospects

In the future multi-junction solar cells on the basis of III-V-semiconductors with efficiencies above 30 % can be used. In combination with an increase of the system size, a bigger concentrator and module, the system cost goals could be achieved.

INFORMATION

Project acronym	HICONPV
Contract no.	SES6-CT-2003-502626
Project title	High Concentration PV Power System
Coordinator	Solucar Energía S.A., Spain
Contact person	Valerio Fernandez Quero +34 913300669 valerio.fernandez@solucar.abengoa.com
Total eligible cost	EUR 4 889 616
EU contribution	EUR 2 699 924
Start date	January 2004
Finish date	December 2006

Partners	Électricité de France, France
	Deutsches Zentrum für Luft- und Raumfahrt E.V., Germany
	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Projektgesellschaft Solare Energiesysteme mbH, Germany
	RWE Space Solar Power GmbH, Germany
	Ben Gurion University Of The Negev, Israel
	University of Malta, Malta
	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Spain
Website	http://smap.ew.eea.europa.eu/fol120392/prj784653/

MOLYCELL

Molecular orientation, low-band gap and new hybrid device concepts for the improvement of flexible organic solar cells

Organic materials appear highly promising due to the advantages they present. However, basic research remains essential to move towards first market applications that require increased power efficiency and longer lifetime. Hence MOLYCELL aims to develop organic solar cells to reach criteria for large-scale production in two different technologies: dye-sensitised solid state solar cells and bulk heterojunction organic solar cells.

Approach

To reach the MOLYCELL goals, the following points are addressed in parallel:

- design and synthesis of new materials to overcome the large mismatch between the absorption characteristics of currently available polymer materials and the solar spectrum and to improve the relatively slow charge transport properties of these polymer materials;
- development of two device concepts to improve efficiencies: the 'all-organic' solar cells concept and the nanocrystalline metal oxides/organic hybrid solar cells concept.

INFORMATION

Project acronym	MOLYCELL
Contract no.	SES6-CT-2003-502783
Project title	Molecular orientation, low-band gap and new hybrid device concepts for the improvement of flexible organic solar cells
Coordinator	Commissariat à l'énergie atomique, France
Contact person	Stephene Guillerez +33 479444540 stephene.guillerez@cea.fr
Total eligible cost	EUR 4 598 629
EU contribution	EUR 2 499 967
Start date	January 2004
Finish date	June 2006
Website	www-molycell.cea.fr

Results to date

Significant progress has been made as part of this project for both organic and hybrid devices. Highlights include the demonstration of:

- polymer/fullerene blend devices with certified efficiencies of 4.8 %, and best lab efficiencies of 5.5 % under simulated AM1.5 sunlight;
- solid state dye-sensitised solar cells with efficiencies of 4.2 %, rising to > 6 % under 1/10th solar irradiation;
- strong progress on the development of organic photovoltaic modules on plastic substrates, including demonstrating of 10 cm^2 module with efficiency of 3 %.

Future prospects

Key conclusions for future directions are as follows:

- for all organic devices, device efficiencies and stabilities are already approaching levels sufficient for niche market applications;
- for dye-sensitised devices, extensive commercialisation programmes are already ongoing. Solid state devices avoid concerns over sealing of organic electrolytes. The development of low-temperature deposition routes for titanium oxide barrier layers required for when using molecular hole conductors remains to significant research challenge;
- glass and flexible substrate mounted devices continue to have distinct merits, with glass mounted devices exhibiting high efficiencies and superior stabilities promising for building integrated applications, whilst flexible substrates and encapsulation enable lower processing costs and are particularly suited for consumer product markets.

Partners	Konarka Austria Forschungs- und Entwicklungs GmbH, Austria
	Linzer Institut für organische Solarzellen – Johannes Kepler Universität, Austria
	Interuniversitair Micro-Electronica Centrum Vzw, Belgium
	Institute of Physical Chemistry and Electrochemistry J. Heyrovsky – Academy of Sciences of the Czech Republic, Czech Republic
	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
	Siemens AG, Germany
	Vilniaus Universitetas, Lithuania
	Energieonderzoek Centrum Nederland, Netherlands
	École polytechnique fédérale de Lausanne, Switzerland
	Konarka Technologies AG, Switzerland
	Ege Universitesi, Turkey
	Imperial College of Science, Technology and Medicine, United Kingdom

orgaPVnet

Coordination action towards stable and low-cost organic solar cell technologies and their application

A strongly increasing R&D effort can be seen in the domain of solar cells based on organic layers. This progress is essentially based on the introduction of nanostructured material systems to enhance the photovoltaic performance of these devices. The growing interest is fuelled by the potentially very low cost of organic solar cells thanks to the low cost of the involved substrates, the low cost of the active materials of the solar cell, the low energy input for the actual solar cell/module process and last but not least, the asset of flexibility.

Approach

The orgaPVnet consortium brings together leading institutions in this field in association with the main industrial players. In this way a powerful Organic Photovoltaic Platform will be created that can sustain the leading R&D position of Europe within this domain and strengthen European competitiveness.

Key actions to reach the above-mentioned objectives are:

- to promote interaction between scientists;
- to take advantage of the previous experience of research groups;
- to join forces to maximise the synergy between individual skills, thus obtaining the best achievable global results;
- to provide an appropriate communication channel between academic groups, small and medium-sized companies and industry.

OrgaPvNet will contribute to this by:

- the exchange of information during the workshops organised by the network;
- scientific exchange between partners by research visits of scientist and student grants;
- set-up of a web-based database containing news, resources, project results, reports, links, seminars, training, etc;
- elaboration of a 'Who's Who' guide in the organic photovoltaic field;
- elaboration of the European Organic Photovoltaic Roadmap, identifying scientific priority areas and research and development strategies.

Results to date and future prospects

- a web page, www.orgapvnet.eu, containing project and partner information;
- the kick-off meeting where all the partners were present;
- the six Expert Working Group Leaders organised a first Workshop in Prague in May 2007 where contributions towards the state of the art of the field were presented and discussed in small round-table discussions after each session;
- two meetings of the Steering Committee were held during which the preparation of the roadmap was initiated;
- a first orgaPVnet International Symposium Organic and dye sensitised solar cells was held in Austria in February 2008;
- the preparation of the second orgaPVnet International Symposium has begun.

INFORMATION

Project acronym	ORGAPVNET
Contract no.	SES6-038889
Project title	Coordination action towards stable and low-cost organic solar cell technologies and their application
Coordinator	Interuniversitair Micro-Electronica Centrum Vzw, Belgium
Contact person	Laurence Lutsen +32 16 28 12 11; laurence.lutsen@uhasselt.be
Total eligible cost	EUR 1 352 631
EU contribution	EUR 1 200 000
Start date	November 2006
Finish date	April 2009
Partners	Konarka Austria Forschungs- und Entwicklungs GmbH, Austria
	Linzer Institut für organische Solarzellen – Johannes Kepler Universität, Austria
	3e N.V., Belgium
	Institute of Physical Chemistry and Electrochemistry J. Heyrovsky – Academy of Sciences of the Czech Republic, Czech Republic
	Centre national de la recherche scientifique, France
	Commissariat à l'énergie atomique, France
	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung E.V., Germany
	Hahn-Meitner-Institut Berlin GmbH, Germany
	University of Patras, Greece
	Bar Ilan University, Israel
	Consiglio Nazionale delle Ricerche, Italy
	Vilniaus Universitetas, Lithuania
	Energieonderzoek Centrum Nederland, Netherlands
	Fundacio Privada Institut Català d'Investigacio Quimica (Iciq), Spain
	Ivf Industrial Research and Development Corporation, Sweden
	École polytechnique fédérale de Lausanne, Switzerland
	Greatcell Solar S.A., Switzerland
	Solaronix S.A., Switzerland
	Ege Universitesi, Turkey
	Imperial College of Science, Technology and Medicine, United Kingdom
	Merck Chemicals Ltd, United Kingdom
Website	www.orgapvnet.eu

Coordinated research activities

The photovoltaics research and expertise is widely distributed throughout the EU; however, thanks in part to the continued emphasis of the European Commission on improving coordination, the European photovoltaics research community is currently a well-connected and consensual network. As part of the wider drive to create a European Research Area, the Commission supports activities aiming at developing common research agendas and pooling expertise in the area of pre-normative research. The Commission also supports photovoltaics in the ambitious task of joint programming of national and regional research programmes.

PERFORMANCE

A science base on photovoltaic performance for increased market transparency and customer confidence

During the current growth of the photovoltaic market and industry, it is of particular importance to lay a sound basis of understanding of the quality and performance of products and systems, harmonise procedures for their testing and labelling, and disseminate the respective knowledge to all players involved.

Approach

PERFORMANCE covers all pre-normative aspects from cell to system level and from instantaneous device characterisation and system measurement to their lifetime performance prediction and assessment. The limitations of current indoor and outdoor calibration measurement technology are investigated and precision will be improved, both in the laboratory and in production facilities. Current technologies are covered as well as new and advanced cell and module concepts. Methods are being developed to connect measurements of module power to module energy production. In addition, methodologies for the assessment of the service lifetime and the long-term performance of photovoltaic modules are under development.

Results to date

Notable results include the outcomes of the first round-robin comparison of module power measurements of crystalline silicon photovoltaic modules in six test labs and of thin-film photovoltaic modules in seven test labs. The results from the participating labs are very close together for crystalline silicon (c-Si) modules; hence the task is now to achieve a similar level of accuracy for thin-film photovoltaic modules. In addition, eight different groups finished two round-robin comparisons of simulation models for photovoltaic modules. The results are also promising, upcoming tasks are related to thin-film modules as well as to the proper modelling of photovoltaic systems instead of photovoltaic modules only.

A survey about module degradation and module failure mechanisms has been carried out among the project partners and external contributors. This served as a database for a subsequent failure mode and effect analysis. Relevant materials for encapsulation of modules have been defined together with their relevant physical properties. Durability tests have been started on a huge variety of modules made using different production technologies and materials. In addition to the determination of material properties, these tests are valuable for assessing and defining future durability test procedures.

INFORMATION

Project acronym	PERFORMANCE
Project full title	A science base on photovoltaics performance for increased market transparency and customer confidence
Proposal/ contract no.	SES6-019718
Coordinator	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
Contact person	Dr. Günther Ebert Head of Department Electrical Energy Systems Fraunhofer-Institut für Solare Energiesysteme ISE Heidenhofstrasse 2, 79110 Freiburg, Germany +49 7614588 5229
Total eligible cost	EUR 11 809 940
EU contribution	EUR 6 999 939
Start date	January 2006
Finish date	December 2009
Partners	Österreichisches Forschungs- und Prüfzentrum Arsenal GmbH, Austria
	Polymer Competence Center Leoben GmbH, Austria
	European Photovoltaic Industry Association, Belgium
	European Commission – Directorate-General Joint Research Centre, EC JRC
	Tallinna Tehnikaulikool, Estonia
	Commissariat à l'énergie atomique, France
	Conergy AG, Germany
	Hochschule Magdeburg-Stendal, Germany
	Meteocontrol GmbH, Germany
	Phoenix Sonnenstrom AG, Germany
	Projektgesellschaft Solare Energiesysteme mbH, Germany
	Schott Solar GmbH, Germany
	Shell Solar GmbH, Germany
	TÜV Immissionsschutz und Energiesysteme GmbH, Germany
	Zentrum für Sonnenenergie- und Wasserstoff-Forschung, Baden-Württemberg, Germany
	Ben Gurion University of The Negev, Israel
	Ecofys B.V., Netherlands
	Energieonderzoek Centrum Nederland, Netherlands
	Scheuten Solar Systems B.V., Netherlands
	Politechnika Wroclawska, Poland
	Sveriges Provnings- och Forskningsinstitut AB, Sweden
	Scuola Universitaria Professionale della Svizzera Italiana (Supsi), Switzerland
	IT Power Limited, United Kingdom
	Loughborough University, United Kingdom
	University of Northumbria at Newcastle, United Kingdom
Website	www.pv-performance.org/

Concerning photovoltaic systems, a concept for the generation of monitoring and performance guidelines has been developed; work has also commenced on updating the standard texts for inclusion in the new guidelines.

Future prospects

The final year of the project will see the accomplishment of a large number of scientific tasks and the integration of all results. PERFORMANCE will create a liaison between standardisation bodies, stakeholders, production and service industries, and end users. Thus, it will contribute to harmonisation and standardisation activities which support the competitiveness of the European solar electricity industry.

PV-ERA-NET

Networking and integration of national and regional programmes in the field of photovoltaic solar energy research and technological development (RTD) in the European Research Area (ERA)

The purpose of PV-ERA-NET is to strengthen Europe's position in photovoltaic technology by improving the cooperation and coordination of photovoltaic RTD programming efforts across Europe. In this context, it aims to improve and create instruments in terms of cooperation as well as to set up new cooperation forms with other organisations and entities dealing with photovoltaic RTD at European level.

Approach

The project takes a three-step bottom-up approach consisting of:

- structured information exchange and development of sustainable dissemination strategies;
- identification of complementarities, gaps and opportunities between various RTD programmes in order to create strategies and instruments for sustained cooperation;
- development of a strategic plan and implementation of joint activities and approaches.

Results to date

In view of a certain fragmentation of photovoltaic RTD efforts in Europe, PV-ERA-NET provides the structure for increased coordination and cooperation with a long-term perspective and a long-lasting structuring effect for photovoltaic research programmes.

Following the basic steps in the ERA-NET scheme, PV-ERA-NET has elaborated on the following concrete results:

- survey reports and a regular structured information exchange among the participating photovoltaic RTD programmes;
- barriers and opportunities have been assessed;
- implementation of joint activities such as a web-based project database providing a detailed overview of ongoing RTD projects in the participating photovoltaic RTD programmes as well as POLYMOL Joint Call for projects in the field of polymer and molecular solar photovoltaic cells and modules.

Future prospects

PV-ERA-NET is developing structures and concrete instruments towards improved cooperation and coordination in photovoltaic RTD strategy development by taking a bottom-up approach. In doing so, it contributes to establish a strong ERA and aims at contributing to a sustainable structuring effect of the European photovoltaic landscape in terms of coherence, innovation and economic growth.

Based on the (internal) experience within PV-ERA-NET and the (external) clear need for an active role of national programmes in taking forward the different initiatives to be implemented in a very near future, it has been concluded that there should be an efficient, straight-forward network of national/regional research and technological development programmes based on PV-ERA-NET.

INFORMATION

Project acronym	PV-ERA-NET
Project full title	Networking and integration of national and regional programmes in the field of photovoltaic solar energy research and technological development (RTD) in the European Research Area (ERA)
Proposal/ contract no.	11814
Coordinator	Forschungszentrum Jülich GmbH, Germany
Contact person	Marcel Gutschner
Total eligible cost	EUR 2 626 344
EU contribution	EUR 2 626 344
Start date	October 2004
Finish date	September 2008
Partners	Ministerstwo Nauki I Informatyzacji (Ministry of Scientific Research and Information Technology), Poland
	Energistyrelsen (Danish Energy Authority), Denmark
	Bundesministerium für Verkehr, Innovation und Technologie, Austria
	Ministerium für Wissenschaft und Forschung Nordrhein-Westfalen, Germany
	Ministerium für Verkehr, Energie und Landesplanung Nordrhein-Westfalen, Germany
	Agence de l'environnement et de la maîtrise de l'énergie (Ademe), France
	Bundesamt für Energie, Switzerland
	Net Nowak Energy & Technology Ltd., Switzerland
	Department of Trade and Industry, United Kingdom
	Ministerio de Educación y Ciencia, Spain
	Forskningsrådet för Miljö, Areela Näringar och Samhällsbyggande, Sweden
	Swedish Energy Agency, Sweden
	Senternovem, Netherlands
	Forschungsförderungsfonds für die Gewerbliche Wirtschaft, Austria
	General Secretariat for Research and Technology – Ministry of Development, Greece
	Centre for Renewable Energy Sources, Greece
Website	www.pv-era.net/

PV-SEC

Strengthen the European photovoltaic sector and support to establish a PV technology platform

The EU Photovoltaic Technology Platform is an initiative aimed at mobilising all actors sharing a long-term European vision for photovoltaic, realising the European Strategic Research Agenda for Photovoltaic for the next decade(s) and giving recommendations for implementation; and ensuring that Europe maintains industrial leadership.

A supporting entity to the Platform, the Photovoltaic Secretariat (PV-SEC) provides organisational support and information to the Steering Committee, Mirror Group and Working Groups and ensures smooth operations between these groups.

Approach

The work plan of PV-SEC is broken down into one main work package dealing with management and coordination and four others focused on logistical support, development of information and communication tools, support for the Strategic Research Agenda and support to Working Groups dealing with non-technical issues.

Results to date

PV-SEC has contributed to the progress of the work within the Working Groups and the Steering Committee. It established an efficient dissemination of results and helped to keep the deadlines set in the project time schedule. PV-SEC uses its dedicated platform website to publish all relevant documents of meetings, workshops and conferences. Printed media were also produced. PV-SEC further supports the Platform by organising events covering relevant issues. PV-SEC is also responsible for the maintenance of the website of the EU Photovoltaic Technology Platform, which is used as the main communication tool for the project.

Future prospects

After three years of activity the EU Photovoltaic Technology Platform can already show several results – in particular its contribution to the progress of the work and efficient dissemination of results.

A Strategic Research Agenda was developed by the main research centres of Europe and the industry setting priorities for the short, medium and long term. The development of the Agenda was supported by PV-SEC through the compilation of documents and gathering of relevant data. It was responsible for the printing procedure for the Agenda. Factsheets have been created to further promote photovoltaic at European level.

Bridges between several sectors such as the construction industry or the electricity sector have been built up to better cooperate and advance together towards the integration of solar electricity in our daily life.

INFORMATION

Project acronym	PV-SEC
Project full title	Secretariat of the PV Technology Platform
Proposal/ contract no.	SES6-513548
Coordinator	EPIA – European Photovoltaic Industry Association, Belgium
Contact person	Eleni Despotou, Policy Director +32 2 465 38 84

Total eligible cost	EUR 652 258
EU contribution	EUR 650 000
Start date	July 2005
Finish date	June 2009
Partners	Eurec-Agency, Belgium
	European Commission – Directorate-General Joint Research Centre, EC JRC
	Wirtschaft und Infrastruktur & Co Planungs KG, Germany
Website	www.photovoltaic-conference.com/

New materials, technologies and processes

For photovoltaic technologies, material properties and process innovation are continually developed and optimised, for all parts of the value chain – e.g. the active layer, the transparent conducting oxide and the encapsulation. New materials are devised to replace scarce or hazardous substances.

Thinner wafers and the scaling up of thin-film deposition require new and standardised equipment, leading to higher throughput and yield. In-line diagnostics is developed for improved quality control and a better understanding of the relationship between process parameters and material characteristics.

BUILD-DSSC

Large area dye-sensitised solar cells for building integrated photovoltaic tile

Dye-sensitised solar cells are considered a viable alternative to amorphous silicon solar devices, due to comparable efficiency, transparency and low cost. BUILD-DSSC aimed to create a technology for producing large-area dye-sensitised solar cells, by using a new class of electron transfer mediators, which are non-corrosive. It addressed application onto opaque substrates (ceramic), for the production of building integrated photovoltaic tiles for roofs and facades.

Approach

An experimental phase was carried out on polypyridine Co(II) complexes, optimising the problems related to slower dye regeneration and faster recombination with photo-injected electrons. Both factors led to poorer performances (ca 20 % less efficient) when compared with the iodide/iodine system.

For the counterelectrode, a new type of ceramic cathode covered by a conductive carbon layer was produced by the project. Carbon was used instead of platinum and permits to regenerate cobalt polypyridine redox mediator by electrochemical reduction closing the circuit. The results also showed for the first time the possibility of using carbon composite ceramic substrates for screen-printed cathodes for a dye-sensitised solar cell system.

The pre-industrial plant in IBE's facilities (Segovia) was adapted to the needs of the modified process steps, to achieve working dye-sensitised solar cell prototypes.

Results to date

The prototypes produced in the project did not achieve the expected targets:

- working samples with stable electrical performances were produced, but the efficiency achieved is only 20 % of that which was expected (< 1 % instead of 5 %). This is due to the limiting factors related to the technological solutions implemented in the short time available;
- the samples using a corrosive iodine mediator presented evident corrosion of metallic fingers;
- the samples using a ceramic substrate achieved the best performance of efficiency equal to 0.66 %.

Future prospects

Technological problems were encountered in the project, but the results demonstrated that, when solving such problems, the dye-sensitised solar cell samples could produce double electrical power in real outdoor conditions under diffuse light conditions, with respect to crystalline silicon c-Si commercial cells.

INFORMATION

Project acronym	BUILD-DSSC
Project full title	Large area dye-sensitised solar cells for building integrated photovoltaic tile
Proposal/ contract no.	512510
Coordinator	Labor S.R.L., Italy
Contact person	Giorgio Recine +39 0640040354
Total eligible cost	EUR 1 030 000
EU contribution	EUR 629 902

Start date	October 2004
Finish date	December 2006
Partners	S.G.G. Di Restagno, Trimboli, Vezzolla & C. S.N.C., Italy
	Gwent Electronic Materials Ltd., United Kingdom
	Mmt S.R.L., Italy
	Limetz, D.O.O., Slovenia
	Ibe Ingenieria e Indústrias Bionergéticas S.L., Spain
	Consorzio Ferrara Ricerche, Italy
	University of Nantes, France
	Centre for Renewable Energy Sources, Greece
Website	http://cordis.europa.eu

NANOPHOTO

Nanocrystalline Si films for low cost photovoltaics

High bulk silicon material costs and environmental risks associated with tellurides and selenides might be the final obstacles to the full development of photovoltaics in the years to come.

The use of thin nanocrystalline silicon (nc-Si) films would provide an answer to this problem, if their full potentialities in terms of low-cost technology and high conversion efficiency could be demonstrated. A mong anticipated breakthroughs, the industrial adoption of the LEPECVD technique was foreseen during the project, bringing the advantage of high quality and very high throughput. In addition, the use of nc-Si was foreseen as an alternative to amorphous silicon a-Si in industrial applications such as solar cells and flat displays, as well as the development of light-emitting diodes operating over a wide range of energies.

Approach

In its bid to respond to this challenge, the NANOPHOTO project aimed to develop computational tools capable of assisting the design and the operation of a new nc-Si growth process. The work covered four main areas:

- deposition of nc-Si thin films using a plasma-enhanced, low-energy chemical vapour deposition (LEPECVD) reactor;
- computer modelling of a 2D and 3D low energy (LEPECVD) reactor, of the kinetics of surface reactions and of the 2D growth of nc-Si films;
- structural, electrical and optoelectronic characterisation of undoped and doped films;
- preparation of prototypes of solar cells and light-emitting devices.

Results to date

- *Modelling:* the development of a 2D model of the deposition reactor has been completed, which fitted very well with the analysis of the plasma distribution and composition on the median part of the reactor. Modelling of the silicon nanocrystal growth also closely matched the transmission electron microscope images.
- *New characterisation tools developed:* in addition to the use of conventional Raman, elipsometry and X-Ray diffraction XRD measurements, new sample preparation methods were developed for high-resolution transmission electron microscopy HRTEM investigations. In addition, a brand new method for local investigation of optoelectronic properties with nanometric resolution was developed.
- *Homogeneous films produced:* microscopically homogeneous films were deposited, consisting of a distribution of Si dots, few nm in size in an amorphous silicon matrix, meeting the requirements for both photovoltaic applications.

INFORMATION

Project acronym	NANOPHOTO
Project full title	Nanocrystalline silicon films for photovoltaic and optoelectronic applications
Proposal/ contract no.	13944
Coordinator	University of Milano-Bicocca, Italy
Contact person	Prof. Sergio Pizzini +39 0264485135
Total eligible cost	EUR 1 970 000
EU contribution	EUR 1 700 000
Start date	June 2005
Finish date	May 2008
Partners	Université Paul Cézanne, Aix-Marseille, France
	University of Konstanz, Germany
	Politecnico di Milano, Italy
	Alma Mater Studiorum-Università di Bologna, Italy
	Consiglio Nazionale delle Ricerche, Italy
	Microsharp Corporation Limited, United Kingdom
Website	www.nanophoto.unimib.it/

SOLARPLAS

Development of plasma-chemical equipment for cost-effective manufacturing in photovoltaics

With typical growth rates of 25 % per annum the production of photovoltaic cells is developing very dynamically. Core technology for power production remains crystalline-silicon-based photovoltaics with a market share of >90 %.

Currently, the photovoltaic industry is under strong pressure to reduce specific costs for electric power production and to increase production capacity substantially. At the project start, solar electricity costs amounted to EUR 0.25-1.00/kWh; the photovoltaic technology development should decrease this value to about EUR 0.10/kWh to realise a breakthrough.

Approach

The state-of-the-art production technology for crystalline-silicon solar wafers is characterised by a combination of batch processing steps. As a result, wafer handling represents a significant additional cost factor. Therefore, the strategic target for the project was to develop a complete in-line manufacturing concept to build up the technological platform for future production of crystalline-silicon solar cells. Innovative atmospheric pressure plasma technologies should be introduced into cell manufacturing lines to achieve such a step change in production technology. Key potential advantages of these technologies are high throughput, continuous in-line processing, and low running costs.

Results to date

In the project, a continuous in-line concept for solar cell fabrication based on atmospheric pressure plasma technologies was developed. Process steps, potentially being replaced by these technologies, are saw damage etch, surface texturisation, removal of front-rear side short (rear side etching), removal of phosphorous glass, and anti-reflective layer deposition.

Against the first intentions, the atmospheric pressure plasma etching of Si wafers appears to be one of the most promising technologies developed in SOLARPLAS. Encouraging results were obtained in several industrial tests for many potential application fields.

Future prospects

SOLARPLAS project produced the following results that may be exploited in the future:

- surface texturisation by plasma etching at atmospheric pressure;
- rear emitter plasma etching at atmospheric pressure;
- plasma chemical etching of PSG at atmospheric pressure;
- PECVD of silicon nitride at atmospheric pressure;
- silicon oxide (SiO_2) barrier layer on polymer foil;
- electrical equipment for long arc plasma under atmospheric pressure.

INFORMATION

Project acronym	SOLARPLAS
Project full title	Development of plasma-chemical equipment for cost-effective manufacturing in photovoltaics
Proposal/ contract no.	17586
Coordinator	Fraunhofer-Gesellschaft zur Förderung der Angewandten Forschung E.V., Germany
Contact person	Dr. Volkmar Hopfe +49 3512583402
Total eligible cost	EUR 1 470 000
EU contribution	EUR 838 560

Start date	July 2005
Finish date	July 2007
Partners	Cvd Technologies Ltd., United Kingdom
	Centrotherm Photovoltaics Gmbh & Co. KG, Germany
	Regatron AG, Elektronik, Switzerland
	Q-Cells Aktiengesellschaft, Germany
	Solartec S.R.O., Czech Republic
	Salford University, United Kingdom
Website	http://cordis.europa.eu

PV components and smart grid issues

Substantial and consistent cost reductions are made at system level, alongside those for the photovoltaic module. These costs can be divided into balance-of-system components (whether part of the energy generation and storage system or components used for control and monitoring) and installation costs. There is scope for cost reduction at the component level, but it is equally important to address installation issues by harmonising, simplifying and integrating components to reduce the site-specific overheads.

A relevant factor in the future development of photovoltaics is the design and deployment of smart grids, a digital upgrade of distribution and long-distance transmission grids to both optimise current operations, as well as open up new markets for alternative energy production. The use of robust two-way communications, advanced sensors, and distributed computing technology will improve the efficiency and reliability of power delivery and use.

OPTISUN

The development of a new more efficient grid connected photovoltaic module

At the outset of this project, no one else was working on embedded conversion of the individual cell watt production. This remains the case, mainly because the idea is simple but also very difficult to bring into production.

OPTISUN succeeded in verifying the electronics concept – that it is possible to make a photovoltaic module with an integrated inverter. The expected improvement of the module efficiency was verified, which is found to be between 20 % and 30 % better than a comparable module in terms of kWh produced per m[2] of cell area.

INFORMATION

Project acronym	OPTISUN
Project full title	The development of a new more efficient grid connected PV module
Proposal/ contract no.	513212
Coordinator	Allsun A/S, Denmark
Contact person	Erik Hansen +45 73831700
Total eligible cost	EUR 1 190 000
EU contribution	EUR 616 185
Start date	February 2005
Finish date	January 2007
Partners	Solartec Sro, Czech Republic
	Semelab Plc, United Kingdom
	Plastas Aps, Denmark
	Solarnova Produktions- und Vertriebsgesellschaft mbH, Germany
	Ibersolar Energía S.A, Spain
	Pera Innovation Limited, United Kingdom
	Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek – Tno, Netherlands
Website	http://cordis.europa.eu

Approach

The technical issues at hand were many and complex. The electronics for the converters need to be compatible with the environment inside the laminate; and the control algorithms for inversion of the multiple converter outputs need to be well understood and made clear in terms of maximum power point tracking. In addition, an idea was devised for collecting more sunlight into the cell through a reflective coating on a plastic carrier which worked, but the production economics forecast did not support the idea going forward.

The work was organised into four main areas:

- scientific study on energy conversion of low input voltage, inverters, and solar cell design and polymer transmission properties;
- development of micro power inverter;
- development of a backlight module;
- integration and industrial trials.

Results to date

The good news for photovoltaic modules is that the developed technology allows for shading to take place without harming the overall production from the system. Furthermore, since shading accounts for many hours of lost kWh production in urban areas, as well as production loss due to bird waste or cracked cells inside the laminate, the OPTISUN project results will set a new standard for module performance.

Today the original idea of the embedded inverter technology is not only verified. Based on the OPTISUN project we have created the company SunSil, which has two patents pending for the developed technology. SunSil will start mass production of the kWh-improved photovoltaic module by the end of 2010.

SOS-PV

Security of supply photovoltaic inverter

Electricity market liberalisation and international pressure to reduce CO_2 emissions have led to new architectures of the future electricity networks with a large penetration of distributed energy resources, in particular from renewable sources.

But the integration of distributed energy resources is performed in such a way that their intermittency can significantly affect the grids, which leads to increasing concerns in terms of power quality and security of supply by the end-users.

Some studies related to photovoltaic systems connected to the grid already show the mutual interaction of photovoltaic systems and the grid:

- limited penetration of photovoltaic, rise of voltage level in concentrated areas, time shift between production and consumption;
- impact on electric loads and photovoltaic system productivity due to poor quality and interruptions of a network.

Approach

SOS-PV aims to develop a multifunctional grid-connected photovoltaic inverter including a storage function with special features so that:

- the photovoltaic system provides grid support on demand;
- the end-user is protected against poor quality power and grid outages.

The relevance for the use of a storage system is manifold as it should:

- improve security of supply;
- increase the global performance ratio of a photovoltaic system by hindering random disconnection or storing the energy produced during the disconnection time and feeding it into the grid after reconnection;
- allow a higher penetration of photovoltaic energy;
- defer the energy injection to the grid during the peaks of load. The result is a smoothing of the load curve.

Results to date

The project has led to the development of:

- innovative inverters, including maximum power point tracking, energy management, load management and a fast switch between the grid connected and stand-alone modes of operation;
- innovative energy storage systems based on a large lithium-ion battery and a hybrid system composed of a lead-acid battery and supercapacitors, both with long lifetime, absorption of peak power pulses in discharge.

Future prospects

Research was conducted to identify the technical and non-technical barriers to the introduction of the SOS-PV system and to the exploitation of its full benefits (for the end-user and the utility): i.e. the possibility of injecting electricity into the network directly from a storage unit, injection of the reactive power, retribution of the photovoltaic system owner for given services, need of communication interfaces between the photovoltaic owner and the utility.

INFORMATION

Project acronym	SOS-PV
Project full title	Security of supply photovoltaic inverter: combined UPS, power quality and grid support function in a photovoltaic inverter for weak low voltage grids
Proposal/ contract no.	19883
Coordinator	Commissariat à l'énergie atomique, France
Contact person	Hervé Colin +33 479444540
Total eligible cost	EUR 2 900 000
EU contribution	EUR 1 500 000
Start date	October 2005
Finish date	September 2008
Partners	Trama Tecnoambiental S.L., Spain
	Enersys Spolka Akcyjna, Poland
	Saft S.A., France
	Martin Sauter GBR, Germany
	Maxwell Technologies Sa, Switzerland
Website	http://cordis.europa.eu

MARKET TRANSFORMATION

The Community instrument the Intelligent Energy – Europe (IEE) programme aims to help achieve EU energy targets (notably the 2020 targets) by tackling the 'softer' factors: removing market barriers, changing behaviour, raising awareness, promoting education and certified training schemes, product standards and labelling, eventually creating a more favourable business environment for energy efficiency and renewables markets.

Launched at the beginning of 2007, the second IEE programme has a budget of some EUR 730 million for seven years. The IEE supports projects converting policy into action on the market and helping to move renewable technologies into mainstream market structures and supply chains. As such, it promotes actions aimed at accelerating deployment of renewable energy systems, including photovoltaics, by creating more favourable market conditions in the various Member States. In other words, EU policies set the targets and the legal framework, whilst IEE projects are aimed at supporting market actors to 'make it happen' on the ground.

In this context, IEE-funded projects address relevant market issues including:

- enabling policies and strategies for the improvement of political-legal conditions and incentive mechanisms for photovoltaics;
- developing innovative financing and investment schemes;
- introducing photovoltaics into the urban-planning process;
- raising awareness of market stakeholders: professionals, urban planners, decision-makers, energy companies, public officers and end-users.

deSOLaSOL

Photovoltaic for small investors in Germany, Spain, France and Portugal

Until very recently it was difficult for private individuals to own a profitable renewable energy installation. In some countries, frameworks were developed to facilitate the introduction of grid-connected photovoltaic installations.

However, it remained complicated to access these installations as investors due to legal and administrative barriers. deSOLaSOL worked to create the tools to overcome these barriers, thus allowing non-professionals to be able to play an important role in the promotion of renewable sources.

Approach

deSOLaSOL fostered the use of energy generation alternatives, minimising/avoiding greenhouse gas emissions by encouraging citizens to become more involved in energy issues, in particular in the participation of photovoltaics projects. Due to the different legislations in force, the proposed approach is economically profitable, and thus, the deSOLaSOL model combined three components of sustainable development.

The approach was to disseminate the best grid-connected jointly owned photovoltaic (JOPV) plants for existing models and experiences in Germany, Spain, France and Portugal. Using the German experience as a basis, the project fostered the increase of photovoltaic installations in the other countries, promoting the improvement of conditions so that small investors were able to set up grid-connected photovoltaic solar energy plants. 'Small investors' meant people and organisations interested in renewable energy, but who face difficulties when building a photovoltaic plant by themselves.

Results to date

There are opportunities in each country to develop JOPV plants, although the legal and market frameworks differ significantly. JOPV are more mature in Germany, with many examples and experiences encouraging citizens to participate. Spain has had a huge photovoltaic development during the project, including JOPV, but work remains to be done. Some JOPV are slowly appearing in France and the new legislation is expected to have a positive impact both on photovoltaic and JOPV. There is more ground to cover in Portugal, but the new decree of micro-producers opened the field for innovative solutions.

Future prospects

The general public is typically interested in such initiatives, although people's motivations can differ, with some wanting to be involved in climate and environmental issues, and others looking for a good investment opportunity. In any case, only if professional structures exist is it possible for JOPV to expand, offering opportunities for the photovoltaic sector.

INFORMATION

Project acronym	deSOLaSOL
Project full title	Photovoltaics for small investors in Germany, Spain, France and Portugal
Proposal/ contract no.	EIE/05/078
Coordinator	Fundación Ecología y Desarrollo, Spain
Contact person	Alicia Lafuente
Total eligible cost	EUR 476 058

EU contribution	EUR 238 028
Start date	January 2006
Finish date	June 2008
Partners	HESPUL, France
	Société financière de la Nef, France
	Triodos Bank, Spain
	ecovision GmbH, Germany
	Associação de produtores florestais, Portugal
Website	www.desolasol.org

PURE

Promoting the use of photovoltaic systems in the urban environment through demo relay nodes

The project aimed to promote photovoltaic energy in buildings, mainly focused on its integration into urban elements, particularly in those European countries with large solar potential but low installed capacity.

PURE worked to overcome the lack of basic information concerning technical and economic aspects of solutions in the participating countries, and the lack of awareness about the importance on integrating renewable energies, notably photovoltaics, into buildings.

The dissemination activities are aimed at agents responsible for managing change concerning the introduction of photovoltaic systems in cities.

Approach

The proposed promotional activities are being addressed through the exploitation of the Photovoltaic Demo Relay Node (PV-DRN), a facility of around 100 m^2, housing several promotional actions. These PV-DRNs are operative in five EU countries: Portugal, Spain, Italy, Greece and Slovakia. The PV-DRN has played a key role in the dissemination activities from its set-up, as they are used as a permanent exhibition and experimental area, as well as a stable contact point for technical, economic and legislation consulting and for celebrating periodical events. In parallel, external actions (replication of successful seminars, visits to target groups and promotion of the PV-DRN) are carried out to extend the dissemination area to other regions.

Results to date

The principal results of the PURE project include the set-up of the five PV-DRN in the participating countries; the participation of PURE partners in more than 30 regional, national and international events talking about BIPV; the generation of useful information about national legislation concerning the implementation of the 2002/91/EC Directive on the energy performance of buildings (2); the publication of several reports on technical and economic solutions for integration of photovoltaic into building publications dealing with the potential and benefits of building integrated photovoltaics; and on a summary of building-integrated photovoltaics best practices.

Future prospects

According to the reported experiences, the PURE project is assumed to have achieved a successful dissemination of the benefits and potential of building-integrated photovoltaics. The concept of the PV-DRN has been assumed in each region and will continue open after the end of the project.

Any renewable energy, especially those with low penetration in the energy mix, should be provided with similar help. Nevertheless, promotion of photovoltaic in general and building-integrated photovoltaics in particular could be still interesting in other European countries or even in other regions of the same countries where PURE project has been performed.

INFORMATION

Project acronym	PURE
Project full title	Promoting the use of photovoltaic systems in the urban environment through demo relay nodes
Proposal/ contract no.	EIE/05/051
Coordinator	Fundación ROBOTIKER, Spain
Contact person	Sabino Elorduizapatarietxe
Total eligible cost	EUR 1 148 080
EU contribution	EUR 574 040
Start date	January 2006
Finish date	December 2008
Partners	Scheuten Solar Technology, Germany
	Environmental Engineering Department/Technical University of Crete, Greece
	Provincia di Savona, Italy
	EVE-Ente Vasco de la Energía, Spain
	Instituto Superior Técnico, Portugal
	Slovak Innovation and Energy Agency (SIEA), Slovakia
Website	www.pure-eie.com

(2) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002L0091:EN:HTM

PV POLICY GROUP

Improving the European and national support systems for photovoltaics

The photovoltaic sector is currently one of the fastest-growing industries worldwide. On the surface, Europe contributes significantly to this development. Closer examination, however, reveals that considerable photovoltaic market deployment takes place only in a few EU Member States.

Approach

The European PV Policy Group is a network of national energy agencies from key 'solar nations', complemented by the photovoltaic industry association. The Group has been established with the objective of stimulating political action throughout Europe for the improvement of political-legal conditions for photovoltaic.

Against the background of an overall photovoltaic strategy, the Group dealt with three major policy areas:

- regulatory frameworks for photovoltaic;
- financial support schemes for photovoltaic;
- monitoring systems for photovoltaic.

Results to date

The main results of the project have been the following:

- European Best Practice Report: a comprehensive study aiming at comparing, assessing and informing about the legal and political framework for the promotion of photovoltaics in 12 EU countries.
- National Position Papers and Action Plans: each of the eight partner countries has presented recommendations and action plans for market introduction of photovoltaic to national policy makers and target groups.
- Joint European Position Paper and Action Plan: this constitutes a set of concrete recommendations for photovoltaic policy design on national and EU level.

Future prospects

- In most countries, the right to access the low-voltage grid still has to be regulated and procedures for grid-connection have to be simplified.
- A sustainable and long-term photovoltaic implementation programme and long-term targets are lacking in many countries.
- Any kind of installation cap for photovoltaic carries the serious risk of a 'stop-and-go' situation, causing uncertainties and therefore preventing the photovoltaic market to develop sustainably.
- Attention should be paid to providing education and training on photovoltaics in all related curricula.
- European political level should exert a strong policy push on countries where solar electricity has potential but where no effective instruments are implemented. On the other hand, in order to endorse the establishment of suitable structures for photovoltaic market introduction it should further apply its available promotional policies and programmes.
- As barriers predominantly persist on national level, future activities should strongly focus the actual implementation of favourable conditions in the Member States themselves.

INFORMATION

Project acronym	PV POLICY GROUP
Project full title	Improving the European and national support systems for photovoltaics
Proposal/ contract no.	EIE/04/058
Coordinator	Deutsche Energie-Agentur GmbH, Germany
Contact person	Jens Altevogt
Total eligible cost	EUR 1 082 587
EU contribution	EUR 541 233
Start date	January 2005
Finish date	April 2007

Partners	Agence de l'environnement et de la maîtrise de l'énergie (ADEME), France
	WIP GmbH & Co Planungs KG, Germany
	Centre for Renewable Energy Sources (CRES), Greece
	Österreichische Energieagentur (AEA), Austria
	European Photovoltaic Industry Association (EPIA), Belgium
	Instituto para la Diversificación y Ahorro de la Energía (IDAE), Spain
	Agencija za prestrukturiranje energetike d.o.o. (APE), Slovenia
	Agência para a Energia (ADENE), Portugal
	SenterNovem, Netherlands
Website	www.pvpolicy.org/

PV-UP-SCALE

Urban scale photovoltaic systems

The successful implementation of photovoltaic on a large scale in cities and villages depends on photovoltaic being:

- part of the urban-planning process of city districts building or renovating, including the energy infrastructure planning;
- available as accepted building product;
- attractive for the electricity sector, for investors, utilities and/or end-users.

Approach/activities

The objective of PV-UP-SCALE is to promote the implementation of dispersed grid-connected photovoltaics in the urban environment. Drivers have been identified that stimulate the decision-makers to apply solar energy.

Solutions for the bottlenecks have been proposed and best practices presented to the stakeholders in the process of planning, application and use of photovoltaic.

The planning process and the connection of many photovoltaic systems to the low-voltage grid has been addressed, as this had been given little attention compared with the issue of photovoltaic as a building product. The knowledge built up the past decade in Europe with building-integrated photovoltaic has been translated to urban-scale applications and stakeholders' needs.

Results to date

- The existing photovoltaic database has been updated with urban-scale and large photovoltaic projects (www.pvdatabase.org).
- 14 case studies have been published on the Internet, providing a detailed look at the processes involved in making an urban-scale photovoltaic project successful.
- The case studies were then used to determine common success factors, problems and solutions.
- Detailed reports on grid issues and economical drivers have been published on the project website.

Future prospects

Although photovoltaic currently appears a costly option for producing electricity compared with other energy sources, many countries support this technology because of its promising future potential and the additional benefits besides generating electricity. These benefits are already effective. Future work needs to address technical developments closely with standards development, as well as changes in regulatory frameworks, so that photovoltaic technology becomes an active part of the tomorrow's electricity networks.

Building-integrated photovoltaic systems can play an essential role in sustainable urban planning since they are easily and visually attractive integrated in building surfaces. In this respect architecturally well-designed building-integrated photovoltaic systems are an important driver to increase market deployment.

INFORMATION

Project acronym	PV-UP-SCALE
Project full title	PV in Urban Policies: a Strategic and Comprehensive Approach for Long-term Expansion
Proposal/ contract no.	EIE/05/171
Coordinator	Energy Research Centre of the Netherlands (ECN), Netherlands
Contact person	Henk F. Kaan
Total eligible cost	EUR 1 096 306
EU contribution	EUR 548 153
Start date	January 2006
Finish date	June 2008
Partners	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V., Germany
	HESPUL, France
	MVV Energie AG, Germany
	Vienna University of Technology, Austria
	Ecofys Energie- und Handelsgesellschaft mbH, Germany
	Universidad Politécnica de Madrid, Spain
	Halcrow Group Ltd, United Kingdom
	HORISUN, Netherlands
	N.V. Continuon Netbeheer BV, Netherlands
Website	www.pvupscale.org/

Acknowledgements

This publication has been prepared on the basis of the photovoltaic projects funded under the Sixth Framework Programme for Research, Technological Development and Demonstration of the European Union coordinated by DG Energy and Transport and by DG Research and under the Intelligent Energy – Europe programme managed by the European Commission's Executive Agency for Competitiveness and Innovation (EACI).

The work has been supervised by Pietro Menna, Andreas Piontek, David Anderson and Gianluca Tondi from the European Commission.

Gabriela Ścibiorska and Kurt Gläser from the European Commission have meaningfully enriched this brochure by their communication competences.

The main authors of this document are all the partners of the projects and have also supplied the photos included in this publication.

The authors wish to thank Aida González Palomino and Jan Prášil for their assistance in preparing this document.

European Commission

Photovoltaic solar energy — Development and current research

Luxembourg: Office for Official Publications of the European Union

2009 — 76 pp. — 21 x 29.7 cm

ISBN 978-92-79-10644-6

KO-81-08-511-EN-C

Publications Office

ISBN 978-92-79-10644-6