EUROPEAN PHOTOVOLTAIC RTD AND DEMONSTRATION PROGRAMME

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ABSTRACT: Renewables and energy efficiency measures are established as key technologies to improve security of energy supply. They also provide Europe with environmental benefits and sustainable technological development. In March 2007, the European Council adopted mandatory targets for 2020 that include increasing renewable energy to 20% of overall consumption and having 10% of gasoline and diesel oil used for transport supplied from bio-fuels. The industrial development of Photovoltaics is supported through the EU Framework Programme, for both research and demonstration activities and through the Intelligent Energy - Europe Programme for non-technological actions. Research focuses on the next generation of PV technologies while the aim of the demonstration activities is to accelerate the market penetration of more cost-effective PV technologies. The Commission supported the launch of a Technology Platform on Photovoltaics to stimulate public-private partnerships between the research community, industry and policy makers with the aim of mobilising greater research and innovation efforts. To accelerate the development, demonstration and market introduction of ever better PV systems, the European Commission is combining an intense legislative initiative with a strong research and demonstration effort and a specific support to promotion and dissemination initiatives enabling the transformation to a reliable, competitive and transparent market.

Keywords: Photovoltaic R&D and Demonstration Programmes; Dissemination, Strategy; Market transformation.

1 INTRODUCTION

Increased concern about green-house gas emissions together with the need to improve the security of supply and enhance business competitiveness, make it ever more vital and pressing for the EU to put in place an integrated policy on energy, combining action at the European and the Member States' level. As a milestone in the creation of an Energy Policy for Europe, and a springboard for further action, in March 2007 the European Council adopted a comprehensive energy Action Plan [1], based on the Commission's Communication "An Energy Policy for Europe" [2]. Today, for the first time, the European Union has a genuine energy policy backed by commitments at the highest political level. The European Council adopted targets for 2020 that include achieving an increase of 20% in energy efficiency, increasing renewable energy to 20% of overall consumption and having 10% of gasoline and diesel oil used for transport supplied from bio-fuels. For the first time ever, these renewable targets are binding and mandatory. Concerns about global warming have been a strong motivation for this shift in policy – a further target decided in March was a commitment to reduce green house gas emission by 20% relative to the 1990 levels by 2020, independent of international agreements. Other motivations are the deep concern about Europe's worsening dependency on energy imports, and the evermore broadly accepted perception that efficient and renewable energy technologies have been an area of competitive advantage for the EU that requires accelerated investment and market stimulation if this leadership is to be preserved. This is why a key element in the package is the work to develop a European Strategic Energy Technology (SET) Plan, for a more integrated and targeted approach to achieve the technological improvements required to meet our energy and associated environmental challenges over the longer term and strengthen the European leadership on the global markets. The leitmotif of the SET-Plan is to turn technology opportunities into business realities that can deliver the policy targets. To achieve this, the energy research and innovation system in Europe must be transformed into a more powerful, efficient and competitive one. In addition, an action plan for energy efficiency was adopted already in October 2006. Higher energy efficiency contributes to tackling the challenge of decoupling energy consumption from economic growth. With regard to this point, the 2005 Green Paper on energy efficiency explains how it is feasible to reach 20% energy savings by 2020 in a cost effective way and without compromising productivity or life-standards [3]. In a more energy-efficient economy and society, renewables can achieve more relevant supply shares. A Framework Directive on renewable energy resources, which is in preparation, will propose a framework for national targets and national action plans to achieve them. Implementation of the framework above will aim at more than one strategy in parallel: Next to security of supply and environmental sustainability, renewable energy and energy efficiency increase employment in Europe and aim at a fast developing new world-market for such technologies.

The share of renewable energy in the overall energy consumption has been growing too slowly. Having carefully examined the feasibility and the technical and economic potential, the Commission has concluded that the overall objective of a 20% contribution of renewable energy to the EU energy mix is possible and necessary. The "Renewable Energy Road Map" describes the massive growth required in all the three renewable

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energy sectors (electricity, biofuels, heating and cooling) to meet the 20% target [4].

To accelerate the growth of EU markets for renewables, a regulatory framework for the renewable electricity sector - which is of direct relevance to the solar photovoltaic sector – was set out earlier. In this context, one very relevant instrument is the Directive on electricity produced from renewable energy sources [5]. The Commission reported on the share of renewable sources in the energy balance of the EU Member States [6] and more recently has adopted a Communication on support schemes for electricity from renewable energy sources [7] and reported on the progress in renewable electricity [8].

According to the first estimates reported in a recent publication, the cumulated installed photovoltaic capacity in Europe had largely surpassed 3,000 MW by the end of the year 2006 [9]. This means that the White Paper target formulated in 1997 for the EU-15 [10] has been achieved four years ahead of time, and furthermore in a EU-25 setting. By far the majority of all the installations are grid-connected.

Since 1999, the European PV-companies featured, on average, a yearly production growth rate higher than 40%. Although care has to be exercised when comparing the different estimates in the PV-sector regarding production, capacity and installation, it would appear that in 2006, Europe accounted for about 50% of the global market, but European manufacturing represented only 30% of global cell production [9], [11]. Europe, therefore, remains a net importer of cells – a trend which may worsen if the growth of production in Europe is outpaced by global counterparts in future years. For instance, the estimated capacity increases in production for 2007 for Japan, Germany and China are 8%, 37% and 53%, respectively [12]. Quality and longevity of PV-cells and modules, and profitable life-cycle features of whole PV-systems may become evermore important in such a highly competitive world market situation.

The European market remains very heterogeneous. It is characterized by a largely dominant German market while that of the other European countries is still limited. According to BSW (the German Solar Industry Association), in 2006, the German PV industry had a turnover of €3.7 billion and employed 35,000 people, including manufacture, R&D, installation and distribution [9]. It has been estimated that the employment figure for the whole EU ranges between 50,000 and 55,000. Although productivity in PV industry progresses with automated production and reduced unit and system costs, the rapid market growth will further create new jobs in Europe. Because solar photovoltaics, like other renewable energy sources, is still relatively new to the market, there is a need for a targeted legislative and commercial infrastructure to encourage rapid market growth. At the same time, there is still a need for high profile demonstration and promotional activities to raise the confidence of investors. The Commission is therefore active in both these areas, with the clear purpose of increasing the share of renewable energy sources in the energy portfolios of the EU Member States.

2 LEGAL INSTRUMENTS

The European Commission has proposed a number of legal instruments to promote renewable energy and energy efficiency during the recent years. The most relevant to the photovoltaic sector are reported below.

2.1 The Green Electricity Directive

The Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources, sets a legal framework for the future development of the renewable electricity (RES-E) markets in the EU [5].

All EU15 Member States have adopted national targets, in line with the reference values listed in Annex I of the Directive and are committed to putting in place support schemes to ensure that these target are achieved. The EU10 Member States have also set up national targets, which were published in the Accession Treaty in April 2003. In addition, 2010 targets have been agreed with Bulgaria and Romania. The Commission continues to monitor and closely follow-up the success which is being achieved by the different support schemes and the resulting progress which is being made towards these targets. Because several of the EU-27 Member States are currently expected to deliver less than their national targets, an overall 2010 contribution of about 19% rather than 21% of electricity consumption from renewable energy sources in the EU is likely to be achieved.

Furthermore, the Directive obliges Member States to ensure guaranteed grid access for RES-E, to issue guarantees of origin for RES-E, and to ensure that the calculation of the costs of connecting new producers of RES-E to the grid and of transmitting green electricity are transparent and non-discriminatory.

Finally, the Directive obliges EU Member States to report on the administrative procedures associated with installing RES-E generators and connecting them to the grid. This is very important for the PV sector because it does not make sense to use the same level of administrative procedure for a typical 3 kW PV system as would be used for a 300 MW conventional power station. In fact, avoidable delays in the permissions for grid-connection in the order of six and more months are still observable in a number of Member States.

2.2 Legislation under preparation

The European Commission is working on a Framework Directive for the promotion of renewable energy sources. The overall target of this Directive will be to reach 20% of European energy consumption supplied through renewable energy sources by 2020.

3 COMMUNICATIONS ON RENEWABLES

3.1 Renewable Energy Road Map

The "Road Map" describes the pathway to bring renewable energies in the fields of electricity, heating and cooling and bio-fuels to the economic and political mainstream and the relevant growth required in the three sectors to meet the 20% target [4].

3.2 Report on Progress in Renewable Electricity

The report assesses the progress made in the EU Member States on the electricity generated from renewables. Figures show that the overall share of renewable electricity will fall just short of the target, reaching 19% by 2010. The report underlines also the

importance of a full and correct implementation of the Directive on renewable electricity, and the immediate lifting of administrative barriers, unfair grid access and complex procedures [8].

3.3 The support of electricity from RES

In 2005, the Commission adopted a new Communication on support schemes of electricity from renewable energy sources [7]. In this Communication, the Commission recommends lighter procedures for small projects and the main conclusions are that the design of the electricity market is essential for the development and take-up of RES-E; a European harmonised system would be premature, and a co-ordinated approach to RES support schemes based on cooperation between countries and optimisation of national schemes should be pursued.

3.4 The Share of Renewable Energy in the EU

In 2004, the Commission reported on the share of renewable sources in the energy balance of the Member States [6]. The Commission analysed the situation and listed the actions that have been taken to promote renewable energy in Europe. Concluding that progress was still not fast enough to ensure that EU targets for 2010 would be met, the Commission called on Member States to do more and proposed that more action should be taken at Member State level.

4. PV RTD AND DEMONSTRATION PROGRAMME

Support for the research development and demonstration of new energy technologies is available through the Framework Programme (FP) for Research of the European Union. Through a series of RTD framework programmes, the Commission has maintained long term support for research, development and demonstration in the PV sector providing a framework within which researchers and industrialists could work together to develop new applications for PV technologies. In terms of research objectives, a combination of actions is needed to address the PV sector, and these are primarily related to cost reduction: (1) fundamental research aimed at achieving progress either through reducing manufacturing costs or through increasing the efficiency of PV cells, and (2) integrated research and demonstration, including the development of system design options and concepts, with a view to expanding the market and providing a basis for economies of scale in PV module and system production.

4.1 6th Framework Programme, FP6 (2003-2006)

The short to medium term activities emphasize mostly demonstration aimed at accelerating the market penetration of more cost-effective PV technologies. More specifically, priority has been given to innovative production concepts for high efficiency cells/modules to be integrated into larger scale photovoltaic production facilities to lower the cost; and including low cost integrated components or devices for PV generators; large area, low cost photovoltaic modules for building integrated PV and autonomous solar electricity generation systems.

The medium to long term part of the programme has focused on cost reduction of crystalline silicon; innovative concepts and fundamental materials research for the next generation of PV technologies; thin film PV technology; PV processing and automated manufacturing technologies; PV components and systems; and research for innovative applications of PV in buildings and the built environment.

During FP6, the European Commission committed €105.6 for supporting PV R&D, thus continuing a 30-year tradition of co-financing the development of solar electricity in Europe. Some of the projects supported under the CONCERTO initiative (launched with the FP6 TREN 2nd Call) include the demonstration of innovative PV systems, for a total of 2.9 MW of power.

To provide some examples of the projects launched under FP6, it is appropriate to start with the activities on feedstock material which represents an appreciable share of the production cost, and has traditionally been sourced from the electronics industry. The ***SISI***, ***FOXY*** and ***SOLSILC*** projects are exploring alternative routes for solar-grade silicon, through carbo-thermic reduction of quartz and refining of metallurgical-grade silicon.

In spite of the feedstock shortage, crystalline silicon has actually increased its market share in recent years, and is expected to remain the dominant technology for many years to come. The largest PV project under FP6 is ***CrystalClear***. The project has the goal of defining a manufacturing process for crystalline silicon capable of realising a production cost of 1 €/W (see also website http://www.ipcrystalclear.info/default.aspx). The ***BITHINK*** project aims to develop and demonstrate new thin bifacial modules, manufactured by an integral screen-printing technique and using a BSF structure. The project aims to obtain low-cost crystalline technology in a multi-megawatt facility. The ***Lab2Line*** project has the goal to bring solar cell processes and materials successfully developed within previous research projects to manufacturing level. In particular, the project will address low-cost options for the laser-grooved solar cell and manufacturing issues related to the use of n-type multi-crystalline silicon. The ***SELFLEX*** project aims to demonstrate cost-effective manufacturing technology for crystalline silicon solar cells based on innovative self-formation processes.

For thin-film technologies, the focus has been on thin-film silicon and copper-indium-diselenide (CIS) technologies. The ***ATHLET*** project is a 4-year project, with a total budget of €20.8M and an EC contribution of €11M. The project targets high-efficiency laboratory cells, module issues, analysis and modelling and environmental aspects. There are also two vertical approaches orientated along the value chain: large-area chalcopyrite modules and the industrial up scaling of silicon tandem cells. The consortium comprises well-known research institutes and solar cell producers and includes also several equipment manufacturers. The main objectives of the project are to improve existing thin-film PV technologies towards module costs of 0.5 €/W (see also http://www.hmi.de/projects/athlet/). Selected results in the first year include the achievement of 14 % CIGS on flexible polyimide and 16.7 % on Titanium.

HIGHSPEEDCIGS is an innovative project which aims to demonstrate the economical production of CIGS solar cells by batch processing of many small circular substrates through a small vacuum chamber. The approach will incorporate high-speed automation

techniques and experience from the optical disc industry. The European Commission is co-financing several projects in the area of flexible thin-film silicon, prepared in a roll-to-roll environment. During the first year of the FLEXCELLENCE project, two new roll-to-roll MW-PECVD and HWCVD systems were built and commissioned, and high-quality µc-Si:H layers deposited by VHF-PECVD at 2nm/s were demonstrated. Regarding the cells, 8.2% efficiency µc-Si:H cells, 6.2% efficiency a-Si:H cells and 9.2% efficiency tandem cells have been obtained on plastic so far. More recently, the SE-POWERFOIL project was launched, coordinated by Helianthos (a Nuon company, formerly Akzo Nobel Chemicals).

In addition to crystalline silicon and thin-film technologies, the European Commission is also supporting new and emerging concepts – comprising both high-efficiency and low-cost approaches. The ***FULLSPECTRUM*** project brings together several of these concepts which have the common aim of making fuller use of the solar spectrum (see http://www.fullspectrum-eu.org/). The multi-junction activity aims to progress as much as possible towards 40% efficiency, and in 2005 the partners achieved a new European record of 35.2% at 600-suns concentration. Other activities include thermo-photovoltaics, intermediate band gap cells, diffuse-light concentrators and up/down converters. Also working on III-V technology, the ***HICONPV*** project (which finished end of 2006) developed, set up and tested a new cost-effective, high-concentration (1000-suns) system. The cost goal for the proposed type of system was €1/W by 2015. Exploring the low-cost route, the ***MOLYCELL*** project aimed to improve the lifetime and efficiency of organic solar cells (see also http://www-molycell.cea.fr).

As the photovoltaic market continues to mature, the importance of standardisation is coming to the fore. The European Commission is co-financing a large pre-normative project called ***PERFORMANCE***, which aims to improve the understanding of measurement issues, and to harmonise procedures for testing, PV-system Monitoring and labelling. The overall efficiency of the PV-value chain in Europe may profit from that. The project, which started in January 2006, receives a contribution of €7M (see also http://www.pv-performance.org/). At the systems level, the ***PV-MIPS*** project aims to significantly reduce the cost of grid-connected PV through the development and demonstration of PV modules with integrated inverters. The cost targets for production are 0.3 €/W for the inverter and 3.0 €/W for the complete PV system. (See also http://www.pvmips.org/over.html). The ***UPP-Sol*** project aims to demonstrate polygeneration (electricity, heating and cooling) from solar photovoltaic systems, based on miniature solar collectors using concentrating photovoltaic technology.

The photovoltaic activities also extend to coordination and support actions. The ***PV-ERA-NET*** project is a four year initiative which aims to improve networking and integration of national and regional RTD programmes (see http://www.pv-era.net). The ***PV-CATAPULT*** project consists of ten diverse work packages, centred on a common goal of accelerating the development of the photovoltaic technology towards market deployment. The ***PV-Employment*** project addresses the strategic objectives of analysing the net amount of jobs created by the European PV industry up to 2020, together with the required qualification profiles of employees to produce recommendations to the policy makers and to the educational sector. ***SUNRISE*** is a coordination action which aims to improve the interaction within the European PV industry and involves all relevant stakeholders, such as semiconductor industry, construction sector, utilities, equipment manufacturers, and the European Commission, in order to support the further growth of PV in the liberalised energy markets of the future. Finally, the European Commission is financing the secretarial support for the Photovoltaic Technology Platform (described below).

4.2 7th Framework Programme, FP7 (2007-2013)

Photovoltaic R&D will be addressed primarily under the Renewable Electricity part of the Energy Theme – for which a budget of €2350 Million has been earmarked for the next 7 years. In December 2006, the first calls of the new 7th Framework Programme were launched. In the Energy Theme, a total of 11 PV topics across the value chain were open for proposals (i.e. feedstock, improved manufacturing processes and equipment, building integration, alternative approaches for crystalline silicon, new and emerging concepts, etc.). At the time of writing, the evaluation of the proposals is in progress. The first projects are expected to commence before the end of the year.

5. INTELLIGENT ENERGY – EUROPE PROGRAMME

The Intelligent Energy - Europe (IEE) programme (2003-2006) - which was a non-technological programme aiming to tackle market barriers - launched four calls for proposals with a total budget of 250 M€.

In the first call, were invited PV proposals aiming to tackle market barriers in line with the RES-E Directive, together with projects aiming to bring together PV market actors to raise awareness as well as sharing knowledge and experience. In the ***PV Policy Group*** project, a network of national energy agencies and the PV industry association analysed key policy issues for PV promotion (www.pvpolicy.org to download all the relevant documents). This project had a considerable impact for the PV sector in several countries. This initiative in fact contributed actively to the development of incentive mechanisms (e.g. the new feed-in-tariff in France) and new legislation/programmes (e.g. in Greece, Austria, the Netherlands) promoting PV.

In the second Call, PV proposals on small scale renewable energy systems were invited. The aim here was to focus on promoting the market for systems which are sold directly to end users and building owners. Within the ***PV-UP-SCALE*** project (www.pvupscale.org,) the *BIPV Database* (www.pvdatabase.org), was realized. The database allows the knowledge built-up in Europe with BIPV to be used in urban-scale applications and to meet the needs of the stakeholders in this new challenge. The database, which in one year was visited by over 11.000 people, helps to introduce PV at an early stage in the planning process, as well as to identify the benefits and added values. In the context of the 2002/91/EC Directive on the Energy Performance of Buildings, the ***PURE*** project (www.pure-eie.com) aims to promote PV

electricity in the urban environment, with an emphasis on BIPV, particularly in those European countries characterized by a large solar potential and lack of PV installed capacity.

Building on the successful experiences in Germany, ***deSOLaSOL*** (www.desolasol.org) provides the necessary information and tools to make joint-investing in grid-connected PV plants much easier. Thus, small users are provided with an opportunity to translate their environmental commitment into concrete action.

A new IEE-II programme was launched at the beginning of 2007 with a 7 year duration (2007-2013), and a budget of €720 Million, which is on average double the annual budget of the first IEE programme. The first call under the new programme has a deadline of 28 September 2007. Annual calls are planned with the next deadline being in summer 2008, and priority will be given to high quality projects involving key market actors and aiming to accelerate the growth of PV markets by means of non-technological actions. New IEE projects should enable EU policies, transform markets, change behaviour, improve access to capital, provide training (http://ec.europa.eu/energy/intelligent/call_for_proposals/index_en.htm)

6 PHOTOVOLTAIC TECHNOLOGY PLATFORM

The EU Photovoltaic Technology Platform is an initiative which aims at mobilising all the actors sharing a long-term European vision for photovoltaic; realising the European Strategic Research Agenda for PV for the next decade(s) and give recommendations for implementation; ensuring that Europe maintains industrial leadership. For further information, see http://www.eupvplatform.org.

The EU Photovoltaic Technology Platform is one of over 30 platforms which bring together researchers, industry and other stakeholders across Europe in key technological fields. For more info: http://cordis.europa.eu/technology-platforms.

In June 2007, the EU Photovoltaic Technology Platform finalised its Strategic Research Agenda (SRA). The document sets out the short, medium and long-term R&D issues deemed necessary for continued cost-reduction of photovoltaic systems, with the aim of reaching grid-parity in the south of Europe by 2015. The SRA aims to serve as a common framework for decision makers at national and European level, in order to increase the coordination of research programmes throughout Europe.

7. LESSONS LEARNED

The EU RTD Framework Programmes have focused on tackling technological barriers to the growth of PV markets by supporting major initiatives aimed at developing new materials and devices, reducing the cost of the modules and systems, and promoting major market developments. The cost-sharing basis of the support programme implies that the risks are also shared with both public and private sector organisations in the different Member States. Currently a substantial number of projects cover the different main strategic lines of the programme.

7.1 Short to medium term RTD

Numerous projects started under the 5th Framework Programme (1998-2002) are now being completed so that it is possible to elaborate some statistics. First of all it is worth noting that about 90% of the projects initially launched will be successfully completed. This is not obvious considering the macro-economic situation; the fact that demonstration projects, which often have a total cost in the range of tens of millions of euros, receive a maximum support of 35%; and the procedural/administrative barriers to overcome at local/national level to complete the installations. As a consequence, project partners and consortia are typically required to be financially robust and very committed.

At the system level, the programme is demonstrating innovative, simple and more cost effective approaches to the integration of system components, such as higher voltage module arrangements to match more efficient and lower cost integrated inverters, like the *PV MIPS* project already discussed above.

At the market level, the programme is demonstrating the benefits which can be achieved by building systems in a context which reaches a critical mass of activities in terms of design, procurement, installation procedures, and eventually operation and maintenance. This provides important insight into the ways to achieve economies of scale and business advantages in the future. For example, the project *Resurgence* (NNE5-2001-340) fits well within this category. With the completion of *Resurgence*, several objectives have been achieved. Notably, 1,354 kW of photovoltaic systems have been installed in five European countries as part of significant urban programmes of regeneration, demonstrating the possibility of using photovoltaics as a re-roofing material in the refurbishment of social housing and also as a means of improving project viability by transferring roofing budgets to the PV budget; the potential for cost reductions through competition and economies of scale has been also demonstrated. The lowest system price achieved in one of the participating countries is about 4 €/W. For further information see www.resurgence.info .

At the level of building integration, the programme has been pioneering through demonstrating the potential of using PV systems in highly efficient and well managed buildings, with advanced ICT (Information Communication Technology) tools for energy management in buildings). Here the potential for the technology is vast but largely unexplored, particularly for achieving a closer integration of PV electricity supply with the energy demand profiles over the day and over the year in different climate conditions, also including the Northern EU Member States. A good example of this category of project is *PV Nord* (*NNE5-2001-264*). Eight high-profile building projects have been completed in the Nordic countries and in the Netherlands, for a total power of 216 kW. It is worth noting the results achieved, among others, with the management aspects of PV integration. Over the years, development activities have focused on aesthetics, design of the PV systems, cabling and PV claddings. Most of the industrial development work as well has been focussed on the PV aspects only. The result is that when the PV system is separated from the rest of the building management and service practices, there is a danger that the performance tracking and maintenance of the PV systems also becomes separated. Integration of the PV system into the building automation systems could easily be achieved, thus increasing the

usability and value of PV. The cost of doing this seems to be lower than adding extra monitoring equipment to the PV system. Thus, the combination of ICT and PV seems not to be an issue of cost, but of awareness.

PV systems significantly improve the quality of life in rural areas of developing countries because they can supply the necessary electricity needs. As such, they represent an important tool to support sustainable development. Within the project *TAQSOLRE* (NNE5-2002-98), an accompanying measure, the actual status of PV rural electrification has been analysed. Estimations on stand-alone PV market size and conclusions about stand-alone systems behaviour have been reported. Reliability has been studied in terms of PV system design, quality of PV modules and Balance of System components, and dimensioning of system components in relation to loads. A reliability database has been designed and completed with data collected through a literature survey and from monitoring activities of the partners involved. A more theoretical analysis of PV system dependability has been developed and applied to field conditions. Based on this study, a software tool has been developed. Besides, quality assurance actions have been implemented in some countries: their effects on PV system performance will be seen in the future.

7.2 Medium to long term RTD

The work in the *SENSE* project *(ENK5-CT-2002-00639)* makes a valuable contribution to the discussion of energy externalities and underlines the environmental attractiveness of renewable energies, an aspect which is often overshadowed by the focus on economical indicators. In anticipation of the expected production growth of thin-film based photovoltaic modules, researchers in the *SENSE* project performed Life Cycle Assessment (LCA) analyses and developed recycling strategies for CIGS, a-Si and CdTe technologies. Using product samples and data from production lines, the researchers performed a thorough analysis of thin-film PV systems, and quantified the significant environmental advantages over conventional energy systems in terms of global warming potential, acidification potential, eutrophication potential and photochemical oxidant potential. The overall objective of *TOPSICLE* (*ENK6-CT-2002-00666*) was to define an industrial process to manufacture low-cost 20% mc-Si solar cells and modules, exploiting the significant potential for improvement of conventional crystalline silicon solar cells. The approach was to develop advanced processes for 1) high-quality Si wafers with low levels of impurities and crystal defects such as grain boundaries and dislocations, 2) super high-efficiency mc-Si solar cells, and 3) novel PV module structures. The highest efficiencies obtained on non-TOPSICLE material were 17,0% with full in-line processing based on screen-printing, 17,2% with mechanically V-texturing and roller printing, and 18.1% with hybrid screen-printed/buried contact processing. It is notable that the latter represents the world record efficiency for large-area mc-Si cell. The project also identified strategies to obtain efficiencies of about 20%, such as improving the rear side passivation scheme with dielectric layers instead of an aluminium back surface field, enhancing the internal rear side reflection, and reducing the shading losses at the front with the so-called angled buried contact concept. As record cell efficiencies in the laboratory are a driving force to implement new technologies and processes in the industry, it is also worthwhile to mention other results that have been achieved by projects supported within the European Framework Programme: 35,2% multi-junction cell European record (*FULLSPECTRUM - SES6-CT-2003-502620*), 11% dye-sensitised cell (*NANOMAX - ENK6-CT-2001-00575*), 14,1% CIS world record cell on flexible polyimide (*METAFLEX - ENK6-CT-2001-00516*), 16.4% Zn(O,S) buffered CIS cell (*NEBULES - ENK6-CT-2002-00664*), 13,7% epitaxial cell on metallurgical Si (*EPIMETSI - ENK6-CT-2002-00618*).

8. CONCLUSIONS AND FUTURE PERSPECTIVES

The European Commission has being carrying out an intense series of activities in the renewable energy and energy efficiency field, with an important component related to the photovoltaic sector. These activities include policy and regulatory measures as well as providing support for concrete actions through the Framework Programme, the Intelligent Energy – Europe (IEE) Programme, and international aid co-operation programmes. These efforts have been instrumental in helping to establish an innovative research basis and a competitive PV industry in Europe.

To bring the current PV technology rapidly to a more significant market share in line with the decision on Renewable energies by the European Council, and to prepare the next successful generation of PV technologies, the European Commission efforts will be further strengthened in the future, particularly through the new FP7 and IEE-II programmes. These programmes, together with the EU regional funds and international co-operation programmes will be important for the future of the European PV industry, because only working at an EU level can deliver the critical mass of activities which are needed for the EU's PV industries to grow fast enough and to compete effectively in today's global PV markets.

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