STUDY III

STUDY ON PRESENT AND PROSPECTIVE PV APPLICATIONS AND CHALLENGES FOR PV INDUSTRY

THE CIRCA GROUP EUROPE

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1 INTRODUCTION

1.1 Study III: Present and prospective PV applications and challenges for PV industry

1.1.1 Study goals and objectives

The main objectives of this study:

To detect PV value chain comprising the PV product market;

Accordingly to PV value chain conduct the overview of the PV products;

To detect and review the major PV product market development trends.

1.1.2 Reasons for the doing this study

The study provides input into the overall foresight study which aims to support industry and R&D players with understanding of the existing variety of PV products on the market, possibilities for Lithuanian producers in the today's PV market as well as with upcoming market needs for new products and innovative solutions along the whole value chain of PV production.

1.1.3 Scope and format

The study is covering the whole PV value chain ranging from Si feedstock products available on the market to the products for the systems for installation. Under this study there was no intention to present exhaustive catalogue of PV products available on the market but to present representative sample of separate categories of the products. Taking into account client's (Lithuanian PV industrial cluster) focus on manufacturing of the PV products as main priority and to less extend on the organization of sales of external to Lithuanian manufacturers products, study was extended by the ovierview of the technologies behind particular products. Taking into account time frame foreseen for the study, main trends in the development of new technological steps as well as products of new design which are already implemented on pilot scale and thus are expected to enter the market until 2025 also are presented.

1.1.4 Methodology and Information sources

In order to meet the requirements of the Study 3 all main aspects of research methodology were addressed, namely: design, data collection and data analysis. The extensive range of secondary sources was analysed, including:

- Peer-reviewed scientific publications (Progress in Photovoltaics: Research and Applications, Solar Cells, Solar Energy Materials & Solar Cells, Journal of Photovoltaics and oth.);
- Presentations and conference proceedings (IEEE Photovoltaic Specialists Conference, European PV Solar Energy Conference and Exhibition and oth.);

- Relevant websites and Specialised information of Photovoltaic technology related online magazines;
- Websites and information leaflets of the companies across the PV value chain.

Further information on the references quoted or used for background information are listed in the References in the annexes.

The report was prepared by three very experienced senior consultants. The team leader was Circa Group's Managing Director. The process used to prepare this report was that:

An outline of the report was prepared by the team working together and initial research was undertaken. This formed the basis of the two monthly progress report submitted to VsI "Perspektyviniu technologiju taikomųju tyrimų institutas".

The research was divided between the team members which allowed for a degree of overlap thus ensuring at least two of the team would cover the same ground.

More detailed research was undertaken, then the team met to review the layout and develop a more detailed format. The writing was allocated to the team members.

Data collection was carried out by using both desktop research and interviews with industry experts and product users. The collected data on products have been analysed by using the Gartner Magic Quadrant methodology which helped to identify four types of technology product providers, where market growth is high and provider differentiation is significant, namely:

Leaders which are the companies which are well-executed, providing products which are well placed against their current vision and who are well positioned for tomorrow;

Visionaries which are the companies are not yet well executed, but which understand where the market is going or having a vision for changing market rules;

Niche Players which are the companies providing successful products focused on a small segment, or are unfocused and do not out-innovate or outperform others as a result of that;

Challengers which are the companies which execute well today or may dominate a large segment, but their products do not yet demonstrate an understanding of market direction.

> Magic Quadrants depict markets in the middle phases of their life cycle by using a two-dimensional matrix that evaluates vendors *use potential to end* user and *value to customer* of provided products. This model is well suited for high-growth and consolidating markets and their products where market and vendor differentiations are distinct.
>
> The *use potential to end* user for PV products was measured by following criteria:

Integrated technologies level (for e.g. advanced metallization technology for PV cells, antireflective coating integration into the PV glass);

Integrability into the system and versatility;

Product comparative performance ratio (e.g. light transmition, generated power, efficiency, material purity);

Certification.

The additional *Use potential to end user* for PV cells, PV modules, BIPV products (foils, modules, tiles and glazing materials) has been measured by using the following criteria:

Actual Tested Maximum Power vs. Advertised is the power value and a primary factor in the design of any solar power system.

Negative Power Tolerance is the manufacturer's deviation from its design target. Higher quality production lines control this variation better and manufacture products with a smaller (tighter) tolerance.

Temperature Coefficient at Maximum Power describes the decreasing power output with increasing temperature. Products with a higher temperature coefficient will have lower LEP.

Nominal Operating Cell Temperature (NOCT) is the characteristic operating temperature of a module. A higher NOCT amplifies the negative effect caused by the temperature coefficient.

Power at Low Irradiance/Power at High Irradiance Ratio reflects a PV module's performance in off-peak conditions. The insolation response combined with the daily insolation is a key component of the LEP.

Annual Power Reduction shows the degradation of a PV module's output over time from lab testing. It is of extreme significance to the manufacturers' warranty policies and is used to calculate LEP.

Total Area Efficiency is the degree of coverage of a module with cells.

The *Value to customer* was measured by evaluating the PV module product sales, which indicate positive willingness to purchase certain PV modules.

Product/Service: Core goods and services offered by the vendor that compete in and serve the market. This category includes product and service capabilities, quality, feature sets and skills, offered natively or through original equipment manufacturers, as defined in the market definition and detailed in subcriteria.

Sales Execution/Pricing: The vendor's capabilities in pre-sales activities and the structure that supports them. This criterion includes deal management, pricing and negotiation, pre-sales support and the overall effectiveness of the sales channel.

Customer Experience: Relationships, products, and services and programs that enable clients to succeed with the products evaluated. This criterion includes the ways customers receive technical support or account support. It can also include ancillary tools, customer support programs (and their quality), availability of user groups and service-level agreements.

Operations: The vendor's ability to meet its goals and commitments. Factors include the quality of the organizational structure, such as skills, experiences, programs, systems and other vehicles that enable the vendor to operate effectively and efficiently.

Initial draft chapters were written and reviewed by the team.

The chapters were redrafted and a final content and presentation agreed.

The whole report was formally proofed and the final edits undertaken.

It was submitted to VsI "Perspektyviniu technologiju taikomųju tyrimų institutas" in April 2013.

1.2 Summary Layout

The layout of the report is outlined in the following paragraphs.

Chapter 1 includes the following sections:

- Introduction – which includes study goals and objectives, reasons for the doing this study, scope and format, methodology and information sources
- Summary layout of the study
- Overview of the content of the study, including presentation of current situation and main trends

Chapter 2 covers the overview of state of the art and prospective PV applications. It includes the following sections:

- Detail analysis of existing products and services, including: PV value chain, silicon raw and ingots, wafers and PV cells, PV modules, PV systems and PV system components, PV services related products and market sizes and segmentation
- Price competitiveness of PV, including: installed system pricing and factors affecting PV system cost reduction
- Detail analysis of new products, including: novel crystalline silicon products, novel thin film silicon products, new concepts of crystalline solar cells and concentrated PV devices
- Forecast of new PV product market development, including: quasi-monocrystalline silicon PV product market development, CIGS products market development and dye-sensitised PV product market development
- Areas of PV application, including: Building integrated PV products, combined PV/solar thermal systems for heating cooling, charging for local (inside building) lighting/sensing/monitoring devices, combined systems with diesel generators and PV for other targeted applications

Chapter 3 provides the overview of Lithuanian PV installation market, including indication on amount of solar energy in Lithuania and trend of photovoltaic installations in Lithuania.

Chapter 4 provides the conclusion of the study.

Finally, the annexes include a glossary and a list of references.

1.3 Overview

1.3.1 Current situation: main trends

1.3.1.1 Main trends in raw Si materials and ingots

Siemens process for poli Silicon production is dominating raw material market and still is demonstrating good prospects for cost effective production in the near future. According to ITRPV roadmap edition of 2013 the only technology which can compete with Siemens process on cost level is Fluidised bad reactor technology. Other technologies are still of low maturity level and are not showing clear prospects for further costs reductions. From the point of view of other PV value chain products poli silicon processing technologies can have main important advantage – processing costs. Requirements for raw material properties are the same for all competitive technologies therefore advantages on physical or chemical properties can be only of second order importance influencing ingot processing costs. The main trend in ingot processing nowadays is increasing throughput of the crystallization process by shifting toward larger size of ingots. This approach is helping to reduce production costs but also is providing possibilities to have higher percentage of ingot bulk material with required crystallinity and electrical properties suitable for further processing of solar cells. The increase in ingot mass for casted silicon materials is expected from available today 500kg to 1200kg in 2023 which will require new generation of furnances to be introduced. As for czochralski monocrystalline Silicon (mono-Si) respectively increase in ingot mass is foreseen from 150kg today to 350kg by 2023 as predicted by the roadmap.

1.3.1.2 Main trends in wafering and solar cell products

Main trend in wafering fron the times of high Si raw material costs (~2006) is remaining the same – movement toward thinner wafers from 300-280μm in 2006 to ~180μm as normal wafer thikness in 2013. Today's wafer thickness is reaching level when further movement toward thinner wafers will have further implications on PV cells and modules production: investments into wafering and handling equipment upgrade will be needed; solar cell concepts suitable for thinner wafers as well as new interconnecting and encapsulating technologies on module level must be demonstrated. Therefore further developments following in line with this trend will be possible only with significant production facilities upgrade in other value chain segments.

In the solar cell products two types of trends can be expected: incremental improvements of existing products and radical changes by introducing novel cell designs. While incremental improvements provides means for producers competitiveness in short term without serious refurbishing of production lines and therefore is most probable approach for mainstream producers, introduction of novel cell designs typically is requiring establishment of new production line with novel equipment therefore is less probable scenario and can be implemented only if clear benefits are demonstrated. There are three major technological areas which will be addressed in standard crystalline silicon PV solar cells in order to make the incremental improvements:

Advanced selective emitter. This technological approach is expected to be main innovation in PV cell production in the very near future. Next upgrade of manufacturing equipment foreseen for 2015-2016 is expected to be dedicated first of all to the introduction of equipment providing possibilities to produce solar cells with selective emitter under PERC solar cell design.

Novel contacts. Available contact metallization process approximately increases the total PV cell costs by 15% and is growing. Therefore manufacturers are looking for solutions to reduce the amount of raw silver pastes or introduce novel cheaper solution of mixtures with cheaper metals like Cu. It is foreseen that thinner silver metal contacts will be introduced to reduce the cost and open a larger area for solar absorption (i.e. reduce shading loses). Although the industry is struggling to introduce the cheaper copper contacts, it is believed that several manufacturers will manage to that in coming 3-5 years.

Novel passivation techniques. Some of PV module manufacturers are trying to reach high efficiencies by widening absorbable solar spectrum and increasing performance under unfavourable light or temperature conditions through introduction of the novel front side texturisation and complementary passivation techniques. Another prospective trend in passivation techniques development is introduction into production lines new passivation layers ensuring better collection of carriers suitable for novel solar cell concepts based on n type Si (e.g. Al_2O_3).

1.3.1.3 Main trends in PV module products

The PV module products come in two major varieties: either they are standard crystalline (monocrystalline, polycrystalline, multicrystalline) or thin film (amorphous silicon, CdTe, CIS, CIGS). The PV module product overview is provided in Table 4. The products selected for the analysis were picked up from the manufacturers having the highest manufacturing capacities between 2011 and 2012.

According to the market research studies, the price of crystalline silicon solar is steadily decreasing due to cost reduction which is fuelled by increased manufacturing capacities and technological improvements in module assembling techniques, cheaper module components or less raw materials (silicon, glass, plastic) used. The crystalline silicon PV module price decrease has made these products much more competitive when comparing with thin-film modules which have been outperformed not only by efficiency but also in price. Consequently recently crystalline silicon PV modules had become mainstream technology with significantly reduced possibilities for thin film PV to compete on the market.

With the ascendance of crystalline modules as the absolutely dominant technology in PV markets, there will be a need for new module design solutions for better integrability, easier and quicker installation, as well as to meet aesthetical requirements. The analysis has shown that the module manufacturers are aware of these needs and plan to address them by making the following improvements:

Novel module framing. The narrower frames will be applied in order to reduce the weight and for less mechanical loads during the operation. It is believed that the weight of rigid PV modules will be reduced by 1kg, which could reduce the costs of transportation and storage as well. As the emerging BIPV applications are drawing more manufacturers' attention each year, some of them has already introduced the frameless modules. It is expected that trend to move into frameless module solutions will be followed in the coming years.

PV module top surface will meet several innovations. First of all, manufacturers already introduced the black silicon cell with higher absorption coefficient, resulting in higher overall modules yields. It is expected that black silicon back contact PV modules will occupy the larger market share during near future. For better solar irradiance absorption and in order to reduce dazzling effect, the top surface of PV module will be equipped with low cost microlensed or antireflection coatings. As analysis of PV cell (a product overview is presented in Table 2) has shown the growing tendency to integrate PV material into buildings, the producers of PV cells have started to manufacture cells with wide selection of front surface colour. PV module top surface also will face several innovations leading to reduced costs, reduced weight and increased transparency for wider solar spectrum region. This will be related with thinner glass application, modified glass structure with higher UV transparency as well as new types of encapsulants with similar optical properties.

Design solution for easier installation and assembly. The PV system installation novadays is becoming most promising part in the whole PV value chain for further cost reduction as it contributes significantly to overall PV system cost and was not demonstrating similar to module price reduction behaviour, therefore manufacturers are dealing with PV module cabling, connection and framing issues as main source for innovations leading to the cost reduction. Until now, some PV modules introduced with longer connection cables and elongated assembly holes which are designated for flexible diagonal assembly. In addition, some manufactures uses special suspension mechanism integrated into PV module to simplify the assembly. Despite mainstream rectangular PV module products domination there is clear need for PV products of different shapes providing installers with the possibilities to cover fully roof area available to the installation. Up to now these customised modules were made in very small quantities and manually because technologies available are not allowing modification of the module shape. Nevertheless as building mounted as well as BIPV products are becoming of more importance there is a need for solution for automated lines to produce modules of any shape and size. This of course will stay as product for the niche market but can be attractive approach for small scale manufacturers.

The study has shown that crystalline silicon (c-Si) PV module manufactures have a wide selection of modules with output power and efficiencies, with applications into residential, commercial and utility segments. In contrary, the decreasing global manufacturing capacities will constrain the application areas for thin film PV modules. Due to slower decreasing cost and lower efficiencies, thin film modules still have better prospects to be applied in the areas were c-Si modules performance is poor. C-Si modules typically have a temperature coefficient of -0.45 to -0.5°C efficiency decrease per degree Celsius, while thin film modules have -0.25 °C, resulting in about half incremental power loss compared to conventional PV modules. In high solar irradiance geographical zones like Sun Belt countries, ambient temperature of PV module usually can reach the 65 °C temperature, so the power output will be reduced by up to 20% of c-Si modules, and the thin film module by 10%.[1] So, in upcoming years thin film PV modules can be attractive alternative in the high solar irradiance geographical zones.

1.3.1.4 Main trends in PV systems and PV system components

PV systems. A smart grid is a new approach to the integration of power generation, transmission systems, distribution networks, and consumption. The smart grid will be able to adapt to all types of generation sources, including conventional large thermal power plants and intermittent renewable energy sources such as wind and solar PV generation without restriction. Most innovative part in the smart grid is its demand response (DR), which is largely facilitated by the use of smart meters and an associated advanced metering infrastructure (AMI). Smart meters can provide real-time information on the demand and price from different suppliers to customers, so as to allow them to decide when they want to buy electricity, from whom, and at what price. This will not only provide "freedom of choice" but also allow customers to interact with the network operators and suppliers in, or near, real time.

Inverters. With much more on-grid PV systems available inverters are becoming increasingly important intermedia device between PV power plant and grid with more and more additional functions desired enshuring grid stability, communication with grid operator, etc. On the other hand there is a strong push for inverters to become cheaper, more efficient, to combine several active functions for generated power monitoring, and maximum power point tracking. The PV system inverter product overview carried out in this study (Table 16), showed that majority of inverter products comprise three-phase string inverters. Although some inverters of A+ class have the efficiency of 98%, the major innovation trend in this area is the products with even higher efficiency for less energy losses in on-grid systems. Furthermore, one of the requirements for modern inverter is to comprise additional Multiple Power Point Trackers (MPPTs), therefore all of the upcoming inverter product will comprise this functionality. Important inverter functionalities are monitoring, diagnostics and early detection of issues related to the

[1] N. Strevel *et. al.* Performance characterization and superior energy yield of First Solar PV power plant in high-temperature conditions. Photovoltaics International Journal. Seventeenth edition. P. 148-154. August 2012

functionality and wireless inverter devices, therefore it is believed that new products will comprise these as well.

Recently inverter market, introduced the micro-inverter products for accurate monitoring and operation on the level of PV module string, to combat the shading losses. The evolution of micro-inverter usage will be significant in PV market.

It must be noted that inverters and especially microinverters markets are significantly influenced by legislative changes due to better understanding and identification of the problems caused to grid operators by RES energy power plants with ustable and to high extend unpredictable power generation. Therefore novel inverters are providing wide flexibility for possible properties to adapt to new and upcoming legislation. This trend of course is not providing possibilities for fast cost reduction in this value chain segment.

Plastics. Innovative solutions for materials that help to achieve solar grid parity will increase the competitiveness of solar energy as an alternative to traditional energy sources.

Photovoltaic modules comprise several plastic materials: encapsulant and module backsheet. Among the encapsulant, ethylene vinyl acetate (EVA) is still the market leader. The reason is its low-cost and optimized properties. Recent developments providing higher electrical resistivity to avoid PID (Potential induced degradation) effects and extended spectral properties are situating this material as leader in PV encapsulants market. As it was mentioned before there is also growing interest to utilise polyvinyl butyral (PVB) as encapsulant material. While basically used for the struggling silicon thin-film module sector, PVB manufacturers are now eying the crystalline backsheet sphere as well as encapsulant for BIPV glas glass products. But this is an unlikely development, because of the higher cost of PVB. Ionomers, a thermoplastic co-polymer of ethylene and (meth)-acrylic acid, have the advantage of good transparency for letting more sunlight through to the module. But, again, that is an expensive option. Another alternative to the market leader - albeit another costly option - is thermoplastic polyurethane (TPU), which not only has good transparency attributes, but decent elasticity as well. Silicone, which has largely been absent from the market for some time, is making a comeback due to its UV stability and a very low UV cut-off value. For emerging cell technologies, such as selective emitters, this product opens the gate to improving solar module efficiencies, as it does not hamper the enhanced blue response - although it also comes at a rather high cost.

An emerging backsheet product composite is polyethylene terephthalate (PET), consisting of polymerized units of the monomer ethylene terephthalate. This product is not new to the PV industry, as it has been used as the core layer between back sheets as a result of its electrical insulation properties. Recently, backsheet manufacturers have only been offering PET layers or PET combined with other fluoro- or non-fluoro-based polymers. Then there is Kynar, based on polyvinylidene fluoride (PVDF), one of the closest fluoropolymers to Tedlar. Fluoropolymers, such as ethylene-tetra-fluoro-ethylene-copolymer (ETFE), ethylene chloro-trifluoroethylene (ECTFE) and other fluoride films, are also preferred by several companies for use in back sheets. Recent development of polyolefin based backsheet material is providing further means for novel solution. Tests of this material is demonstrating outstanding properties with no need for multilayer solutions, high durability, highest electrical insulation, improved water vapour barrier as well as excellent bond to EVA encapsulant.

Silicones. Silicones are already strongly available in PV products and are demonstrating prospects to lower costs, improve durability and performance of solar products across the value chain covering encapsulants, sealants, potting agents and coatings. Silicone materials provide clear advantages over plastic competitors available on the market.Encapsulats for PV modules have following advantages:

- Excellent and long-lasting elasticity and flexibility;
- Good dielectric properties resolving PID related prolems
- Extended comparing to plastics transparency to solar irradiation.
- Stability to wide range of solar spectrum irradiation especially important stability in UV region.

Despite advantageous properties prospects for fast uptake of silicons as encapsulants in module production are low due to the need to modify standard production lines with liquid processing steps and can be more expected in new lines established for production of new type of PV modules for example in BIPV. Utilization of liquid processing in module production is resulting in lower total cost of ownership for both crystalline and thin-film modules because of lower capital cost, lower processing costs and improved processing efficiency.

PV solar sealants and adhesives are already available in PV products providing long-lasting bonding of solar photovoltaic modules with good durability and structural strength. These products have following advantages:

- Good adhesive properties: resistivity to mechanical and thermal shock and vibration
- Resistance to moisture and environmental attack: water repellence and resistance to water or snow, thermal shock, chemicals, oxidation and corrosion,
- Stability and low degradation in high or low temperature;
- Low aging effect – no hardening, cracking, peeling or drying out.

PV potting agents are already available in PV products especially for photovoltaic junction box applications. Potting agents improve the durability of PV modules under the demanding outdoor exposures which are typical for photovoltaic applications. Pottants provide following advantages:

- Fire resistance;
- Electrical insulation of components;

- Stability and flexibility over a wide temperature range.

Conductive plastics (organic photovoltaic). Conductive plastics are considered an important part of the world's energy future because they would decrease the costs of manufacturing electricity from solar energy. Conductive plastics offer these advantages:

Better Designs. Conductive plastics are flexible and are easy to bond to flexible substrates such as plastic and metal foils, creating opportunity for integrated, flexible applications. For example, mobile phones could generate their own power.

Costs. Relatively inexpensive plastic is used as the active material to convert solar energy into electricity. Only a few tenths of a micrometer of conductive plastics are needed to generate electricity.

Printing capability. Conductive solar cells can be printed in processes similar to printing on newspaper. The fabrication process is described as low temperature and environmentally friendly.

The discovery of pure conductive organic polymers (such as oxidized iodine doped polyacetylene) in the late 20th century was very promising and the research on these materials were boosted for the last 10 years by the concerns about climate change. To date, organic photovoltaics have been largely limited to charging consumer electronics because of their short lifetimes, lasting only a couple of years, and low efficiencies (3% to 8%). Research is focusing on increasing the lifetime and efficiencies for organic photovoltaics.

In 2012 German company Heliatek GmbH has announced the reached record for the efficiency of organic solar cells. The 9.8% efficiency for a 1.1 cm^2 tandem cell manufactured during the low temperature deposition process was reached. By synthetizing materials suitable for the absorber layer Heliatek was able to optimize its properties and achieve record-breaking cells efficiencies. On the other hand improved deposition process led to significantly improved cell morphology, contributing this way to an increase in power output and in fill factor.[2] It must be noted that upscaling of organic PV materials production in Europe is hampered by absence of encapsulants producers thus indicating to the real need for introducing such manufacturing capacities in complementary industries namely plastic industry.

Legislative trends. The short-term peak experienced in the European Union PV market during 2011-2012 was highly influenced by the expectations of feed-in-tariff (FIT) rate cuts.[3] Solar installations were booming for the last few years which were fuelled by the favourable government FIT rates. The solar FIT programmes were guaranteeing above-market solar power rates for producers. Solar FIT programs worked too well and have brought the negative aspects to this system. Favourable FIT programs have helped to

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[2] ECN: Electronic Component News, 2012. Heliatec organic solar cells achieve a record 9.8 percent efficiency, 7-8 pages.

[3] NewsRx, 2011. Energy, Utilities: Future looks sunny for solar power market. Retrieved on ProQuest Business Collection data base, ID: 901354769.

exceed national goals and it has become too expensive to continue the programs with the same FIT rates.[4]

Germany, as a Europe's biggest solar market, can be first listed having problems in maintaining FIT programs for the still growing solar installations in the country. The government of Germany has decided to limit the FIT once the installed capacity has exceeded 52 GW. The tariffs were reduced by 20% - 30% for the solar fed into the grid starting from the July 1, 2012. Starting the same day, all solar installations will have payments reduced by 1% a month. 18.5 eurocents/kWh will be paid for installations between 10-40 kW and no premium rate will be available for the installations larger than 10MW.[5]

Other European countries have also introduced (or are planning to introduce) cuts on FIT rates. United Kingdom is planning to reduce subsidies for new solar power projects when the overall country's predetermined level of solar installations will be reached.[6] Spain was the first country to cut the subsidiary tariffs for solar and other renewables. When the crisis has hit Spain economy in 2008, the subsidies were reduced by 35%. At the beginning of 2012 Spain government has decided to suspend temporarily all subsidies for renewables. Country was expecting to save 160 million of Euros, but at the same time the thousands of job places will be lost.[7] Greece, of which economy was drastically hit by crisis, has also cut feed-in-tariff rates for solar and other renewables. Initial rate was cut by nearly 13% and is planned to be reduced twice a year until August 2014.[8]

Despite these negative legislative trends, solar manufacturers do not evaluate this as the end of solar market. On the contrary, solar companies admit that manufacturing costs has been reducing and they expect solar energy to get even cheaper by 2015.[8]

1.3.1.5 Main trends in novel PV products

In reference to analysis of novel PV product market, the main trends of quasi mono crystalline silicon PV modules and BIPV will be presented.

Main trends in quasi monocrystalline PV module products. At this time frame quasi-monocrystalline silicon production still remains at the emerging stage and unsolved

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[4] Silvio Marcacci, 2012 February 6. European subsidy reductions could slow solar industry boom. [online] Earth & Industry. Available from: <http://earthandindustry.com/2012/02/european-subsidy-reductions-could-slow-solar-industry-boom/> [06-02-2013]

[5] Sustainable Business News, 2012 June 27. Germany decided on solar FiT cuts, China ready to step in. [Online]. Available from: <http://www.sustainablebusiness.com/index.cfm/go/news.display/id/23828> [06-02-2013]

[6] Alex Morales, 2012 February 1. U.K. said to plan solar subsidy cuts at regular intervals. [Online] Bloomberg. Available from: <http://www.bloomberg.com/news/2012-02-01/u-k-said-to-plan-cuts-to-solar-subsidy-at-predictable-intervals.html> [06-02-2013]

[7] Daniel Silva, 2012 February 2. Clouds gather over Spain's renewables sector as aid cut. [Online] AFP. Available from: <http://www.google.com/hostednews/afp/article/ALeqM5jSXzVAOcOfXPpYoYoilu5_kOvuFQ?hl=en>[06-02-2013]

[8] Silvio Marcacci, 2012 February 6. European subsidy reductions could slow solar industry boom. [online] Earth & Industry. Available from: <http://earthandindustry.com/2012/02/european-subsidy-reductions-could-slow-solar-industry-boom/> [06-02-2013]

problems of non-uniform silicon block formation, complicated control of dislocations and defects aggravates the penetration into the PV market. On the other hand, multicrystalline silicon producers, with some low cost equipment retrofication can use their direct solidification furnaces for a new raw material manufacturing for solar cells with higher overall efficiency and reduced oxygen content. As quasi-monocrystalline features lower price and higher power output than multicrystalline or polycrystalline silicon PV modules, the novel PV module product might take over the market share.

Main trends in novel BIPV module products. BIPV (Building integrated photovoltaics) comprise a group of technologies that are introduced into building envelope, instead of mounted on the top surface of building wall, roof and etc. BIPV modules (or envelopes) can replace wall, curtain walls, rooftops, windows and other parts of buildings and at the same time generate electricity which would be supplied to consumer in a very near proximity.

The integration of PV modules into buildings is still struggling due to unsolved standardization and cost problems. The major trends of BIPV products development are seen in three product groups:

BIPV foil products are lightweight and flexible, which is ideal for easy installation and the weight constrain most roofs has. Most promising products are those replacing the bitumous membranes this way significantly reducing PV installation costs becoming integral part of envelope construction costs.

The BIPV tile products can cover the entire roof or just parts of the roof

Solar cell glazing products provide a great variety of options for windows, glassed or tiled facades and roofs.

It is foreseen that BIPV product will comprise wide selection of PV products: starting from monocrystalline modules integrated into building wall, thin film glass to glass PV modules, glazing materials for transparent facades or foils comprising thin films of amorphous silicon, CIGS, CdTe and dye sensitized solar cells.

BIPV products have to comply with architectural and building design requirements thus without solving colouring issues BIPV products market penetration will be hampered. Main trends are to modify PV cell surface colour by modifying antireflection coating and modification of cover glass by optical gratings of desired colour. This is causing of course reduction of overall efficiency of PV system but it is compensated by high user acceptance.

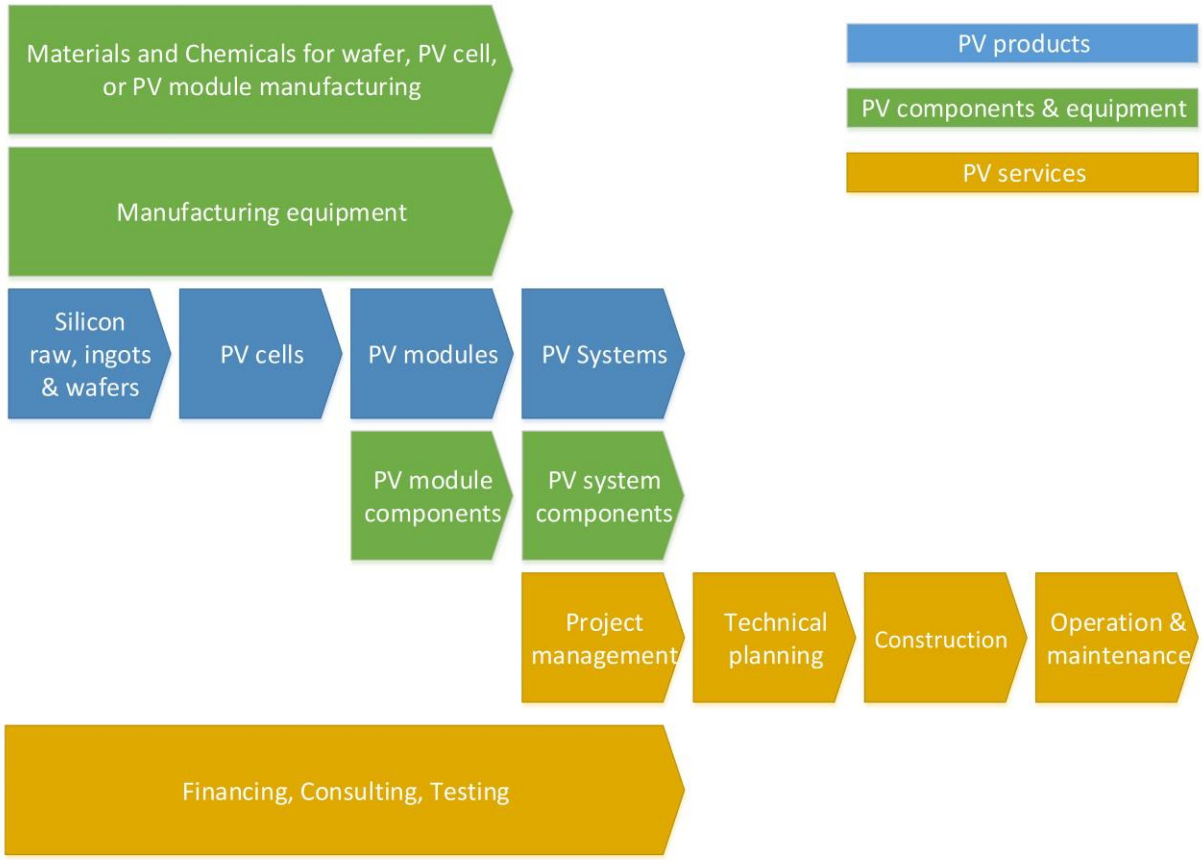
2 OVERVIEW OF STATE OF THE ART AND PROSPECTIVE PV APPLICATIONS

2.1 Detail analysis of existing products and services

2.1.1 PV value chain

The PV value chain was analysed from the perspective of PV products, PV components and equipment and PV services. The study analysed the following PV product categories: silicon raw ingots & wafers (Table 1), PV cells (Table 2), PV modules (Table 4) and PV systems (Table 15). The analysed PV components and equipment included materials and chemicals for PV product manufacturing and processing, manufacturing equipment, and PV module and system components. The PV services addressed in the study covered project management, technical PV plant installation planning, construction, operation and maintenance as well as financing, consulting and testing. The overall PV value chain used for the analysis of the presented study is provided in Figure 1.

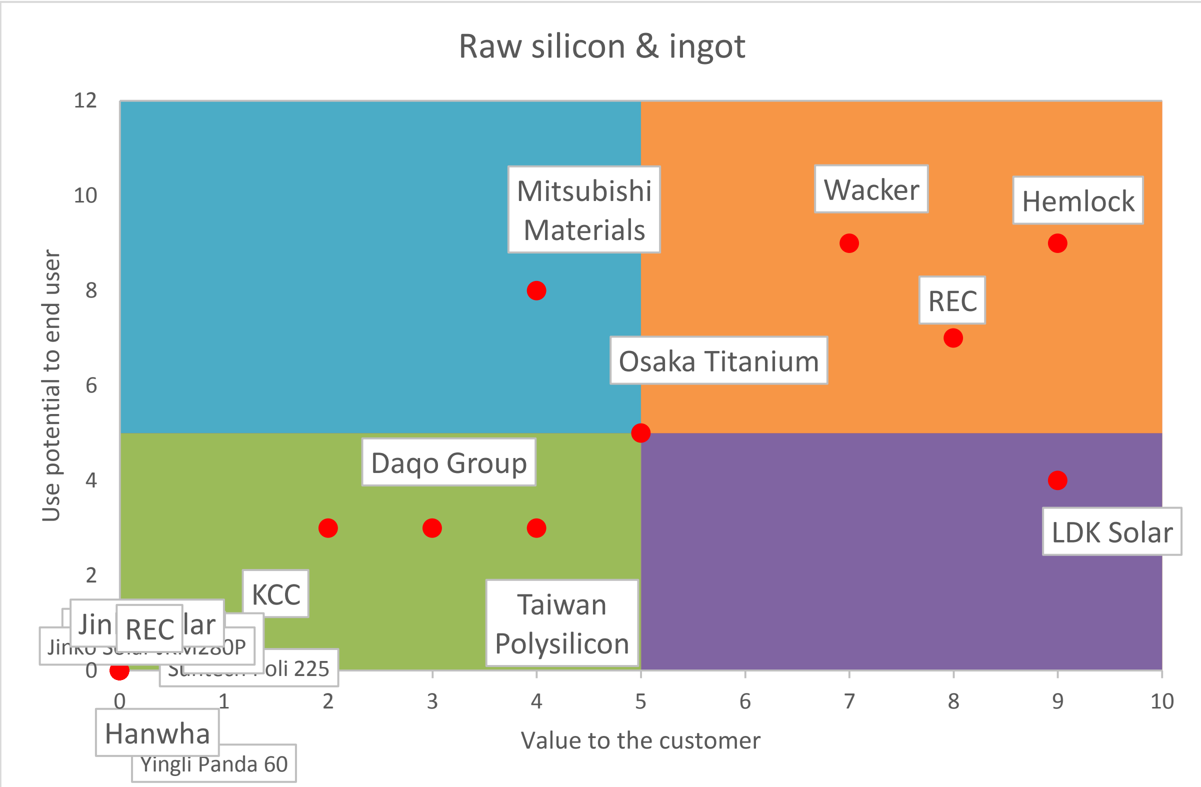
Figure 1: PV market value chain



2.1.2 Silicon raw and ingots

Silicon is a semiconductor material suitable for PV applications, with energy band gap of 1.1eV. Crystalline silicon (c-Si) is the material most commonly used in the PV industry and currently dominates the market. Silicon raw and ingot manufacturers provides these products in crystalls of two different crystallinity types (monocrystalline and poly/multi crystalline). The raw poly/multicrystalline silicon can be manufactured from metal grade silicon in three-four different forms namely chunks, rods, flowable chips, fines. These products are designated for manufacturers who own equipment for ingot recrystallization and further processing. Ingots are usually manufactured by Czochralski, directional solidification or float zone recrystallization and purification techniques. Already recrystallized and purified ingots of monocrystalline and poly/multi crystalline silicon are provided for companies having their own wafer sawing and cutting. The quadrant analysis of raw silicon & ingots is provided in Figure 2. It was identified that Hemlock, REC and Wacker products are leading in PV market.

Figure 2: Raw silicon and ingot product analysis by quadrants methodology



The overview of silicon raw and ingots products are given in Table 1.

Table 1: Overview of silicon raw and ingot product

Manufacturer	Illustration, Blueprints	Product type	Basic parameters	Comments
Hemlock semiconductor	   	Polysilicon: chunks, rods, flowable chips, fines	Purity 9N-11N	Directly suitable for solidification of ingots both mono and multicrystalline Si
LDK Solar Co	Monocrystallin	Monocrystalline	Purity 9N-11N	Product used for further

Manufacturer	Illustration, Blueprints	Product type	Basic parameters	Comments
	e Ingot  Multicrystalline Ingot 	Ingot Multicrystalline Ingot		si wafer processing
REC	Siemens chunk polysilicon  FBR granular polysilicon 	Siemens chunk polysilicon FBR granular polysilicon	Purity 5N-11N	REC Silicon Granular polysilicon is packaged in 1,200 kg Flexible Intermediate Bulk Containers.

2.1.3 Wafers and PV cells

2.1.3.1 Analysis of wafer and PV cell technologies

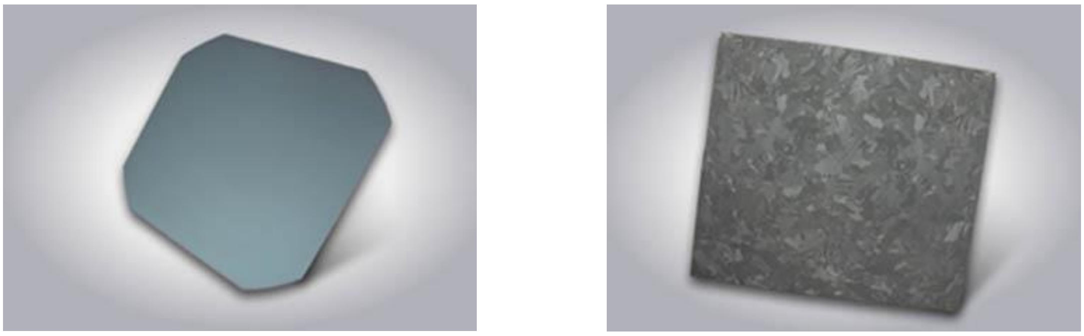
2.1.3.1.1 First generation PV cells: Crystalline silicon

Crystalline silicon cells are classified into two main types according to raw material physical and chemical parameters (Figure 3):

Monocrystalline. This type silicon crystal lattice is continuous and unchanging through all material bulk. Under such crystallinity the highest conductivity and solar cell efficiency could be achieved.

Polycrystalline and multicrystalline. Silicon of this form of crystallinity is a material consisting of multiple small silicon monocrystalline crystals which are forming clusters of different sizes and orientation.

Figure 3: Monocrystalline (left) and polycrystalline (right) silicon wafers



These two types of wafers for solar cells are main working horse for PV industry for the long time. There is permanent ongoing discussion which type of solar cells and modules are better performing in outdoors environment. Although on monocrystalline Si wafer based solar cells are demonstrating highest efficiencies in laboratory when it is coming to overall energy generated in real conditions through the day there are advantages on polycrystalline Si solar cells which are better performing under difused solar illumination or have better performance in higher temperatures. Policrystalline wafers also are more attractive because of their rectangular shape and possibility to fill the whole area of PV module with active surface of solar cells this way increasing overall efficiency of the final product – PV module. Therefore there are no clear winner technology and new products are in permanent development for both crystallinity types solar cells.

Wafer conductivity. Solar cells market is dominated by p type Si material when p type conductivity is obtained by Boron doping. However, cell performance degradations have been observed for cells made from this material causing reduction of module efficiency. It is caused by oxygen available in the standard substrates which reacts with boron forming B-O complexes and this way reducing the minority carrier lifetimes in the substrate. This degradation problem can be avoided by the use of low oxygen content materials, such as by MCZ (magnetically confined Czochralski) and FZ (float zone) technology prepared materials.

Another recent approach is to utilise n type Si material which is avoiding most of p type matarial problems and have excellent electrical properties. Initial material for production of the n-type silicon crystals is the same polysilicon raw material used for production of the p-type Si crystals. The main difference between these two is different doping impurities provided during crystallization. For production of p-Si boron is main dopant, while for the n-type Si crystals usual dopand is phosphorus.

Recent developments with record efficiences of Si based solar cells are reported on n type material wafers. Research carried out during the past 10 years on n-type (mainly phosphorus-doped) Si material and related cell processes is confirming that compared to standard p-type (boron-doped) Si solar cells, n-type silicon cells is demonstrating two important advantages: 1. these solar cells are more stable and are not suffering from light induced degradation (LID) which is caused in p type solar cells by the simultaneous presence in the wafers of the boron and oxygen. 2. n-type Si wafers are less sensitive to impurities that are usually present in silicon feedstock; consequently, fewer efforts have to be made to obtain n-type Si wafers with a high electronic quality. Accordingly, n-type wafers can be produced with lower costs than high quality p-type wafers for the same quality of the solar cell.

One of the challenges in the wafer material production is the homogeneity of the electrical properties within the silicon crystal. Standard cell concepts demonstrating prospects for stable efficiencies are developed assuming homogeneous wafer resistivity distribution. Comparing to standard p-type (boron-doped) Si, n-type (phosphorus-doped) Si crystals are demonstrating typically wider dissipation of specific electrical resistance. For boron doping, dissipation of a range from one to three ohm centimeters (Ωcm) can be easily maintained, while for the phosphorus doping, this range increases to 3-12 Ωcm. Large variation of the resistivity means decreased yield with stable cell efficiency in the production and consequently increasing overall production costs.

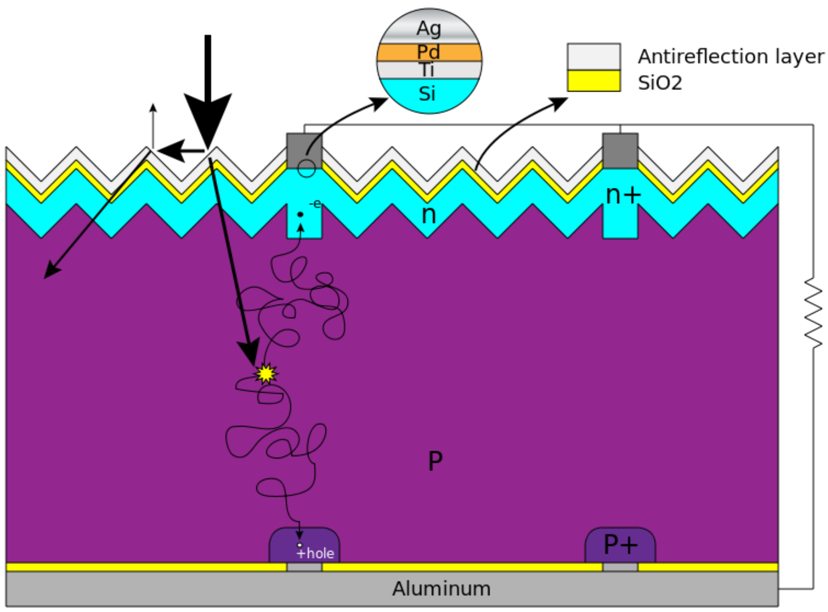
Despite existing problems there are already many n-type wafer suppliers on the market (Topsil, Norsun, Pillar, MEMC, BOSCH, LDK).

Wafer size and thickness. Si wafer production technology is overcoming permanent changes addressing two issues: scaling up of the PV industry and requirement for cost reduction through the material savings. It means that during last ten years PV industry faced shift from 5 to 6 inch wafer sizes resulting in significant equipment upgrade. Wafers with the current standard format (156x156 mm^2) are expected to stay standard until 2023; larger wafers (210x210 mm^2) are not expected to appear in production soon. Another trend in wafer technologies is reduction of wafer thickness this way addressing material saving issue. During the years of high Si prices (2004-2008) there was strong push to reduce wafer thickness which resulted in moving from 280 to 180 µm thick wafers used in the production lines. Although on laboratory and pilot scale solar cell concepts on down to 100 µm wafers are already demonstrated, further reduction of the wafer thickness on industrial scale is hampered by the need to refurbish existing production lines with equipment able to handle thinner wafers without reduction of handling speed and without increasing breakage rate. Trend to implement solar cells on thin layers was very attractive during the years of high Si feedstock prices. After significant drop in Si prices interest to invest into further material savings through novel solar cells designs on thin wafers is diminishing. Therefore introduction of new technological solutions for 100 µm wafers application in solar cell production can not be expected in the upcoming few years.

Types of Si solar cells

P-type Si solar cells. Typical for main stream product solar cell structure is presented in Figure 4.

Figure 4: Silicon Solar cell structure and mechanism. ***Sourece: Wikipedia***



Solar cell is most simple implementation of a large-area p-n junction made on Si wafer. Bulk material of solar cell is typically p type Si on the surface of which n type thin layer is formed, usually by phosphorus diffusion. Top surface of n type is typically situated toward solar irradiation to absorb solar light. Because flat Si surface have high reflectivity (up to 30%) top surface is texturised to create corrugated surface (so called pyramids) this way reducing significantly reflected sunlight down to 4%. To provide possibility to collect generated in the solar cell carriers to the electrical circuit both top and bottom surfaces are covered by metal contacts. Top surface is covered with narrow (60-150μm wide) grid of metal "fingers" while bottom surface is covered by metal contact 100%. The last important element in solar cell is passivation layers on top and recently on the bottom. These layers are introduced to reduce recombination losses which occurres on the surfaces this way increasing number of carriers collected in the contacts.

The main driver for solar cell technology development is to find ways to reduce costs of this product and to become competitive energy generation technology on the market. It can be done two ways: by increasing overall solar cell efficiency or reducing production costs by cheaper materials or technological steps. Provided that the additional production costs related to more complex cell can be not acceptable for industry, targeting high solar cell efficiencies without additional production costs can be very attractive way to reduce the cost of PV products.

The standard p-type solar cell with a homogeneous emitter and aluminum back surface field (Al-BSF) has an efficiency limit of about 19 percent applying typical standard passivation and metallization concepts. With introduction of the selective emitter, 19.5 percent is possible to achieve and if additional changes are made on the rear side (for so called passivated emitter and rear cell, or PERC concept see below), 20 percent can be reached (for example Centrotherm Centaurus concept).

In 2011, around 84 percent of PV module production was based on p-type crystalline silicon (Si) technology and only 4% were n-type solar cells. The p-type versus n-type Si solar cells has historical reasons. The very first solar cell – fabricated in 1954 in the Bell-Labs – was made of a monocrystalline n-type Si wafer.

Until the 1980s, the main industrial application of PV was for space applications where p-type Si proved to be less sensitive to degradation caused by exposure to cosmic irradiation namely high-energy protons and electrons). Therefore for long time industrial PV cell development was dominated by technologies for p-type silicon.

Consequently, on an industrial level the key processes such as emitter diffusion and metallization were available only for p-type Si wafer substrates.

N-type solar cells. In the last decade, there is clear growth of interest to investigate n-type Si-based technology. The research has proven potential of this material to outperform standard p-type Si solar cells first of all in terms of efficiency. As a consequence, there is growing interest in the development of industrial processes and industrial implementation of n-type Si based cell. International Technology Roadmap for

Photovoltaics (ITRPV 03/2012) is predicting growing share for n type Si solar cells up to 30 percent of the monocrystalline silicon solar module market by 2015.

With each year more and more companies are considering n-type solar cells as good option for inmplementation of new products because of the higher efficiency potential of these concepts. The following n-type solar cell concepts can be found on the PV market:

Sanyo (HIT)

Roth and Rau (HELiA)

Yingli (Panda)

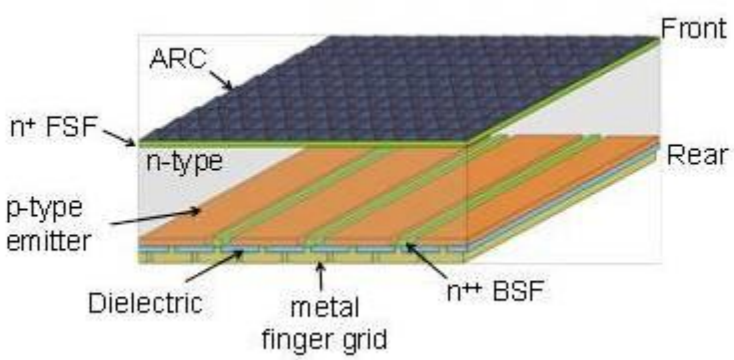
PVGS (EarthON)

SunPower (IBC)

PV companies' R&D departments are working on the aforementioned concepts, bringing these technologies to pilot line implementation level. It means that these products can be available in the market in the time frame under consideration by this study.

Interdigitated back contact solar cells. Concept of the interdigitated back contact solar cell was introduced as a possibility to utilize benefits from total 100% opening of front surface to the solar light. Despite higher efficiencies this product is staying in high prices PV products segment due to higher complexity of technology and is produced on large scale by only one producer – SunPower. There are permanent R&D efforts to reduce costs of production of solar cells with this design.

Figure 5: Schematics of an IBC solar cell

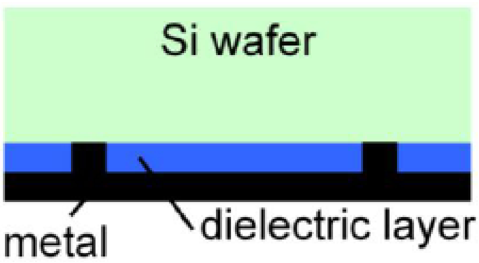


IBC solar cells can be implemented on both p and n type wafers but n-type solar cells, see Figure 5, are already on the market and are percepted as high conversion efficiency solar cells, with values recently announced as high as 24.2% (reported by SunPower). Record high efficiencies are enabled by few factors: high bulk lifetime silicon wafer material, the cell structure, with the absence of front side metal shading, thus allowing beter optimization of optical and passivation properties, and low series resistance metal scheme. On the module production side there are also some additional advantages in terms of easier module integration when both metal contacts are located on the rear of the cell. Main issue for ongoing IBC silicon solar cell development is the balance between cell performance and process complexity resulting in higher cost. Additional issue is related with module production because there is no standard module technology for IBC silicon solar cells as the majority of the silicon solar cells produced are typically two-side contacted and therefore standard module producers are not able to absorb IBC cells in their production.

Passivated emitter and rear cell (PERC) solar cell.

Recently, significant progress has been made improving the front-side design of industrial crystalline silicon (c-Si) solar cells. After successful implementation of homogeneous and selective emitter (SE) structures with enhanced spectral response in the blue wavelength region in mass production, the large-area aluminum back-surface field (Al-BSF) has become the most dominant efficiency limiting factor for these devices. The rear-surface passivation and internal reflectivity are greatly improved by dielectric passivation in combination with aluminum local back-surface field technology (Al-LBSF). This appears to be the most promising approach for industrial applications. Based on the original idea of a PERC, different technologies like the industrial PERC or laser-fired contact (LFC) technology have been developed. On industrial-size monocrystalline Si wafers, cell efficiencies between 19.4% and 20.2% have recently been obtained.[9] For the implementation of this new high-efficiency feature of a dielectric rear-surface passivation in commercial production, it is critical to obtain a high-efficiency gain, to keep the process sequence simple with a minimum number of process steps, and to be compatible with different wafer types, e. g., Czochralski-grown monocrystalline silicon (Cz-Si), multicrystalline silicon (mc-Si), and quasi-monocrystalline silicon (quasi-mono-Si). A schematic design of a PERC cell is shown in Figure 6.

Figure 6: Schematic representation of passivated emitter and rear cell (PERC)



The deposition of the rear-surface dielectric passivation layer stack is performed with plasma-enhanced chemical vapor deposition (PECVD) system using temperatures lower than 500 °C. The stack consists either of a thin silicon oxide or a thin aluminum oxide film of less than 100 nm capped by a silicon nitride film. Standard cells, the rear-side metallization for the PERC cells is based on industry-proven and cost-effective screen-printing and firing of commercially available Al paste. Alternative developments are based on laser ablation when contact openings are formed laser. As process is optimized

[9] Y. Gassenbauer, K. Ramspeck, B. Bethmann, K. Dressler, J. D. Moschner, M. Fiedler, E. Brouwer, R. Dr¨oßler, N. Lenck, F. Heyer, M. Feldhaus, A. Seidl, M. Muller, and A. Metz, Rear-Surface Passivation Technology for Crystalline Silicon Solar Cells: A Versatile Process for Mass Production, IEEE journal of photovoltaics, Vol. 3, No. 1, January 2013

for the use of low deposition temperatures and is flexible in the local contact geometry due to an easily adjustable laser system, the PERC process is applicable for the variety of wafer materials mentioned before, regardless the crystallization type and base resistivity up to 3.5 Ω·cm.

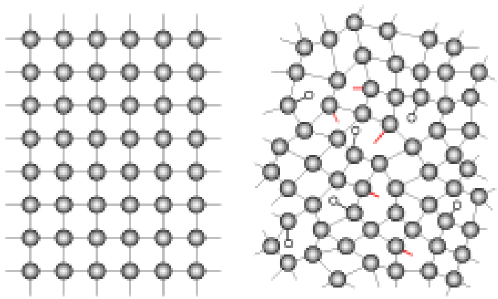
2.1.3.1.2 Second generation PV cells: Thin film

Thin-film solar cells are comprised of successive thin layers, just 1 to 4 μm thick, of solar cells deposited onto a large, inexpensive substrate such as glass, polymer, or metal. As a consequence, they require a lot less semiconductor material to manufacture in order to absorb the same amount of sunlight. In addition, thin films can be packaged into flexible and lightweight structures, which can be easily integrated into building construction components.

The most common materials for thin film solar cell are amorphous silicon (a-Si), cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS).

Amorphous silicon (a-Si) is disordered thin-film PV material unlike crystalline silicon or polycrystalline. For amorphous silicon, several percent of silicon atoms make covalent bonds with only 3 neighbouring silicon atoms, the remaining electron bonds with a hydrogen atom (Figure 7).

Figure 7: Comparison of crystalline (left) and amorphous silicon lattices (right)



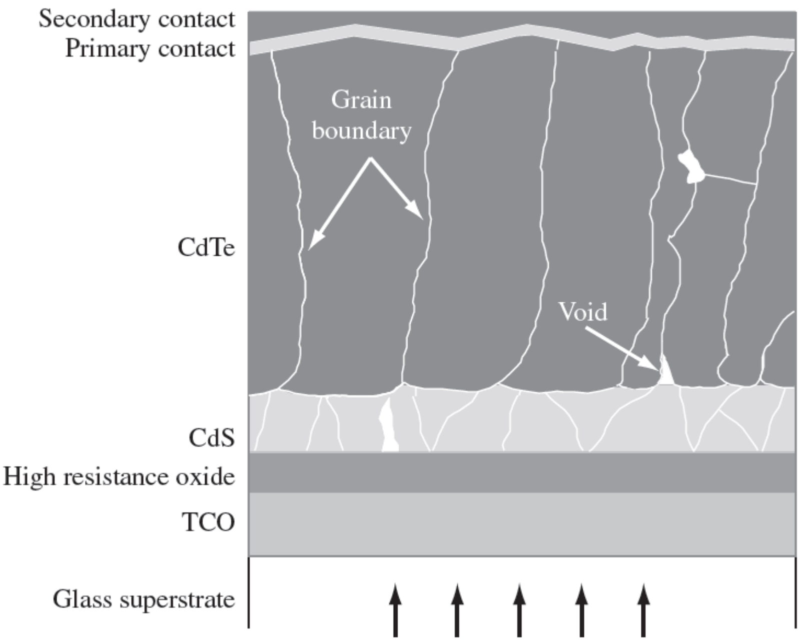
Such atomic disorder provides totally different electronic properties, therefore the amorphous silicon solar cell can be utilized in thin films (unlikely crystalline silicon) with higher absorption coefficient. As all thin film solar cells, a-Si can be utilized as flexible ones, therefore the integrability into buildings is higher than of conventional solar panels, although the efficiency does not exceed 8%. Another unsolved issue is Staebler-Wronksi effect which determines the long term degradation and generated power drop which means that this type of product can not compete in durability with wafer based PV modules.

Cadmium telluride (CdTe). Large-area monolithic thin-film modules demonstrate long-term stability, competitive performance, and thus ability to attract production-scale capital investments even in this period of growth slowdown for PV industry. The cross section view of standard CdTe solar cell is shown in Figure 8. One of the best thin film solar cells efficiency (16.7%[10]) and recent advancements in manufacturing process

[10] M. A. Green, *et. al*. Solar Cell Efficiency Tables (Version 37), Progress in Photovoltaics: Research and Applications, Vol. 19, pps 84-92, John Wiley & Sons Ltd., N.J. 2011

optimization made these solar cells one of the most promising alternatives to conventional crystalline silicon SC. Nevertheless, the main bottleneck fro this technology is tellurium resources constrain and toxic cadmium usage which slows down further penetration onto the market.

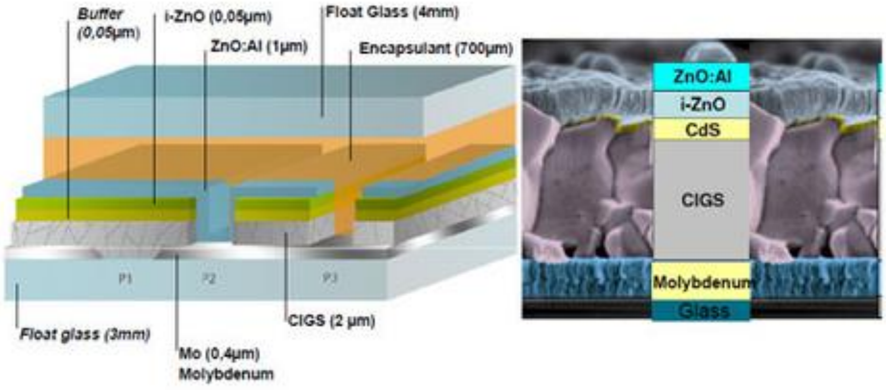
Figure 8: Cross section view of CdTe thin film solar cell[11]



Copper indium gallium diselenide (CIS or CIGS). CIGS PV cell cross section view is shown in Figure 9: the thin film is deposited on glass substrate, then the molybdenum contact, CIGS layer, CdS and ZnO windows with antireflection coating and nickel-aluminium contacts are utilized for efficient charge carrier extraction. These solar cell offer the highest conversion efficiency (7-16%), moreover laboratory scale cells achieve 20.3% value. One of the major bottlenecks of CIGS commercialization is the production method difficulties (thin film deposition from gas phase). However companies in conjunction with several universities are striving to simplify gas deposition technologies and to deliver cheap reliable and most importantly efficient CIGS solar cells to the market.

[11] B. E. McCandless *et. al*. Cadmium Telluride Solar Cells. John Wiley and Sons. Ltd., N.J. 2003

Figure 9: Cross section view of CIGS solar cell[12]



It must be noted that thin film PV cells technologies are integrating cell production and module production steps, this way creating advantageous technological approach toward cost reduction in product production. Therefore there is no separate thin film cell products on the market and overview of these products are presented in the PV module products section.

Despite the many challenges, innovation continued along the value chain with advances in efficiencies, process improvements, developments of organic materials, plastics, and finance, among others, and cost reductions continued their downwards trajectory, averaging 7–8% annually. Thin film producers continued to improve efficiencies, increase adoption for rooftops and other uses, and reduce costs.

2.1.3.1.3 Third generation PV cells

So called third generation solar cells can be distinguished into three categories – cells for concentrating PV, dye sensitized and organic solar cells.

Concentrating PV utilizes the optical system for direct and indirect solar radiation like lenses, mirrors and prisms. Some of these concentrated PV systems need a high precision sun tracking system, to orient the PV array onto the sun. As concentrating devices severs from high temperature, there is a need for tailored solutions for panel cooling as well. There are three types of concentrating PV: high (up to 500 suns), medium (up to 100 suns) and low (up to 10 suns) concentration PV devices. Whole CPV market is in a development stage, although there are some signs of rapid increase due to the overall grown of demand for higher generated green power output. It is estimated, that CPV market will reach €200.0 million in 2014.[13] In comparison, the highest growth prospective is foreseen in HCPV (high concentration PV) area, because of several advantages: this type of technology mitigates land requirement, provides possibilities for higher power output with lower cost, and has good prospects for significant active material (most costly part of energy converting device) savings. For comparison

[12] Manz AG, Manz Background info CIGS fab. September 2012. Reviewed on 14 February, 2013
[13] Markets and Markets: Concentrated Photovoltaic and Solar Photovoltaic Global Markets. 2009 – 2014

commercial flat Si module is a assembled of 16-17% efficiency polycrystalline silicon solar cells with power rating at 110-160 W/m(2) and active semiconductor area of ~100x100cm when in CPV module one unit operating at 500 suns and 0.55x0.55cm active element with efficiency of ~37% and with 800-870 W/m(2) power rating have active semiconductor area of ~4.5x4.5cm.

Concentrating PV concept is based on utilization of wide range of solar spectrum through so called multijunction solar cells produced mainly on the basis of A_3B_5 alloys.

Multijunction solar cells were first introduced in the late 1970s when dual-junction solar cells were performed on the basis of AlGaAs and GaAs solar cells interconnected by a semiconductor tunnel junction. In parallel another concept for multijunction solar cell was developed as stack of GaInP junction formed on top of a GaAs junction grown on an inactive Ge substrate. In 1990s triple junction (3-junction) solar cells with GaInP and GaAs both grown on top of an active Ge bottom cell substrate were introduced.

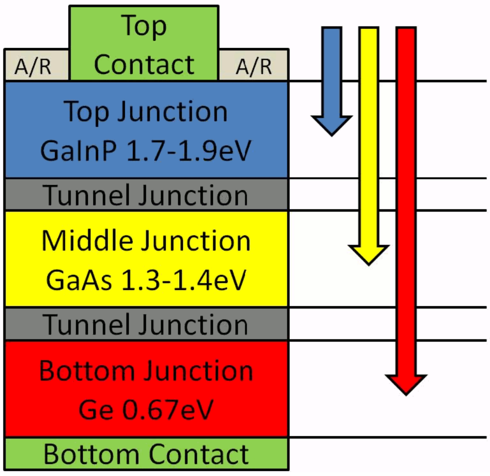
The high-efficiency of multijunction solar cells makes them highly attractive for cost-effective terrestrial concentrator systems. III–V multijunction concentrator solar cells are not only most efficient but also is demonstrating most rapidly growing efficiency comparing any other type of solar cell technology. In July 2013 it was announced that Sharp has achieved the world's highest solar cell conversion efficiency of 44.4% up to now, by using a concentrator triple-junction solar cell under a light concentration of 302 times.

PV systems are becoming attractive for the utility scale power generation but balance of the system (BOS) costs are taking increasingly large part of costs in these systems. Since raw materials used in BOS like metals, glasses, and composites have little margin for further cost reduction, thus lowering CPV competitiveness comparing with mainstream crystalline technologies, other approaches must be considered. For now increase in cell efficiencies and lowering cell costs were main drivers for the system costs mitigation. Progress in CPV cells is directly related to the progress in technologies behind such multijuncion structures grow. The main issue is to form individual layers as crystalline semiconductor layer on the substrate. For that different types of epitaxial layer deposition techniques are used namely LPE, OMVPE, MBE, MOMBE, ALE, HVPE, etc. In general, all epitaxial techniques differ in method for delivering atoms to the crystalline substrate, and each technique has its individual strengths and weaknesses.

High efficiency multijunction solar cells require layer growth, and simple deposition of polycrystalline material by for example chemical vapor-phase deposition is not acceptable.

Cell architecture for CPV. A typical 3-junction solar cell structure comprises of three n–p junctions made from different band gap materials layers for example GaInP, GaInAs and Ge stacked on top of each other - each layer with a band gap energy higher than the layer below it to utilize as much solar spectrum as possible. These layers are assembled with low resistive tunnel junctions who are formed on a substrate by the same as layers epitaxial growth techniques to obtain series-connected structure. Figure 10 shows a generalized device structure for a 3-junction solar cell.

Figure 10: Generalized device structure for a 3-junction solar cell



The top p–n junction which points toward the sun has the highest band gap energy and collects light from the highest energy and shortest wavelengths in the solar spectrum.

For the photons with energy lower than the band gap of the top layer, it is transparent therefore they pass to the lower junction. Photons with energy lower than band gap of the second junction are able to reach third junction where they are aborbed.

There are several requirements which must be met in fabrication of these devices in order to obtain top efficiencies:

- High quality of the material. High material purity of all layers is necessary for minority carrier electrons and holes to be collected.
- High crystal quality. The device atomic structures must be similar in atomic spacing and provide the multiple band gaps necessary to produce the junctions.
- Efficient passivation layers. These layers include front and back surface passivation layers which are typically much higher in band gap than the active layers within the cell.
- Good interconnection layers. It means that wide ranges in doping levels must be attainable and controllable. These layers are tunnel-junctions which act as diodes connected in reverse polarity to the original configuration of the stack. It allows tunneling of carriers through the junction so that current is transported vertically through the device.

As it was noted in the study 2 CPV technology is still lacking maturity therefore it can be only indications regarding most advanced and thus mainly available on the market structures for this type of cells which is the AlGaInP/GaInAs/Ge system. Among the most developed other structures are AlGaInP/GaInAs/Ge and AlGaAs/GaInAs/Ge material systems, GaInN/InN, AlGaInAs/GaInAsP/InP and GaPN/Si combinations.

Despite complicated technology, CPV is increasingly percepted as competitor for mainstream crystalline Si even with existing device production and system assembling techniques of low automation. Another very promising approach, alternative to the cell efficiency gain, is introduction of the more automated processes into CPV devices production lines having good prospects for significant reduction of production costs. By introducing production lines for fully automated CPV systems assembly this technology can become stong competitor for existing mainstream technologies especially in market segment of utility scale installations (Figure 11) and in emerging markets of high solar irradiation (Sun Belt countries).

Figure 11: HCPV solar park in Italy (Aveani and Savini)

Dye-sensitized PV cells (or Grätzel cells). Dye-sensitized solar cells (DSSC) are type of thin-film photovoltaic cell with the construction mimicking the natural photosynthesis (Figure 12). Existing in production DSSCs are based on a concept invented in 1988 by Brian O'Regan and Michael Grätzel. The principal of these cells is that the semiconducting structures are placed between photo-sensitised anode and an electrolyte. The nanocrystals of semiconductor acts as an antenna that harvest the sunlight and dye molecules are responsible for the charge separation. Although these cells are not stable under the UV irradiation, they are attractive because of low manufacturing cost material usage. Even though the conversion efficiency of dye-sensitized PV cells is lower than that of some other thin-film cells, their price to performance ratio is very attractive to consider them as an important technology for photovoltaic market. DSSCs are easy to manufacture with roll-to–roll printing techniques, and are semi-transparent and are demonstrating significant flexibility, this way allowing applications which are not accessible for mainstream rigid photovoltaic systems. Most of the materials used are low-cost, however some more costly materials are necessary, such as ruthenium and platinum. Another shortcome of this technology is requirement for liquid electrolyte which must be able to remain in the liquid phase in all kinds of weather conditions reducing their applicability in cold climate.

Main advantages of DSSCs are as follows:

- They are absorbing more sunlight per surface area than standard silicon-based solar cells;

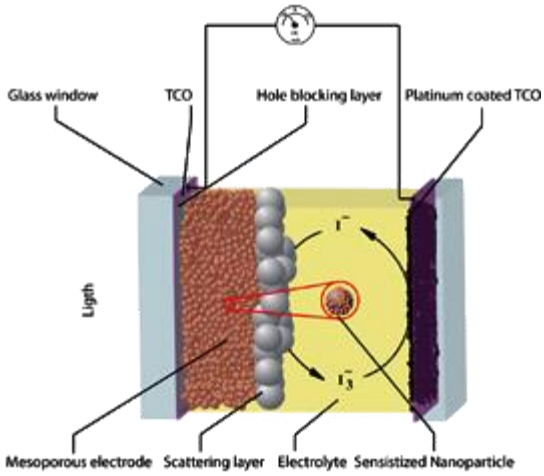
- Light weight and mechanical robustness;
- Are performing even in low-light conditions such as non-direct sunlight, cloudy skies or indoor environment;
- Easy to manufacture and are utilizing abundant and stable resource materials.

Main disadvantages of DSSCs are as follows:

- Low conversion efficiencies in the range of few percents.
- Low durability comparing with mainstream technologies.

Main developments in DSSCs are focusing on exploiting advantages and overcoming main disadvantages by utilising different new materials, structures and production techniques. Most of the present research on DSSCs is focused on improving spectral absorbance by making modifications in the dye, enhancing hole transport, replacement of the liquid electrolyte with conducting polymers or ionic solids and improving electron transport using alternative core-shell structures or wide band gap semiconductor materials.

Figure 12: Structure of Dye-sensitized PV cells



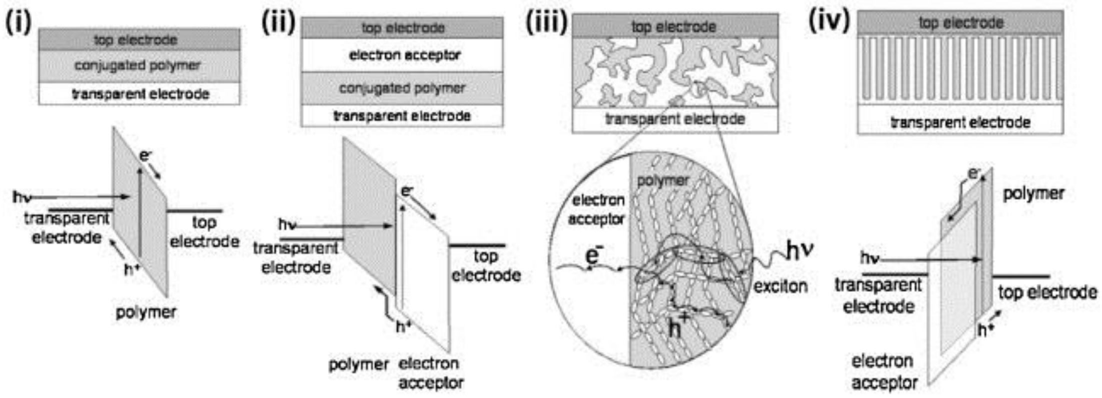
In the mainstream production DSSCs based PV products have invisibly small fraction of share and are available only in form of consumer electronics products such as flexible chargers on non-flat surfaces, etc.

Organic photovoltaic (OPV) cells. Organic solar cells utilize the organic or polymeric materials (see chapter on conductive plastics) which show significant sensitivity to solar irradiation by generating electrical power. New type of organic solar cell is formed using several layers of organic materials doped with donors or acceptors. To this day organic PV cells and panels have shown low efficiency of conversion, although the low production costs provide some possibilities for further commercialization. In addition to low efficiency, the prominent problem is organic or polymer material degradation due to UV irradiation.

OPV, a developing sector of PV technology, has emerged rapidly in the past two decades, due to the strong interest from the academic and industrial sectors. An OPV is essentially an excitonic solar cell where the physical properties of organic semiconductors are fundamentally different from the inorganic counterparts. Research in these fields greatly enhanced understanding of these new materials, which in turn increased the performance of OPV devices. With the development of processable bulk heterojunction (BHJ) OPVs, either in the form of polymer blends, small molecule blends or organic-inorganic hybrids, this technology became even more exciting, since the well-established industrial wet coating and printing streamlines can be directly implemented in high throughput device fabrication. As a result, low cost, thin flexible plastic based OPVs can be produced. The more recent developments of transparent electrodes and high efficiency semi-transparent cells and has enabled the integration of OPV technology into building materials, like curtains and windows, taking advantage of the intrinsic nature of UV absorption.

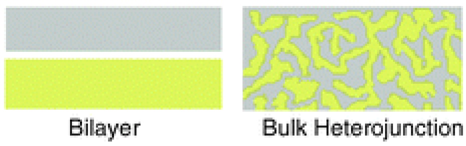
The BHJ OPV cell is a thin film device comprised of a mixture of a donor material and acceptor material that is sandwiched between a pair of asymmetric electrodes. The donor material, either a polymer or a small molecule, forms hole-transporting pathways to the anode, while the acceptor material, either fullerenes or an inorganic material, forms the electron-transporting pathway to the cathode. Conjugated donor materials absorb light, are transformed into an excited state and produce bound electron-hole pairs or excitons. These excitons diffuse between the domains of the donor and acceptor material and dissociate to form positive and negative charge carriers, due to the energy level offset at that interface. Once dissociated, the carriers are transported through the bicontinuous donor and acceptor pathways to their respective electrodes (see iii in Figure 13).

Figure 13: Four device architectures of conjugated polymer-based photovoltaic cells: (i) single-layer PV cell; (ii) bilayer PV cell; (iii) bulk heterojunction; (iv) ordered bulk heterojunction[14]



Thin film OPV technology was first developed as a bilayer device by Tang in 1986, who used the sequential thermal vacuum deposition of two small molecules to form the bilayer (Figure 14). While clearly demonstrating the function and feasibility of OPVs, the interfacial area, where exciton dissociation occurs, was severely limited, since there was only one interface between the layers.

Figure 14: Bilayer versus bulk heterojunction structures[15]



A breakthrough was made in 1995 and with the introduction of the BHJ device structure, where a mixture of a conjugated polymer (the donor) and a modified fullerene or n-type material (the acceptor) produced a bicontinuous, phase separated morphology. The interfacial area was massively increased, significantly increasing the number of excitons that were dissociated, and, consequently, significantly improving device performance. In addition, solution processing was possible, opening the path to a commercially viable process. Now, the smaller the size of the domains in the BHJ, the larger the interfacial area is for exciton dissociation. For OPV devices, the exciton diffusion length is ~10 nm. Thus, a domain size of this length scale reduces the recombination losses and improves the device efficiency. Current research has focused on controlling the morphology of donor-acceptor mixtures or block copolymers, attempting to balance charge transport and increased light absorption. A maximum efficiency of 9.2% was obtained for a single layer BHJ device[16] thus puting OPV on the map of prospective PV products.

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[14] Feng Liu, Yu Gu, Xiaobo Shen, Sunzida Ferdous, sin-Wei Wang, Thomas P. Russell, Characterization of the morphology of solution-processed bulk heterojunction organic photovoltaics, Progress in Polymer Science, 2013

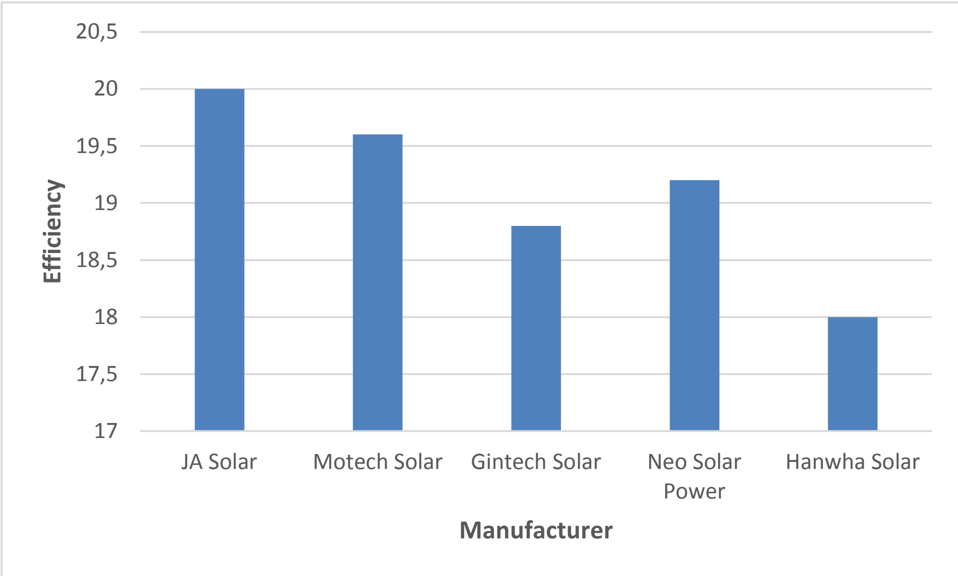
[15] Jiaoli Li, Andrew C. Grimsdale, Carbazole-based polymers for organic photovoltaic devices, Chem. Soc. Rev. , 2010, 39, 2399-2410

[16] Z. He, C. Zhong, S. Su, M. Xu, H. Wu, Y. Cao, Enhanced power-conversion efficiency in polymer solar cells using an inverted device structure, Nat Photon, 6 (2012), pp. 593–597

2.1.3.2 Overview and analysis of PV cell products on the market

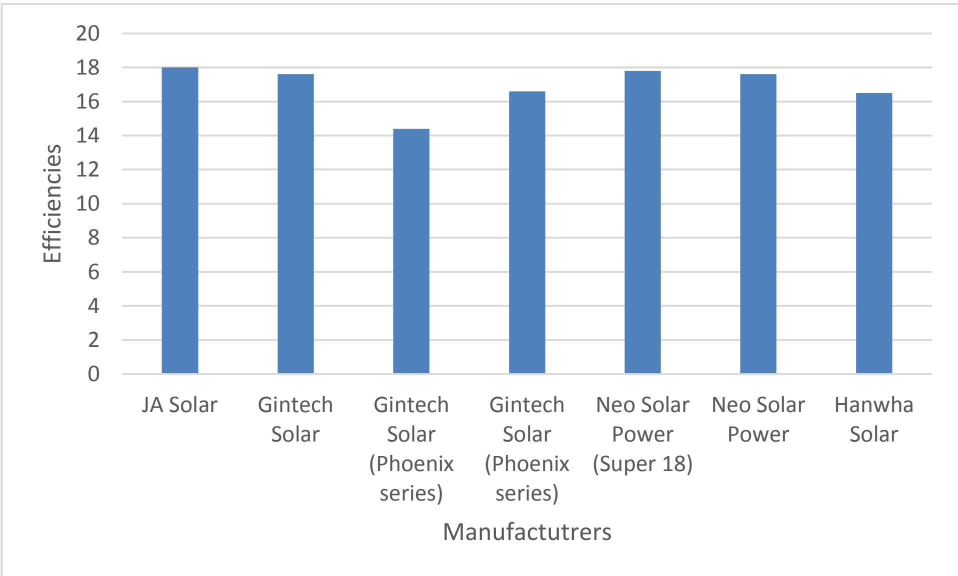
Table 2 provides the overview of crystalline PV cells products. As global PV market dictates mostly the need for crystalline silicon PV modules, the PV cell suppliers are manufacturing monocrystalline, multicrystalline and polycrystalline silicon PV cells. Although different crystallinity raw material needs different processing, most manufacturers are able to implement both crystallinity PV cells production. The analysis of monocrystalline and poly/multicrystalline PV cell efficiency is presented in Figure 15 and Figure 16 respectively, which shows the higher figures for monocrystalline silicon PV cells (18-20%) and lower for polycrystalline and multicrystalline silicon PV cells (16.5-18%).

Figure 15: Distribution of monocrystalline silicon PV cells efficiency



The analysis showed that the highest 20% efficiency is reached in JA Solar Monocrystalline JACM5SF-2 PV cells. The PV cells with efficiency of 19.60% are manufactured by Motech Solar Company (PV cell model- XS156B3-200R).

Figure 16: Distribution of poly/multicrystalline silicon PV cells efficiency



The poly/multicrystalline PV cell with the highest 18.00% efficiency is provided by JA Solar company as well. The PV cells with 17.6% are provided by Gintech Solar (Phoenix series multicrystalline silicon PV cells) and Neo Solar Power.

The majority of provided PV cell product have standard design, when both contacts are formed on front and back surface of cell, and mostly silver pastes are used for front contact grid (1.4 mm or 1.5 mm wide bus bars) screen printing and aluminium deposition is used for back contact and back surface formation. Most of manufacturers provide PV monocrystalline cells products with blue silicon nitride anti-reflective coatings and silver contact on silicon nitride, although some of them (for e.g. Gintech Solar), forms dark blue, blue or indigo front colours for aesthetic reasons. Usually the back surface is covered by homogenous aluminium coating so called full-surface aluminium back-surface field, although some manufacturers are able to process back surface field with local contacts. Some of PV manufacturers are introducing wide selection of different front surface colour (black, red, blue, yellow or brown) for BIPV glazing material applications.

The quadrant analysis of PV cells is given in Figure 17. The identified leader products are manufactured in JA Solar, Neo Solar Power and Motech Solar.

Figure 17: PV cell product analysis by quadrants methodology

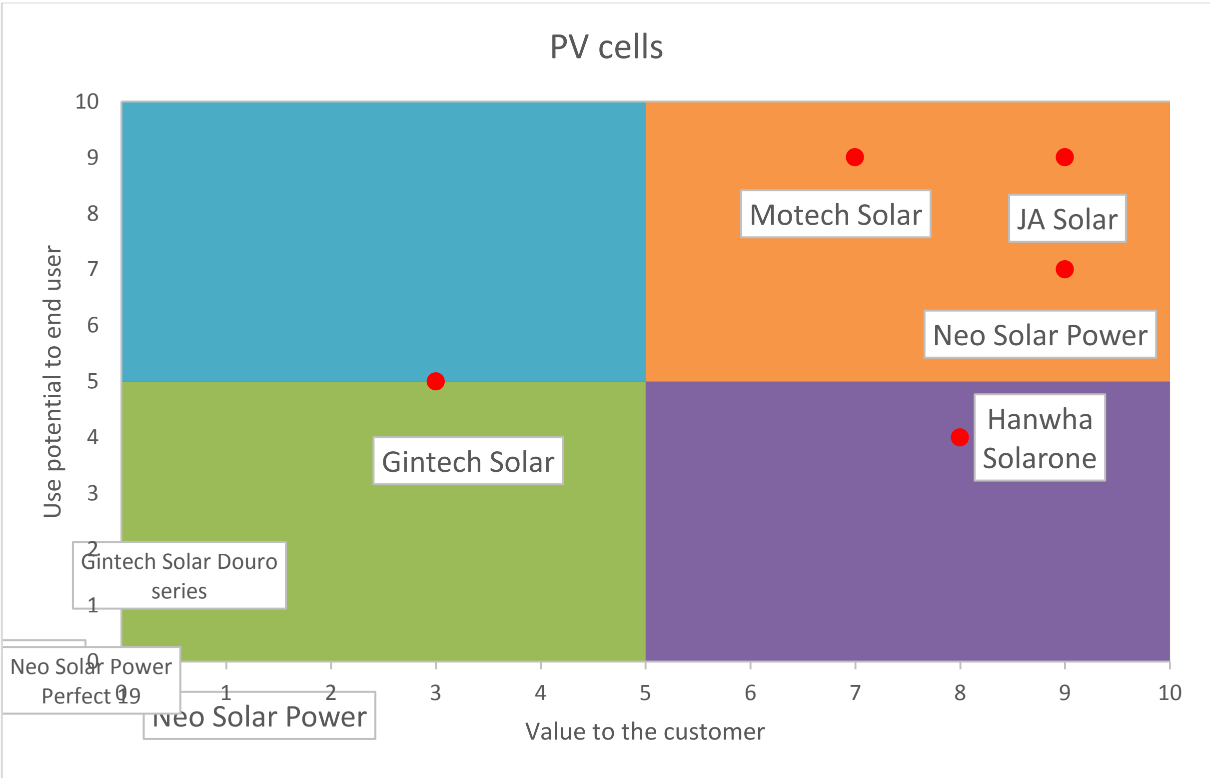
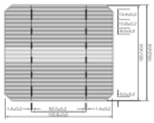
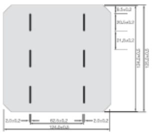
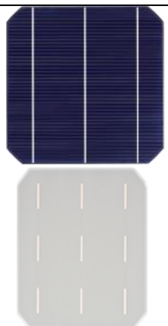
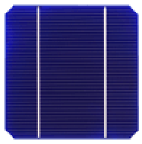


Table 2: Overview of PV cell products

Manufacturer	Illustration	Product type	Basic parameters	Comments
JA Solar	Front  Back 	Monocrystalline: JAC M5SF-2 JAC M6SF-3 Polycrystalline: JAC P6RF-2 JAC P6RF-s3	**Monocrystalline JACM5SF-2:** Efficiency 20.00% V_{oc} 0.637 V V_{mp} 0.537 V I_{sc} 7.12 A I_{mp} 5.531 A P_{max} 2.97 W FF 79.19% Dimensions 125 × 125 × 0.5 mm **Polycrystalline JACP6RF-2:** Efficiency 17.80-18.00% V_{oc} 0.634 V V_{mp} 0.526 V I_{sc} 8.783 A I_{mp} 8.227 A P_{max} 4.33 W FF 77.74%	Front of solar cell: 1.4 mm bus bars(silver), blue anti-reflecting coating(silicon nitride) Back of solar cell: 2 mm wide soldering pads(silver) back surfaced (aluminium)
Motech Solar		XS156B3 Monocrystalline Cells IM156 Multicrystalline Cells IM156B3 Multicrystalline Cells	**XS156B3-200R (Monocrystalline Cells):** Efficiency 19.60% V_{oc} 0.643 V V_{mp} 0.547 V I_{sc} 8.99 I_{mp} 8.56 A P_{max} 4.68 W	Front: Anisotropically textured surface and dark with silicon nitride ARC coating 1.4 mm silver busbars Back: Full surface aluminium back surface, 2.5 mm (silver/aluminium) back surface aluminium discontinuous soldering pads
Gintech Solar	**Douro series**  **Phoenix series**	**Douro series** (Monocrystalline, Multicrystalline) **Phoenix series** (Multicrystalline)	**Douro series:** Dimensions 156 × 156 × 0.5 mm **Monocrystalline**: Efficiency 18.80% V_{oc} 0.634 V V_{mp} 0.532 V I_{sc} 9.06 I_{mp} 8.55 A P_{max} 4.49 W **Multicrystalline:** Efficiency 17.60% V_{oc} 0.633 V V_{mp} 0.529 V I_{sc} 8.78 I_{mp} 8.25 A P_{max} 4.28 W **Phoenix series** Thickness 180-200 µm	**Douro series:** Alkaline textured surface with SiNx anti-reflecting coating Colour: Dark Blue, Blue, Indigo 2 bus-bars in 1.5 mm ± 0.1 mm width Distance between bus-bars: 75 mm Negative pole [-] **Phoenix series:** Alkaline or acid textured surface with SiNx anti-reflecting coating 2 bus-bars in 2.0 mm ± 0.1 mm

Manufacturer	Illustration	Product type	Basic parameters	Comments
	 Fresh Green  Glitter Red  Diamond Blue  Cocoa Brown  Sparkling Gold  Maple Red		Dimensions 156 × 156 × 0.5 mm **Diamond blue:** Efficiency range 14.40-16.60% Power range 3.50-4.04 W **Fresh green:** Efficiency range 14.00-16.20% Power range 3.41-3.94 W **Cocoa Brown:** Efficiency range 14.60-16.00% Power range 3.55-3.89 W **Sparkling gold:** Efficiency range 14.40-15.80% Power range 3.50-3.85 W **Glitter red:** Efficiency range 14.00-16.20% Power range 3.41-3.94 W **Maple red:** Efficiency range 13.60-14.80% Power range 3.31-3.60 W	width Distance between bus-bars: 75 mm Negative pole [-]
Neo Solar Power	**Super17 (Multicrystalline)**  **Perfect19 (Monocrystalline)**  **Black19+**	**Classic line:** Super17 (Multicrystalline) Black19 (Monocrystalline) **Super18** (Multicrystalline) **Perfect19** (Monocrystalline) **Black19+** (Monocrystalline) **NeoMono**(Crystalline silicon)	**Super17**: Efficiency 17.6% V_{oc} 0.637 V V_{mp} 0.527 V I_{sc} 8.681 A I_{mp} 8.127 A P_{max} 4.283 W **Perfect19**: Efficiency 19.2% V_{oc} 0.644 V V_{mp} 0.535 V I_{sc} 9.256 A I_{mp} 8.734 A P_{max} 4.673 W **Black19+**: Efficiency 19.5% V_{oc} 0.646 V V_{mp} 0.548 V	**Perfect19:** Front Three 1.5 mm wide bus bars (silver) with distance 52 mm alkaline texturized surface with dark silicon AR coating. Back 2.1 mm wide silver aluminium soldering pads, aluminium back surface field

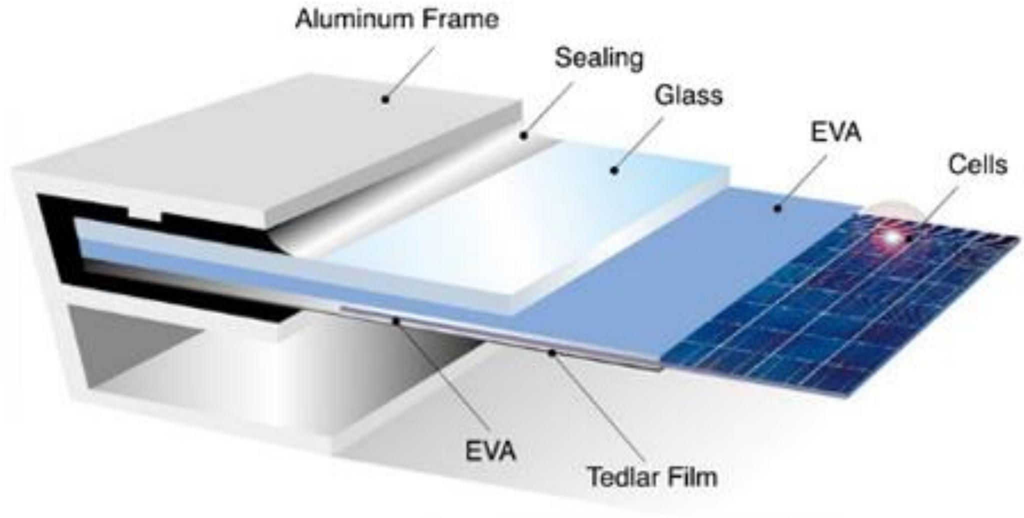
Manufacturer	Illustration	Product type	Basic parameters	Comments
			I_{sc} 9.054 A I_{mp} 8.498 A P_{max} 4.660 W	
Hanwha Solar One	Monocrystalline Cells  Polycrystalline Cells 	Monocrystalline Cells Polycrystalline Cells	**Monocrystalline Cells:** Efficiencies up to 18% Dimensions 125 mm x 125 mm ± 0.5 mm Thickness 200 µm ± 20 µm **Polycrystalline Cells:** Efficiencies up to 16.5% Dimensions 156 mm x 156 mm ± 0.5 mm Thickness 220 µm ± 20 µm	**Front** Blue silicon nitride anti-reflective coatings 1.5 mm-width silver contact on silicon nitride **Back** Full-surface aluminium back-surface field 3 mm-width silver-aluminium back contact strips

2.1.4 PV modules

2.1.4.1 Overview of crystalline and thin film PV modules types

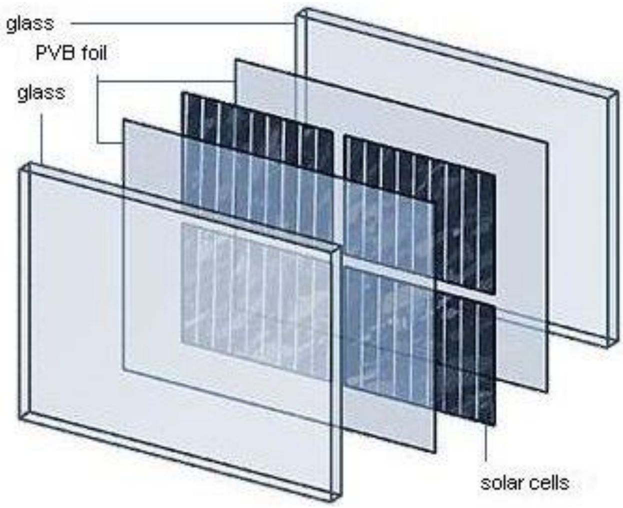
In order to protect solar cells from harsh environmental conditions and integrate solar cells into homogenous electric circuit, various sealing, framing and layering technologies are used. Schematic cross-section view of standard crystalline silicon solar module is shown in Figure 18: the whole solar module has a rigid aluminium frame and outer sealing to avoid moisture, snow or rain interaction with flowing electricity which could lead to short circuits and irreversible damage. Usually solar cells are embedded between EVA thermoplastic encapsulant layers containing ethylene vinyl acetate (EVA polymer) for better insulation and overall module strength. On the top of module (plane which faces the solar irradiation) the glass with suitable solar spectrum transmittance is used to protect solar cells and electronics from environmental conditions. Finally standard solar modules comprise PV back sheet of Tedlar films. This back sheet laminate protects the module from UV, moisture and acts as an insulator as well.

Figure 18: Standard solar module structure[17]



Some of the solar module applications (for e.g. building integrated photovoltaic modules, BIPV) contain a glass back sheet to meet architectural and aesthetic requirements. These glass-to-glass PV modules are semi-transparent and frameless. The the glass-to-glass semi-transparent PV modules are composed from silicon solar cells that is spaced so that some portion of light passed through the glass area. Such PV module is consisted of several layers: glass, encapsulation material (Ethylene Vinyl Acetate (EAV) Sheet or polyvinyl butyral (PVB) foil), PV cells, again encapsulation material and glass. Figure 19 shows the layers of the PV module.

Figure 19: Glass-to-glass module structure[18]



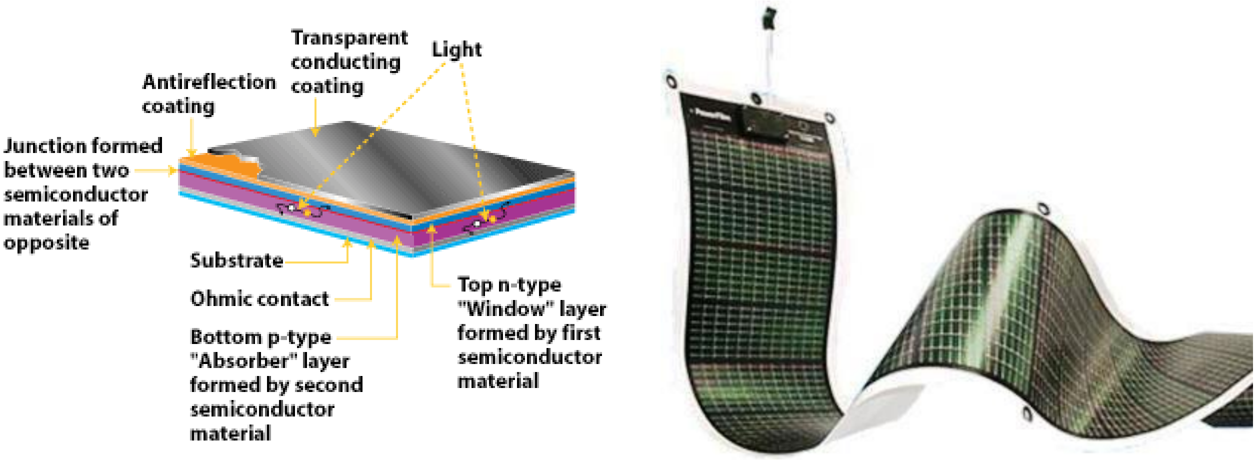
Apart from architectural and aesthetic requirements glass-to-glass PV technology provides these functionalities: sun protection, weather proofing, protection from sounds and noise, and provides thermal insulation. The BIPV glass market growth is clear indication about demand for glass-to-glass products which currently has revenues of US$1.5 billion (€1.12 billion) for 2012 and is expected to rise to $6.4 billion (€4.8

[17] Ritek Solar. Product catalog. Crystalline (C-Si) solar modules
[18] http://www.solarfassade.info/en/fundamentals/components/module_structures.php

billion) by 2016. Industry standard is to produce BIPV glass panels by gluing together small opaque solar panels and window glass leaving part of the glass transparent. This is forming semitransparent glasing surface suitable for glass roofs or walls where only partial transparency is acceptable, thus targeting only very limited market. Today's BIPV modules provide transparency that is varying from 60% to well below 50 %.[19]

Typical thin film modules are able to be folded, therefore such photosensitive material are deposited on flexible substrates (Figure 20, right). Flexible thin film solar module structure is shown in (Figure 20, left). Unlike standard solar panels with crystalline silicon solar cells, the second generation PV panels has a transparent conducting coating, different conductivity thin film semiconductor layers forming p-n junction and a bottom contact with flexible (plastic) or rigid (glass) back sheet.

Figure 20: Thin film solar panel structure (left) and example of flexible thin film solar panel (right)



2.1.4.1.1 PV module product on the market analysis

In Table 4 and Table 5 standard monocrystalline, polycrystalline, multicrystalline (all together called crystalline silicon PV modules) and thin film amorphous silicon, CIGS, CIS, CdTe module products are presented. These products feature several different solar cell efficiencies, peak powers, contact metallization technologies etc., therefore suitable application areas of residential, commercial utility are indicated in these tables.

Figure 21 presents the PV module products distribution of generated power, which shows that Siliken manufacturer provides products with one of the highest power output (332 W), although these products comprise more than 48 PV cells. Another significant trend-the majority of PV modules are formed to generate approximately 250 W power output; such products are manufactured by Algatec, Gahelios, Hanwha Solarone, REW Solar, Sunways, Trina Solar for off-grid, residential, commercial and utility segment applications.

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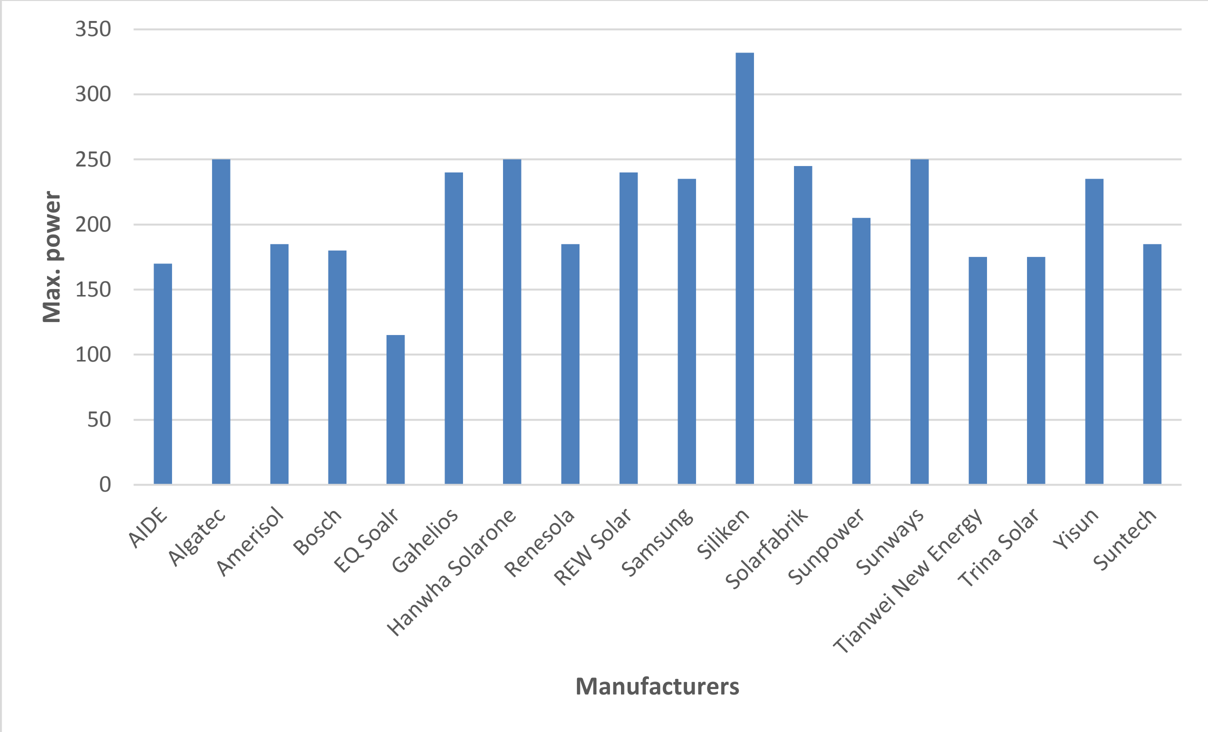
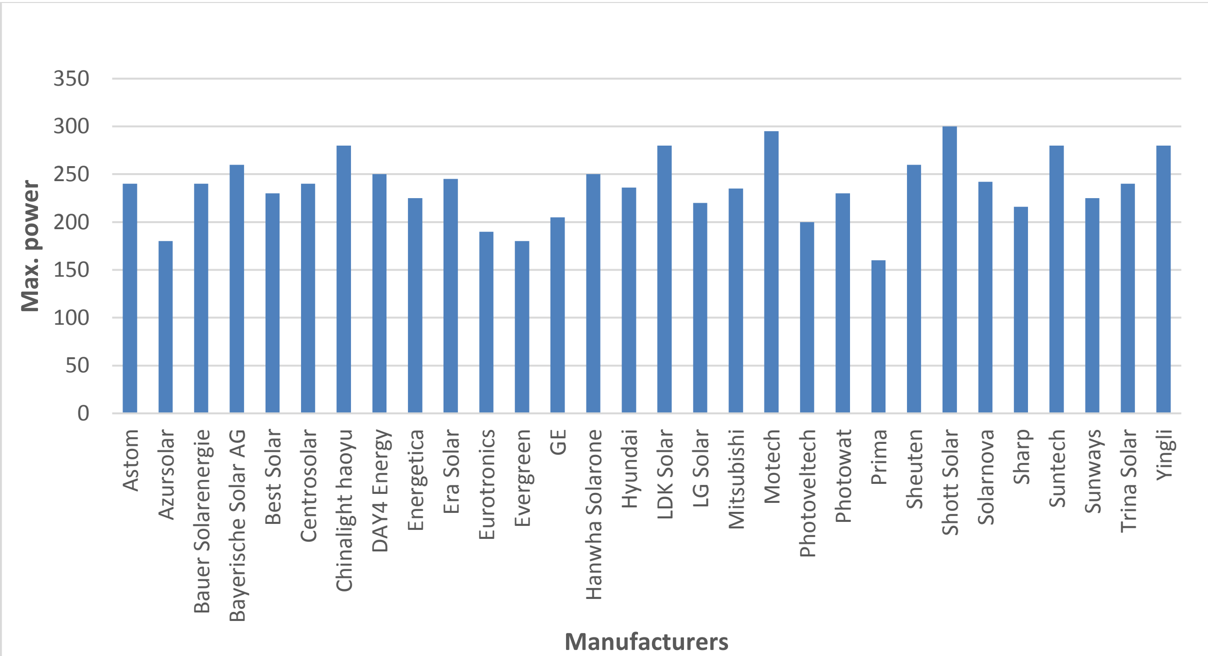
[19] http://www.pv-magazine.com/news/details/beitrag/bipv-glass-markets-to-rise-rapidly_100005859/#axzz2fu5BskJs. Reviewed 15th Feb, 2013

Figure 21: Monocrystalline PV module power distribution



The Figure 22 presents the distribution of poly/multicrystalline PV module products power, which shows the highest generated power of 300 W. The products with highest power output are manufactured by Motech, Shott Solar, Chinalight Hanoyu and LDK Solar. Similar to monocrystalline, most of poly/multicrystalline PV module products are optimized to approximate 250 W power generation.

Figure 22: Poly/Multicrystalline PV module power distribution



The given PV module generated power distribution is not very informative data for the end user or PV system operator. Usually the PV module power drop temperature coefficient is used to determine the actual power drop at the certain temperature increase. As it is shown in Figure 23 and Figure 24 the majority of monocrystalline and poly/multicrystalline PV modules temperature coefficient ranges from -0.5 to -0.4 %/º. The PV modules with lowest power drop are manufactured by Trina Solar (Monocrystalline and PV), Era Solar and Hanwha SolarOne (Poly/Multicrystalline) PV modules.

Figure 23: Monocrystalline temperature coefficient distribution if monocrystalline silicon PV modules

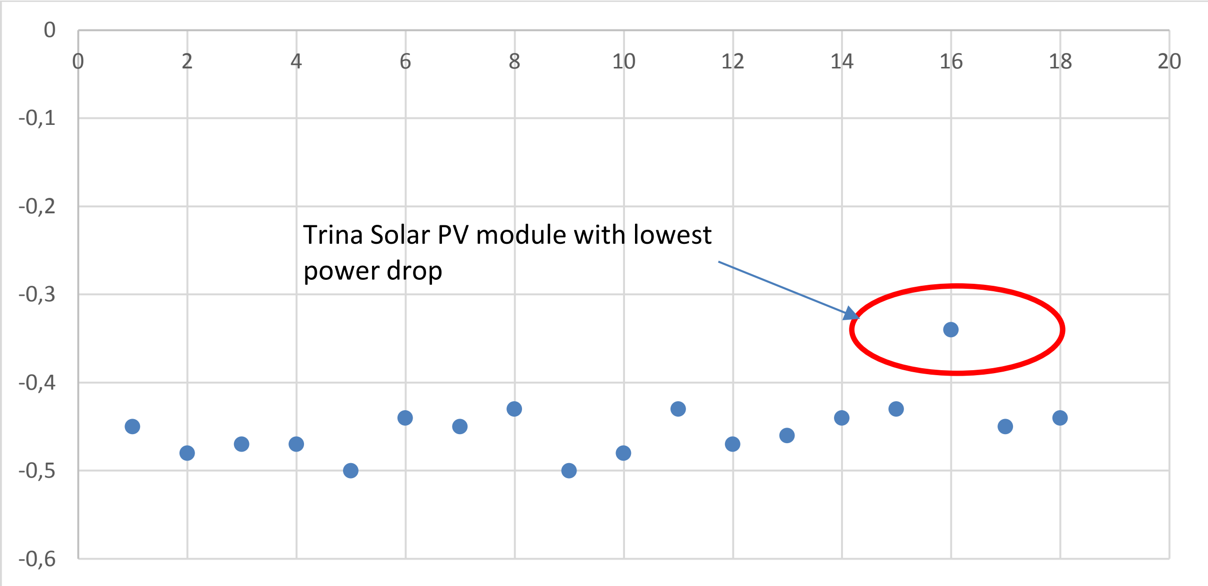
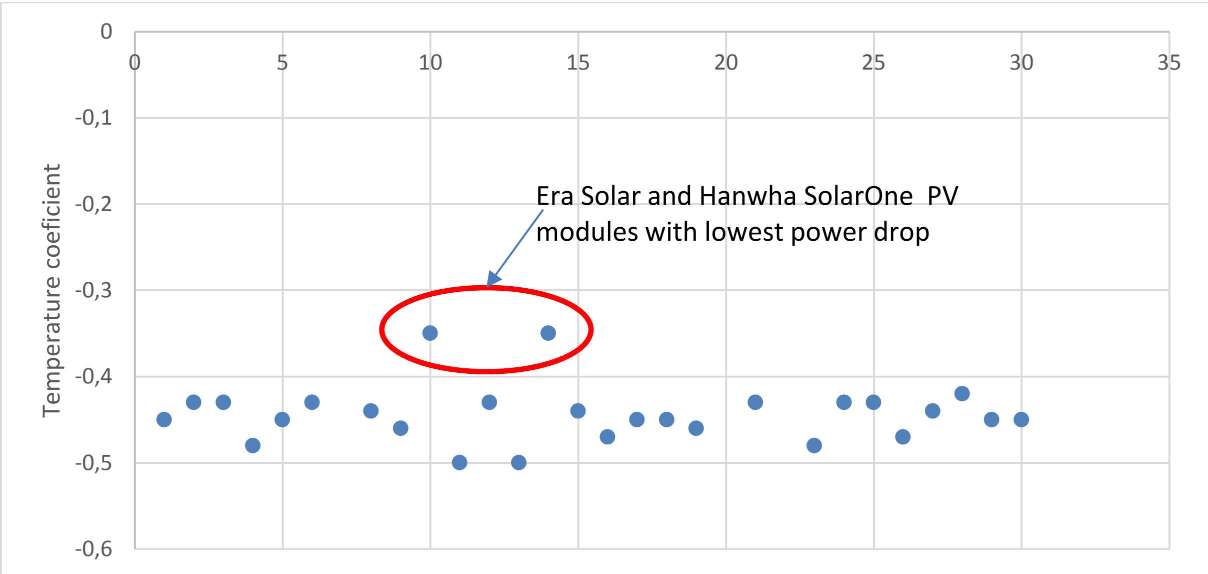


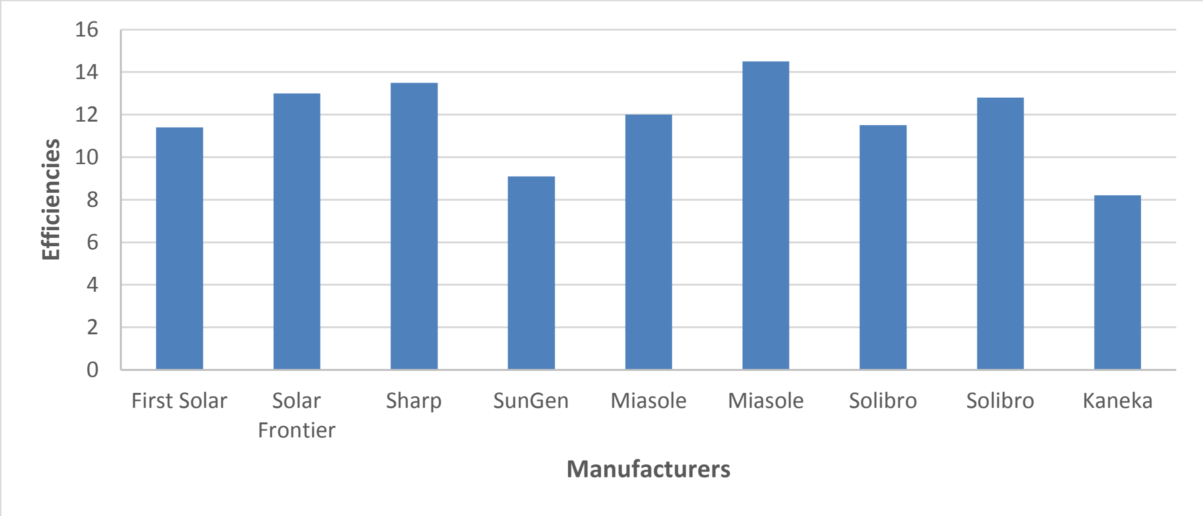
Figure 24: Poly/Multicrystalline PV module temperature coefficient distribution



Thin film PV modules of CIGS (Copper-indium/gallium sulfur/diselenide) type have the highest efficiency (10-13.5%), the second accordingly goes CdTe (Cadmium telluride) with 8-10% efficiency, then the microamorphous tandem thin film modules with the 9-11% efficiency and finally the amorphous silicon PV modules have the lowest efficiency of 5-8%. The distribution of thin film PV module products efficiency is presented in

Figure 25. The highest thin film efficiency PV modules are manufactured by Miasole (CIGS) and Sharp (Microamorphous Silicon).

Figure 25: Thin film PV module efficiency distribution



The generated power for thin film PV modules usually ranges from 70 to 160 W. The overall distribution of thin film module generated power is given in Figure 26. PV module with the highest generated peak power is formed using CIGS technology, which enables to reach relatively high 160 W; such PV modules are manufactured by Solar Frontier

Figure 26: Thin film PV module generated power distribution

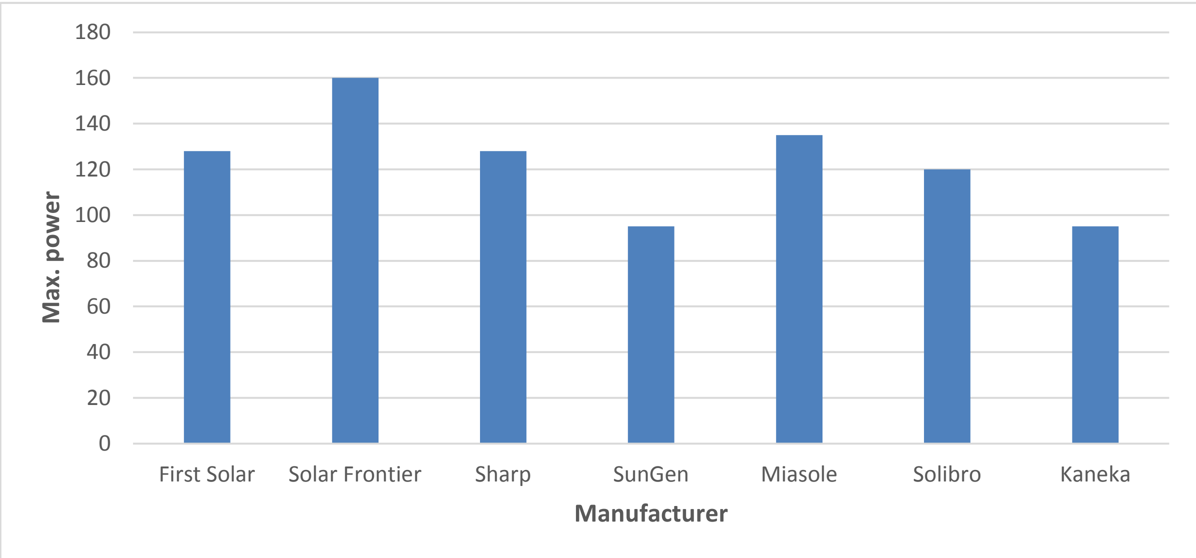


Table 3: Summary of PV crystalline and thin film module product analysis

PV module type	Module efficiency	Generated power of 48 cell PV module	Temp. Coefficient	Surface area needed for 1 kW_p PV plant
Monocrystalline silicon	13-20%	180-300 W	-0.45 %/º	5-8 m^2
Polycrystalline and multicrystalline silicon	11-16%	145-190 W	-0.44 %/º	7-9 m^2
Amorphous silicon	5-8%	70-90 W	-0.2 %/º	13-20 m^2
Microamorphous tandem	8-10%	110-130 W	-0.2 %/º	10-12 m^2
CIGS	10-12%	100-120 W	-0.4%/º	8-10 m^2
CdTe	9-11%	80-100 W	-0.25 %/º	9-11 m^2

Crystalline silicon PV module product analysis (given above) showed that mostly monocrystalline PV modules due to material purity and crystal order features the highest efficiency range of 13-20% and highest module power between 180-340 W, while polycrystalline and multicrystalline silicon PV modules have lower efficiency range of 11-16% and slightly lower power range 160-300 W.

To compare the temperature coefficient, the monocrystalline silicon, polycrystalline and multicrystalline silicon feature -0.45 and 0.44 %/º, while the thin film have low -0.2 %/º temperature (amorphous silicon, microamorphous thin film PV modules). Due to low power drop in high temperatures, thin film PV modules are tend to be used in high temperature climate areas.

Another useful parameter is the surface area needed to cover, in order to generate 1 kW_p power. It was estimated that the smallest area of 5-8 m^2 installed system, when monocrystalline silicon PV modules are used, therefore the end users and installers could vary their selection on this parameter as well. Usually, the efficiency and peak generated power of PV modules determine whether modules are designated for residential, commercial or utility installation segment: crystalline PV modules (comprising 48 or 60 PV cells) with the peak power below 220 W are usually applied in residential and commercial installation segment, and modules over the 200 W (comprising 72 PV cells) are applied in utility scale installation project. Although this result of product analysis indicates the distribution of application areas of PV modules, the particular PV installers selects the needed module peak power value in flexible manner, in order to meet the condition of sun irradiation, and other geographically influenced parameters.

Further overview of PV module products given in Table 4 and Table 5, showed that companies introduced various additional technologies in order to increase efficiency, integrability (for e.g. into buildings), easier installation procedure or in order to improve overall performance and durability of their products.

Chinese manufacture Suntech uses highly sophisticated passivated emitter, rear locally-diffused (PERL) technology, to achieve high 19% efficiency. Sunpower (USA) introduced several technologies to achieve one of the highest efficiency in the market of 24% by integrating back contact solar cells. Other manufacturers introduced modules with integrated high transparent (low iron) front glass, glass with antireflective coatings or three bus bar contact design for better absorption coefficient and in order to reduce the shading losses respectively, which both contributes to increased efficiency and generated power.

Although the majority of manufacturers that fell under the scope of product overview provides PV modules with front glass of 2-3 mm thickness, other provide modules with tempered 4 mm thick glass for longer PV module lifetime and improved durability.

Some manufacturers are putting efforts to decrease the installation costs by integrating novel techniques for easier and quicker PV system assembling and installation. Until now, some PV modules introduced with longer connection cables and elongated assembly holes which are designated for flexible diagonal assembly. In addition, some manufactures uses special suspension mechanism or multi connect functionality into integrated PV module to simplify the assembly.

Most of the overviewed thin film PV module products are designated for residential and commercial segments, and only SunGen and Miasole provides amorphous silicon and CIGS PV modules respectively for all three segment installations. As thin film market is in a decrease, most of thin film PV module manufactures are rearranging the application areas, therefore additionally indicates that these products could be used in off grid PV systems. Some of manufactures provides thin film embedded into glass to glass or frameless modules for integration into buildings (building applied or building integrated PV application areas).

According to applied methodology, the highest grades scored Sunpower, Suntech, Trina Solar PV module products, therefore these manufacturers were recognized as *leaders*. The *challenger* quadrant was occupied by Canadian Solar, Sharp and REC PV modules. These modules feature lower value to customer, on the other hand have almost the same integrated technology level as *leader* quadrant. Further the *visionaries* quadrant is taken by Jinko Solar. These modules have opportunity in near future to occupy the *challengers* or even *leader* quadrant due to their high value to customer grade. *Niche* quadrant is taken by SunGen and Hanwha Solarone, which comprise PV module products with the lowest us potential and the lowest value to the customer.

Figure 27: Crystalline silicon PV module product analysis by quadrants methodology

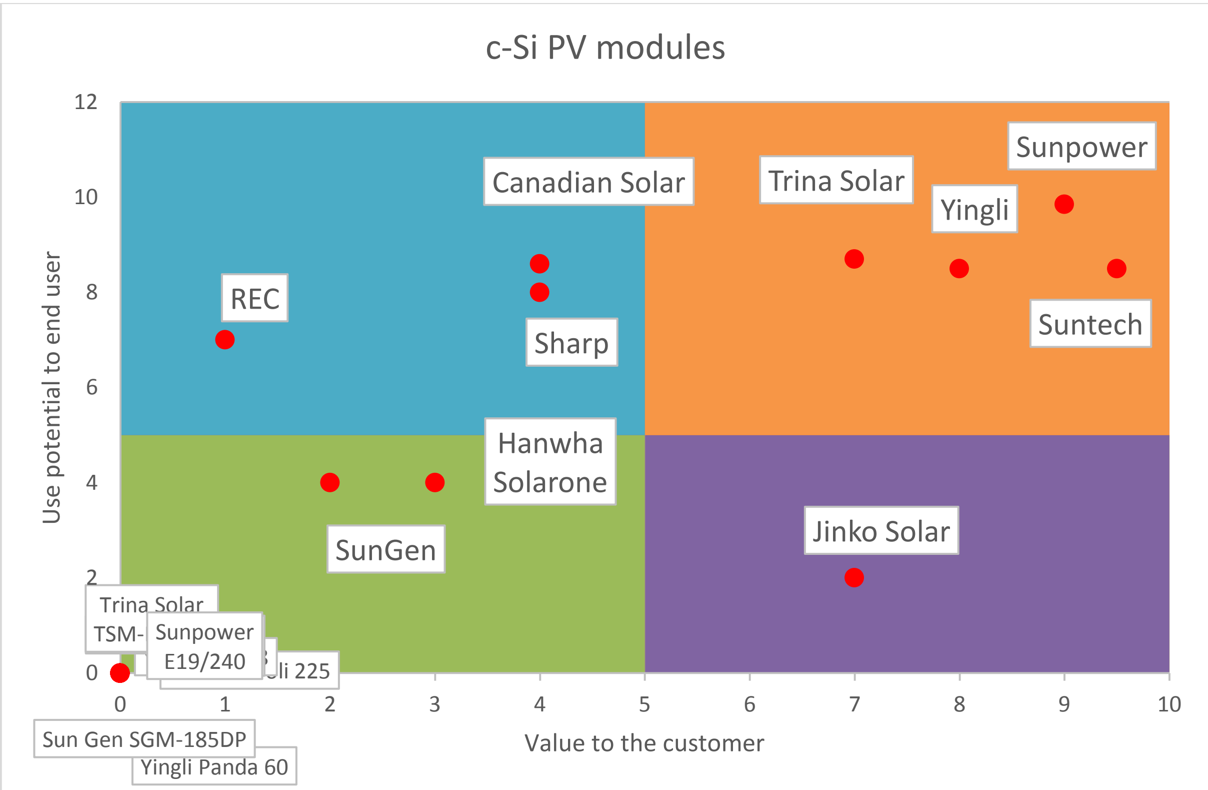
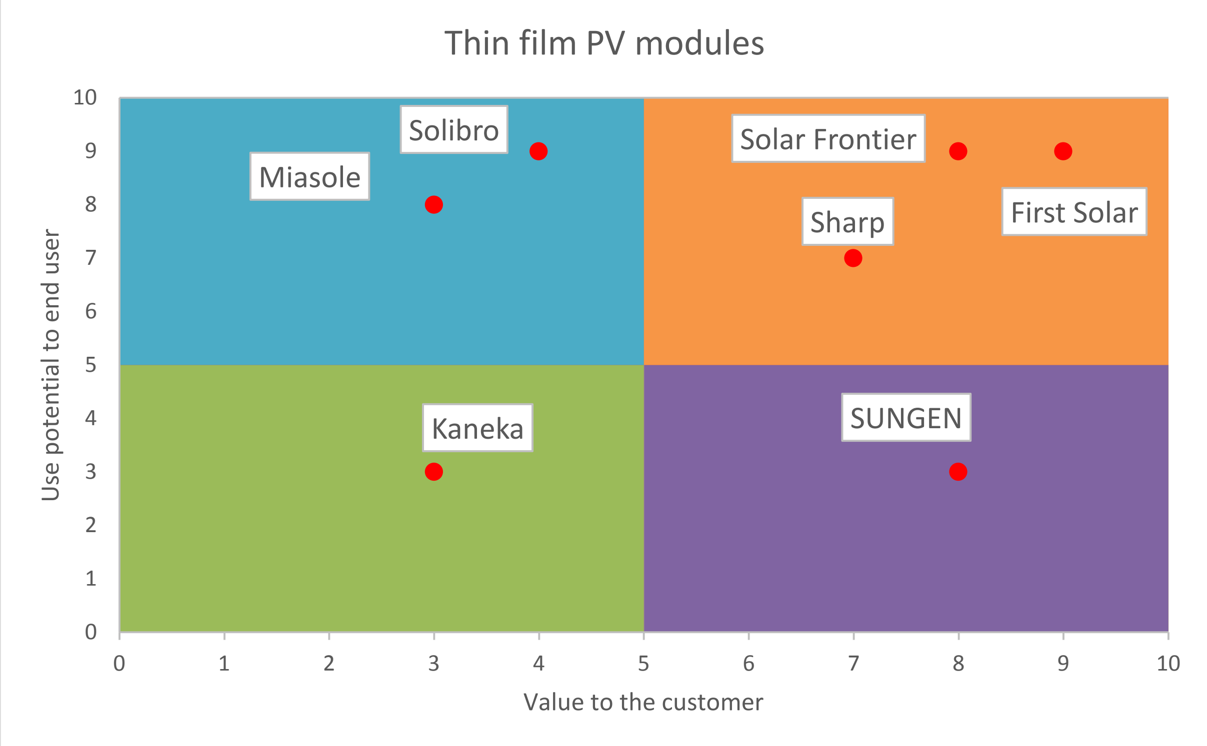


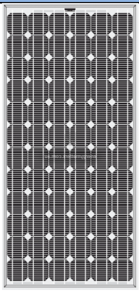
Figure 28: Thin film PV module product analysis by quadrants methodology

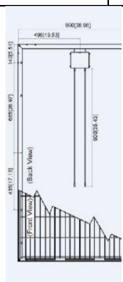


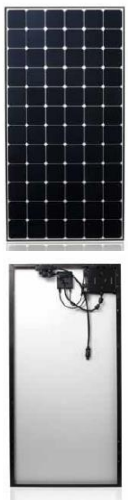
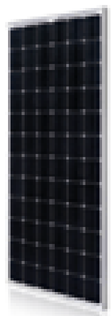
Further crystalline silicon and thin film PV module product overview are presented in Table 4 and Table 5.

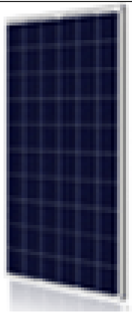
Table 4: Crystalline silicon module products overview

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Suntech	Residential		Polycrystalline	Efficiency 14.4% V_{oc} 44.8 V V_{mp} 35.2 V I_{sc} 8.33 A I_{mp} 7.95 A P_{max} 225 W Dimensions 1956×992×50 mm Weight 24 kg	Guaranteed 0-5W positive power output tolerance Anti-reflective, hydrophobic coating Three bus-bar design Entire module certified to withstand high wind loads (2400 Pascal) and snow loads (5400 Pascal) 4.0 mm thick tempered glass improves module durability

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Suntech	Residential		Monocrystalline	Efficiency 14.4% V_{oc} 44.3 V V_{mp} 35 V I_{sc} 8.04 A I_{mp} 7.43 A P_{max} 260 W Dimensions 1956×992×50 mm Weight 23 kg	Nominal 24 V DC for standard output High transparent low-iron, tempered glass Multi Connect Type
Suntech	Residential		Monocrystalline	Efficiency 19% V_{oc} 45.9 V V_{mp} 38.3 V I_{sc} 5.47 A I_{mp} 5.10 A P_{max} 195 W Dimensions 1956 × 908 × 35 mm Weight 15.5 kg	Certification: ISO9001:2000;ISO14001:2004; IEC61215; IEC61730 Module based on PERL technology
Yingli Solar	Residential Commercial Utility		Multicrystalline	**YGE 48 Cell Series**: V_{oc} 28.6 V V_{mp} 22.3 V I_{sc} 7.07 A I_{mp} 6.56 A P_{max} 144.9 W Weight 15.2 kg Dimensions 1310 × 990 × 40 mm **YGE 60 Cell Series**: V_{oc} 35.4 V V_{mp} 27.6 V I_{sc} 7.12 A I_{mp} 6.56 A P_{max} 181.1 W Weight 19.1 kg Dimensions 1650 × 990 × 40 mm **YGE 72 Cell Series**: V_{oc} 46.3 V V_{mp} 36.7 V I_{sc} 8.77 A I_{mp} 8.17 A P_{max} 300 W Efficiency 15.4% Weight 26.8 kg Dimensions 1970 × 990 × 50 mm	Certification: IEC61215; IEC61730, CE, ISO 9001:2008, BS OHSAS 18001:2007, SA 8000, PV Cycle
Yingli Solar	Residential Commercial Utility		Monocrystalline	Efficiency 16.5% **PANDA 48**: V_{oc} 30.7 V V_{mp} 24.6 V I_{sc} 9.15 A I_{mp} 8.74 A P_{max} 215 W Weight 15.4 kg **PANDA 60**:	Certification: IEC61215; IEC61730, CE, ISO 9001:2008, BS OHSAS 18001:2007, SA 8000, PV Cycle

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
				V_{oc} 39.0 V V_{mp} 28.3 V I_{sc} 9.06 A I_{mp} 6.91 A P_{max} 270 W Dimensions 1330 × 990 × 40 mm	
Trina Solar	Residential		Mono Series TSM-DC01A Monocrystalline	Efficiency 14.9% V_{oc} 45.1 V V_{mp} 36.6 V I_{sc} 5.52 A I_{mp} 5.19 A P_{max} 190 W Dimensions 1581x809x35mm Weight 14.9 kg	Certification: CE Certificate MCS (UK) Certificate TUV Rheiland IEC61215 and IEC61730 Salt Mist from Intertek DLG Ammonia Test
Trina Solar	Commercial		TSM-PC05 Multicrystalline	Efficiency 14.9% V_{oc} 45.1 V V_{mp} 36.6 V I_{sc} 5.52 A I_{mp} 5.19 A P_{max} 190 W Dimensions 1581x809x35mm Weight 14.9 kg	Certification: CE Certificate IEC61215 EN61730, MCS (UK), IEC61215, IEC61730, IEC61215, IEC61730, IEC61215 EN61730 DLG Ammonia Test
Trina Solar	Commercial		TSM-PC05.08 Multicrystalline	Efficiency 15% V_{oc} 37.1 V V_{mp} 29.2 V I_{sc} 8.53 A I_{mp} 7.90 A P_{max} 230 W Dimensions 1650x941x40mm Weight 14.9 kg	Certification: CE Certificate IEC61215 EN61730, MCS (UK), IEC61215, IEC61730, IEC61215, IEC61730, IEC61215 EN61730 DLG Ammonia Test
SunGen	Off-grid Residential Commercial		SUNGEN SGM-D Series Monocrystalline	SGM-185D Efficiency 15% V_{oc} 46.1 V V_{mp} 38.6 V I_{sc} 5.27 A I_{mp} 4.79 A P_{max} 185 W Dimensions 1580x808x40mm Weight 15.5 kg	EN/IEC 61215 certified EN/IEC 61730 certified UL 1703 certified
SunGen	Off-grid Residential Commercial		SUNGEN SGM-P Series Polycrystalline	SGM-220P Efficiency 13.5% V_{oc} 35.9 V V_{mp} 29.4 V I_{sc} 8.40 A I_{mp} 7.48 A P_{max} 220 W Dimensions 1650x990x40mm	EN/IEC 61215 certified EN/IEC 61730 certified UL 1703 certified

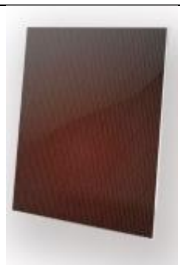
Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
				Weight 19.5 kg	
Sharp	Residence		Sharp NU-A188EY Monocrystalline	Efficiency 15.99% V_{oc} 29.6 V V_{mp} 24 V I_{sc} 8.60 A I_{mp} 7.84 A P_{max} 179-188 W Dimensions 1328x994x57.5mm Weight 16.5 kg	
Sharp	Off grid Residence Utility		Multicrystalline	Efficiency 15.99% V_{oc} 21.3 V V_{mp} 17.1 V I_{sc} 7.81 A I_{mp} 7.02 A P_{max} 120 W Dimensions 1499x662x46mm Weight 16.5 kg	
Sunpower	Residential		E19/240 AC Solar panel Monocrystalline	Efficiency 19.3% V_{oc} 48.6 V V_{mp} 40.5 V I_{sc} 6.30 A I_{mp} 5.93 A P_{max} 240 W Dimensions 1559x798x46mm Weight 17.1 kg	All-back-contact solar cells
Sunpower	Off-grid Residential Commercial Utility		E20 series/327 Solar panel Monocrystalline	Efficiency 20.1% V_{oc} 64.9 V V_{mp} 54.7 V I_{sc} 6.46 A I_{mp} 5.98A P_{max} 327 W Dimensions 1559x1046x46mm Weight 18.6 kg	Highest efficiency panels available on the market All-back-contact solar cells with 24% efficiency
Hanwha Solarone	Off-grid Residential Commercial Utility		SF160 (170W, 175W, 180W, 190W, 195W) HSL48 Mono (190 W, 195 W, 200 W, 205 W, 210 W, 215 W) HSL 60 Mono (235 W, 240 W, 245 W, 250 W, 255 W, 260 W)	**SF160-24-1M170:** Efficiency 15% V_{oc} 43.8 V V_{mp} 35.0 V I_{sc} 5.36 A I_{mp} 4.86 A P_{max} 170 W Dimensions 1494x1000x40 mm	

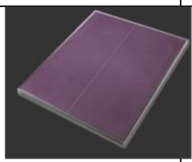
Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
			Monocrystalline	Weight 14 kg **HSL48 M6-HA-1-190:** Efficiency 17.1% V_{oc} 30.0 V V_{mp} 23.9 V I_{sc} 8.41 A I_{mp} 7.95 A P_{max} 190 W Dimensions 1338x1000x35mm Weight 13 kg **HSL60-M6-HA-1-260:** Efficiency 16.4% V_{oc} 36.6 V V_{mp} 30.0 V I_{sc} 8.45 A I_{mp} 7.84 A P_{max} 235 W Dimensions 1652x1000x45mm Weight 20 kg	
Hanwha Solarone	Off-grid Residential Commercial Utility		**Standard series:** SF190 SF220 SF260 **X-tra series:** SF 190 poly x-tra SF 220 poly x-tra SF 260 poly x-tra Polycrystalline	**SF190-27-195:** Efficiency 15% V_{oc} 32.7 V V_{mp} 26.8 V I_{sc} 8.06 A I_{mp} 7.28 A P_{max} 195 W Dimensions 1494x1000x40mm Weight 17 kg	
Jinko Solar	On-grid Off-grid Residential Commercial Utility		JKM250M JKM255M JKM260M JKM265M JKM270M Monocrystalline	**JKM 250M:** Efficiency 14.46% V_{oc} 59.9 V V_{mp} 49.5 V I_{sc} 5.61 A I_{mp} 5.05 A P_{max} 250 W Dimensions 1575x1082x45mm Weight 20 kg **JKM 270M:** Efficiency 15.85% V_{oc} 62.3 V V_{mp} 51.5 V I_{sc} 5.82 A I_{mp} 5.24 A P_{max} 270 W Dimensions 1575x1082x45mm	

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
				Weight 20 kg	
Jinko Solar	Off-grid Residential Commercial Utility		JKM 280P JKM285P JKM290P JKM295P JKM300P Polycrystalline	**JKM 280P:** Efficiency 14.43% V_{oc} 44.5 V V_{mp} 35.5 V I_{sc} 8.81 A I_{mp} 7.89 A P_{max} 280 W Dimensions 1956x992x50mm Weight 27 kg **JKM 300P:** Efficiency 15.46% V_{oc} 45.4 V V_{mp} 37.2 V I_{sc} 8.98 A I_{mp} 8.07 A P_{max} 300 W Dimensions 1956x992x50mm Weight 27 kg	
REC Solar	Off-grid Residential Commercial Utility		Peak Energy Eco Series: 235PE 240PE 245PE 250PE 255PE Multicrystallin e	**235PE:** Efficiency 14.20% V_{oc} 36.6 V V_{mp} 29.5 V I_{sc} 8.66 A I_{mp} 8.06 A P_{max} 235 W Dimensions 1165x991x38mm Weight 18 kg	Three bus bars and improved contact between the cell and metal fingers
REC Solar	Off-grid Residential Commercial Utility		Peak Energy Plus Series: 235PE 240PE 245PE 250PE 255PE Multicrystallin e	**235PE:** Efficiency 14.20% V_{oc} 36.6 V V_{mp} 29.5 V I_{sc} 8.70 A I_{mp} 8.12 A P_{max} 235 W Dimensions 11665x991x38m m Weight 18 kg	

Table 5: Thin film module product overview

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
First Solar	Off-grid Residential Commercial		FS-380 FS-382 FS-385 FS-387 FS-390 FS-270, FS-272, FS-277, FS-280 Cadmium Telluride	**FS-380:** Efficiency 11.4% V_{oc} 60.8 V V_{mp} 48.5 V I_{sc} 1.88 A I_{mp} 1.65 A P_{max} 80 W Dimensions 1200x600x6.8m m Weight 12 kg	25 years at 80%, 10 years at 90% of the minimal rated power output Frameless solar module

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Solar Frontier	Off-grid Residential Commercial		CIS (Copper, Indium, Selenium) SF series: SF140-S SF145-S SF150-S SF-155-S SF-160-S	**SF140-S:** Efficiency 11.4% V_{oc} 107.0 V V_{mp} 80.5 V I_{sc} 2.10 A I_{mp} 1.74 A P_{max} 128 W Dimensions 1257x977x35mm Weight 20 kg **SF-160-S:** Efficiency 13% V_{oc} 110.0 V V_{mp} 84.0 V I_{sc} 2.20 A I_{mp} 1.91 A P_{max} 160 W Dimensions 1257x977x35mm Weight 20 kg	Cadmium and lead free thin film module Energy payback time of under a year
Sharp	Off-grid Residential Commercial		Sharp Solar Panel 128Watt Microamorphous Silicon Thin-Film Solar	Efficiency 13.5% V_{oc} 59.9 V V_{mp} 45.4 V I_{sc} 3.45 A I_{mp} 2.82 A P_{max} 128 W Dimensions 1409x1009x46 mm Weight 18 kg	Tandem structure with an amorphous and a microcrystalline silicon
SunGen	Off-grid Residential Commercial Utility		SUNGEN SG-HN-GG Series amorphous silicon (a-Si)	SGM-HN95-GG V_{oc} 92.0 V V_{mp} 70.0 V I_{sc} 1.67 A I_{mp} 1.35 A P_{max} 95 W Dimensions 1400x1100x71 mm Weight 26.4 kg	Glass to glass laminated module EN/IEC 61646 EN/IEC 61730 UL 1703
Miasole	Off-grid Residential Commercial Utility		MS SERIES -02 (135, 140, 145, 150, 155 W) MS SERIES (120, 125, 130, 135, 140 W) MR Series (111, 100 W) Copper indium gallium diselenide	**MS Series-02, M135GG-02:** V_{oc} 29.0 V V_{mp} 23.0 V I_{sc} 6.80 A I_{mp} 5.87 A P_{max} 135 W Dimensions 1611x655x7.5mm Weight 18 kg **MR Series, MR107**: V_{oc} 24.9 V V_{mp} 19.4 V I_{sc} 6.8 A I_{mp} 5.7 A	**MS Series-02** Efficiencies up to 14.5% Certifications: IEC 61646, IEC 61730 **MR Series:** Designed for large scale, low cost installations Certifications: UL 1703, IEC 61646 and IEC 61730

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
				P_{max} 111 W	
Solibro	Off-grid Residential Commercial		CIGS Solarmodul SL2 Copper Indium Gallium Diselenide	Nominal power classes 100 – 120 W Nominal module efficiency up to 12.8 % Dimensions: 1190 mm x 789.5 mm x 7.3 mm Weight 16.5 kg	
Kaneka	Off-grid Residential Commercial		**U-EA type:** U-EA100 U-EA105 U-EA110 **U-SA type:** U-SA100 U-SA105 U-SA110 Amorphous microcrystalline thin film silicon	Efficiency 8.2% V_{oc} 71 V V_{mp} 45.4 V I_{sc} 2.25 A I_{mp} 1.87 A P_{max} 95.0 W Dimensions 1409x1009x46 mm Weight 18 kg	25 year warranty

2.1.4.2 Building integrated photovoltaics

BIPV (Building integrated photovoltaics) comprise a group of technologies that are introduced into building envelope, instead of mounted on the top surface of building wall, roof and etc. BIPV modules (or envelopes) can replace wall, curtain walls, rooftops, windows and other parts of buildings and at the same time generate electricity which would be supplied to consumer in a very near proximity. [20]

The four main options for building integration of PV modules are on sloped roofs, flat roofs, facades and shading systems. South- facing sloped roofs are usually best suited for PV installation because of the favourable angle with the sun. One option is to mount PV modules above the roofing system. Another option is PV modules that replace conventional building materials in parts of the building envelopes, such as the roofs or facades.

For flat roofs there are three options: (1) modules mechanically fixed to the roof structure, (2) based on weight foundation and (3) an integrated solution. Depending on the geographical position of the structure, the PV modules might have to be inclinated. This is more difficult with integrated solutions. The integrated systems can include the properties of one roofing element or several. Lack of air flow underneath the module can be a challenge (in order to decrease the temperature). The use of PV in the facade can replace a glass or tile skin. Geographic position plays an important role when planning the use of photovoltaic modules in facades, and the output is higher at northern than

[20] Kostas Sinapis and Menno van den Donker, 2013. BIPV report 2013: State of the art in building integrated photovoltaics. Available from: <http://www.seac.cc/fileadmin/seac/user/doc/SEAC_BIPV_Report_2013.pdf> [12-03-2013].

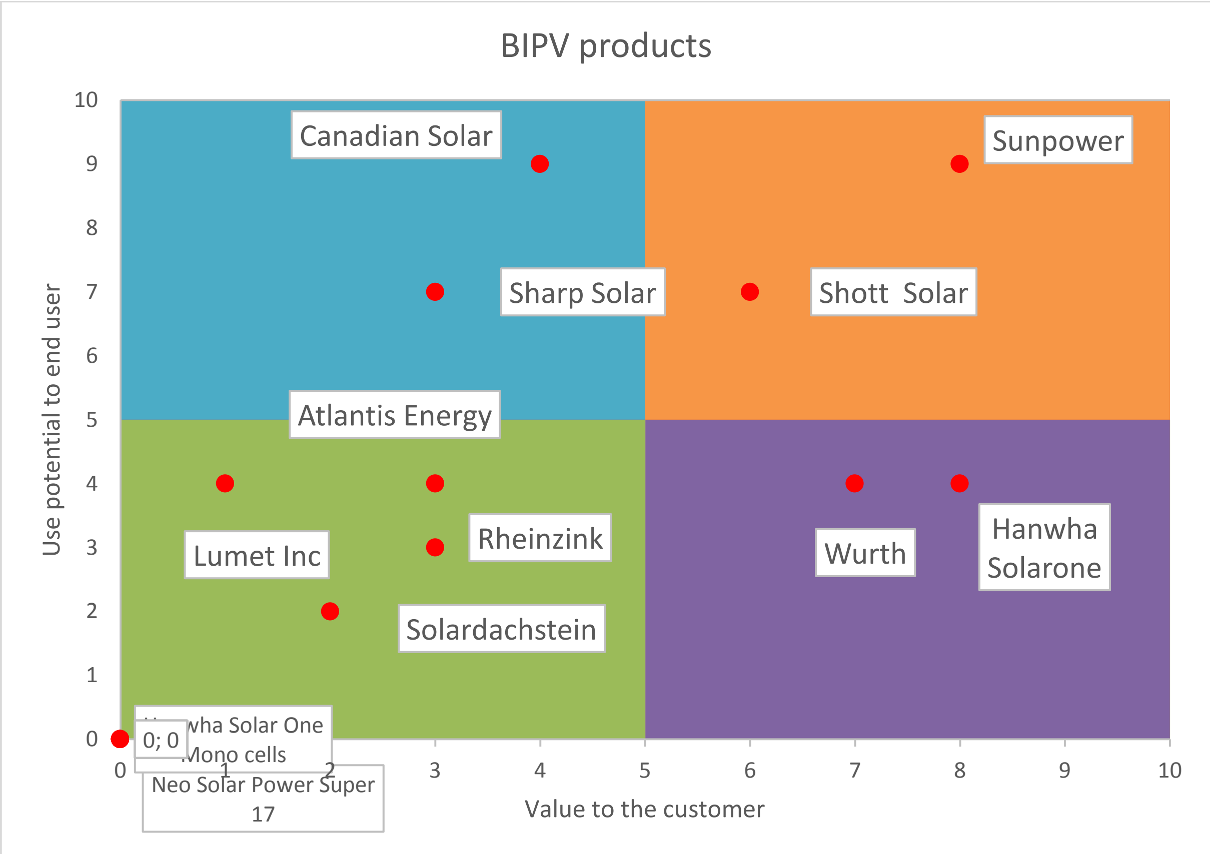
southern latitudes. The two main categories are ventilated and non-ventilated facades. The category sets the criteria for the choice of solar cell material.

The area to be covered by PV modules varies from case to case. In general, areas that are shaded for the majority of the day should be avoided. If the project is subsidized, the subsidies might be given for a certain level of power produced, and therefore the size of the PV-covered area may depend upon this. This can lead to solutions with only a few spread PV modules, and therefore some producers even offer dummy modules to provide a more aesthetical and consistent look for the roof or facade.

There is a wide range of different BIPV products. Categories considered in this study are foils, tiles, modules and solar cell glazing products.

Overall quadrant analysis (Figure 29) has identified only Sunpower and Shott Solar products leading in market. Other product provided by Canadian Solar and Sharp are regarded as challengers.

Figure 29: BIPV product analysis by quadrants methodology



BIPV foil products. These foils are lightweight and flexible, which is ideal for easy installation and the weight constraints most roofs have. The photovoltaic cells are often made from thin-film cells to maintain the flexibility in the foil and the efficiency regarding high temperatures for use on non-ventilated roof solutions. Unfortunately, there are few producers in the market that provide weather tight solutions, therefore only Alwitra GmbH&Co foil products assortment is overviewed in Table 6.

Table 6: BIPV foil products

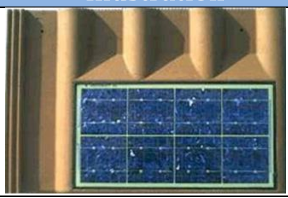
Manufacturer	Illustration	Product type	Basic parameters	Comments
Alwitra GmbH&Co.		EVALON V Solar 408 EVALON V Solar 272 EVALON V Solar 204 EVALON V Solar 136	EVALON V Solar 408 V_{oc} 138.6 V I_{sc} 5.1 A P_{max} 4.08 W FF 0.58 Dimensions 1550 x 6000 x 5.1 mm	Amorphous silicon from Uni-Solar

The BIPV tile products. BIPV tiles can cover the entire roof or just parts of the roof. They are normally arranged in modules with the appearance and properties of standard roof tiles and substitute a certain number of tiles. This is a good option for retrofitting of the roofs. The cell type and tile shape varies.

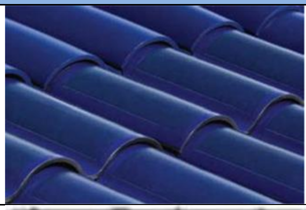
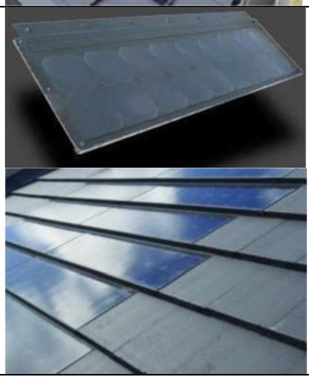
Figure 30: Building roof covered by BIPV tiles[21]

Some tile products resemble curved ceramic tiles (see Fig. 3) and will not be an area effective due to the curved surface area, but may be more aesthetically pleasing. The overview of BIPV tile products is given in Table 7.

Table 7: BIPV tile products

Manufacturer	Illustration	Product type	Basic parameters	Comments
Solardachstein		STEPdesign	V_{oc} 0.595 V I_{sc} 3 A P_{max} 1.36 W (per cell) FF 0.76 Dimensions 100 x 100 mm	Polycrystalline silicon cells

[21] Solar Thermal Magazine, The Curved Solar Power Rooftop Tile, Homeowners Now Have Better Looking Options. 210

Manufacturer	Illustration	Product type	Basic parameters	Comments
SRS Energy		Sole´ Powertile	V_{oc} 6.3 V I_{sc} 4.6 A P_{max} 15.75 W FF 0.54 Dimensions 868 x 457 x 76.2 mm	Amorphous silicon cells from Uni-Solar,
Eagle		SolarBlend Roofing tiles	V_{oc} 8.6 V I_{sc} 7.95 A P_{max} 50 W FF 0.73 Dimensions 1194 x 432 x 32 mm	Cells from Suntech
Lumeta Inc		Solar S Tile Solar Flat Tile	Solar S Tile V_{oc} 7.4 V I_{sc} 5.2 A P_{max} 28 W FF 0.73 Dimensions 432 x 968 x 76 mm	Monocrystalline silicon cells
Applied Solar		3 ft Roofing tile 4 ft Roofing tile	3 ft Roofing tile V_{oc} 6.07 V I_{sc} 7.76 A P_{max} 34 W FF 0.72 Dimensions 914 x 432 x 25 mm	Cells from Suntech
Sharp		ND-62RU1 ND-62RU2	ND-62RU1 V_{oc} 10.8 V I_{sc} 8.0 A P_{max} 62 W FF 0.72 Dimensions 1498 x 396 x 34 mm	Polycrystalline silicon cells
Solar Century		C21e Tile	V_{oc} 12.0 V I_{sc} 5.55 A P_{max} 52 W FF 0.78 Dimensions 1220 x 420 x 30 mm	Monocrystalline cells
SunPower		Sun Tile	V_{oc} 14.6 V I_{sc} 5.65 A	Monocrystalline cells

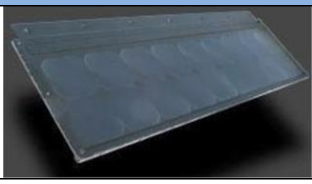
Manufacturer	Illustration	Product type	Basic parameters	Comments
	 		P_{max} 63 W FF 0.76 Dimensions 1499 x 432 mm	

The BIPV module products. The BIPV module products presented already introduces into the market are somewhat similar to conventional PV modules. The difference, however, is that they are made with weather skin solutions. Some of the products can replace different types of roofing, or they fit with a specific roof solution produced by its manufacturer, e.g. these mounting systems increase the ease of installation. There is a large amount of products on the market (BIPV module products are overviewed in Table 8) and some of them are promoted as BIPV products without functioning as weather skin. Other products are not very specific on how they are mounted, which leads to uncertainty whether they are BIPVs or BAPVs. Some of the products in this category are premade modules with insulation or other elements included in the body. Table 8 gives examples of BIPV module products.

Table 8: BIPV module products

Manufacturer	Illustration	Product type	Basic parameters	Comments
Atlantis Energy	    	Sunslates 5 Sunslates 6 TallSlate TallSlate Grandee MegaSlate	Sunslates 5 V_{oc} 3.70 V I_{sc} 4.80 A Dimensions 400 x 327 mm Sunslates 6 V_{oc} 3.70 V I_{sc} 8.0 A Dimensions 500 x 368 mm TallSlate Grandee V_{oc} 11.11 V I_{sc} 5.35 A Dimensions 1200 x 400 mm MegaSlate V_{oc} 24 V I_{sc} 7.70 A Dimensions 1320 x 998 mm	Monocrystalline silicon cells

Manufacturer	Illustration	Product type	Basic parameters	Comments
Creaton AG		Creaton Solesia	V_{oc} 13.86 V I_{sc} 8.46 A P_{max} 90 W FF 0.77 Dimensions 1778 x 355 mm	Monocrystalline silicon cells
PV Solar Energy pty Ltd		Sharp BP	Sharp P_{max} 185 W Dimensions 1634 x 868 x 15 mm BP P_{max} 160 W Dimensions 1648 x 841 x 15 mm	
Rheinzink		PV Quickstep	V_{oc} 17.10 V I_{sc} 5.12 A P_{max} 68 W FF 0.78 Dimensions 2000 x 365 mm	Crystalline silicon cells
Hanwha Solar One		Black Diamond: Black Diamond Module HSL 48 Mono Black Diamond HSL 60 Mono Black Diamond Greenhouse	HSL 48 Mono Black Diamond: Efficiency 18.2% V_{oc} 37.6 V V_{mp} 30.9 V I_{sc} 8.90 A I_{mp} 8.41 A P_{max} 260 W Dimensions 1652x1000x45 mm Weight 20 kg	
Wurth Solar	 	WSG0036E070 WSG0037E070 WSG0036E075 WSG0037E075 WSG0036E080	WSG0037E070 V_{oc} 42.3 V I_{sc} 2.4 A Dimensions 1205x605x35 mm WSG0037E070 V_{oc} 42.5 V I_{sc} 2.4 A Dimensions 1200x600x22.75 mm	CIS cells these modules can be used building integrated in the system DESIGNline
Solar Century		C21e Slate	V_{oc} 12 V I_{sc} 12 A P_{max} 52 W Dimensions 1174x318x14 mm	Monocrystalline silicon solar cells

Manufacturer	Illustration	Product type	Basic parameters	Comments
				

Solar cell glazing products provide a great variety of options for windows, glassed or tiled facades and roofs (Different colours and transparencies can make many different aesthetically pleasing results possible. The modules transmit daylight and serve as water and sun protection. There is also a wide selection of customized modules regarding shape, cell material, colour and transparency level, i.e. distance between cells (for example transparent BIPV ceilings shown in Figure 31).

Figure 31: BIPV transparent ceilings[22]

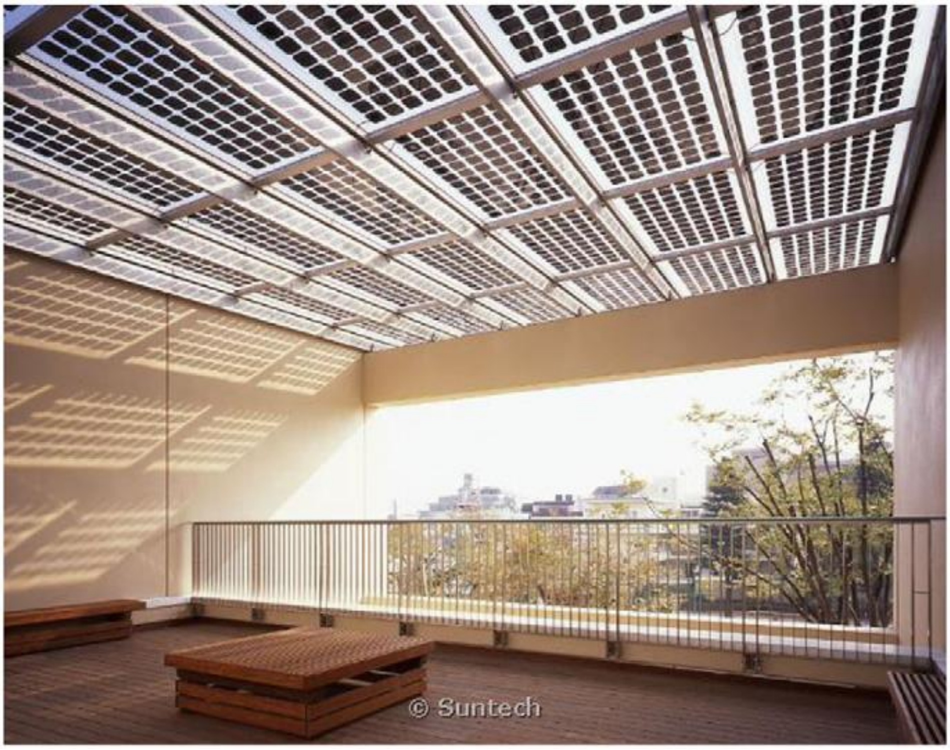
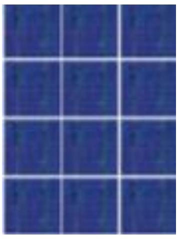


Table 9: BIPV glazing products

Manufacturer	Illustration	Product type	Basic parameters	Comments
Canadian Solar	 		P_{max} 63 W Dimensions 1200 x 400 mm	Monocrystalline silicon cells

[22] Global Energy Network Institute, Suntech to develop 20% of BIPV solar rooftop program projects, Suntech, 2009

Manufacturer	Illustration	Product type	Basic parameters	Comments
Shott		Asi Thru-2-L Asi Thru-2-IO Asi OPAK-2-L	Asi Thru-2-L Efficiency 18.2% V_{oc} 111 V V_{mp} 83 V I_{sc} 1.11 A I_{mp} 0.94 A P_{max} 95 W Dimensions 1122x1331	
Sapa Building System	     	Amorphous silicon Polycrystalline Monocrystalline high efficient Amorphous silicon thin film 10% or 20% opacity Monocrystalline semi-transparent Monocrystalline high efficient 25 mm distance with 36% opacity	Amorphous silicon Efficiency 5% per cell P_{max} 52 W Dimensions 576x976 mm Monocrystalline high efficient Efficiency 5% per cell P_{max} 2.90-3.11 W	

Manufacturer	Illustration	Product type	Basic parameters	Comments
		Polycrystalline 50 mm distance 42.5% transparency		
Hanwha Solar One	 	SolarIris Polycrystalline	SolarIris: V_{oc} 30.8 V V_{mp} 26.1 V I_{sc} 5.2 A I_{mp} 4.6 A P_{max} 120 W Dimensions 1760x576x23 mm Weight 40 kg Number of cells 52	SolarIris Polycrystalline solar cells (125x125 mm) Design: Front glass / solar cell / glass / small pieces of colourful glass – spacer inner glass pane Solarlris modules are frameless BIPV products with sharp glass edges as known from glazing industry

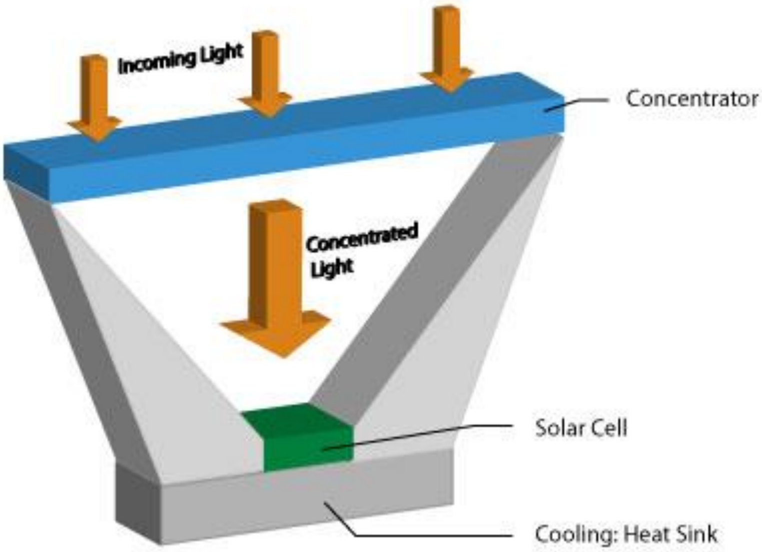
Overall, the opportunities for future PV integration in builing environment are promising. Decreasing not only the cost of raw materials, but of modules and additional systems, lessens the price gap between PV and BIPV. In order to take larger market share, the tailored BIPV solutions has to be developed to overcome the major conversion efficiency degradations. Together with the BIPV design and technological development the policy schemes that support distributed generation systems are also increasing the BIPV products market penetration.

2.1.4.3 Overview of Concentrating Photovoltaics (CPV) modules

Third category of available on the market products for PV installations are the systems based on Concentrating Photovoltaics (CPV). In these producs a large area of sunlight is focused onto the very small area specific solar cell through the optical device (Figure 32). These products have three competitive advantages:

- Requires less active material to collect the same sunlight as in flat panels non-concentrating PV.
- Due to high efficiency of solar cells used in CPV requires less space for generating the same amount of electricity.
- Except active element (solar cell) other system elements are build from standard low cost materials which is promising reduction of generation costs.

Figure 32: Principal Sheme of Cncentrating device. Source: Green Rhino energy



Main shortcoming of this technology is the need for two axes tracking system pointing optical elements directly to the sun which is leading to significant increase in costs of these products.

CPV products only recently entered solar market as a viable alternative. Therefore as it is always in nonmatured young technology, there are many different products and no single dominant design. Classification of CPV modules is based on the degree of solar light concentration on solar cell in number of "suns" (Table 10).

Table 10: Classification of CPV- modules is by the degree of concentration. Source: Green Rhino energy

	Low concentration	Medium concentration	High concentration
Degree of concentration	2 - 10	10 - 100	> 100
Need for tracking	No need for tracking	1-axis tracking	Dual axis tracking
Need for cooling	No cooling	Passive cooling	Active cooling
Photovoltaic Material	Silicon	Multi-junction cells	Multi-junction cells
Degree of concentration	2 - 10	10 - 100	> 100

CPV module construction. Main concentrator technologies are point concentrators and line concentrators with no clear winner up to now. Single concentrating elements are integrated into arrows or blocs of tens or hundreds to be mounted on single tracking system. As concentrating device for single concentrating element Fresnel lenses, parabolic mirrors and reflectors for both point and line concentrators are used. Each solution has specific properties and advantages.

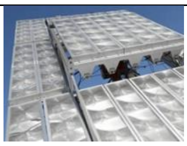
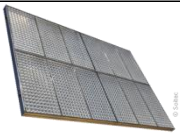
A Fresnel lens has reduced weight and thickness comparing with a standard lens. Main advantage of Fresnel lens is possibility to achieve short focal lenght and large aperture and high concentration ratio up to 500. Main disadvantage – high cost of production of optical element.

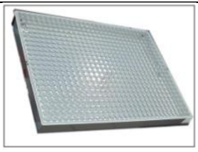
Parabolic mirrors advantage is that it does not require any optical lenses which are quite expensive construction element. Although concentration ratio of 500 can be achieved mirrors have higher losses.

Reflectors are used for low concentration photovoltaic modules as cheapest solution providing extra sunlight onto the solar cell. This construction is providing possibility to achieve concentration ratios in the range of 1.5-2.5.

One more essential component for CPV devices is cooling element. CPV modules must be equipped with cooling element because of high temperatures which occures under high concentration of solar irradiation. Most common is passive cooling solution when solar cells are cladded on ceramic substrate with high thermal conductivity, but in line concentrators also liquid metal is used as cooling fluid. CPV module product overview is presented in Table 11.

Table 11: CPV module product overview

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Entech Solar	Low-concentration module		Linear Fresnel concentrator devices	Concentrates sunlight 20X Dimensions 65.0”x39.6”x6.0” Weight 25 kg MonoSi solar cells V_{oc} 41V V_{pmax} 33V I_{sc} 7.2A I_{pmax} 6.7A P_{max} 220W	
EnFocus	High concentration module		High concentration 300x "Diamond Power"	Concentrates sunlight 300X Weight 45 kg An average output of about 288W Capable of generating 720kWh annually	A Diamond-Power™ panel lets soft cool sunlight in for high quality daylighting and converts the harsh hot sunlight into power at the same time.
Soitec	High concentration module		CPV modules Concentrix™	Concentrates sunlight 500X Efficiency 31,8%.	CPV modules are certified according to IEC62108 and UL62108 standards
SahajSolar	High concentration module		CPV modules SS-CPV	Concentrates sunlight 500X V_{oc} 90V V_{pmax} 79.2Vdc I_{sc} 4.16A I_{pmax} 3.36A	

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Amonix	High concentration module		MEGAMODULE®	Dimension 10'x49' Multijunction solar cells One module contains 36 sets of lenses and receiver plates with multijunction solar cells, producing ~10 kW (DC)	
Semprius	High concentration module		CPV modules	Concentrates sunlight 1100X High shading tolerance Robust silicone-on-glass primary lens array Ultra-thin module profile	
Cpower	Low-concentration module@		Rondine® R4120	Concentrates sunlight 20X Peak power 110–120W V_{oc} 45.70V V_{pmax} 35.48–36.52V I_{sc} 3.70–3.77A I_{pmax} 3.10–3.28A	The light is concentrated on special solar cells of monocristalline silicon by reflective “funnels for light” named Rondine concentrators

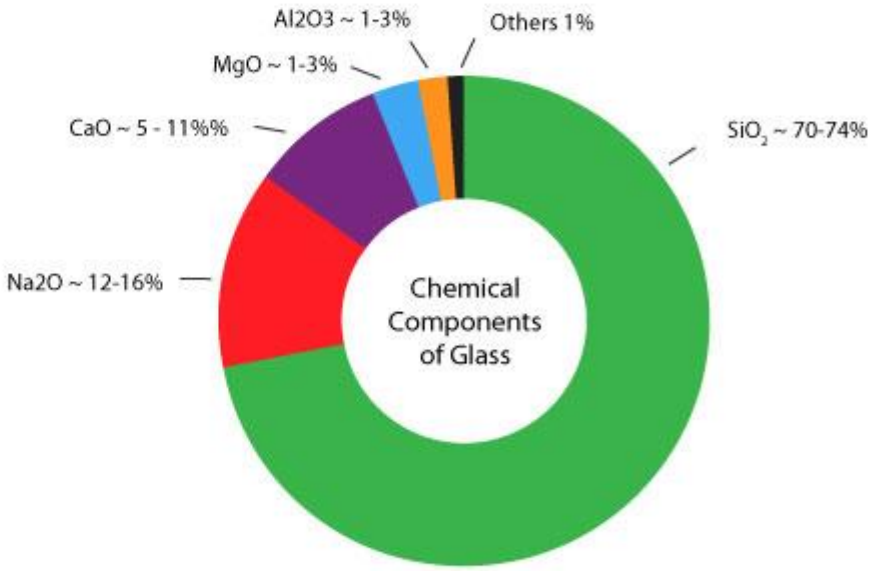
2.1.4.4 PV module component products

In this section, the product assortments of PV module components namely solar glass used for front PV module protection and PV plastics used for PV cell encapsulation and backsheets will be presented.

2.1.4.4.1 PV glass

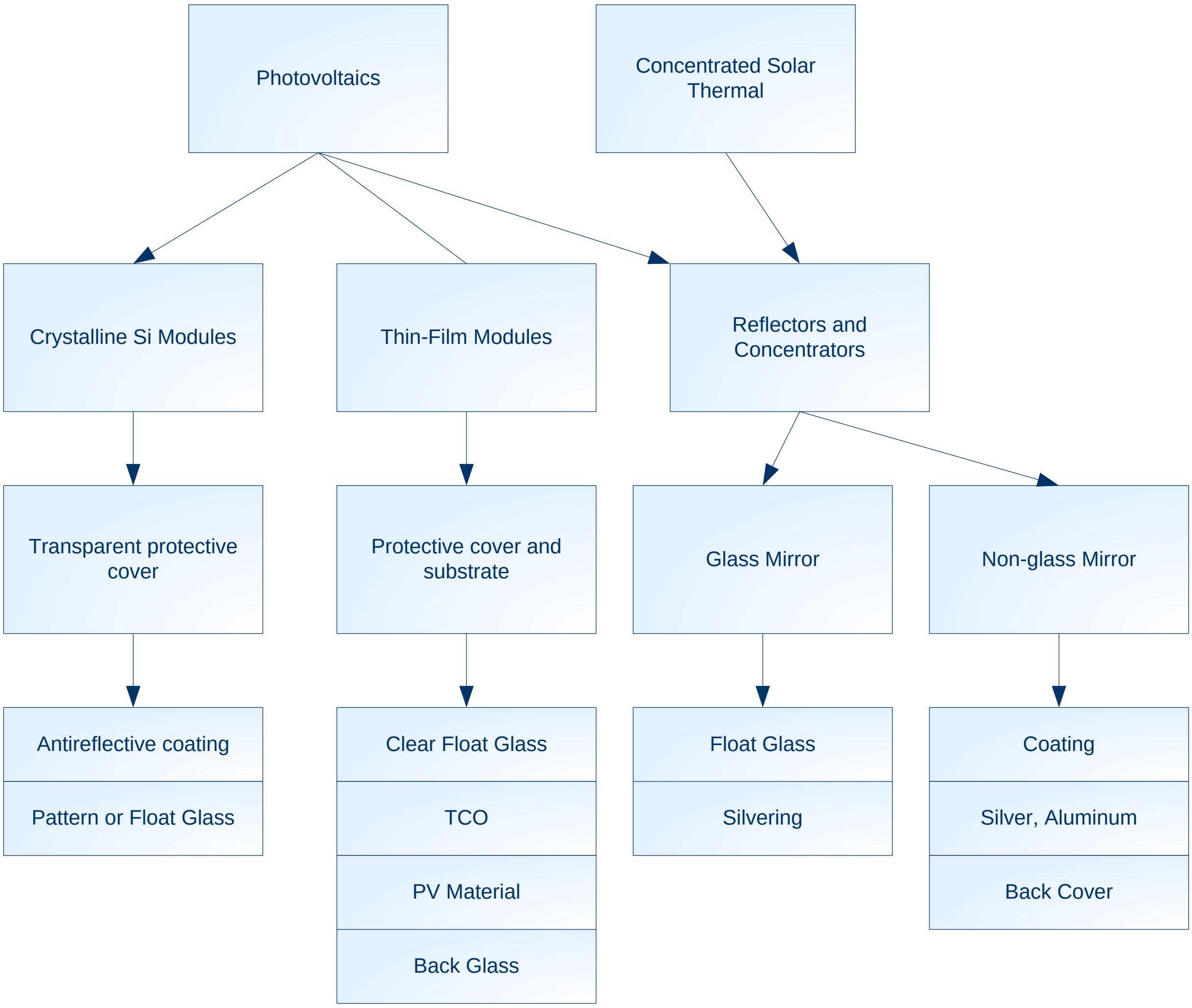
PV glass is designed to protect the PV cells and efficiently transmit the light for energy generation. For solar applications the main requirements for glass are high light transmission, mechanical strength and specific weight. Seeking to implement these fundamental goals PV manufacturers are trying to avoid impurities available in the standard glass (Figure 33) to produce extra clear glass with low levels of impurities enshuring increased transparency. The main component in glass is SiO2, which is found in sandstone. Raw sandstone is milled and heated in a furnace at temperatures above 1560°C and after cooling annealed glass is obtained. After that glass is heat-treated by heating up to ~620°C with following rapid cooling. As a result, tempered glass is obtained which have few times higher hardiness than standard glass enshuring high mechanical strength of the material. Specific weight is also important feature for that PV module construction and main tendency is to lower glass thickness. As density of glass is about 2.5kg/m2 per 1mm thickness and typical crystalline modules use 3mm front glass, 67% of a crystalline module weight is caused by glass. For thin-film modules containing two laminated glass layers of 3 mm each for front and back this number is higher and is reaching even 96% of total TF module weight. Reduced thickness also is increasing glass transparency. The most important for glass trasparency are iron impurities in the form of iron salts. Elimination of these impurities can be implemented in two ways: by using special raw materials such as low iron sand and limestone, or using furnaces designed to handle higher melting and refining temperatures which is explaining higher prices for PV glass on the market comparing with glass for construction applications.

Figure 33: Impurities commonly present in the standard glass



Either float or patterned glass is usually covered with antireflection films to optimize the light transmission and further absorption. Glass is also the typical basis for mirrors used in concentrated PV to concentrate sunlight, although it must be pointed out that the new technologies namely coated plastic avoiding glass are emerging. In Figure 34 is presented cumulative information on the use of glass in PV products.

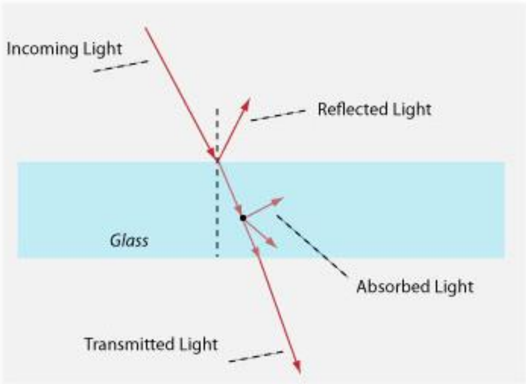
Figure 34: Overview of use of glass in PV products

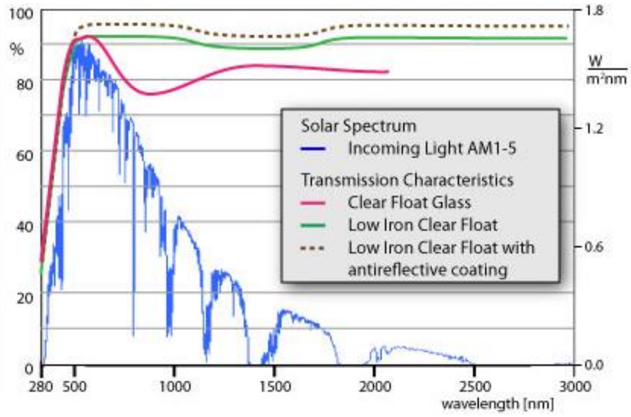


Thin films are increasingly used to enshure increased functionality of the glass cover, for example, transparent protective covers are increasing resistance to dirt and dust (so called self-cleaning effect), antireflective coatings are providing additional antireflective transparent conductive coatings are added as contacts for thin film PV modules.

Standard commercial glass has a solar transmission of 83.7%. The energy loss is due to the reflection on the surface and absorption within the glass mainly related to iron impurities (Figure 35).

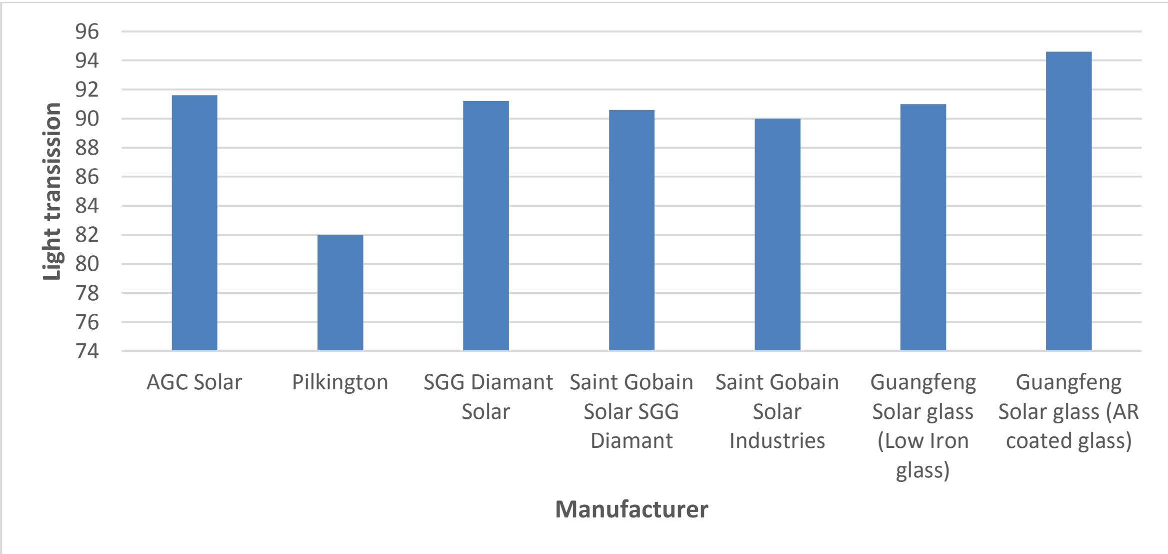
Figure 35: Transmission of solar radiation through glass





The graph below (Figure 36) shows that available on the market PV glass light transmission ranges from 82% to 95 % depending on thin films used.

Figure 36: Light transmition of PV glass products



The quadrant analysis (Figure 37) identified Saint Gobain Guardian ad AGC PV glass products leading in market.

Figure 37: PV glass product analysis by quadrants methodology

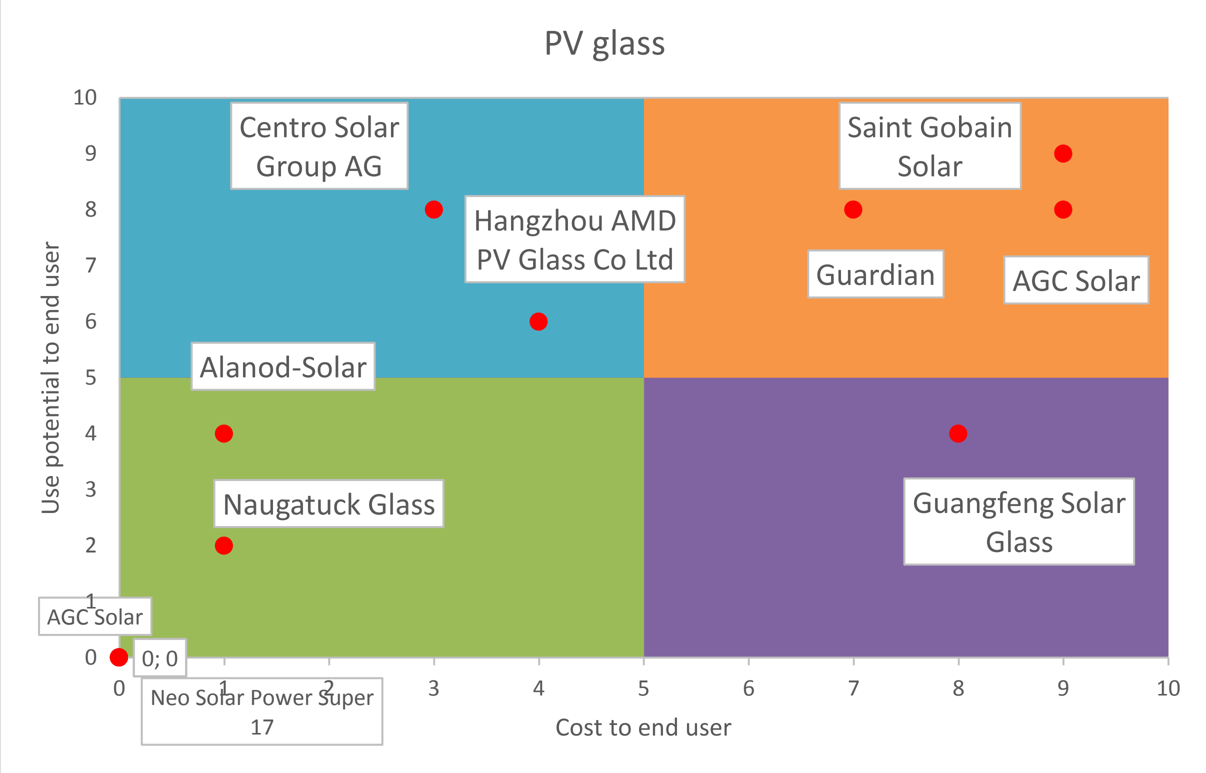
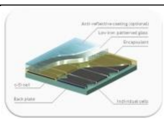


Table 12 overviews the PV glass products and their parameters.

Table 12: Overview of PV module glass products

Manufacturer	Illustration	Product type	Basic parameters	Comments
AGC Solar		Solite™ Solatex™	**Solite™** Transmission 91.6% Specific weight 3.2 kg/m^2 Mechanical strength 90 MPa Density 2500 kg/m^3	Extra clear patterned glasses are used in solar photovoltaics (crystalline and CIGS) and in solar thermal applications.
Pilkington		**NSG TEC™** Pilkington Optiwhite™ Pilkington Sunplus™	NSG TEC™ A7 Transmission 82% Sheet Resistance 7 Ω/sq Thickness 2.2 mm Haze 5%	SG TEC™ is a group of products, with TCO glass (Transparent Conductive Oxide coated glass), optimised for thin film solar cells
Guardian Industries		**EcoGuard PV Series**	Transmission 88.9-91.3%	
Saint Gobain Solar		SGG Diamant SGG Diamant Solar SGG Planilux	**SGG Diamant** Transmission 90.6% Thickness 2.9 mm **SGG Diamant Solar** Transmission 91.2% Thickness 2.9 mm, 3.2 mm, 3.9 mm	
Guangfeng Solar glass		Low Iron Float Tempered Glass AR coated glass	**Low Iron Float Tempered Glass** Transmission 91% Thickness 3.2 mm **AR coated glass** Transmission 94.6% Thickness 3.2 mm or 4 mm	

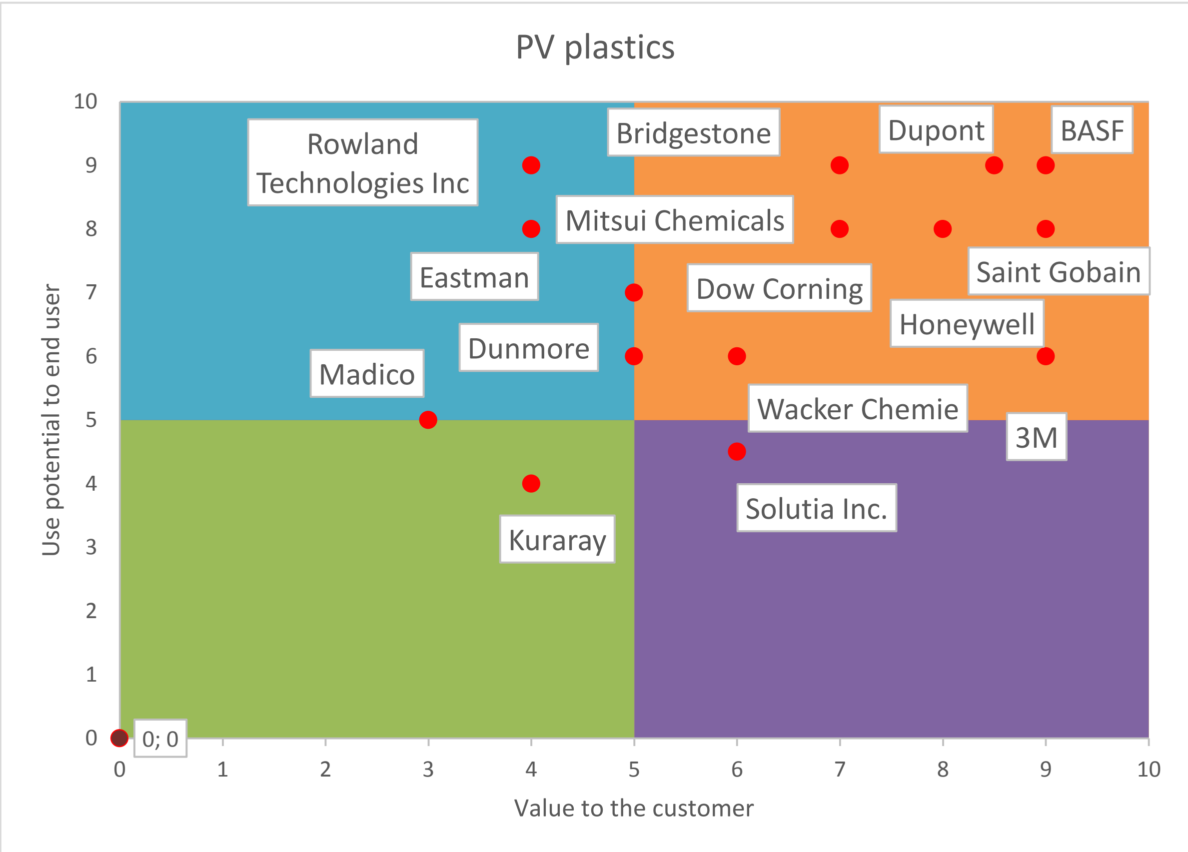
2.1.4.4.2 PV plastics

In following tables Table 13 and Table 14 the PV backsheet and encapsulation plastics products are presented.

Photovoltaic modules comprise several plastic materials: encapsulant and module backsheet. Among the encapsulant, ethylene vinyl acetate (EVA) is still the market leader. The reason is its low-cost, optimized properties. There is also polyvinyl butyral (PVB). While basically used for the struggling silicon thin-film module sector, PVB manufacturers are now eying the crystalline backsheet sphere. But this is an unlikely development, given the extra expense of PVB. Ionomers, a thermoplastic co-polymer of ethylene and (meth)-acrylic acid, have the advantage of good transparency for letting more sunlight through to the module. But, again, that is an expensive option. Another alternative to the market leader - albeit another costly option - is thermoplastic polyurethane (TPU), which not only has good transparency attributes, but decent elasticity as well. Silicone, which has largely been absent from the market for some time, is making a comeback due to its UV stability and a very low UV cut-off value. For emerging cell technologies, such as selective emitters, this product opens the gate to improving solar module efficiencies, as it does not hamper the enhanced blue response- although it also comes at a rather high cost.

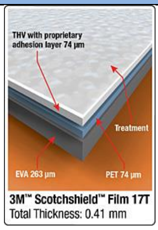
The analysis showed that BASF, Dupont, Saint Gobain, 3M etc. products scored highest evaluation of use potential to end user and value to the customer, therefore occupied leader quadrant in graph given in Figure 38.

Figure 38: PV plastics product analysis by quadrants methodology



The PV plastic product overview is given in Table 13 and Table 14.

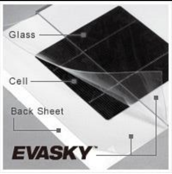
Table 13: PV module backsheet product overview

Manufacturer	Illustration	Product type	Basic parameters	Comments
3M		Scotchshield™ Film 17T Scotchshield™ Film 17 Scotchshield™ Film 15T Scotchshield™ Film 15T Black Scotchshield™ Film 17HTT Scotchshield™ Film 15HTT	Construction THV/PET **Scotchshield™ Film 17T** Thickness 410 µm PDR[23] >1100 VDC **Scotchshield™ Film 15HTT** Thickness 364 µm PDR>1000 VDC	Features a fluoropolymer layer as a key component for resistance to degradation from sources such as UV, heat and moisture.
Dunmore		DUN-SOLAR™ PV backsheet	**PPE+** Construction PET/PET/PE Thickness 360 µm Dielectric strength 27 kV PDR >1000 VDC **TPE** Construction PVF/PET/PE Thickness 250 µm Dielectric strength 15.55 kV PDR >1000 VDC **TPT** Construction PVF/PET/PVF Thickness 325 µm Dielectric strength 17.9 kV PDR >1000 VDC **EPE** Construction PE/PET/PE Thickness 265 µm PDR >1950 VDC	PV backsheet constructions: TPT, TPE using DuPont Tedlar®, FPE fluorinated products and PPE+ all polyester constructions Certifications IEC 61215, IEC 61730, IEC 61646 and UL 1703
Du Pont		**Tedlar®** PV2000 Series PV2100 Series **Mylar®** **Melinex®** **Teijin®** **Tetoron®**	**Tedlar®** Construction Tedlar®/PET/Tedlar® Thickness 250 µm PDR >1100 VDC	Tedlar® fluoropolymer to protect both sides of the polyester from photo-degradation Mylar®, Melinex® and Teijin® Tetoron® are PET films designated for backsheet lamination
Honeywell		**PowerShield®** **PowerShield® 3W**	Construction Fluoropolymer/PET/Fluoropolymer	
Saint-Gobain		**FluoroSol®** FT FP	Polymer fluoropolymers **FT** Transmission 96% Tensile Strength 7000 psi (48 MPa) Elongation 300% **FP**	

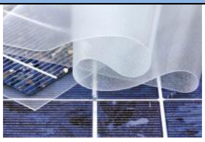
[23] Partial Discharge Rating

Manufacturer	Illustration	Product type	Basic parameters	Comments
			Transmission 97% Tensile Strength 3500 psi (24 MPa) Elongation 300%	

Table 14: PV module encapsulation foil (including encapsulants for frameless modules) products overview

Manufacturer	Illustration	Product type	Basic parameters	Comments
Bridgestone		EVASKY	Polymer EVA Light Transmission 92% Haze 3% Viscosity $1 \cdot 10^5$ Pa s (at 80° C)	
Dow Corning		PV-6100 Encapsulant	**Polymer Silicone elastomer** Light Transmission 95% Viscosity: 430 mPa s Boiling Point: > 65° C Specific Gravity @ 25° C: 0.97	
Du Pont		DuPont™ Elvax® PV EVA resins DuPont™ PV5200 Series encapsulant sheets DuPont™ PV5300 Series encapsulant sheets DuPont™ PV5400 Series ionomer-based encapsulants	**Elvax® PV** Polymer EVA Density 0.957 g/cm^3 MMFR[24] 3 (190° C/2.16 kg, ASTM D1238);	Elvax® PV resins for EVA solar encapsulation are designated for traditional rigid solar modules.
Mitsui Chemicals		SOLAR EVA™		
Saint-Gobain		**SolarBond™** Membrane **LightSwitch™** ETFE FEP	**LightSwitch™ ETFE** Polymer EVA Light Transmission >96% Tensile Strength 700 psi (48 MPa) Elongation 300%	LightSwitch™ Encapsulant is suitable for both flexible and rigid modules

[24] Melt Mass Flow Rate (g/10 min)

Manufacturer	Illustration	Product type	Basic parameters	Comments
Wacker Chemie		TECTOSIL®	Polymer Silicon based encapsulate Transmittance 93-94%	TECTOSIL® and can be utilized in all standard laminators. No chemical crosslinking
Solutia Inc.		**High Flow PVB Encapsulant** Saflex® PA41 **Solar PVB Encapsulant** Saflex® PA61 Saflex® PG41 **Multi Junction PVB Encapsulant** Saflex® PS41	Refractive index 1.48 Thermal conductivity 0.20W/m-K Specific heat 2080J/kg-°C Tensile strength >200kg/cm^2 Elongation at break >200 % Thermal expansion coefficient 1.7E-4 1/K Glass adhesion >15N/mm^2	Dedicated for application in building integrated photovoltaics (in complience with the construction sector requirements)
Trosifol		Trosifol solar R40 Trosifol R40 ultra white Trosifol solar UV+ Trosifol solar R100	**Trosifol solar R40** Density 1.065g/cm^3 Refractive index 1.482 Thermal conductivity 0.20W/m Specific resistivity 2.0E12Ω x cm Specific heat 1.85J/WK Tensile strength >23N/mm^2 Elongation at break >250 % Thermal expansion coefficient 2.2 E-4 1/K UV transmittance from 375nm Light transmittance 91% Glass adhesion >16N/mm^2 **Trosifol R40 ultra white** Density 1.060g/cm^3 Thermal conductivity 0.22W/m Specific resistivity 1.0E14Ω x cm Specific heat 1.85J/WK Tensile strength >23N/mm^2 Elongation at break >250%	Dedicated for application in building integrated photovoltaics (in complience with the construction sector requirements)

Manufacturer	Illustration	Product type	Basic parameters	Comments
			Thermal expansion coefficient 2.0 E-4 1/K Light transmittance <1% Glass adhesion >16N/mm^2 **Trosifol solar UV+** Density 1.065g/cm^3 Refractive index 1.482 Thermal conductivity 0.20W/m Specific resistivity 2.0E14Ω x cm Specific heat 1.85J/WK Tensile strength >23N/mm^2 Elongation at break >250% Thermal expansion coefficient 2.2E-4 1/K UV transmittance from 280nm Light transmittance 89% Glass adhesion >16N/mm^2 **Trosifol solar R100** Density 1.065g/cm^3 Refractive index 1.482 Thermal conductivity 0.20W/m Specific resistivity 2.0E14Ω x cm Specific heat 1.85J/WK Tensile strength >23N/mm^2 Elongation at break >250% Thermal expansion coefficient 2.2E-4 1/K UV transmittance from 375nm Light transmittance 91% Glass adhesion >16N/mm^2	

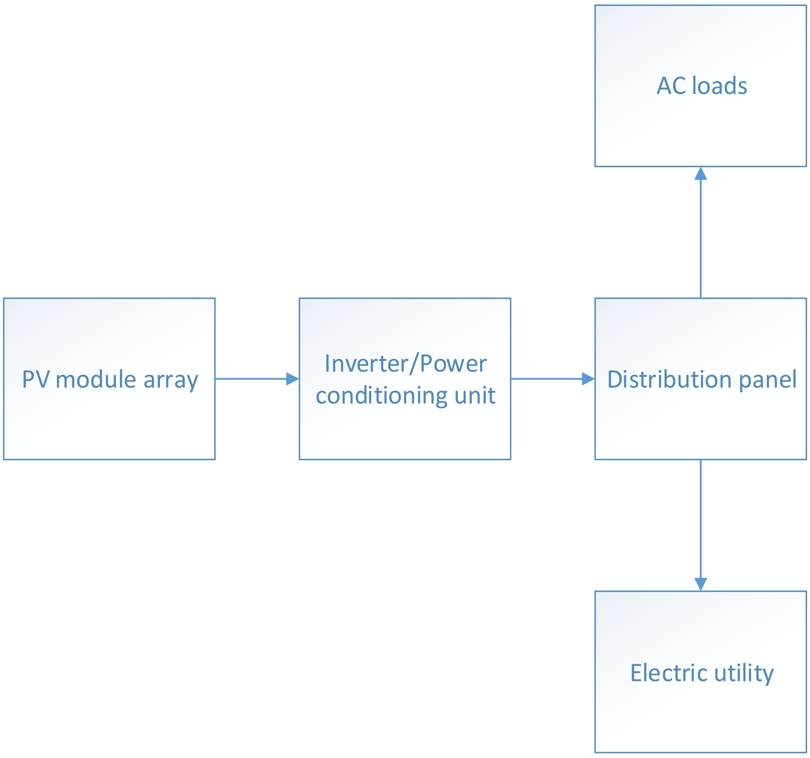
2.1.5 PV systems and PV system components

2.1.5.1 Types of PV system

Usually PV systems are divided into three types, which are presented below.

On-grid (Grid connected). This type of power supply system is usually connected to main power network and allows to provide not utilized electric energy to external network for determined Feed-in-tariffs (FIT). Households which have a grid connected PV system block diagram is shown in Figure 39: the primary system components is PV module array, which supply generated electrical power through inverter or power conditioning unit to distribution panel, which controls the ratio of power fed to grid or and to households consumptions (AC loads). Bi-directional interface made between distribution panel and electrical unit enables to distribute the produced renewable energy to be consumed in household AC loads or be fed to the external electrical utility grid. When solar illumination is not sufficient the controller feeds the AC loads from external network.

Figure 39: Grid connected system block diagram

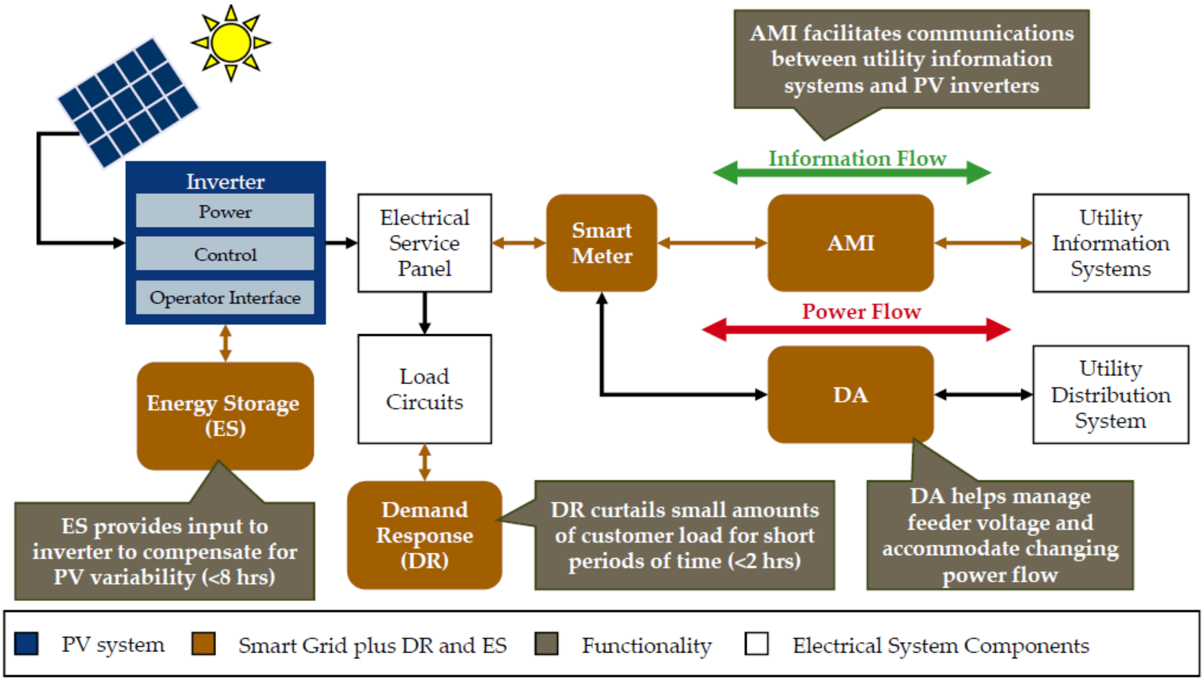


There is an emerging trend to connect the on-grid PV systems into a smart grid which is a new approach to the integration of power generation, transmission systems, distribution networks, and consumption. The smart grid should be able to adapt to all types of generation sources, including conventional large thermal power plants and intermittent renewable energy sources such as wind and solar PV generation without restriction. Most innovative part in the smart grid is its demand response (DR), which is largely facilitated by the use of smart meters and an associated advanced metering infrastructure (AMI). Smart meters can provide real-time information on the demand and price from different suppliers to customers, so as to allow them to decide when they want to buy electricity, from whom, and at what price. This will not only provide "freedom of choice" but also allow customers to interact with the network operators and suppliers in, or near, real time.

The detailed PV smart grid block diagram is shown in Figure 40. PV smart grid system is divided into three groups:

1. PV system components:
   a) Inverter with power, control and operator interface;
2. Smart grid components:
   a) Energy storage comprising Li-ion or lead-acid battery packs, which provide input to inverter to compensate for PV variability;
   b) Demand response block, which curtails small amounts if customer load for short periods of time (<2 hours)
   c) Smart meter
   d) Advanced Metering Infrastructure (AMI), which facilitates the communication between utility information systems and PV inverters;
   e) DA helps manage feeder voltage and accommodate changing power flow.
3. Electrical system components:
   a) Electrical service panel
   b) Load circuits
   c) Utility information systems
   d) Utility distribution system

Figure 40: Detailed sheme of PV system components[25]



Off-grid (stand-alone systems). Off-grid PV systems (or stand-alone) (block diagram shown in Figure 41) are designated to operate independently from the external energy supply networks.

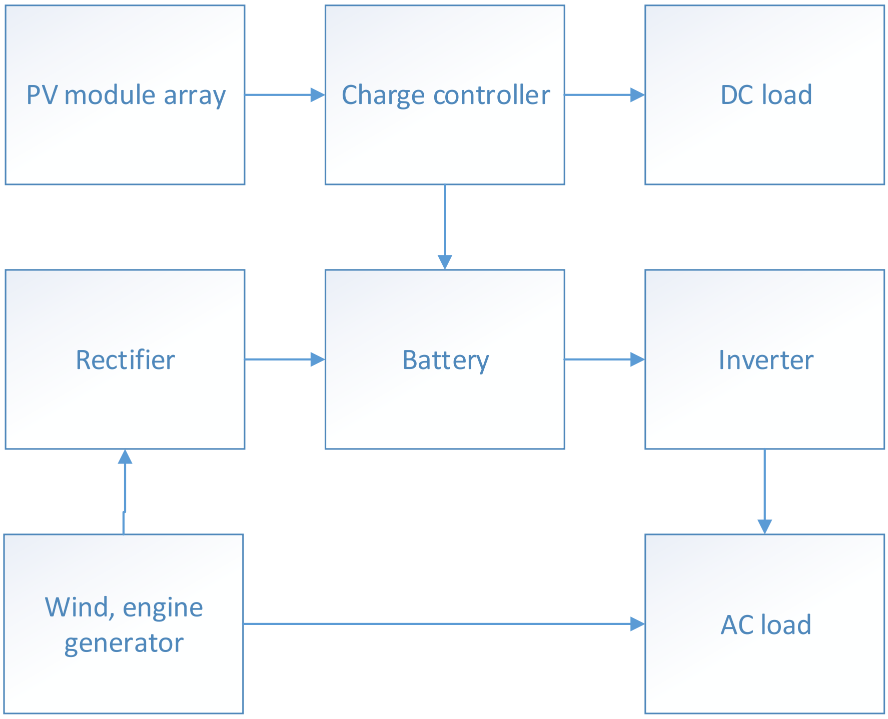
Figure 41: Off-grid PV system

As off-grid PV systems can operate only on sunlight hours, they are designated to power the ventilation fans, heat and water pumps or other low power systems. In order to provide 24 hour power supply, the system is usually coupled with batteries.

Hybrid systems. In order to balance the insufficient power supply from PV arrays (due to cloudy weather) the PV arrays are integrated with battery storage and backup power source of wind or engine generators. The block diagram of hybrid systems is shown in Figure 42.

[25] F. Small. Navigant Consulting. Smart Grids in the US and PV-Grid Integration. Smart Grids Conference. Salzburg 2009

Figure 42: Hybrid PV system block diagram



Below, the commercial PV on-grid and off-grid systems product examples are presented.

Table 15: Overview of off-grid PV system products

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
Mitsubishi Electric	On-grid		Diamond Kit	System power 3.0 kW, 5. 1 kW, 7,6 kW, 10,2 kW Inverter Solar Edge Power Optimizer inverter system, Fronius inverter	
Yingli Solar	Off-grid		YLSYS300 SERIES	Module Type YGE 140 series × 2 Inverter Type YLCI 500-24 x 1 Battery Type 12V/150Ah × 2 Cables and Other Components 1 set Recommended Load Energy-saving lamp (9W), 4 sets, 4 hours/day TV & IRD (120W), 1 set, 4 hours/day DVD player (40W), 1 set, 4 hours/day	Certification: ISO 9001:2008, ISO 14001:2004, BS OHSAS 18001:2007, PV Cycle
Solar First Energy	Off-grid			Module Type Monocrystalline 72-6-260M × 2 Inverter Type	

Manufacturer	Application area	Illustration	Product type	Basic parameters	Comments
				DC17.5V.DC35.5V Battery Type Lead-acid 12V/150Ah × 2	

2.1.5.2 PV system components

2.1.5.2.1 Overview of PV system components

In order to exploit PV system and integrate to standard power supply grids, the system must comprise several components:

Inverters convert DC (direct current) power coming from PV module array to AC (Alternating current). This component is one of the most important, because it maximizes the voltage from PV array by utilization of the maximum power point tracking (MPPT) and adjusts the voltage and current from the PV module. They are divided into groups by the efficiency and power range. These components are also divided into groups by its application area: off-grid (Stand-alone) (Figure 41), grid connected (grid-tie), and battery backup inverters. The first group of inverters are used in off-grid PV systems and comprise the battery banks (for operation in the range of 100 A), and do not comprise any anti-islanding protection equipment. Grid connected inverters are designated to convert the energy flowing from PV array and to match it with the external grid. In addition, these inverters have a functionality to automatically shut down when the utility supply is lost. The battery backup inverters are able to draw energy from PV battery, control the battery charge, and distribute power to the external (utility) grid. These inverters comprise anti-islanding protection.

Charge controllers are used in PV system with battery block. The charge controller basic functionality is to control voltage or current flowing from PV array to batteries. This device through the period of battery charging, continuously monitors battery voltage and reduce or stop the charging when voltage is too high and protect from deep discharges. In addition, some controller can equalize the battery state-of-charge. The charge controller is therefore the energy manager in stand-alone PV system, ensuring that the battery is cycled under conditions which do not reduce its ability to deliver its rated capacity over expected lifetime.[26]

PV system (utility) meters monitors the amount of generated electricity and amount of power fed to external grid. The monitoring systems could be mounted on sight or wireless ones can be used, with the functionality to detect real time power plant electrical characteristics. There is possibility to observe PV plant performance straight on the cell phones as well.

[26] IEA International Energy Agency. Recommended Practices for charge controllers. IEA PVPS T3-05:1998

2.1.5.2.2 Overview and analysis of PV inverter products

PV system inverter product overview carried out in this study (Table 16), showed that majority of inverter products comprise three-phase string inverters with string inverter technology. Such devices are able to detect the weakest module by the generated maximum power parameter. These devices are called string inverters, as separate PV module strings are connected to inverter. In addition, standard inverters feature independent MPP (maximum Power Point) tracking systems. These devices usually are divided into active and passive inverter groups by their ability to detect islanding situation: active islanding is carried out by interrupting the grid and monitoring to prevent persons and PV system equipment from casualties and passive islanding does not interferre into the system, since they are only monitoring the condition.

The analysis of PV inverter products showed that these products are divided into classes by their efficiencies. As shown in Figure 43, the A+ class comprise SMA, Steca and Siemens PV inverters. Although the majority of PV inverters are selected by their class, very important parameters are inverter voltage threshold and voltage range (shown in Figure 44). According to this data, the widest covered voltage range provided by Sputnik PV inverter.

Figure 43: Distribution of PV inverter efficiencies and classes

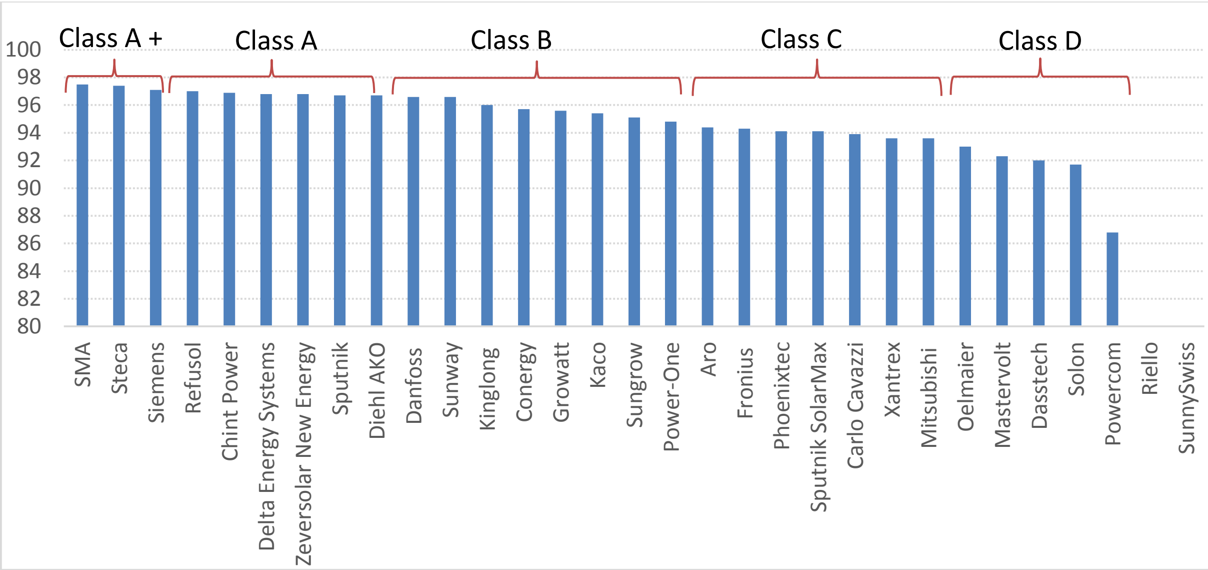
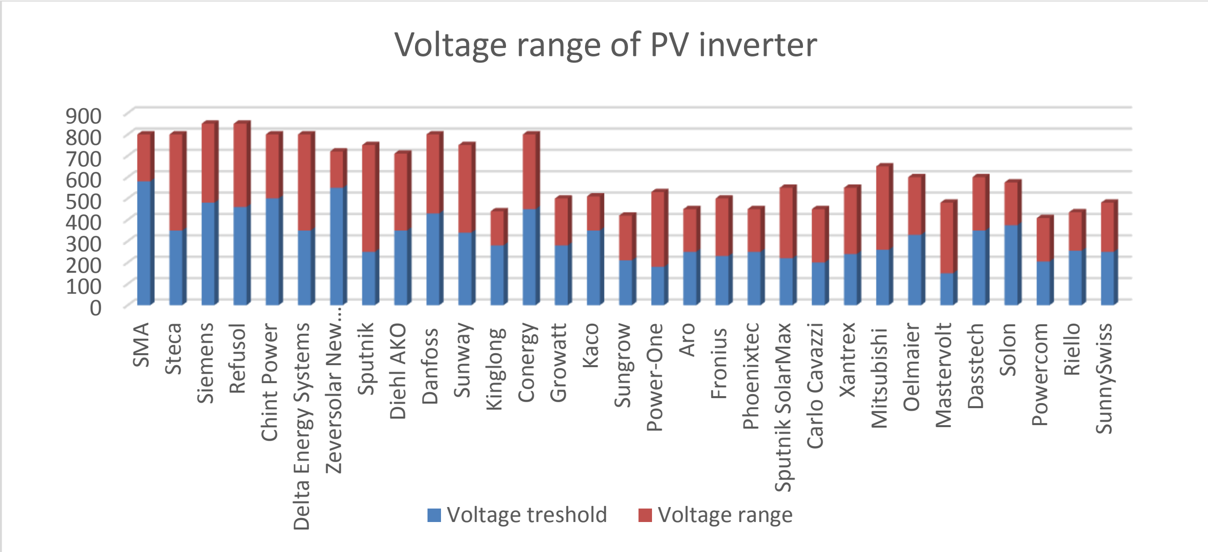


Figure 44: Distribution of PV inverter voltage threshold and voltage range



Although some inverters given in Table 16 of A+ class have the efficiency of 97%, the major innovation trend in this area is the products with even higher efficiency for less energy losses in on-grid systems. Furthermore, one of the requirements for modern inverter is to comprise additional Multiple Power Point Trackers (MPPTs), therefore all of the upcoming inverter product will comprise this functionality. Another important inverter functionalities are monitoring, diagnostics and early detection of issues related to their functionality as well as wireless inverter devices, therefore it is believed that new products will comprise these as well.

Product analysis (Figure 45) has shown SMA, Fronius, Kaco, Power One and Delta Energy Systems PV inverters are leading the market.

Figure 45: PV inverter product analysis by quadrants methodology

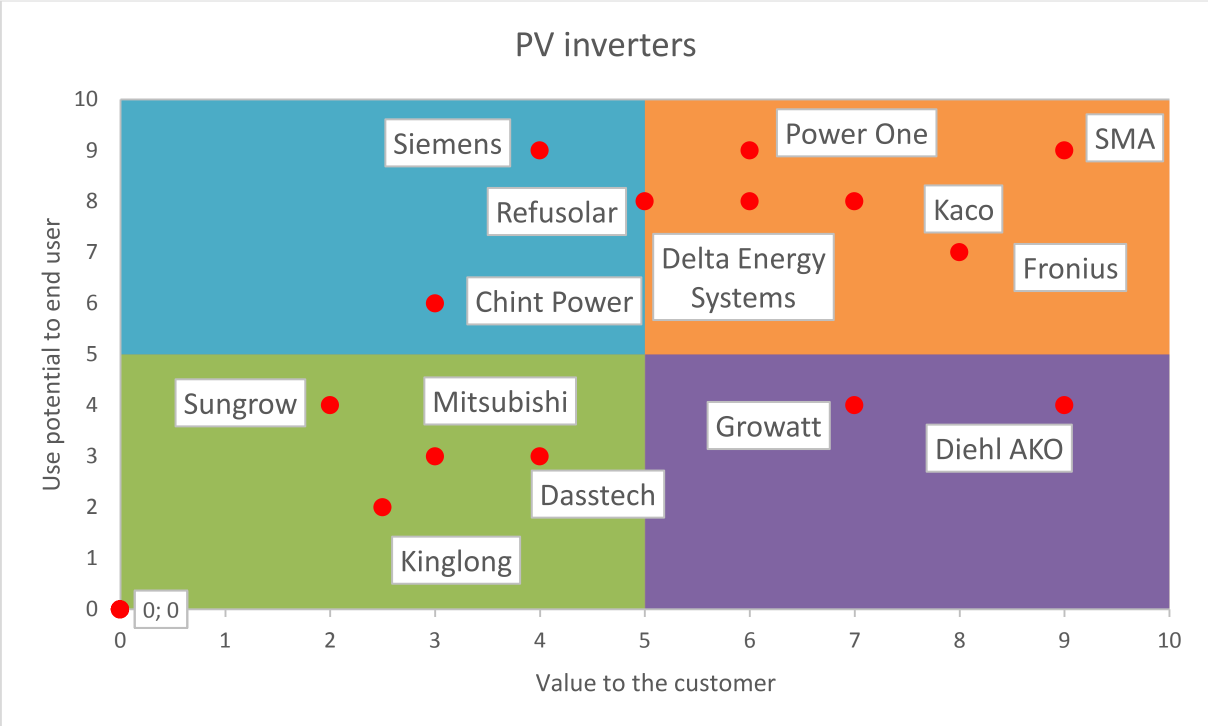


Table 16: Overview of PV inverter products

Manufacturer	Illustration	Product type	Basic parameters
SMA		STP 20000TLHE	Voltage range 460-850 V Efficiency 97.4% Classification grade A+
Siemens		Sinvert PVM17	Voltage range 460-850 V Efficiency 97.4% Classification grade A
Refusol		017K	Voltage range 460-850 V Efficiency 97.4% Classification grade A+
Danfoss		TLX15 k	Voltage range 430-800 V Efficiency 96.7% Classification grade A+
Sunways		PT33k	Voltage range 460-800 V Efficiency 96.7% Classification grade A
Growatt’s		5000TL	Voltage range 350-510 V Efficiency 97.4% Classification grade A

Manufacturer	Illustration	Product type	Basic parameters
Fronius		IG Plus 100	Voltage range 230-500 V Efficiency 94.8% Classification grade B
Mitsubishi		PB-PNS06ATL-GER	Voltage range 260-650 V Efficiency 93.9% Classification grade C
Sunways		NT 2600	Voltage range 476-749 V Efficiency 92.3% Classification grade C
SunnySwiss		SSP-6000	Voltage range 250-480 V Efficiency 86.8% Classification grade F

2.1.5.2.3 PV system mounting products

PV module mounting and tracking systems. In respect to the household condition, several PV module mounting system are proposed by PV installers. In areas with most limited amount of sunlight the pole mounted PV module are proposed. Usually up to four modules are connected on the painted steel or galvanized pipes. In large areas, the ground mounted PV power plants are installed. In order to preserve PV module from various loads (snow or wind) the constructions are put on the concrete base. An example of PV power plant built on concrete base is shown on Figure 46, left.

Figure 46: Ground (left) and roof mounted (right) PV systems

So called building applied PV (BAPV) arrays are usually mounted on roof (Figure 46, right). For optimized generated electrical power, the PV modules are usually mounted with some tilt angle. The needed tilt angle varies with the time of the year and the geographical latitude.

Ground mounting systems. The most common solution for PV plants is free-standing modules mounted on ground oriented toward sun with optimised angle. Angle depends on the latitude and is increasing toward north. Dominating winds and its speeds need to be taken into account too when designing mounting systems for particular PV plant. As rule of thumb mounting for the PV systems in the north there are higer requirements to withstand external forses.

Mounting systems with tracking are used to increase harvesting of solar irradiation during the day and during the year. Tracking platforms can tilt the active PV modules surface along one or two axis. Although gain in energy harvested is significant (up to 30%) tracking systems are also significantly raising total system cost. Therefore two axis tracking systems are used only in CPV systems where exact pointing to the sun is essential for system performance. For flat PV panels a good compromise for the mounting system is tracking with only one axis changing panel's position during the day. Even cheaper solution can be so called Seasonal Tilt mounting system when tracking is performed with only allowing two tilt angles, one optimised for summer, the other for winter when customer is changing the angle manually according to season.

Building applied PV mounting systems. Roof mounting systems are designed according to the type of the roof and can be distinguished into flat roof and tilted roof systems. Flat roofs are providing best space for solar systems in building environment because are avoiding most of the problems such as shading of other buildings, orientation of the surface and competitive use of the same space. Commercial rooftops are most desirable for PV installations and are seen as one of the most promising market segments in the near future. On flat roofs standard flat panels are installed in the same way as ground mounted systems with fixed tilt angle but sytems must be designed for the integration into roof without damaging roof insulating envelope. It must be noted that mounting systems for the roof are designed to resist stronger winds and have special solutions for that. For flat roofs there are many innovative solutions on the market like PV modules integrated with insulating envelope materials or systems like well known Solyndra system of thin film module in cylindrical shape (Figure 47). In these modules thin film active layer is wrapped around the cylinders allowing light collection from any angle without any need for tracking or tilting of the systems. Although of lower efficiency, they were lighter due to module unique geometry and because of that there were no problems with wind activity.

Figure 47: Example of lasrge scale Solyndra system of thin film module in cylindrical shape

For tilted roofs main issue is orientation of the roof to the south. Other requirements also are important:

- Weight - structure and roof are able to carry partiular load especially in snowy regions.
- Wind levels: mounting system must withstand significant winds creating forces between the roof and the panels.
- Roof slope must be of the same angle as required for particular place latitude but can not be higher that 60°.
- Lighting protection is requirement coming for building construction standards.

There are number of mounting systems developed specifically for PV modules on tilted roofs to reduce efforts and costs for mounting the system. Typically for the mounting systems are used aluminium profiles with wide variety of gripping elements suitable for most of typical roof envelopes such as tiles or tin or bituminous surfaces (Figure 48).

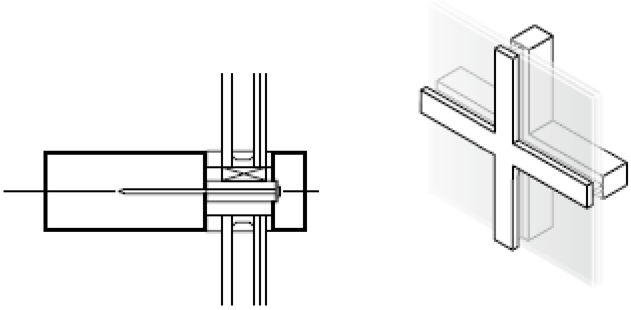
Figure 48: Example of flat panels and mounting the system on tilted roof

Building integrated PV mounting systems. Due to the specific properties of the system, such as shading, for example, and the regulatory specifications with regard to the safety and loading capacity of the materials used, the chosen type and method of fixing have a decisive impact on the design of the solar module.

Linear mounting systems:

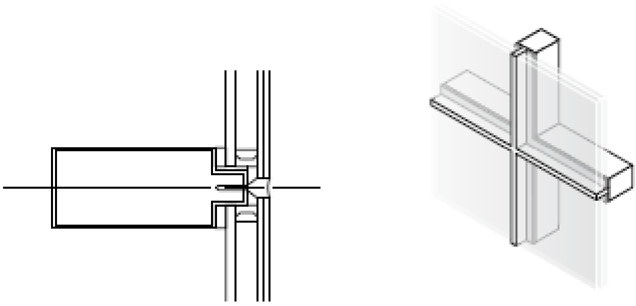
- Mullion-transom constructions consists of vertical mullions and horizontal transoms (Figure 49). The mullions transfer the main loads and the transoms act as horizontal bracing. The solar modules are set in this framework structure as fill elements. Clamping rails are fitted from the outside as linear fixings for the modules. The circumferential profiles, however, can shade the solar modules and also result in the accumulation of dirt and snow. The module design should be adapted to take this shading into account. The costs for maintenance and cleaning should also be taken into account, if applicable, particularly for roofing applications. The dimensions of the facade grid vary from project to project and customised solar modules are usually required. Mullion-and-transom facades count as “warm” or thermally insulating facades. Consequently, not only must the profiles be thermally separated, but the U values of the fill elements must be correspondingly low. For this reason, PV modules are often integrated in a thermal insulation glazing structure.

Figure 49: Mullion-transom faēades



- With structural sealant glazing facades (Figure 50) the solar modules are fixed in place on a metal frame by means of circumferential load-transferring bonds. This produces facades with a homogeneous and smooth appearance. Furthermore, SSG facades have no external protruding parts, which means that shading and dirt traps are avoided. In some countries regulations require an additional mechanical safeguard to prevent panels installed above a height of 8 m from plummeting. In addition, provision for the mechanical transfer of loads must be made. The combination of SSG with solar modules is usualy treated as a special system, so that both product-specific building permission and project specific building permission must be obtained.

Figure 50: Structural sealant glazing (SSG)

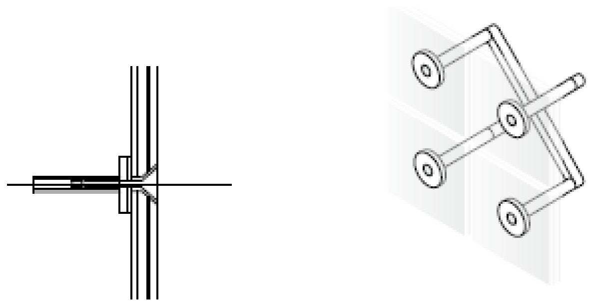


Point-fixing systems. Particularly delicate designs can be achieved using point-fixed facade systems. Although point-fixing systems cause hardly any shading in comparison to frame systems and are less prone to accumulating dirt, they can only be used with a few types of solar module. Since holes drilled in glass must maintain a minimum offset from the edge of the pane and since drilled spot fixing always shade part of the module, the only solar modules that can be used here are those that allow cut-outs to be made in these areas in the module design and permit drilled panes to be used independently of the cell production. Standard thin-film modules are not usually favourable or cannot be used at all in such cases.

Typical point-fixing systems are clamp fixings, drilled glass panes with drilled spot fixing, and undercut anchor fixing systems:

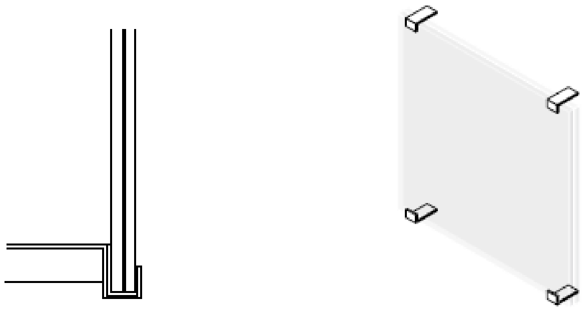
- Drilled spot fixing (Figure 51) are construction components that are used for point-fixing glass panes. They comprise two metal discs and a bolt that is inserted through a drilled cylindrical hole in the glass pane to connect the two discs. These circular pads must measure at least 50mm in diameter and be offset from the edge of the glass by 12mm.

Figure 51: Drilled spot fixing



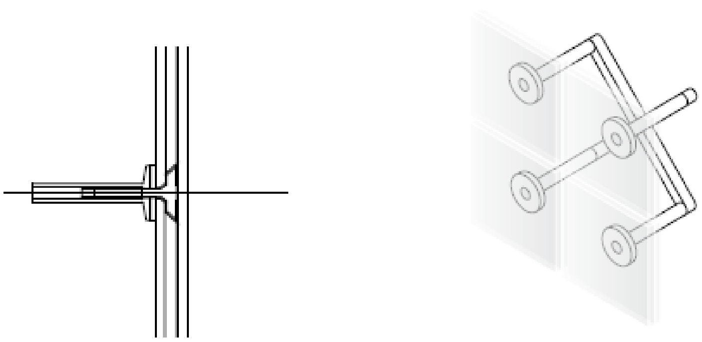
- Clamp fixings (Figure 52) are U-shaped brackets that fit around the edge of glass panes and dispense with the need to drill holes in the glass. The fixings must overlap the glass by at least 25 mm and the clamped area must be greater than 1000 mm^2.

Figure 52: Clamp fixings



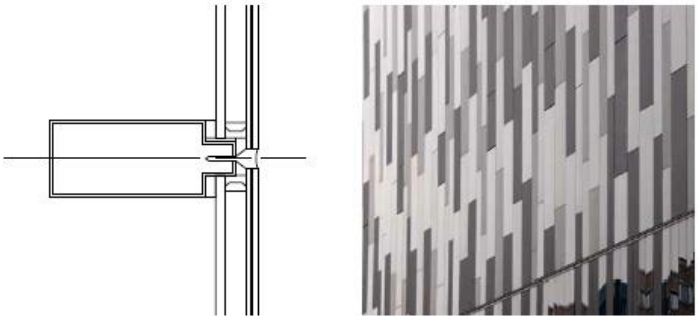
- Undercut anchor fixings are mechanical point-fixings that remain invisible, since the glass is not drilled right through. This allows more efficient use of the PV surface area. These fixings generate higher stresses due the reduced contact area of their cylindro-conical drilled holes, which means that toughened glass, semi-tempered glass or laminated safety glass must be used.

Figure 53: Undercut anchor fixings



Ventilated curtain wall systems. The function of the cladding of ventilated curtain wall systems (Figure 54) is to provide weather protection and to serve as an architectural design element. This outer cladding is fixed to a rear load-bearing wall using a fixing system (agraffes and/ or rails). A layer of air between the load-bearing wall (or the insulation layer attached to it) and the building envelope ventilates the solar modules from the rear and can be used for laying electrical components and sockets.

Figure 54: Ventilated curtain wall systems

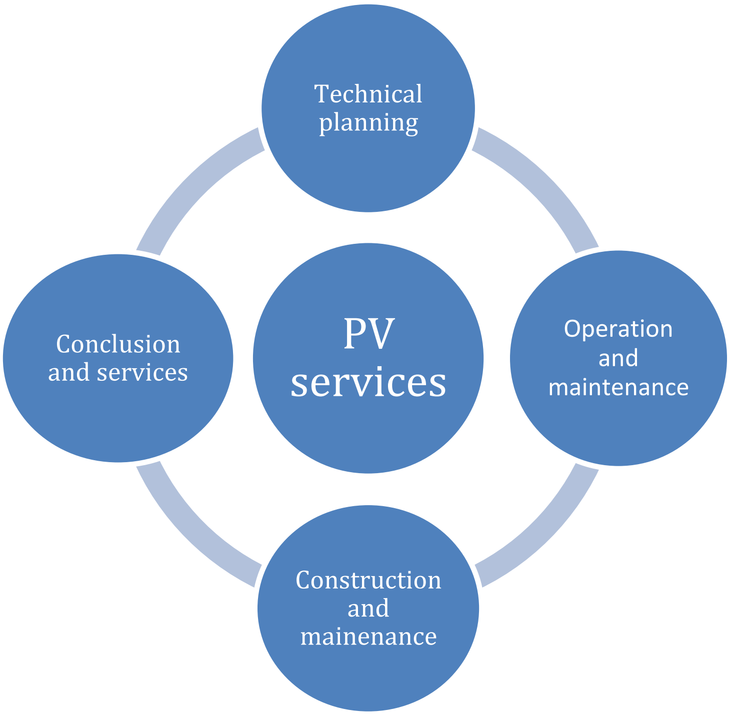


Many different types of material, such as plaster, ceramic tiles, bricks, glass or metal can be used for this kind of construction. Facades can thus be created using a wide variety of material combinations together with PV modules. Above all, ventilated curtain wall systems are taken into consideration in energyefficient facade renovation projects.

2.1.6 PV services related products

Vertically integrated module manufacturer or separate PV system installers provide specialized services during and after PV system installation. Major services groups are given in Figure 55.

Figure 55: PV services



1. **Technical planning.** Different geographical locations features the different solar illumination, therefore the evaluation of ratio of actually generated to theoretical yield is of high importance. The evaluation of this ratio gives the power plant performance ratio (PR), which provides the critical information about the plant efficiency. The calculations of PR ratio made in Germany are as follows: a plant with peak 1 MW power connected to the grid would produce an 863 MWh of electricity each year, therefore the performance ratio would stand for 75%. With the PR calculation the needed set of modules, inverters and other components can be

indicated. During the technical planning of PV installation project, the grid connection, consulting services, electrical planning, and design are also evaluated.

2. **Construction and installation**. The certification is required. The activities are comprised of:

   - Organization of PV installation (review of project documents including array placement and electrical diagrams, analysis of electrode system and electrical service, analysis of PV system specifications for inverter and panels, analysis of racking specifications, calculation of maximum PV system voltage, calculation of circuit sizing and current);
   - Construction of PV array (planning of the PV array, layout of the PV array support structure, attachment of the array support structure, installion of PV panels and string PV panels);
   - Installalion of DC wiring and equipment (mounting of DC equipment, installion of DC conduit, wiring of DC equipment)
   - Installation of AC wiring and equipment (mounting of AC equipment, installion of AC conduit, wiring AC equipment)
   - Implementation of PV system installation project.

3. **Operation and maintenance.** This type of services is needed to ensure the ongoing PV system optimization for high energy yields. One of the most important part of these services are the centralized monitoring of PV system operation and alerts of occurring issues and failures or decreased energy generation due to material degradation. Monitoring comprises the period reporting with actual yields and other parameters accessible to PV power plant owner. Services also include the maintenance of all system components namely inverter block, PV module, cabling system etc. As some of the PV plants are installed in remote areas, the companies also provide the surveillance services.

4. **PV project conclusion and after sales service.** PV project conclusion involves the preparation of project quality management, documentation, measurement protocols. After sale services comprise the real-time PV power plant monitoring to ensure correct operation of every solar panel. Possible after sales service is visual inspection of PV power plants for solar module or system components degradation. The company which implements the after sales services, also provides the preventive maintenance of all equipment in order to maintain maximum electricity generation.

In Table 17 an overview of software tools covering different categories like analysis, planning, economic evaluation, monitoring etc. are presented.

Table 17: Overview of PV software tools

Category of software tool	Tool name	Main functionalities	Website of developer
Simulation tools	INSEL	Planning, monitoring and visualising energy systems, including simulating meteorological data, electrical and thermal energy components etc.	http://www.insel.eu/
	TRNSYS - (TRaNsient SYstem Simulation Program)	Analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc. Includes a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package.	http://sel.me.wisc.edu/trnsys/
Economic evaluation tools	HOMER	Designing and analyzing hybrid power systems, which contain a mix of conventional generators, cogeneration, wind turbines, solar photovoltaics, hydropower, batteries, fuel cells, hydropower, biomass and other inputs.	http://www.homerenergy.com/
Analysis and planning tools	pvPlanner	Calculator of potential PV electricity production. It can compare PV output on the basis of different technology options such as module type, inverter efficiency, and mounting type. It also allows for easy comparison among sites and contains interactive horizont editor for purposes of shading analysis.	http://solargis.info/doc/4
	Archelios	Evaluation of solar radiation of a site, to design a photovoltaic system and calculation of the energy produced and the profitability.	http://www.archelios.com/
	Renewable Energy Associates	String Design Tool for sizing module strings to operate within the parameters of the selected inverter. Option to select from a wide variety of products and manufacturer's.	http://renewableassociates.com/design-tools/
	PV*SOL	multi-product suite of software for the design, simulation and financial analysis of photovoltaic systems ranging from small off-grid residential systems to large commercial grid-connected and utility-scale systems. The range of PV*SOL programs include: PV*SOL basic for the quick design, financial analysis and creation of customer proposals for residential and small commercial PV systems up to 300kW. PV*SOL Pro for	http://www.valentin.de/

Category of software tool	Tool name	Main functionalities	Website of developer
		the detailed analysis of complex PV systems of up to 100MW comprised of up to six different arrays, each can be designed using different sizes, orientations, modules, inverters and losses. PV*SOL Expert which contains all the capabilities of PV*SOL Pro plus the added capability of 3D array design and detailed near shade analysis. The calculations installers, engineers and designers can make are based on hourly data and results can be presented in 3D graphic form, in a detailed project report or in a results summary.	
	BlueSol	Top features are: use of wizards or direct editing for the dimensioning of the photovoltaic system; insertion and verification of cables and electrical components; integrated CAD system to arrange modules, strings, cables, panels and inverters in the planimetry; 3D visualization of layout with simulations of shading of near obstacles and assessments of irradiations on surfaces; electrical scheme automatically created; irradiations specified by the user, from NASA-SSE world wide data, or imported from PVGIS; default and user templates of documents with integrated word processor.	http://www.bluesolpv.com/dnnsite/default.aspx
	PV F-CHART	Provides monthly-average performance estimates for each hour of the day. The calculations are based upon methods developed at the University of Wisconsin which use solar radiation utilizability to account for statistical variation of radiation and the load.	http://www.fchart.com/
	Solmetric PV Designer™	Dedicated to design of residential and smaller commercial systems of 15 kW or less with either a single inverter or multiple inverters	http://www.solmetric.com/
	DDS-CAD PV	Planning and visualization of complete photovoltaic systems (roof-mounted, roof and facade installation as well as in open spaces)	http://www.dds-cad.net/
	Polysun	Planning, designing and defining the system, also enables to figure out solar yields and energy savings and get an accurate cost analysis.	http://www.velasolaris.com/
	PVSYST	For sizing, simulation and data analysis of complete PV systems. It is suitable for grid-connected, stand-alone and DC-grid (public transport) systems, and offers an extensive meteorological and PV-	http://www.pvsyst.com/en/

Category of software tool	Tool name	Main functionalities	Website of developer
	PVSYST	components database. This software is oriented towards architects, engineers, and researchers, and holds very helpful tools for education.	
Monitoring and control tools TOOLS	Meteocontrol	Tool for local and/or remote monitoring of photovoltaic systems.	http://www.meteocontrol.de/
	SPYCE - Satellite Photovoltaic Yield Control & Evaluation	A sattelite based tool for remote monitoring and solar yield analysis of photovoltaic systems. The SPYCE methodology was developed by the EU project PVSAT. Some of main features are: Automatic failure detection and alarm dramatically minimizes any down time. Failures may be detected before expiry of warranty. No on-site radiation measurements are required. The SPYCE website allows access to the system's yields, reference values and analyses at any time.	http://spyce.ch/
	pvSpot solargis	An online tool that offers accurate yield-to-yield comparison instead of yield-to-irradiance comparison. The main advantage of pvSpot is that it provides an independent and reliable analysis of performance of a PV system. pvSpot uses real-time satellite-based solar and meteo data and a new generation software to calculate the expected energy yield of a PV system and does not require installation of any data logger or ground sensors. Hence, simulated yield is not influenced by faulty or ill-maintained sensors.	http://solargis.info/doc/76
Site analysis tools	Autodesk ECOTECT Analysis AUTODESK	Building analysis program that allows designers to work easily in 3D and apply all the tools neccesary for an energy efficient and sustainable future.	http://usa.autodesk.com/ecotect-analysis/
	METEONORM - Global Meteorological Database for Solar Energy and Applied Meteorology METEOTEST	Climatological database for solar energy applications: a meteorological database containing comprehensive climatological data for solar engineering applications at all points of the globe between the polar circles; a computer program for climatological calculations; a data source for engineering design programs in the passive, active and photovoltaic application of solar energy with comprehensive data interfaces; a standardization tool permitting developers and users of engineering design programs access to a comprehensive, uniform data basis.	http://www.meteotest.ch/
	Shadow Analyser	Parametric CAD tool for professionals in the area of Solar Energy Engineering and Architecture.	http://www.drbaumresearch.com/prod38.htm

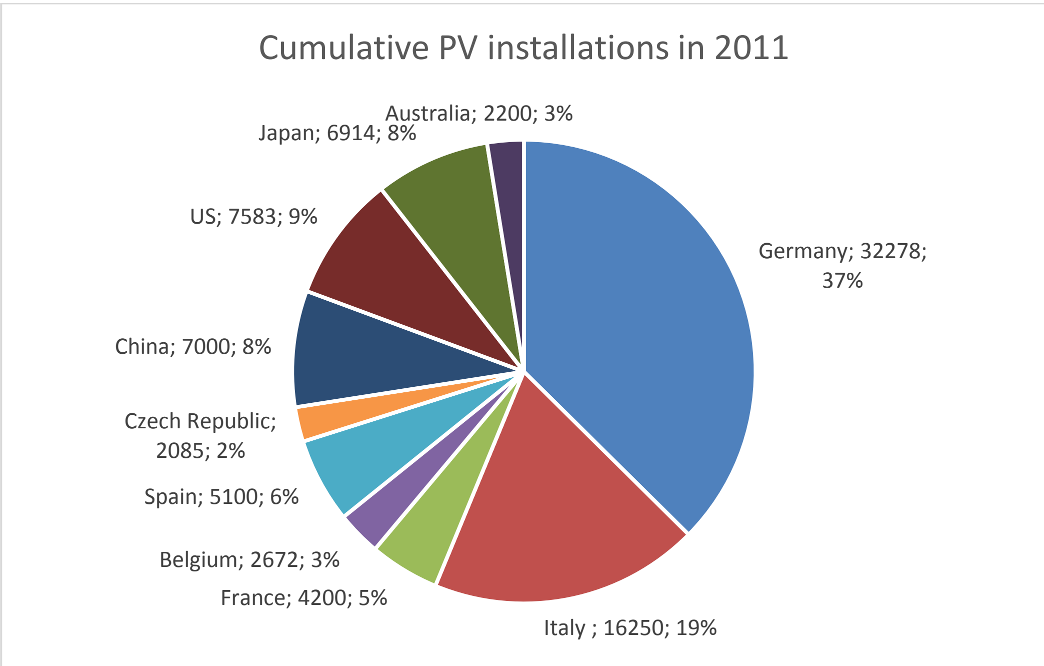
Category of software tool	Tool name	Main functionalities	Website of developer
	Amethyst ShadowFX	A sun and shadow modeling program for architects and town planners, enables to generate shadow profiles cast by buildings and other objects for any latitude, longitude and time of year.	http://www.shadowfx.co.uk/shadowfx.htm
	Sombrero	A tool to calculate shadows on arbitrarily oriented surfaces. For both, active use of solar energy (domestic hot water, photovoitaics) as well as for passive solar architecture, shading or lighting, including the quantitative results for the shading of collectors or windows by buildings, trees, overhangs or the horizon.	http://nesa1.uni-siegen.de/
	Skelion	Solar Energy Design Plugin for Google Sketchup 8.	http://skelion.com/index.htm

2.1.7 Market sizes and segmentation

2.1.7.1 Global and European PV installations

From its emergence on global energy supply system market photovoltaics showed a robust growth and until 2011 reached total installed power of 69 GW. With such capacity 20 million households could be provided with electricity. In terms of installed capacity European countries namely Germany (36% of global installed capacity) and Italy (18%) with Japan, Spain, USA and China were global leaders (Figure 56).

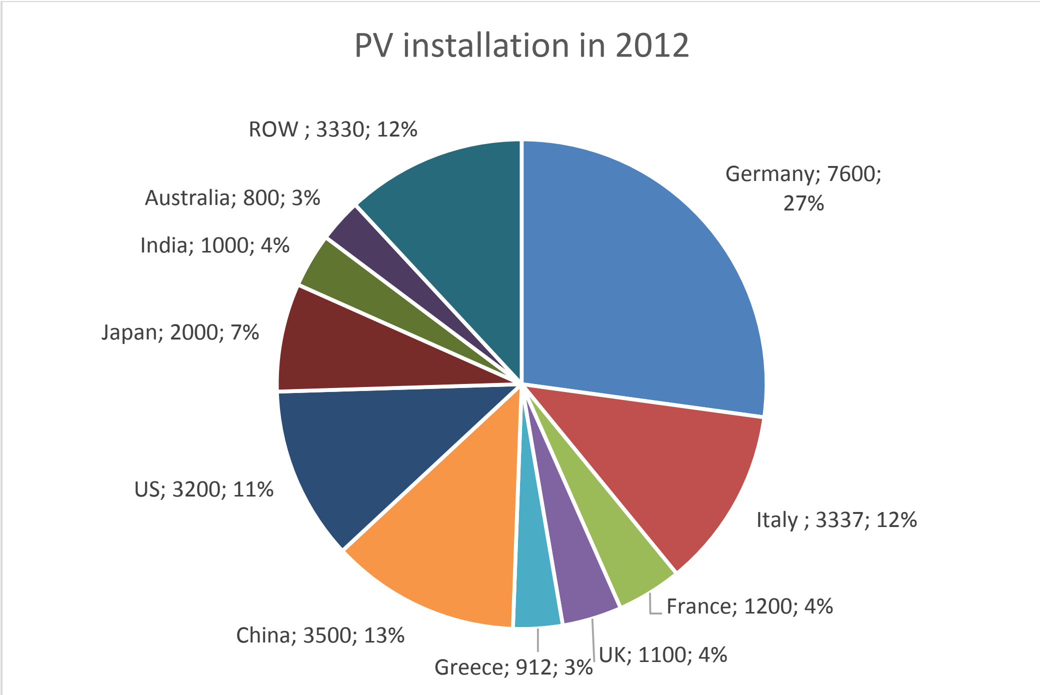
Figure 56: Global cumulative PV installations in 2011[27]



[27] European Photovoltaic Industry Association EPIA. Global Market Outlook for Photovoltaics until 2016. May 2012

Europe maintained leader position, although the line of top 5 installers has slightly changed comparing to 2011: the first place taken by Germany (27% of installation in 2012), the second by China (13%) then Italy (12%) fell in to the third place, USA (11%), and Japan (7%) taken fourth and fifth places respectively. The overall PV installation of the year 2012 is given in Figure 57.

Figure 57: PV installation in 2012



During June 2012 Germany enjoyed a 600 % increase in installations, mainly because few major projects ended at that time (see section 2.1.7.2). Estimations show that total installed capacity will stand for 7.9 GW in 2012, in comparison with 7.5 GW in 2011. Mainly because of second quarter Germany maintained its number one country by PV installations.

Looking at the global prospective, one of the most promising PV installers will be China. It is estimated that China shown more than 50 % Y/Y growth rate. This figure qualifies China straight after Germany as a second largest PV installer. Moreover China is already reducing the solar module shipments to Europe, due to anti-dumping investigation in Europe, therefore the focus on domestic PV installations will be more and more prominent.

Italy, the world's largest PV market in 2011, falls to third place this year with 3.5 GW, down from 7.7 GW.

In fourth place there are United States with 3.2 GW, up from 1.9 GW last year, with significant 79% growth from 1.9 GW in 2011. The market will see another robust 32% increase next year when solar installation capacity reaches 4.5 GW, on its way to some 5.4 GW by 2016.[28]

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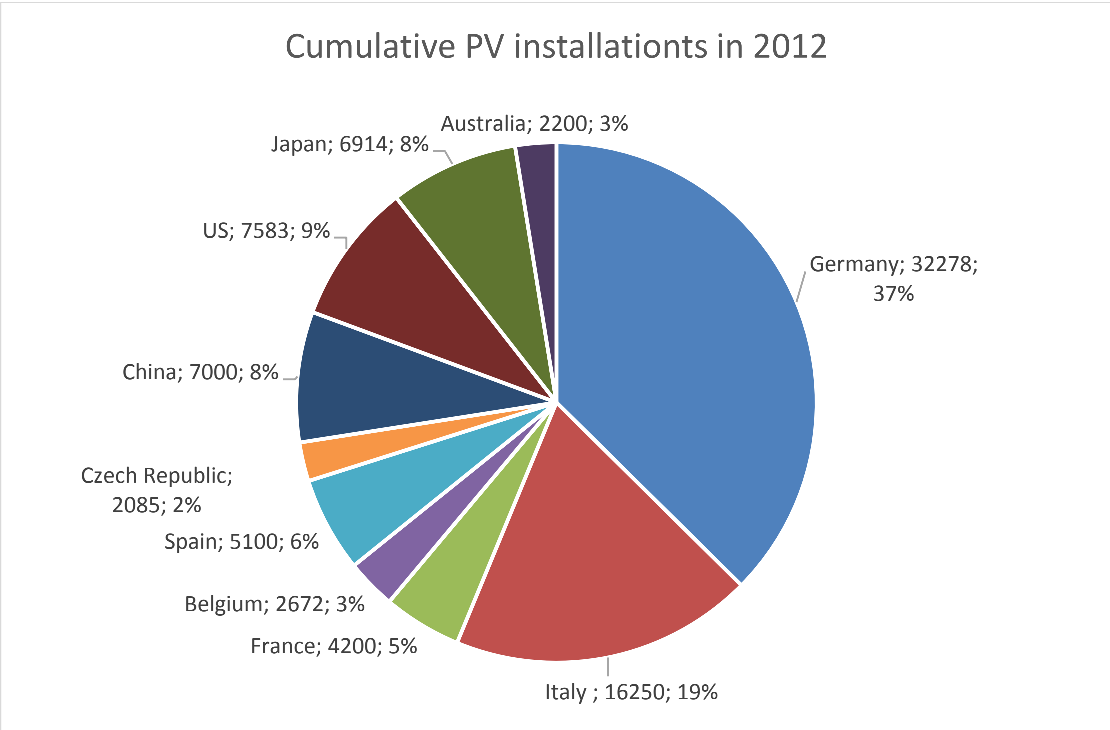
[28]M. Sheppard. IHS iSuppli. PV North America Q3 2012 Market Tracker. October 22, 2012

Japan (as well as China and Germany) is waiting for a new solar subsidy program. If these changes will be adopted quickly, more than a 2.5 GW installations will be implemented (in comparison with 1.3 GW of installations in 2011). Even though with these figures Japan takes a fifth place globally.

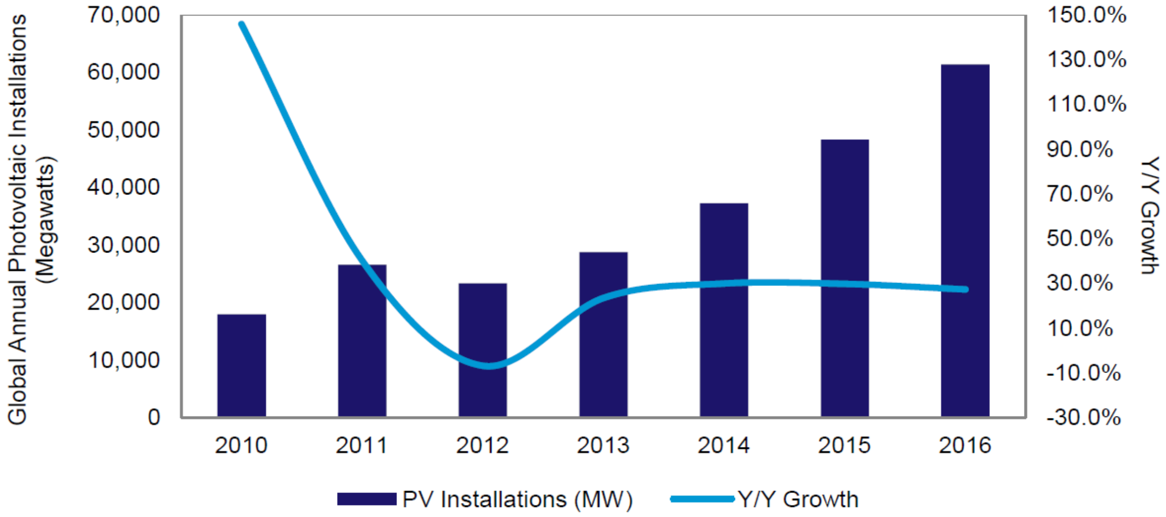
In 2012 important milestone was reached, because global cumulative PV system installations (Figure 58) has exceeded the 100 GW. Globally Europe holds a position and typically Germany is listed in the first place with the over 32 GW PV installations (37% market share). The second place is taken by Italy with cumulative installation of 16.25 GW (19% market share). Together Germany and Italy has 54% of all cumulative global installations.

Figure 58: Global cumulative PV installations in 2012



According to worldwide installation forecast (shown in Figure 59)[15], in 2013 global PV installations will not exceed the 35 GW total peak power, while for the year 2016 the 60 GW of installed peak power is expected to be reached.

Figure 59: Worldwide PV installation forecast and year to year growth rate[29]



Overall, the Europe still holds a worldwide leader position of PV module and system installations, although there are some hints that Asian markets (especially China) could start intensive installations in near future.

2.1.7.2 Major PV installation projects in EU (2012)

As Germany is the global and European leader in PV installation, the majority of European commercial and utility PV installations are implemented in this country, although France and relatively new countries like Bulgaria and Ukraine has already build one of the largest PV parks in Europe. In this section all major PV installation projects held in 2012 are presented.

1. **Neuhardenberg Solar Park.** The largest solar project in Germany, developed by ENFO AG in conjunction with the owner of Neuhardenberg airfield, Airport Development A/S. Solar Park in Neuhardenberg is installed on the grounds of the airfield in Neuhardenberg and has a power of 145MW and covers an area of around 240 hectares. Large PV power plant consists of various type 600 000 PV modules manufactured by various companies and generates electrical power for 48 000 households.

[29] H. Wicht, S. de Haan. IHS iSuppli. PV system demand market tracker. October, 2012

Figure 60: Air view of Neuhardenberg Solar Park

2. **Templin Solar Park**. Solar Park has an area of 214 hectares and will generate 128 megawatt line. The park is built by the Bavarian company Belectric - with First Solar modules in Frankfurt (Oder)
3. **Toul-Rosières Solar Park.** Solar Park (located at the Toul-Rosières Air Base) has a capacity of 115 MW power, which makes it the largest solar farm in France. The project is developed by EDF Énergies Nouvelles (EDF EN). The solar park has about 1.4 million thin-film PV panels made by First Solar. It covers area of 367 hectares. In 2012, the Luxembourg-based Marguerite Fund acquired 36 MW stake in the solar park. 24 MW stake was sold to the independent power producer Sonnedix.
4. **Karadzhalovo Solar Park.** Solar Park is situated in Bulgaria has a capacity of 60.4 MW with 214 000 photovoltaic panels. Solar farm was built by American based company SunEdison, which invested in the solar park along with a subsidiary of the MEMC Electronic Materials. The project cost EUR 191 million, of which EUR 155 million were lent by the International Financial Corporation (IFC), part of the World Bank, UniCredit Group, and Overseas Private Investment Corporation (OPIC). UniCredit Bulbank Bulgaria also funded the project. The IFC ensured EUR 46.1 million, UniCredit - EUR 41.1 million, and OPIC - EUR 50 million. UniCredit Bulbank granted a EUR 30 million loan.
5. **Starokozache Solar Park**. Solar Park was constructed through two phases. Overall, the plant takes 80 hectares of land and is comprised of 185,952 multicrystalline photovoltaic modules. Power plant will generate 54,106 megawatt hours of electricity annually – enough to meet the needs of around 11,000 households. Starokozache Solar Park was constructed by Austrian company Active Solar.
6. **Jannersdorf Solar Park.** Solar farm situated in Brandenburg (Prignitz) generates 40.5 MW and takes 90 hectare of area. PV plant consists of 167,550 Trina Solar, Suntech and Hareon modules as well as 1,894 Siemens inverters and

5.216 Schletter module tables. The project was implemented by Parabel who will also hold responsibility for the management of the solar park.

7. **Pompogne Solar Park.** The park covers a total area of 75 hectares, comprising four sections and a central transformer station, was planned and built by north German general contractor GP JOULE. The energy generated by the four sections of the solar park is fed into four transmission routes with a total length of 57 kilometres. Approximately 175,000 modules from REC Solar und 57 central inverters from Refusol have been installed on the four sections.
8. **Litten Solar Park.** The plant provides 38 Megawatts of peak electrical power, which could satisfy 10 000 households, although the plant has not been connected to grid yet. The plant comprises 160 000 Chinese made modules. The solar farm was built by Eneraparc residing in Hamburg Germany.

Figure 61: Litten Solar Park situated near air runway

9. **Delitsch Solar Park**. The solar park Delitzsch was developed by the Enerparc team Leipzig and financed and implemented by Enerparc group. The unused commercial space in the city Delitzsch was sold to the Enerparc group in May. The construction of large-scale solar plant took only six weeks. In record time, over 140,000 solar modules were mounted on an area of about 51 hectares and produce now more than 30 million kilowatt hours of climate-friendly electricity per year.
10. **Güstrow Solar Park.** The nominal capacity of solar farm is 31 megawatts, equals to 8 000 household energy expenses. The solar farm is constructed on former sugar factory and take the 75 hectares area.

Major PV projects installed until 2012 last quarter are summarised in the table below.

Table 18: Major PV projects installed until 2012 last quarter

Name	Location	Nominal power (MW_p)	Construction cost (M€)	Plant type	Project financers and developers	Year completed
Neuhardenberg Solar Park	Germany	145		Monocrystalline silicon PV modules	Airport Development A/S ENFO AG	October 2012
Templin Solar Park	Germany	128.48			Belectric	September 2012
Toul-Rosières Solar Park	France	115	430	Thin-film PV panels	EDF Énergies Nouvelles	November 2012
Karadzhalovo Solar Park	Bulgaria	60.4	191		SunEdison	March 2012
Starokozache Solar Park	Ukraine	42.95		Multicrystalline silicon photovoltaic modules	Activ Solar	July 2012
Jännersdorf Solar Park	Germany	40.5		Polycrystalline silicon silicon PV modules	Parabel AG	June 2012
Pompogne Solar Park	France	40			GP Joule	June 2012
Litten Solar Park	Germany	38.3			Enerparc Group	September 2012
Delitsch Solar Park	Germany	32	50		Enerparc Group	June 2012
Güstrow Solarpark	Germany	31			Wirsol Solar AG	September 2012

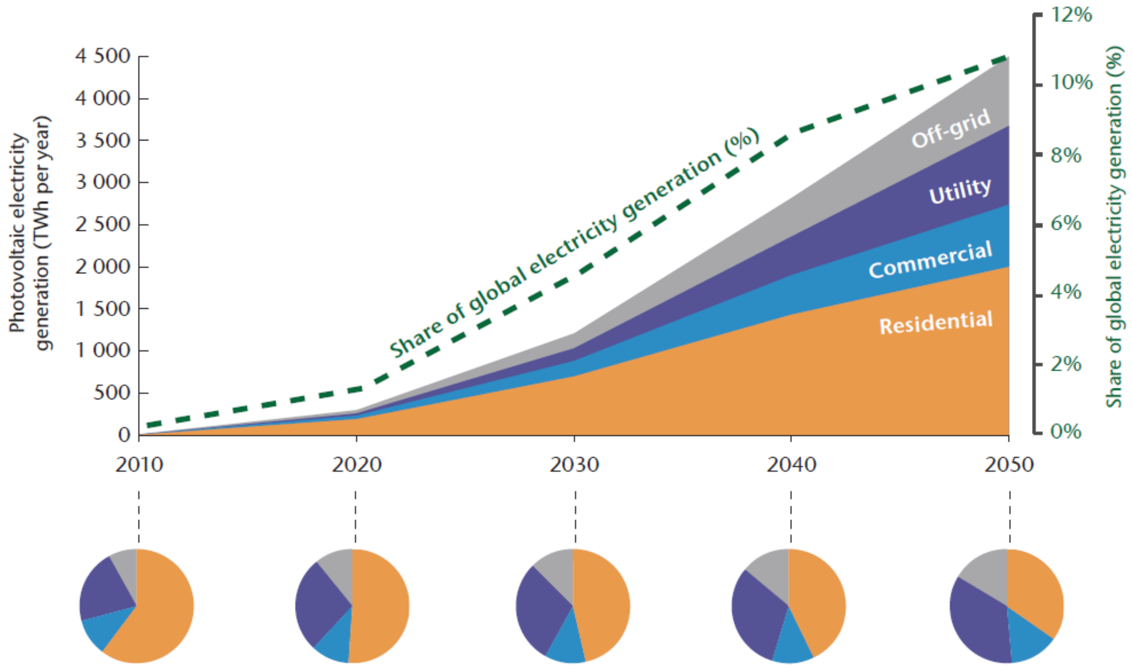
2.1.7.3 PV market segments

The PV market segmentation depends on the different authors. While the global PV market is divided into off-grid, residential (below 20 kW of PV power plant), commercial (below 1 MW) and utility (larger than 1 MW), segments, the European market is classified into ground mounted, commercial/industrial and residential segments.

According to Figure 62[30] more than 50% of the PV installations were implemented in residential segment in 2010. At the same year, the second place was taken by utility segment and stood for approximately 20% of overall PV installations. It is foreseen that the residential installations in upcoming years will shrink below the 50% market share, while the utility will show the most intensive growth and will reach more than a 20% market share in 2020. The further decrease of residential segment and the constant growth of utility segment is expected after 2020 because of emerging new market segments from countries of high solar irradiation (Sun Belt countries).

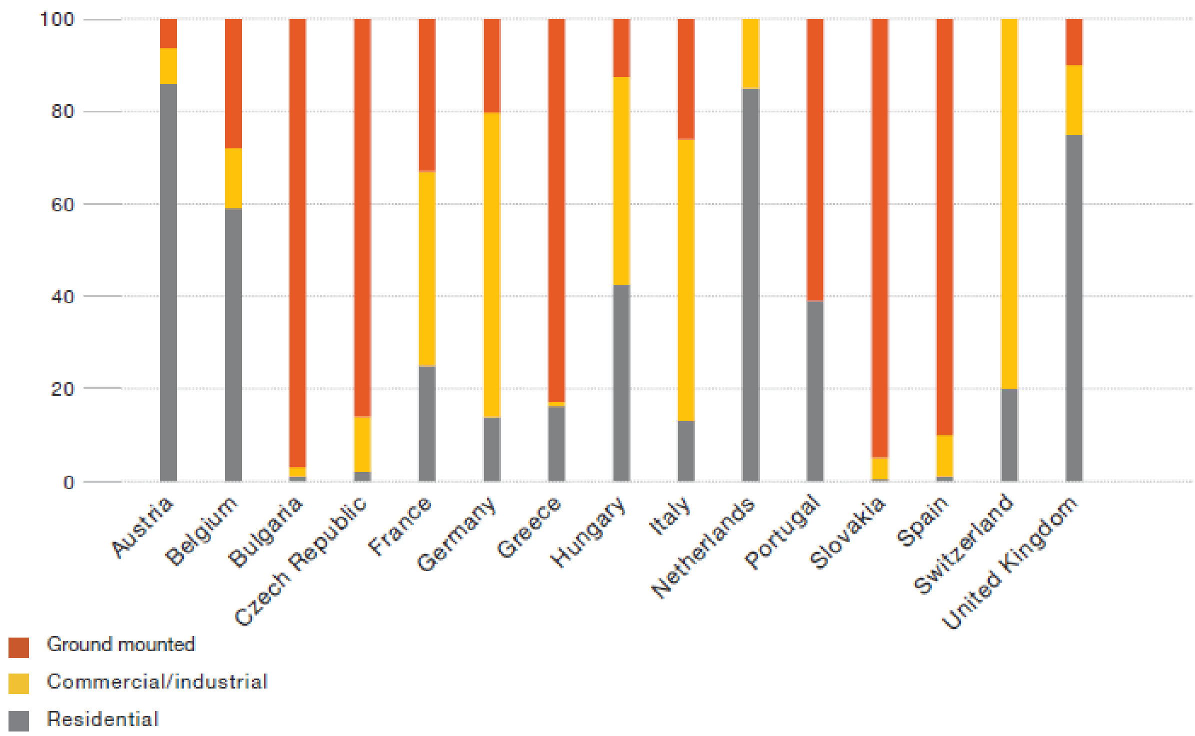
[30] International Energy Agency. Technology Roadmap: Solar Photovoltaic Energy

Figure 62: Global PV market segmentation[30]



The European PV market segmentation is implemented differently mainly because it depends on the regional structure of support schemes. The 2011 European PV market segmentation is shown in Figure 63 which shows the high concentration of commercial rooftop segment, this trend will be noticeable in upcoming years.

Figure 63: European PV cumulative market segmentation in 2011[31]



[31] European Photovoltaic Industry Association EPIA. Global Market Outlook for Photovoltaics until 2016. May 2012

Overall the trends of global and European segmentation will be different due to European funding schemes. The forecast suggests that the global residential and utility PV market segments will take the largest share (up to 75%). In European region, the ground-mounted PV segment will be constrained and the most intensive installations will be held in commercial rooftop segment.

This insight is providing views for the upcoming needs for new innovative products with clear focus on residential segment as most innovation absorbing sector. Residential segment is supposed to be most growing comparing with other segments and on the other hand is in clear need for non mainstream products which are used in utility segment.

2.1.7.4 PV product supply-demand analysis

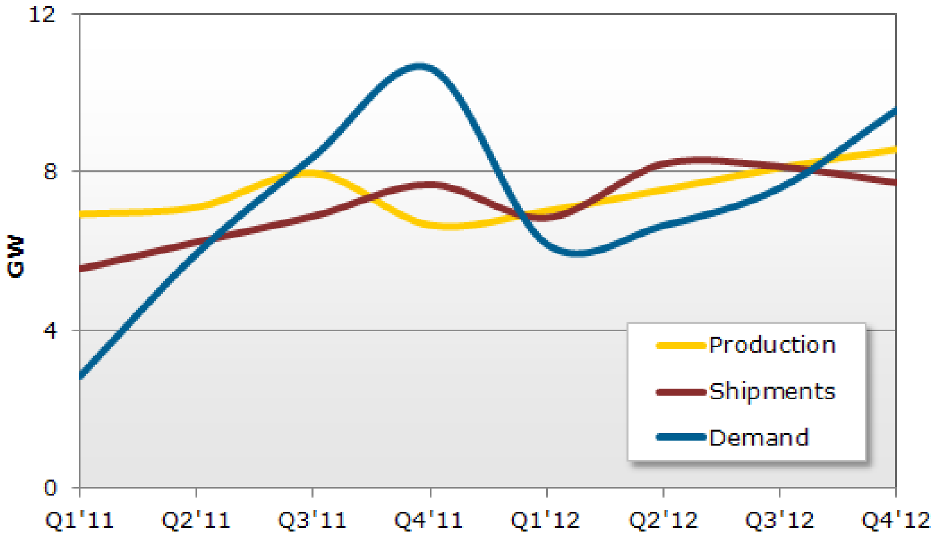
As for 2012, governments in Europe have been reconsidering solar incentive policies and plan to make cuts to subsidies. Major solar markets such as Germany, Italy, and France all face demand dwindling. However, many new markets such as Japan, China, India and the US have emerged due to cost reductions of the solar PV systems. Strong demand from these new markets may offset the impact of the decreasing markets in Europe. Further growth ofPV market is expected due to the raising demand in developing countries of high solar irradiation where growing need for electricity supply is mostly expected.

Capacity expansions taken up by the solar firms in recent years have caused situation when supply significantly exceed demand especially during the last 18 months. Hence, despite a continued increase in demand, the industry will likely continue to suffer due to oversupply.[32]

Global PV demand for 2012 is expected to exceed 30 GW (up 8% Y/Y), driven by strong Q4'12 pull from emerging Asia Pacific regions, in particular China. With a 2H'12 demand of over 5 GW, the growth of the domestic Chinese market will provide welcome relief for Chinese c-Si manufacturers, more than offsetting any impacts from the recent US Department of Commerce (DoC) ruling or potential 'anti-dumping' filings within Europe (demand-supply analysis shown in Figure 64).[33]

[32] C. Liang, DIGITIMES Research, Taipei. April 2012
[33] Michael Barker. Asia Pacific Major PV Markets Quarterly. 2012

Figure 64: Supply demand dynamics through period of 2011-2012[34]



Price increases will first impact firms that lack improved technologies and have relatively higher production costs. Asia-based firms will continue to increase their market share. However, the supply chain is not likely to get rid of an oversupply problem until 2014 when demand shows significant growth and excess capacity exits the market.[11]

2.1.7.5 PV module manufacturers

During last decade there was noticeable manufacturing power transition from western to eastern countries: USA and Europe had PV cells and modules manufacturing companies reaching over 80% capacities of whole world. Until 2012 the production leadership shifted to Asian countries namely Japan, China and South Korea. By 2011, 12 of the top 15 manufacturers were situated in Asia. Moreover, in 2011 more than 60% of global production capacity accumulated in China and Taiwan while Europe and Japan accounted only for 14% and 5% respectively. US share of global PV production capacity decreased to 4% (32% of tit was thin film manufacturing) in 2011.

It is expected that over 180 PV module manufacturers will leave the market or simply will be acquired by larger market players. According to study carried out by GTM researchers,[35] cost per W_p of manufactured PV module in China stands for €0.43-0.51, as the manufactured PV module cost per W_p of PV module manufactured in western countries exceeds €0.80, therefore, they will not be able to compete with such price gap. All in all, the ensured transition of manufacturing capabilities from western to eastern countries will be noticeable in next coming years. GTM researchers also forecast that following market leaders will hold their position and will be safe from any acquisition or market exit possibilities until 2015:

- Canadian Solar manufacturer of crystalline PV cells and modules;

[34] NPD Solarbuzz Quarterly report. Q2, 2012
[35] S. Mehta Global PV Module Manufacturing 2013: Competitive Positioning, Consolidation and the China Factor

- First Solar, leader in CdTe thin film PV module manufacturing;
- Hanwha Group, a manufacturer of PV cells and modules
- JA Solar, a producer of monocrystalline PV cells;
- Jinko Solar, of Haining, China, a manufacturer of PV cells and wafers;
- SunPower, a producer of manufactures PV roof tiles and solar panels based on a silicon all-back-contact PV cell;
- Talesun, a high quality PV module manufacturer;
- Trina Solar, manufacturer of crystalline PV modules;
- Yingli Solar, manufacturer of crystalline PV modules.

In following sections, the crystalline silicon and thin film manufacturers will be presented.

2.1.7.5.1 Global crystalline silicon PV module manufacturers

The top global crystalline silicon PV module manufacturers list is given in Table 19. Yingli Green Energy took the first place with the module shipments of 2.2 GW, which is the record of any PV module supplier in the world. Another most noticeable change was made by JA Solar which took the 8 place in the list, and was registered as number 15 on year ago. The reach result was made due to the JA Solar change of business model and expanded c-Si manufacturing capacity. Total module shipment from the top companies was equal to less than 50% of global module demand in 2012. The top manufacturer of thin film PV module is registered second in this list.

Table 19: Top 9 crystalline silicon PV panel manufacturers[36]

2012 Ranking	Company	Country	Change from 2011
1	Yingli Green Energy	China	+1
2	Suntech	China	-2
3	Trina Solar	China	-1
4	Canadian Solar	Canada	-
5	Sharp Solar	Japan	-
6	Jinko Solar	China	+2
7	JA Solar	China	+7
8	SunPower	USA	-1
9	Hanwha SolarOne	China	-3

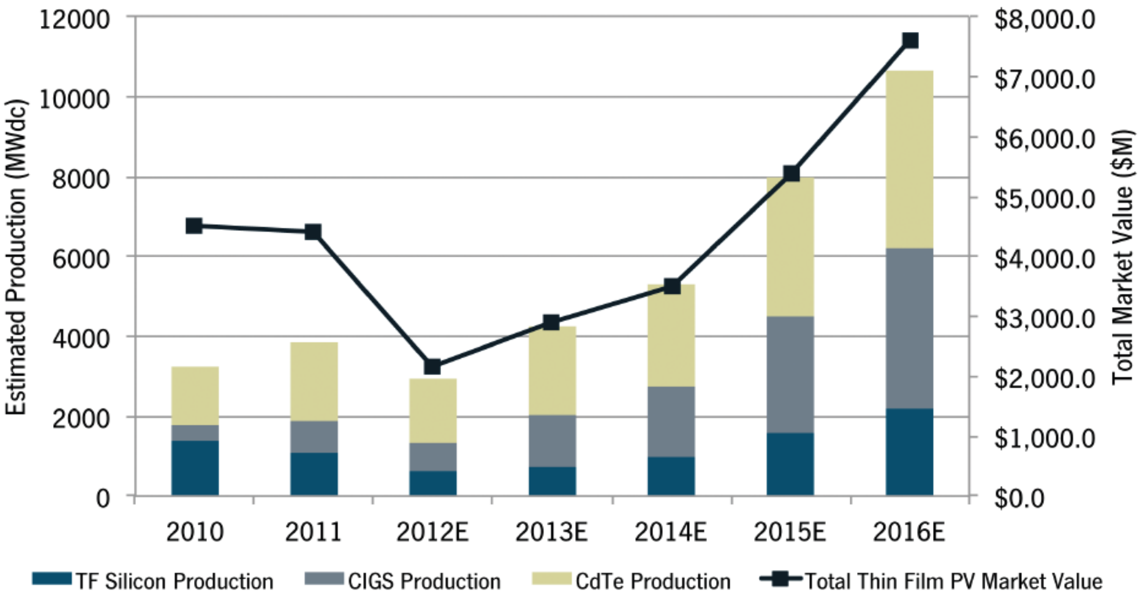
2.1.7.5.2 Global thin film PV module manufacturers

This particular solar PV thin film market has its own trends which significantly differ from overall or crystalline silicon PV module market. During 2004-2009, thin film PV module market has been through several ups and downs: thin film PV module shipments grew from 68 MW to 2GW worldwide. On 2009 thin film stood for 18% PV cell market share and showed no signs of slowing down. During 2009-2011, due to raw silicon price fluctuations, the new polycrystalline silicon raw material emerged as viable solution for

[36] NPD Solarbuzz. Analysis featured in forthcoming Marketbuzz report. January 2013

solar cell wafers. Although until 2011 the total thin film shipment grown to 3.7 GW, cheap polycrystalline silicon raw material started to concur the market share from thin films. During 2011-2012 the price of crystalline silicon solar cells drop by 40 weakened the value proposition of thin film PV modules.[37] Figure 65 shows the change of three thin film product manufacturing and total market value. It is estimated that the total produces capacity of thin film was beneath the 3000 MW mark, and the largest market share was taken by CdTe PV modules. The forecasts indicate, that the overall production capacities will increase and exceed 11000 MW capacity.

Figure 65: Thin film market value and production[12]



The view of thin film module manufacturers was intensively changing. In 2012, major market largest manufacturing capabilities and shipments were made by First Solar, which takes the second place in overall PV module manufacturers list.

Table 20: Top 10 Thin film solar panel manufacturers

Manufacturer	Thin film solar cell type	Country	Company group/Joint venture/Parent company
First Solar	CdTe	USA	-
Solar Frontier	CIGS	Japan	Showa Shell Sekiyu
Astronergy	Thin film silicon	China	CHINT Group Corporation
Sharp Solar	Thin film silicon	Japan	Sharp Corporation
NexPower	Thin film silicon	Taiwan	-
Trony Solar	Thin film silicon	China	-
Miasole	CdTe	USA	-
T-Solar	Thin film silicon	Spain	T-Solar Group
3Sun	Thin film silicon	Italy	Enel Green Power, Sharp, STMicroelectronics
Solibro	CdTe	Germany	Q-Cells

2.2 Price competitiveness of PV

The capital cost of PV system is comprised of PV module and Balance of system cost. The PV module price is affected by the raw material price (silicon etc.), PV cell

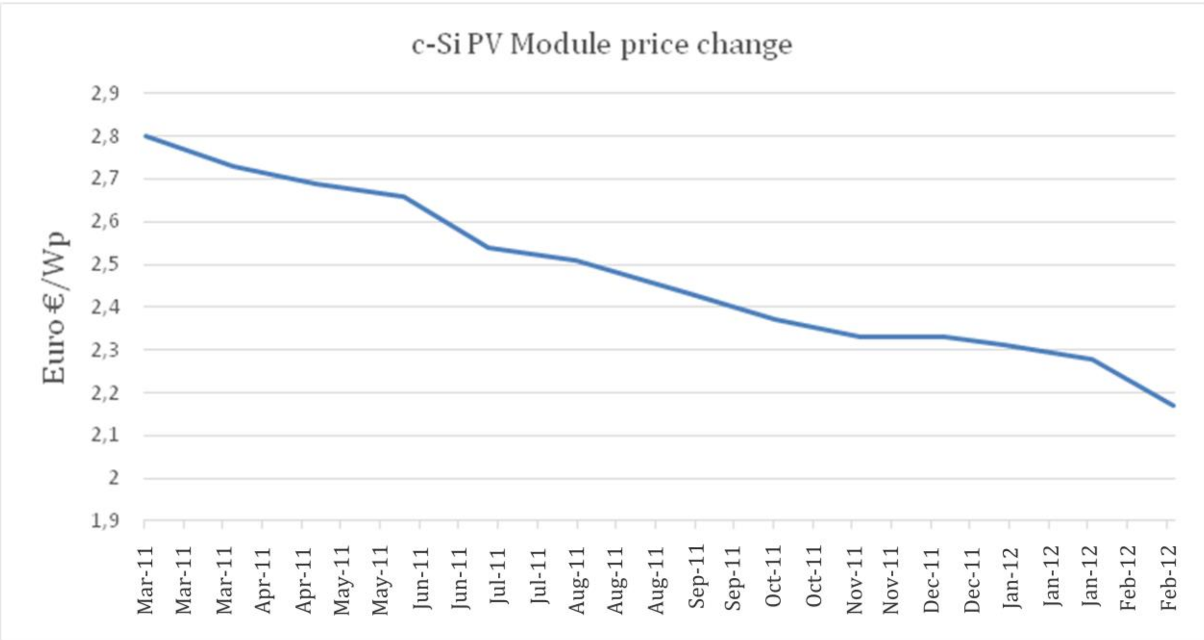
[37] MJ Shiao. GTM Research. Thin Film 2012–2016: Technologies, Markets and Strategies for Survival. 2012

manufacturing and module assembly cost. The Balance of system costs include structural costs (the installation, mounting, site preparation) PV system component costs like inverters, transformers, wiring, battery, monitors and etc. PV system cost also depends on the PV technology is used: the crystalline silicon modules are most expensive while thin film PV modules are significantly cheaper. In this section the historical and most prominent trends of PV prices will be presented. In order to prove the PV price competitiveness and efficiency the factors affecting the PV system cost reduction and investment return analysis will be reviewed.

2.2.1 Installed system pricing

In reference to different studies and reviews[38], the module makes up a 40-50% cost share of overall installed PV system. For that reason, the price of these devices is of high importance. In March of 2011, the average price of crystalline PV module was 2.8 €/W_p and the lowest price did not exceed 0.81 €/W_p (Figure 66). European PV module prices experienced over 20% drop and stood for 2.2 €/W_p in February 2012. According to the latest data, the average PV module below the 2 €/W_p and the minimum is below 0.7 €/W_p.

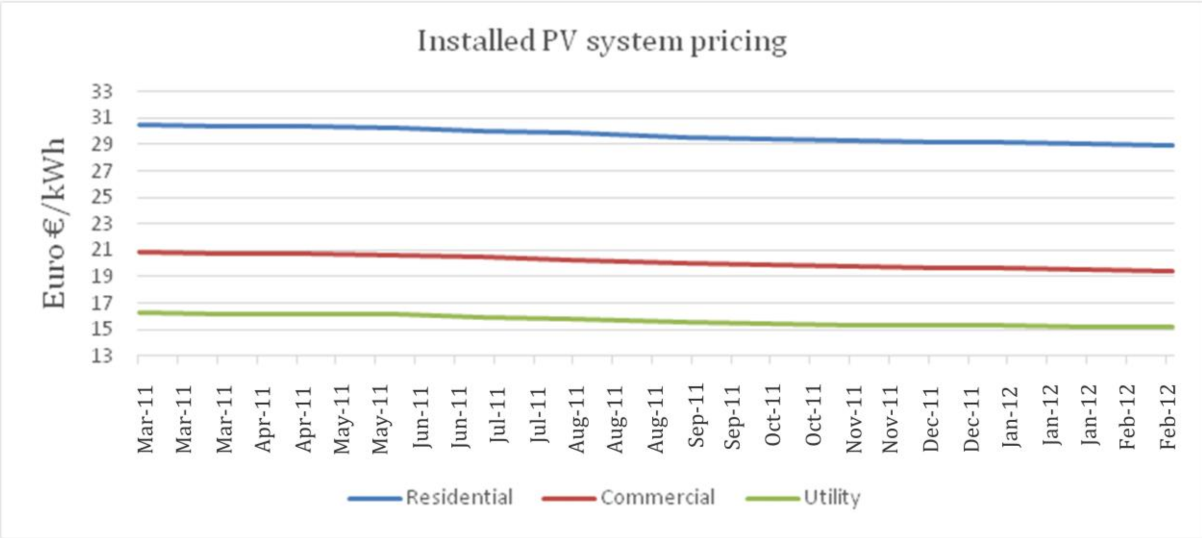
Figure 66: C-Si PV module price evolution between 2011-2012



The PV system price (given in Figure 67 graph) strongly depends on the segment i. e. on the PV power plant output. As residential PV system are usually with the lowest output (below 20 kW) the average price of installed system was around 30 €/kWh in 2011-2012, which is the highest comparing the commercial and utility segments. The prices of mentioned systems fluctuated around 20 €/kWh and 16 €/kWh respectively.

[38] International Renewable Energy Agency. Renewable energy technologies: cost analysis series. Solar Photovoltaics. Volume 1: Power Sector Issue 4/5. June 2012

Figure 67: Installed residential, commercial and utility PV system pricing evolution between 2011-2012



2.2.2 Factors affecting PV system cost reduction

For achievement of grid parity, there is a need for ongoing PV system cost reduction. According to EPIA there are several ways of doing that:

1. **Technological innovation**. In order to introduce advanced PV panels, the research and technological activities are held to increase energy conversion efficiency, to reduce the usage of raw materials (aluminium frames, raw silicon, glass and plastics) or integrate environmental friendly materials (for e.g. bioplastic backsheets) or avoid rear metals. Technological innovation also comprise the next generation PV technology introduction, which could possibly increase the efficiency or cost per watt (€/W_p) ratio.
2. **Diversification of products portfolio**. With new growing market segments for PV products specialised products for niche markets can bring benefits in terms of cost reduction in various value chain segments especially on installation part of it. Plastics replacing metal constructions for on roof installations reducing weight and time, roll on roof modules integral with roof insulation are only two examples of such new products leading to significant cost reduction.
3. **Production optimisation**. As the mass production of PV modules scale up, the companies tend to use more automation which usually leads to reduction of production time and usage of raw materials. Improved PV module processing enable to save up the costs.
4. **Economies of scale.** By building a larger production facilities manufacturers can reduce costs by spreading them between larger amounts of PV module units. It is believed that economies of scale in PV market could be achieved by following points:

- Bulk buying of raw materials;

- Obtaining more favourable interest rates for financing;
- Efficient marketing.

  Estimations show that approximately 22% decrease of cost per unit could be achieved, when production capacities are doubled.

5. **Increasing the performance ratio of PV systems.** The reduction of system losses and increase of performance ratio, enables to reduce PV system cost. Main solutions in this area are the introduction of energy generation and monitoring on the PV module or PV system level. PV module energy generation control is implemented by introducing series of strings comprising PV cells, which could be disconnected from the circuit if the shadowing is present.
6. **Extending the life of PV systems**. Most of the PV module manufacturers give the 25 year warranty, which is considered minimum lifetime. Critical PV module components that are sensitive for long term operation are insulation and encapsulation materials which are susceptible to degradation. Although some manufacturers introduced some alternative materials for example to replace encapsulants, the industry is very cautious because it has to go through series of testing procedures over long-term.

2.3 Detail analysis of new products

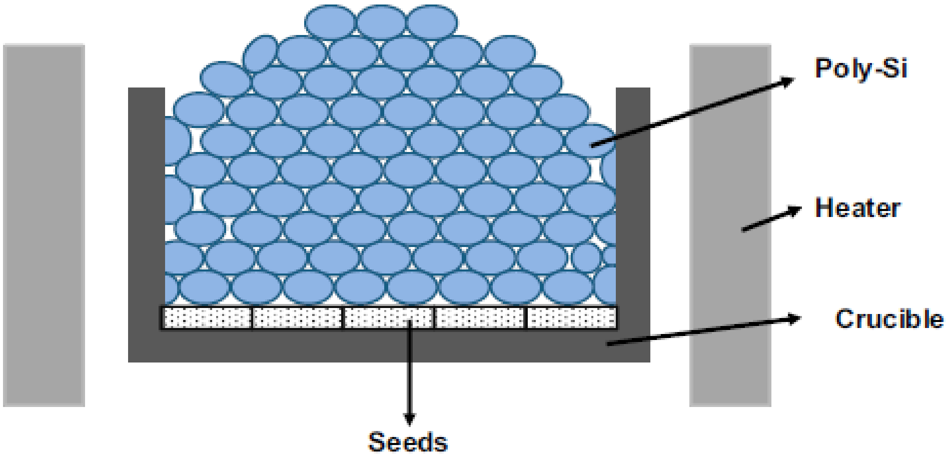
2.3.1 Novel crystalline silicon products

2.3.1.1 Quasi-monocrystalline silicon wafers and applications in PV industry

Crystalline silicon wafers, both the single crystalline and the multi-crystalline (mc) silicon, are the dominating substrate materials for solar cells in current photovoltaic industry. However, these two kinds of materials are not the most appropriate for the solar cell fabrication. On the one hand, compared to the mc silicon, the single crystalline silicon, usually the B-doped p-type Czochralski (CZ) silicon wafers, results in higher solar cell performance due to the low defect density and the well textured surface of low reflectance. But the round CZ silicon wafers have to be cut into pseudo-squares with round corners for the sake of solar modules, leading to the loss of material as well as to the coverage loss in the final module. What is worse, the B-doped p-type CZ silicon solar cells are unavoidably suffering from the serious light-induced degradation (LID) of efficiency under the sunlight, further decreasing the cost-effectiveness of this material. On the other hand, the square cast mc silicon is less expensive and hence more cost-effective for solar modules. But the average efficiency of mc silicon solar cells is far lower than that of monocrystalline silicon cells since the electrical performance of mc silicon solar cells is restrained by the ubiquitous structural defects in them such as grain boundaries and in particular the high density of dislocations in some grains and the metallic impurity precipitate at these structural defect sites. These defects can act as the recombination centre for minority carriers, degrading the bulk lifetime of silicon wafers and further the solar cell performance. Another disadvantage of mc silicon wafers has been recognized as the high surface reflectance after texturing. The random orientation of grains makes the alkali etching futile, and the isochemical etching for mc silicon wafers is far behind the alkali etching in reflectance, which leads to the optical losses of solar cells. Therefore, both mono and mc silicon have their own pros and cons and the decision on the substrate materials of silicon solar cells depends on the trade-off between the power output and the cost. Recently in PV were introduced novel crystalline silicon production technique, which is designed to produce the single crystalline material inheriting the advantages of both mono and mc silicon. This material can become good replacement for available on the market products: having square shape, single crystalline, of low structural defect density and with fabrication cost comparable with mc Si. Due to the indispensability of the crucible in the cast process, state-of-the-art till now is only the cast quasi-single crystalline (QSC) silicon or the so-called monolike silicon, quasi-mono silicon, etc., that is, the cast crystal with one large dominating grain in the centre and small grains surrounded. Recently up to 17% solar cell efficiencies were achieved on QSC wafers using seed-assisted directional solidification (SDS) process. Of course there is still long way forward for this technology to become mainstream material supplier for Si solar cells, but modules with this type of solar cells are already available on the market. In 2011-2012, majority of PV leading companies started to manufacture new type of PV modules comprising quasi-monocrystalline silicon solar cells. At this section, the comparison of new type of silicon raw production process and possibilities to penetrate into PV market will be presented.

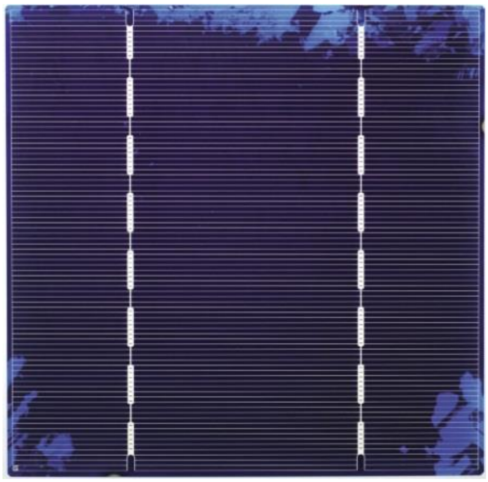
The manufacturing technology is based on directional solidification technique, when the polycrystalline silicon chunks after chemical treatment are placed into to the thermal furnace with the controllable temperature gradients. The most important part of this solidification technology is that the polycrystalline silicon chunks are melted on the top of highly orientated monocrystalline silicon seed wafers (<100> orientation) (shown below in Figure 68). As the direction of thermal front is reversed, the melted silicon is starting to crystallize, accordingly to the seed wafer orientation. The recrystallized silicon block is sliced into wafers and sent for further processing in order to proceed with solar cell production.

Figure 68: Quasi-monocrystalline silicon raw production furnace[39]



Although the technology is similar to multicrystalline (polycrystalline) silicon solar cell technology, the monocrystalline silicon (with high crystallization order) area occupies almost the whole wafer as shown in Figure 69. However, some multi-crystalline grains are unavoidably generated at the edge region of the ingot due to the undercooling near the crucible, therefore high crystallinity area takes 90%.[40]

Figure 69: Quasi-monocrystalline silicon solar cell front view showing different orientation crystalline clusters[41]



At this time quasi-monocrystalline silicon production still remains at the young stage and unsolved problems of non-uniform silicon block formation, complicated control of dislocations and defects aggravates the penetration into the PV market. On the other hand, multicrystalline silicon producers, with some low cost equipment retrofication can

[39] X.Gu *et. al.*, Solar Energy Materials & Solar Cells 101 (2012) 95
[40]Renesola. VIRTUS High efficiency solar modules catalogue. http://www.europe-solar.de/catalog/images/solar/Renesola-virtus-modules.pdf. Reviewed on 14-01-2013
[41]http://www.pv-magazine.com/news/details/beitrag/the-latest-hybrid_100007152/#axzz2HwLirIip. Reviewed on 14-01-2013

use their direct solidification furnaces for a new raw material manufacturing for PV cells with higher overall efficiency and reduced oxygen content.[42]

2.3.2 Kerf-less wafering technologies

Kerf-less wafering tehcnologies hold the promise of cost reduction in one of the most expensive parts of the PV module – raw material - wafers - for the solar cells preparation as kerf-loss currently consumes > 50% of polysilicon. Moreover currently employed sawing is a rough mechanical process and industry is encountering difficulties scaling down wire-sawn wafer thickness. However, despite kerfless technologies are eliminating most costly part of the solar silicon wafering process, conventional ingot wafering step is much less expensive than it was just a few years ago because of several innovations reducing wasted silicon saw dust (kerf) amounts as well as due to the drop in Si prices. On the same time the costs of wafers made by kerfless technologies are still too high and not competitive (Figure 70), especially because solar cells efficiencies produced on these wafers are lower than those of the standard multi-crystalline cells. It is estimated that today higher than 16 percent efficiencies are required when using low-cost processing and significantly higher values are required if expensive processing is employed.

Figure 70: Polysilicon costs per wafer for various kerfless wafer approaches as a function of polysilicon price[43]

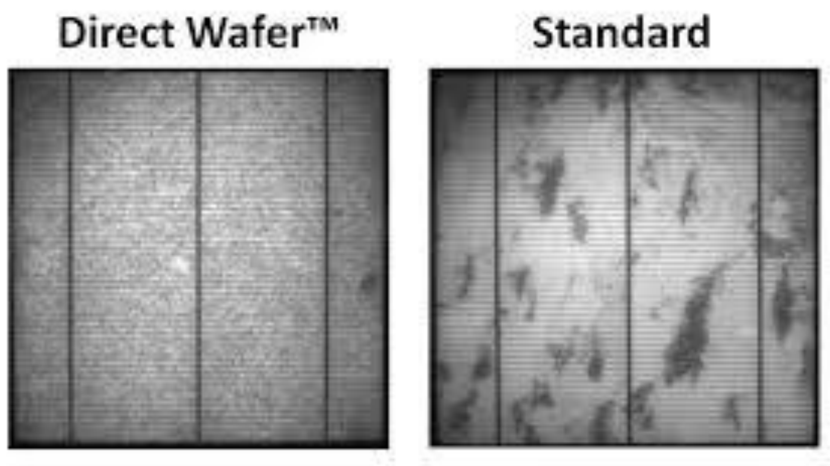
Solexel and 1366 Technologies are the only two firms that show distinct promise to deliver this type of products to the market on competitive price so far:

[42] Dr. P. Dold. Is there a "best technology" in casting? Fraunhofer CSP. PV Fab Manager Forum, March 26, 2012

[43] A. M. Gabor, S. Mehta. Inovations in Crystalline Silicon PV 2013: Markets, Strategies and Leaders in Nine Technology Areas. 2012, GTM Research

- Solexel is utilising technology for exfoliating an epitaxially grown layer (gas-to-silicon) from a donor wafer. This approach is demonstrating cost savings already, but what sets Solexel apart from the competition is company success with innovations at the cell and module level. The company is unique in the kerfless field by virtue of having demonstrated 20 percent cell average efficiencies with champion results as high as 20.6 percent. The firm's 156 mm back-contacted, silver-free cells are larger than Sunpower's (a Solexel investor) and have lower processing costs as well. Fro the integration into module Solexel's cells are attached to a flexible carrier. While the firm's success at low volume is impressive, it will need to demonstrate robust reuse of the monocrystalline substrates in mass production (higher than 30 reuses) and this can be most sensitive issue scaling up this technology.
- Also promising is 1366 Technologies approach with its Direct Wafer technology (Figure 71). These wafers, grown directly from molten silicon, look remarkably like standard square multicrystalline wafers, albeit with smaller grains. Small-grained wafers with lower dislocation density likely represent the direction for the multicrystalline industry. Direct Wafer produces one wafer at a time so each wafer sees identical processing conditions, enabling more spatially uniform wafers with lower dislocation densities and impurities. This unique feature offers a roadmap for cell efficiencies above those offered by the conventional ingot casting and sawing wafer process.

Figure 71: Comparison of Direct Wafer and Standard solar cells



Direct Wafers also have much more consistent quality than multi wafers, and the resulting cells have an extremely narrow efficiency distribution. The efficiency tail (yield loss) of a standard multi cell line is largely due to low-quality wafers, so there is considerable value in uniformity of the parameters demonstrated by this technology. Cell efficiencies in customer trials using standard processing are now above 16.5 percent. In only a few years of development, Direct Wafer technology has surpassed String Ribbon performance. The potential savings in polysilicon feedstock has dropped to less than €0.14 per wafer as feedstock prices have plummeted to €15 per kilogram. However, Direct Wafers still enjoy considerable cost savings for avoiding the ingot and wafering steps, with projected total savings of more than €0.33 per wafer even at €15 per kilogram feedstock prices. Scaling is expected to begin in 2013.

Two kerfless wafer companies shut down their operations: Twin Creeks sold its intellectual property and other parts to GT Advanced Technologies - for non-PV applications; and silicon-film-on-metal-foil company Ampulse found no exploitation opportunities for its National Labs-developed technology. Some other companies are still struggling with achievement of anticipated efficiencies:

- Crystal Solar has a similar epitaxy approach to that of Solexel, but uses a less advanced cell structure using p-type wafers supported by a coverglass carrier.
- AstroWatt has only reported 14.9 percent cell efficiencies with advanced and expensive heterojunction cell processing.
- AmberWave is pursuing technology with similarities to the Solexel approach where silicon films are epitaxially grown on monocrystalline substrate wafers, and then a flexible carrier of steel or other materials is bonded to one or more wafers and the films are exfoliated from the substrate wafers. However, no achieved efficiencies are reported so far.

2.3.3 Novel thin film silicon products

2.3.3.1 Flexible ultra-thin silicon and applications in PV industry

As it was presented on section 2.1.4, current flexible PV market is led by copper gallium diselenide (CIGS), amorphous silicon, and organic (OPV) modules. Due to insufficient efficiencies and resulting lower generated power, the overall market share of flexible PV is in a downturn, which is expected to continue, as crystalline silicon price is decreasing. At the end of year 2012, new product line emerged on PV market, which combines, the crystalline silicon efficiencies and flexible PV module low prices – flexible ultrathin silicon PV modules. The new PV market product line is introduced by US based company Solexel. The basics of exploited technology is taken from the deposition of LED (light emitting diode), when ultrathin monocrystalline silicon cell film is deposited on substrate. The Solexel technology is patented[44] and is based on the Chemical Vapour Deposition (CVD) technique. The other important process is the separation of deposited ultra-thin silicon film (35 μm thickness) from the substrate, which patented under US patent 8,193,076.[45] Solexel technology steps (shown in Figure 72) are following:

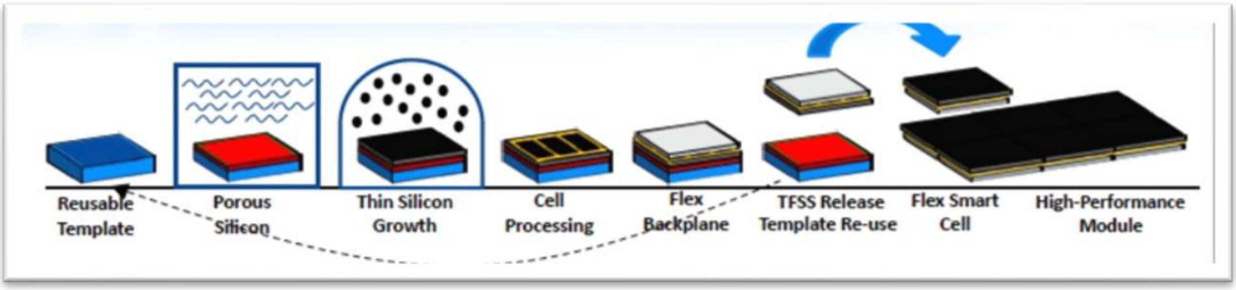
1. Reusable monocrystalline silicon template is put into the porous silicon deposition chamber.

[44] M. M. Moslehi. US patent 8,193,076. Three-dimensional thin-film solar cells. . Solexel, Inc. 2011

[45] M. M. Moslehi *et. al*. US patent 8,035,028. Double-sided reusable template for fabrication of semiconductor substrates for photovoltaic cell and microelectronics device manufacturing. Solexel, Inc. 2011.

2. Deposited porous silicon film with the template is put in to the CVD deposition chamber. The ultra-thin silicon layer is deposited at a rate of 2.5 microns per minute.
3. The ultra-thin film wafer is processed in order to form the p-n junction and the back contacts as well as the antireflective front surface for increased absorption rate. Company states that developed solar cell is the largest of the back contact cells.
4. Manufactured cells are integrated with the flexible substrates and integrated into high-performance flexible PV module.

Figure 72: Solexel ultra-thin film solar cell production process[46]



The company is going to produce back contact ultra-thin silicon modules, in order to eliminate shading losses. Owing to back contact usage and high efficiency silicon raw material, the Solexel PV module (Figure 73) (156 mm x 156 mm solar cell dimensions) is expected to achieve the 20% conversion efficiency with a cost of \$0.42 per watt at the module level.[47] The company also is planning to introduce the ultra-thin film silicon modules with the efficiency of 21.5%.

Figure 73: Solexel ultrathin-film back contact silicon solar cell (left) and Solexel PV module (right)[48]

[46] Solexel. Disruptive Technology and Production Process Proven in Semi, Mapped and scaled to Solar. InterSolar 2012. USA

[47] http://www.greentechmedia.com/articles/read/Solexel-Thin-Silicon-Solar-Startup-Raises. Reviewed on the 11th of January, 2013

[48] http://optics.org/indepth/3/7/3. Reviewed on 11th January, 2013

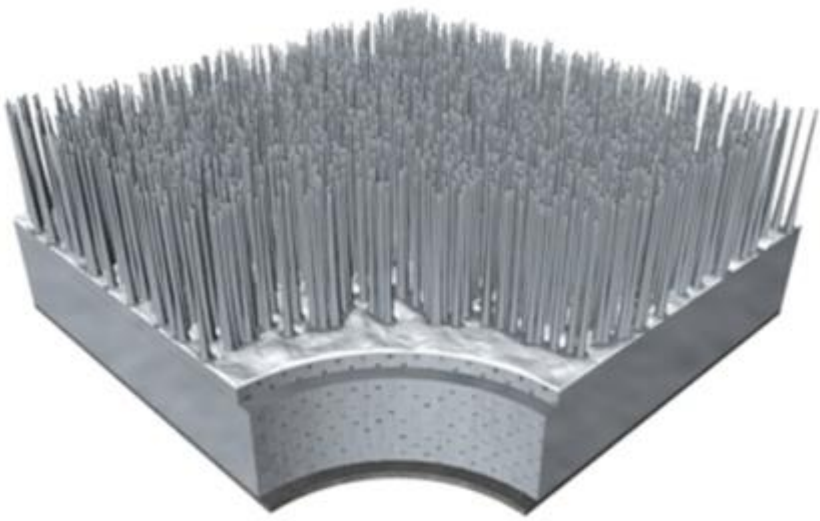
Solarex manufacturing facilities is operating in Milpitas, California, and has signed the memorandum to build the same facility in Malaysia with annual output of 1 GW. In cooperation with Owens-Corning, Solarex will develop BIPV roofing shingle.

Another emerging ultra-thin silicon manufacturers Twin Creek developed technology of solar cell wafers of 20-30 μm thickness and applied the p-n junction formation by the Proton-Induced Exfoliation (PIE).

Ampulse Company claims that their ultra-thin c-Si PV manufacturing technology saves cost for equipment, material, labour and energy simply by exploiting Hot Wire Chemical Vapour Deposition technique to form uniquely textured flexible semiconducting film. Ampulse technology comprises technologies from Oak Ridge National Laboratory (ORNL) and The National Renewable Energy Laboratory (NREL). Manufactured Ampulse PV modules will be frameless; therefore the cost will be lower due to elimination of aluminium, steel and glass. The application areas (Figure 74) will comprise BAPV (Building Applied PV), BIPV (flexible roof shingles etc.) and standard PV modules.[49]

All ultra-thin silicon solar cells manufacturers are using front antireflective structures for increased solar irradiation capturing. The Bandgap Engineering company has developed methods for nano-structuring silicon, which decrease solar cell reflection (at normal incidence) below 1% (in comparison standard c-Si solar cell has 5-8% reflections). The nanostructured front of solar cell enables to absorb solar irradiation in first four microns, which impacts solar cell efficiency and raw silicon usage. The final design of nanostructured solar cell is shown in Figure 74.

Figure 74: Bandgap Engineering developed ultra-thin silicon solar cell nano structure for enhanced absorption over wide solar spectrum[50]



[49] http://www.greentechmedia.com/articles/read/Solexel-Thin-Silicon-Solar-Startup-Raises. Reviewed on 11th January, 2013

[50] http://www.bandgap.com/Device-Design.html. Reviewed on 14-01-2013

2.3.3.2 Silicon ribbon and applications in PV industry

As one more interesting alternative, there are the ribbon technologies that make excellent use of silicon, as wafers are crystallized directly from the melt at the desired thickness and no kerf losses occur. Therefore, they also offer a high potential for PV industry significantly reducing photovoltaic electricity costs as compared to the technologies based on wafers cut from ingots.

Established methods of production based on CZ growth, directional solidification, and ingot casting have flourished, while a new generation of ribbon technologies has moved past the R&D stage into large scale manufacturing and are in competition with these conventional approaches. A number of ribbon technologies, some of which entered R&D already in the early 1970s, have now reached maturity with the start up of manufacturing on a MW scale: Edge-defined Film-fed Growth (EFG), String Ribbon, and Silicon Filmt. Dendritic Web growth and the RGS silicon foil process are moving to pilot demonstration phases. Development has not been continuous for some of the methods listed above. R&D has been interrupted and then restarted in several cases when the technological status changed to generate new opportunities for cost effective production. Dendritic Web, String Ribbon, and RGS R&D all have been strengthened in the past several years after a period of decreased activity in the late 1980s and early 1990s, and after being taken over by new owners. Dendritic Web development was initiated under funding from Westinghouse in 1970s, but now is being carried out by Ebara Solar. String Ribbon technology had an early R&D phase in the 1980s at the National Renewable Energy Laboratory and at Arthur D. Little, before being taken up in 1994 at Evergreen Solar. RGS foil development was initiated at Bayer, but now is continuing with ECN of the Netherlands under a multi-national cooperative agreement with the new owner Deutsche Solar. EFG development has the longest continuous history after Tyco technology was strongly supported with funding from Mobil in 1975. Ribbon and foil technologies face significant challenges and technical barriers if they are to continue to expand manufacturing and to position themselves as competitive in the next decade. Challenges to be met are: productivity increases on a per furnace basis to drive down labor and overhead (capital) costs; improved electronic quality of ribbon wafers together with the development of low cost solar cell designs which will raise efficiencies to 18–20%; and reduction of wafer thickness while maintaining high yields in order to reduce demand on silicon feedstock. Achievement of these goals in the next decade can lead to cost reduction which will drive additional volume expansion for ribbon technology and allow these new generation technologies to become market leaders in silicon wafer production.

Among the different ribbon Si materials, there is the RST which stands for ribbon on a sacrificial template. RST, formerly known as the ‘‘ribbon against drop’’ (RAD) technique, is presently produced at Solarforce. The RST technique is characterized by a vertical growth direction combined with the use of a substrate. So far RST ribbons up to 8 cm in width were grown with thickness down to 80 mm. However, like multicrystalline silicon wafers, such ribbon sheets contain high densities of grain boundaries and dislocations.

In addition, they contain larger concentrations of impurities than single crystalline wafers. The crystal defects and impurities result in recombination centres for minority carriers, which reduce the solar cell efficiency. The particularity of the ribbon materials is that extended defects can be decorated by a higher density of smaller precipitates than in ingot-grown mc-Si because the ribbons are cooled much more rapidly after crystallization. There are mainly two process steps which reduce the recombination in the wafer: gettering of impurities and hydrogen passivation.

In fact, N-type silicon material in general has several advantages over the use of the traditional P-type Si. Thus N-type silicon has been proven to have a higher tolerance to common transition metal impurities, such as those present in silicon produced from quartz and carbon. Consequently, silicon solar cells based on N-type silicon wafers are less sensitive to carrier lifetime degradation due to several common and harmful metal impurities (such as Fe, Ti, V, Mo) than P-base cells. This is mainly due to the much larger capture cross-sections of these impurities in P-type silicon than in N-type silicon. Moreover, N-type wafers generally allow much higher lifetimes than P-type wafers after gettering and passivation. In contrast to boron doped P-type material, boron–oxygen complexes are absent in N-type material. Therefore it will not suffer from lifetime degradation due to formation of a boron–oxygen related metastable defect upon illumination or in general upon minority carrier injection.

Concerning the cell fabrication, the most important differences of the N-type solar cell process compared to P-type are the boron emitter diffusion as well as the front surface passivation and metallization. Due to the lower diffusivity of boron in silicon, the B-emitter diffusion takes place at higher temperatures as compared to that of a P-emitter resulting in the same sheet resistances. Thus, the thermal load for ribbon wafers is higher and present impurity species can diffuse more easily throughout the wafer causing a reduction in lifetime. Further on, the emitter profile of a B-emitter differs from a P-emitter due to a boron rich layer (BRL) present on the wafer surface upon thermal diffusion. Since this BRL is resistant to chemical etching it has to be removed by thermal oxidation subsequent to emitter diffusion and followed by chemical removal.

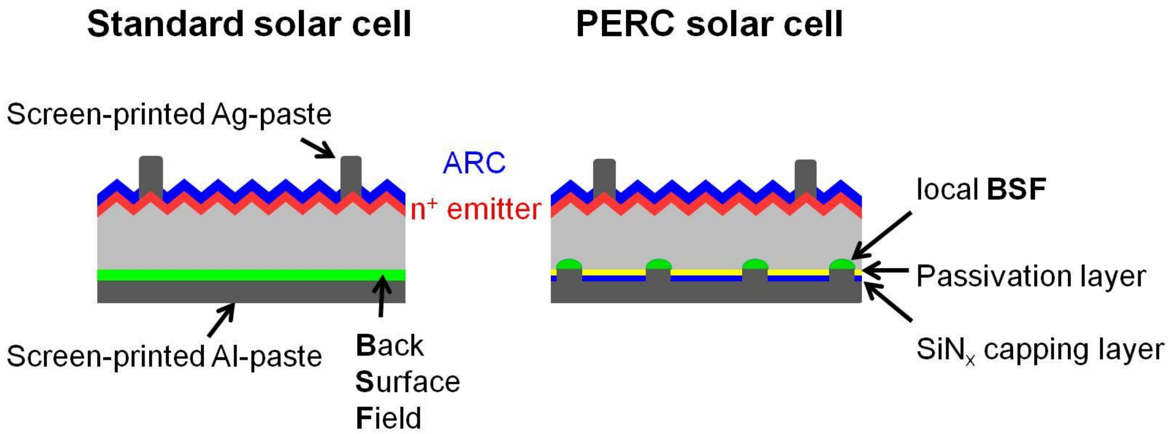
For all these reasons, N-type silicon ribbon is a promising material that can potentially fulfill the objectives of low cost and high efficiency with only modest changes to the current wafer and cell production processes. This tendency in ribbon technologies is in line with overall move of PV industry toward n-type Si based solar cells and if successful can bring additional benefits for these technologies to compete with standard wafering technologies for wafer supply.

2.3.4 New concepts of crystalline solar cells

2.3.4.1 Passivated Emitter and Rear Cell (PERC)

PERC cell concept (Figure 75) is currently most advanced in terms of industrialization Si solar cell design promising industrially, economically justifiable cell of high efficiency and thus overall power increasing technology. It is expected that upcoming manufacturing equipment upgrade in PV Si production lines will be dedicated to the introduction of PERC cell technology on large scale.

Figure 75: Comparison of structures of standard and PERC solar cells. Source: Institut für Solarenergieforschung Hameln, 2012



As it is stated in the abbreviation of this type of the cell PERC solar cell have additional passivation layer on rear side. Rear-side dielectric passivation layers are used to increase of both passivation quality and internal reflectance in comparison to a conventional full-area aluminium back surface field (BSF). The need for better internal reflectance is coming from tendency to utilise in solar cells production thinner and thinner wafers coming to the level when significant part of solar irradiation is going through the Si bulk material without generating carriers. Introduction of passivation layer having reflectance properties leads to an increase in the effective absorption length of light. In this type of cell the full-area aluminium paste applied with screen-printing technology contrary to the standard cell is contacting the rear side of the cell (base) only locally in the areas in which the dielectric layer has previously been removed by a laser or by other means (etching etc.). Another structural properties are situated similarly to current industrial solar cells, namely homogenous emitter is located on the front side which is contacted with a screen-printed silver paste.

Application of passivation layer is allowing to increase overall solar cell efficiency by 1 to 1,5% and on pilot line level implementation is allowing to reach ~20,5% with top achievements reported of 21%.

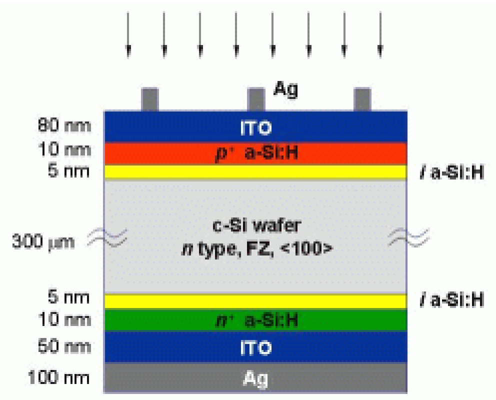
2.3.4.2 PERT/PERL

Passivated emitter, rear totally diffused (PERT) and passivated emitter, rear locally diffused (PERL) cells are further modifications of PERC structure demonstrating better prospects for further increase in cell efficiencies. This type of solar cell is still in laboratory and pilot scale implementation stage and are demonstrating up to 24,5 %. Main innovation in this type of cell is introduction of p+ layer enshuring better cell properties on the rear side. From recent publications it is clear that this cell design also can be brought to industrial implementation in parallel or with slight delay after PERC cell introduction.

2.3.4.3 a-Si/c-Si Heterojunction Solar Cells

Silicon heterojunction technology (Si-HJT) is a hot topic in crystalline silicon photovoltaic as it allows for solar cells with energy conversion efficiencies above 20%, also at industrial-production level. These solar cells consist of thin amorphous silicon layers on monocrystalline silicon wafers (Figure 76). The key point of these structures is the displacement of highly recombination-active (ohmic) contacts from the crystalline surface by insertion of a film with wide bandgap. To reach the full device potential, the hetero-interface state density should be minimal. Practically, hydrogenated amorphous silicon (a-Si:H) films of only a few nanometer thin are appealing candidates for this: Their bandgap is wider than that of c-Si and, when intrinsic, such films can reduce the c-Si surface state density by hydrogenation. In addition, these films can be doped relatively easily, either n- or p-type, allowing for the (lithography-free) fabrication of contacts with record-low values for the saturation-current density. Impressive large-area (> 100 cm2) energy-conversion efficiencies (~23%) have been reported by Sanyo, Japan for such devices.

Figure 76: Schematic diagram of a heterojunction solar cell (drawn not to scale). The basic device features on the front side successively an intrinsic a-Si:H passivation layer and a p-doped amorphous silicon emitter. On top of the silicon layers, an antireflective transparent conductive oxide and the charge collection is made by a screen-printed metallic contacting grid. On the back side, the stack is realized of an intrinsic a-Si:H passivation layer, a back-surface field layer made of n-type amorphous silicon both deposited by PECVD, a TCO layer and a metallic contacting layer[51]



For any high-efficiency solar cell, surface passivation is of extreme importance. Films of a-Si:H have attracted considerable attention for this, and have proved to be on par with the best dielectric films.

2.3.4.4 Novel technological processes for new designs of crystalline solar cells

For the processing of the presented here new concepts of solar cells targeted at incremental improvement of technology the same processing equipment can be utilised with some modifications and/or upgrade. Nevertheless for introduction to the industrial implementation understanding on integrity with existing technological process and cost efficiency of the overall process is needed. Below are presented main issues related with

[51] S. De Wolf, B. Demaurex, J. Geissbuehler, N. Holm, M. Ledinsky, P. Löper, S. Martin de Nicolas, B. Paviet, J. Seif, A. Tomasi. High-efficiency crystalline / amorphous silicon heterojunction solar cells. Photovoltaics-Laboratory (PV-Lab) of IMT, 2012

process modifications and the need for upgrade of equipment introducing new concepts for crystalline Si solar cells

2.3.4.4.1 Emitter formation

A most common and low cost process for the boron emitter formation is high temperature diffusion of boron from various precursors. In existing lines diffusion is carried in a quartz tube or in-line furnace from gases carrying boron.

Alternative processes for B doping are diffusion from doped oxides, screen printing, spin-on, spraying and dispensing. These methods are requiring additional equipment with consequitive use of the same furnance therefore are increasing cost of ownership and must be evaluated estimating value added from the point of the efficiency gain.

There is also growing interest in ion implantation process which has long lasting history in p-n junction formation in semiconductors. This method offers possibility to create very sharp p-n junction which is improving overall junction properties and with implantation equipment available for selective diffusion in semiconductors can become serious competitor for tube furnace diffusions. However, an additional high temperature annealing process is still needed after the ion bombardment of the surface, but of significantly shorter times.

2.3.4.4.2 Passivation

Passivation of the solar cell surfaces was always of high importance reaching high efficiencies therefore for novel concepts of solar cells this technological step is even of higher importance allowing to collect as much as possible of carriers generated by solar irradiation. The main two trends in improving passivation of the solar cell surface are selection of the best suitable material for particular surface (type of p+, n+, p, n) and consequitive deposition technique as well as surface cleaning process that is applied before the creation of the passivating layer. These two technological steps and corresponding equipment have decisive impact on the efficiency of the final device and of coure on production cost.

Passivation of standard p-type material solar cell n+ doped (phosphorus-doped) emitter can be performed by the same equipment without the need for additional investment for deposition of a silicon nitride (SiNx) layer by plasma enhanced chemical vapor deposition (PECVD). This passivation layer at the same time is forming well established and efficient anti-reflection coating.

For the passivation of p+ surfaces this approach is not suitable as for the boron-doped p+ emitter of an n-type cell not only has no passivating effect, but even deteriorates the surface passivation with respect to an unpassivated surface. The most common approach for this type of the surface is a stack of thin thermal SiO_2 and a PECVD SiNx layer. Another solution is an aluminum oxide (Al_2O_3) layer, deposited either by atomic layer deposition technology or PECVD. For this material deposition special equipment is needed which is crucial introducing this process into large scale production.

One more alternative can be boron emitter passivation by a stack of boron silicate glass (BSG) and PECVD SiNx. The advantage of this technique is that there is no need for additional equipment when BSG can be formed during the formation of the boron emitter, while the SiNx requires only standard PECVD equipment as used in p-type cell production lines.

2.3.4.4.3 Metallization

Metallization is always the last step in the process but also very important as sometimes the entire device can be harmed if this is not correctly applied. The deposition of a transparent conductive layer – known as a transparent conductive oxide (TCO) is one of the options for contacting front side of the solar cell. The two most common materials used as a TCO are indium tin oxide (ITO) and aluminum-doped zinc oxide (AZO). Both are usually deposited on the top of the solar cell as thin layers by sputtering. As sputtering is a high-vacuum process, the TCO deposition represents a not insignificant cost contribution, therefore for now can not be competitive to standard metallization processes. Further modification of technology for solar cells with TCO is neded also as TCO layers are not stable against high temperatures, thus the use of low temperature firing metal pastes are required for screen printing of the front contacts.

The classical screen printing process can be applied for all the n-type devices as well. However the pastes have to be modified, p+ surfaces have to be contacted, which is not possible with a simple Ag paste. Therefore AgAl is used and still optimized by all suppliers which offer this product (mainly Dupont, Heraeus and Ferro). The Al in the paste allows a good contact resistance, but strongly reduces conductivity and, in addition, limits the open circuit voltage (Voc) due to penetration into the space charge region. Therefore, paste manufacturers are looking for a substitute of the Al in the paste. In addition to the metallization by screen printing, other screen printed products such as diffusion pastes, diffusion barriers, etching and isolation pastes are gaining more and more importance for advanced cell concepts, not only for n-type but also for p-type devices of higher complexity as in the case of PERC and IBC structures.

2.3.4.4.4 Laser process

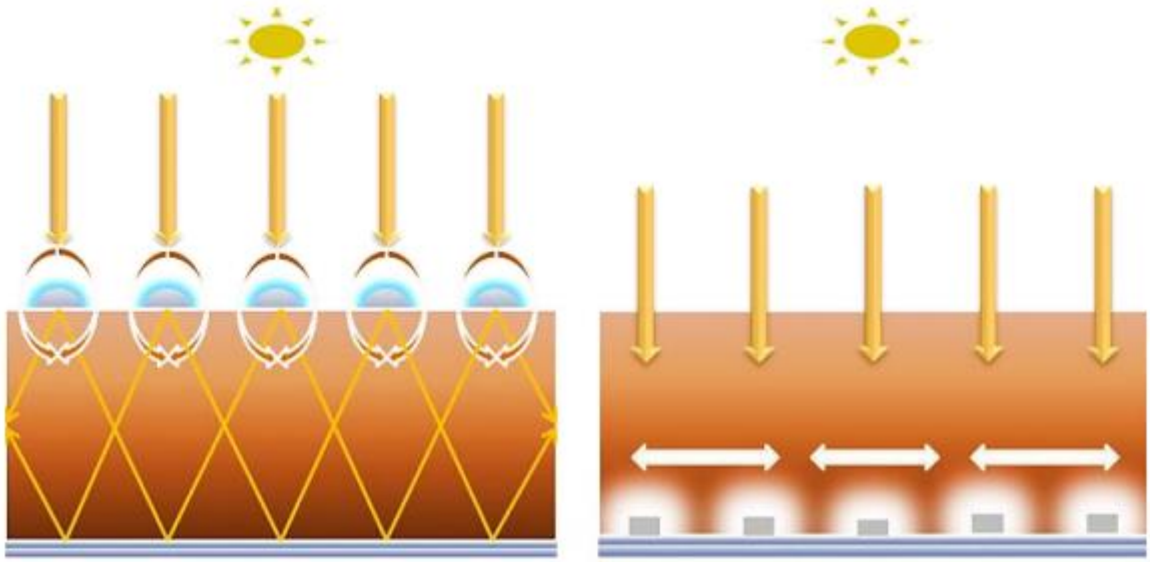
Diffusion barriers are an important topic for processing devices with selective diffusions. Laser processes are getting more and more important for the fabrication of devices of higher complexity. Lasers can always be applied when selective processes are needed as in the case for selective doping, opening of passivating dielectrics or opening of diffusion barriers. For these specific applications, the choice of the right laser power, frequency and operation speed is of highest importance.

2.3.4.5 Solar cell concepts enhanced by nanophotonic approach

In order to improve light trapping (or control) in the bulk of solar cells, the new plasmonic structures were introduced. At this section the usage of plasmonic structures for thin film silicon, organic and other types of bulk material will be reviewed.

From a ray-optics perspective, conventional light trapping exploits the effect of total internal reflection between the semiconductor material (such as silicon, with a refractive index n ~ 3.5) and the surrounding medium (usually assumed to be air). By roughening the semiconductor–air interface, one randomizes the light propagation direction inside the material. The effect of total internal reflection results in a much longer propagation distance inside the material and hence a substantial absorption enhancement. In photovoltaics the front surface metal nano particles are used with the back plasmonic metal grids (Figure 77).

Figure 77: Light trapping in solar cell bulk by using plasmonic structures of nano particles (on the top surface) and back metal grids



Thin film solar cells offer the advantage of reduced material costs but, as absorber layers become thinner, transmission losses increase and reduce cell performance. For thin-film silicon solar cells, the Si absorber has a thickness of the order of only a few micrometers and is deposited on foreign substrates such as glass, ceramics, plastic, or metal for mechanical support. However, the efficiencies of such silicon thin-film cells at the moment are low compared to wafer-based silicon cells because of the relatively poor light absorption, as well as high bulk and surface recombination. Because thin-film solar cells are only a few microns thick, standard methods of increasing the light absorption, which use surface textures that are typically around 10 microns in size, cannot be used. Plasma etching techniques, which can be used to etch submicron-sized features, can damage the silicon, thereby reducing the cell efficiency. Another alternative to direct texturing of Si is the texturing of the substrate. However, this also results in increased recombination losses through increased surface area. Though in practice it has been experimentally proven to be very difficult to reduce recombination losses beyond a certain limit, theoretically energy conversion efficiency of above 24% even for 1 m cells can be achieved. This highlights the need to incorporate better light-trapping mechanisms that do not increase recombination losses in thin-film solar cells to extract the full potential of the cells. Therefore the plasmonic structures are well suited for this type of photosensitive materials.

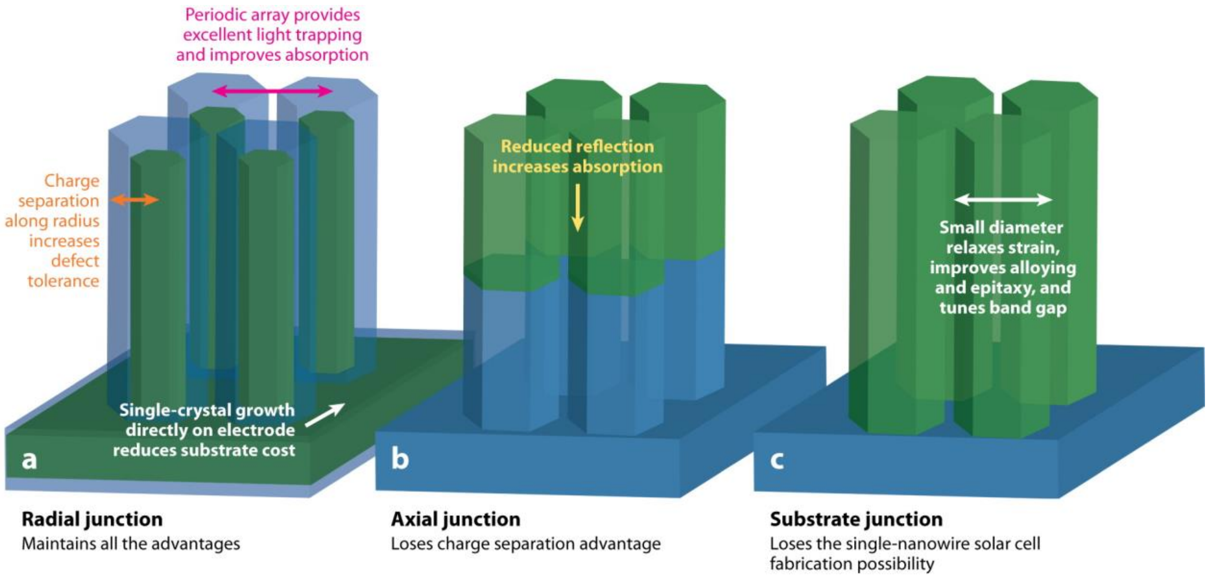
Organic solar cells (OSCs) are attractive due to the advantages of light weight, low cost, suitability for large-area fabrication and mechanical flexibility. Further, the stability of OSCs was improved remarkably in recent years. However, compared with most commercial inorganic solar cells, the efficiency is still the main problem in the practical application of the OSCs. A limitation in most OSCs technologies is that the light absorption depth is 10 times longer than the exciton diffusion length in most polymers (the ‘‘excitonic bottleneck’’), which forces a trade-off between light absorption and exciton diffusion. The inducement of plasmonics by introducing the metal nanostructures into the organic matrix is a promising approach to resolve this problem. Plasmonic structures can improve the absorption efficiency of the photovoltaic absorber layers by preferentially scattering and exciting localized surface Three-dimensional (3-D) nanostructures with high surface to volume ratio are potentially applicable as optical antennas and scattering centres in solar cells. Due to the large surface area and dimension scalability, they can provide stronger scattering and better spectral overlap between the active layer absorption and the Localized surface plasmon resonance (LSPR) of the nanostructures (as the size increases, the LSPR peak red-shifts; further, enhanced optical absorption and improved device performance can be expected.

Hydrogenated microcrystalline-silicon (μc-Si:H) thin films prepared by plasma-enhanced chemical vapor deposition (PECVD) are promising materials for various applications in optoelectronic devices, since μc-Si:H shows high stability under light-soaking conditions and high absorption of light in the near infrared region of the solar spectrum as compared to hydrogenated amorphous silicon (aSi:H). When considering the application in μc-Si:H-based solar cells, light trapping plays an indispensable role in enhancing the photocurrent and efficiency. This is because μc-Si:H has low optical absorption coefficient in the visible range of the solar spectrum due to its indirect band gap. In general, μc-Si:H based substrate type (n-i-p) solar cell allows one to design and fabricate its light trapping schemes before the deposition sequence of the silicon based layers at low temperature, thus offering more flexibility in the choice of fabrication methods. Light trapping method for efficient light absorption using textured substrate with high surface roughness has been utilized as one of the most useful techniques. However, it has been frequently experienced that the photovoltaic performance of μc-Si:H n-i-p solar cells deteriorates by using highly textured substrate due to defective grain-boundary formation, and/or poor surface coverage of p-type μc-Si:H layer. Therefore, a novel back reflector with strong scattering (diffusing) of light to enhance optical path in an intrinsic μc-Si:H active layer, as well as small surface roughness to avoid the deterioration of photovoltaic performance, is needed.

2.3.4.6 Nanorods and nanopillars

In any solar cell, there are many sources of loss that must be minimized. The steps required to convert light to electricity are photon absorption, exciton creation, exciton separation to free carriers, and carrier collection by the electrodes. Using nanowires instead of wafers or thin films provides opportunities to minimize losses in each step at lower costs. The potential cost benefits come primarily from lowering the purity standard and the amount of semiconductor material needed to obtain high efficiencies; increasing the defect tolerance; and enabling new single-crystalline materials to be used without expensive, lattice-matched substrates. The major benefits associated with each photoconversion step are depicted in Figure 78.

Figure 78: Schematic manowired solar cells with indicated benefits over planar cells[52]



Even in the optimal configuration, it is unlikely that nanowire cells will exceed the efficiency limits of planar devices; instead, they relax the requirements needed to approach those limits, opening up the door to low-cost, previously discarded materials and processing options. Functioning nanowire photovoltaics have been fabricated using a wide variety of materials including silicon, germanium, zinc oxide, zinc sulfide, cadmium telluride, cadmium selenide, copper oxide, titanium oxide, gallium nitride, indium gallium nitride, gallium arsenide, indium arsenide, and many polymer/nanowire combinations. Output efficiencies have steadily increased so that most material systems have now achieved efficiencies higher than 1%, with some close to 10%, but a number of unresolved questions must be answered before such materials can be used in commercial devices. Current planar technology imposes lower limits on the quantity and quality of material that must be used to realize high-efficiency solar cells. The nanowire geometry, especially when it incorporates a radial junction, relaxes these requirements, opening up the possibility to use a small amount of abundant, nontoxic, low-cost material to make solar cells with performance close to that of current planar technology. The ability to make single-crystalline nanowires on low-cost substrates such as aluminum foil and to relax strain in subsequent epitaxial layers removes two more major cost hurdles associated with high-efficiency planar solar cells. Despite the tremendous promise offered by nanowire solar cells, some daunting challenges must be

[52] E.C. Garnett et al. Annu Rev. Mater. Res. 2011, 41:269-95

addressed before the benefits can be realized commercially. These challenges include surface and interface recombination, surface roughness, mechanical and chemical stability, fine morphology and doping control, nanowire array uniformity, and synthetic scalability. Great progress has been made in most of these areas, but much more work is needed, especially that related to understanding of surfaces and interfaces. Even if nanowire devices can realize efficiencies comparable to those of planar devices at much lower costs, practical issues that have not yet been seriously explored such as rapid scaling, integration into modules and device packaging must be addressed. The rapid improvements in efficiency within the past five years and the potential for cost reductions far below planar technology limits certainly warrant further research into nanowire solar cells.

2.3.4.7 Next generation PV cell structures for concentrated PV

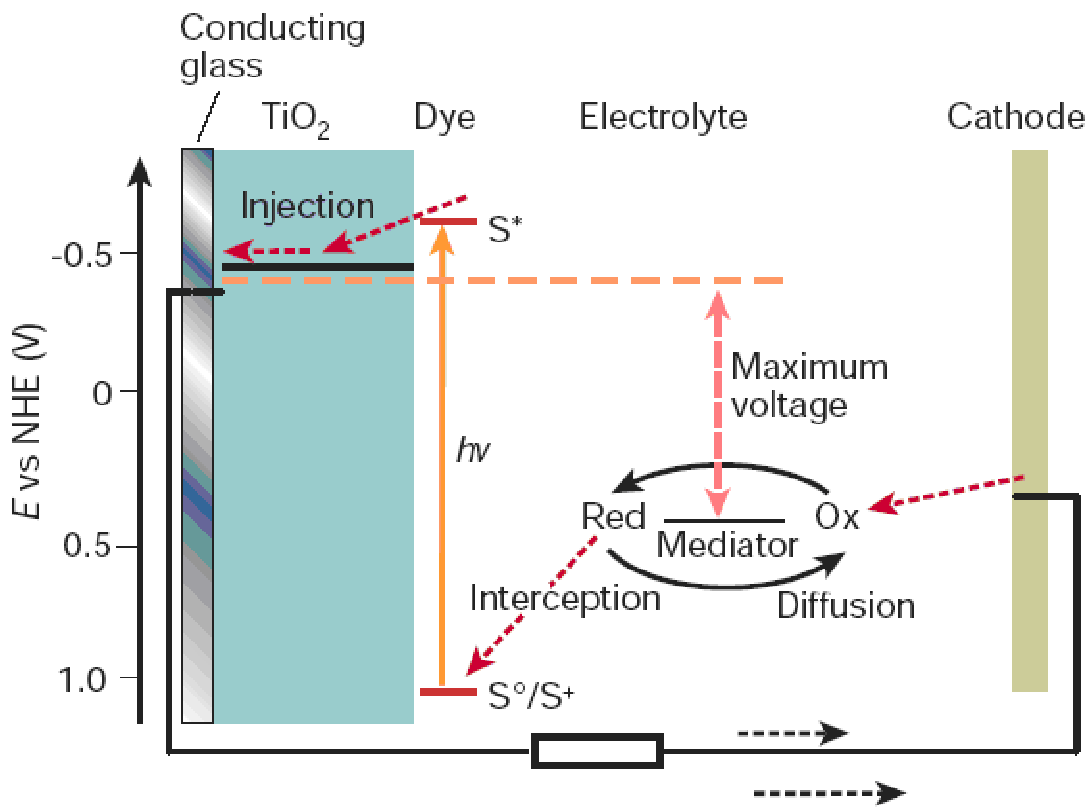
Multijunction solar cells are main working horse for concentrated PV products. One of the promising ways to increase overall multijunction solar cell efficiency is to increase range of solar spectrum which is absorbed in the material. For that wider band gap differences in upper two junctions must be implemented leading to more significant lattice mismatches. This was implemented by proposing 3-junction GaInP/GaInAs/Ge metamorphic (MM) solar cells, when GaInP and GaInAs subcells are grown on a metamorphic buffer such that these two subcells are lattice-matched (LM) to each other, but are both lattice-mismatched to the Ge growth substrate and subcell. The mismatched design provided possibility to grown layers with lower band gaps than it was ossible in LM case. The MM cell design uses a step-graded metamorphic buffer to shift from the lattice constant of the substrate to that of the upper subcells.

Another approach is to introduce higer number of layers with p-n junctions of different band gap. There are developments of 4-, 5- and even 6- junction solar cells to achieve higher efficiency. Of course this approach is causing significant increase in production costs and is not expecting to be transferred to mass production in the near future.

2.3.4.8 Dye-sensitized PV modules

Dye-sensitized solar cells (DSSCs), which are characterized by low cost, high efficiency, and capability for environmental protection, have shown considerable potential as a new generation commercial solar cells. Traditional dye-sensitized solar cell consists of a photoanode, electrolyte, and counter electrode. The photoanode is the critical component of the dye-sensitized solar cell, which is generally a dye-sensitized porous titanium dioxide (TiO_2) film that adheres to FTO glass substrate. In contrast to the conventional PV systems where the semiconductor assume both the task of light absorption and charge carrier transport the two functions are separated here. Light is absorbed by a sensitizer, which is anchored to the surface of a wide band semiconductor. Charge separation takes place at the interface via photo-induced electron injection from the dye into the conduction band of the solid. Carriers are transported in the conduction band of the semiconductor to the charge collector. The use of sensitizers having a broad absorption band in conjunction with oxide films of nanocrystalline morphology permits to harvest a large fraction of sunlight. Nearly quantitative conversion of incident photon into electric current is achieved over a large spectral range extending from the UV to the near IR region.[53] The cross section view of typical DSC solar cell is shown in Figure 79.

Figure 79: Light harvesting in DSC solar cells[54]



The operation of DSC solar cell could be summarized by three steps:

1. Light is absorbed by a dye-derivatized mesoporous film made of a network of undoped (insulating) TiO_2 nanocrystallites.
2. The sensitizer is grafted onto the TiO_2 surface through suitable anchoring groups, e.g., carboxylate, phosphonate or hydroxamate.
3. Light-induced electron injection from the adsorbed dye into the nanocrystallites renders the TiO_2 conductive.

Currently, the photoelectric conversion efficiency of liquid dye-sensitized solar cell using an acetonitrile electrolyte and a platinized FTO as counter electrode, has been demonstrated to attain 12%, which is almost the same as that of amorphous silicon. However, further industrial application faces many problems, including obvious efficiency decline of large area DSSCs module, leakage of liquid electrolyte, expensive transparent conductive materials, and other disadvantages. To address the above

[53] M. Grätzel. Review: Dye-sensitized solar cells. Journal of Photochemistry and Photobiology C: Photochemistry Reviews 4 (2003) 145–153

[54] N Sekar and Vishal Y Gehlot. Metal Complex Dyes for Dye-Sensitized Solar Cells: Recent Developments. RESONANCE. September 2010

problems, researchers have sought for numerous solutions. Solid electrolytes (CuI, CuSCN, Spiro-OMeTAD, etc.), ionic liquid electrolytes, and quasi-solid electrolytes were utilized to replace volatile and corrosive liquid electrolytes. However, the efficiency of the device has been found unsatisfactory. On the other hand, researchers attempted to reduce or avoid the usage of transparent conductive materials. Cheap metal mesh or metal foil was adopted as a substrate of the photoanode to replace FTO. For example, Kang *et al.*[55] prepared flexible dye sensitized solar cells (with efficiency of 4.2%) using stainless steel substrate as the working electrode. Ito *et al*.[56] prepared DSSC (efficiency 7.2%) with TiO_2 film on Ti foil as the photoanode. Fan *et al*.[57] used mesh-like DSSC as the photoanode and obtained 1.5% photoelectric conversion efficiency, which was achieved by coating the stainless steel mesh with TiO_2 nanoparticles. However, these solar cells did not totally get rid of FTO nor addressed completely the leakage problem of electrolyte. Recently, a breakthrough on the flat sandwich design of traditional dye-sensitized solar cells was proposed to improve the simplicity of cell encapsulation. Tachan *et al*.[58] prepared a dye sensitized solar cell tube successfully. The results showed that it is helpful to solve the problems related to the encapsulation of liquid electrolyte. Moreover, the tube demonstrated highly efficient collection capacity of photon because of its cylindrical design. However, in their devices, obtaining high transparent and conductive glass tube in this kind of structure remained a challenge.

Low-cost fiber shaped dye-sensitized solar cell, which emerged in recent years, has the potential to solve the leakage of electrolyte. Generally, fiber shaped dye-sensitized solar cell utilizes conductive metal wire as the working electrode and counter electrode substrate. Compared with traditional flat dye-sensitized solar cell, it does not use transparent conductive materials. Moreover, its light-capturing ability is higher. However, the diameter of current photoanode of fiber shaped solar cell is only several hundred micrometres, and overall output power is low because of its small effective area, which does not facilitate the application of fiber shaped solar cell in large-scale power generation. For example, researches use high purified and small diameter (i.e. from two hundred micrometres to three hundred micrometres) Ti wire as the electrode substrate, which is expensive and would further hinder fiber shaped solar cell for practical applications.

2.3.4.9 Organic PV

OPV devices are comprised of a number of layers (Figure 80). In the standard configuration (Figure 80 (a)), a transparent substrate (glass or plastic) is coated with a transparent conductor that serves as the anode. In between the anode and the absorbing

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[55] M.G. Kang, *et. al.*, A 4.2% efficient flexible dye-sensitized TiO_2 solar cells using stainless steel substrate, Solar Energy Materials and Solar Cells 90 (2006) 574–581.

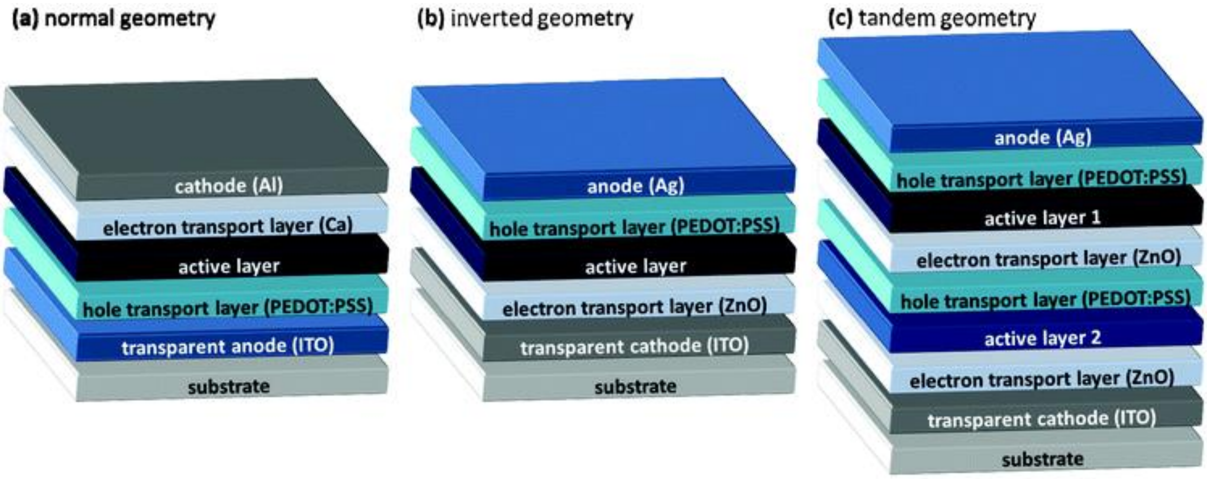
[56] S. Ito. *et. al.*, High-efficiency (7.2%) flexible dye sensitized solar cells with Ti-metal substrate for nanocrystalline-TiO2 photoanode, Chemical Communications (2007) 4004–4006.

[57] X. Fan, *et. al.*, Conductive mesh based flexible dye-sensitized solar cells, Applied Physics Letters 90 (2007) 073501-1–073501-3.

[58] Z. Tachan. Dye-sensitized solar tubes: a new solar cell design for efficient current collection and improved cell sealing, Solar Energy Materials and Solar Cells 94 (2010) 317–322

active layer is a hole-transport buffer layer that prevents electrons from reaching the anode. Likewise, on the other side of the active layer is an electron-transport buffer layer serving the complementary role, followed by the (optically reflective) cathode. Often, the low-work function metals are used for the electron-transport layer in this configuration which are highly reactive and contribute to device degradation, so inverted geometries (Figure 80 (b)) are sometimes employed where the electrodes are switched and different buffer layers are applied. Inverted architectures are also generally more compatible with roll-to-roll processing.

Figure 80: Schematics of common layer structure of OPV devices in (a) normal, (b) inverted, and (c) tandem geometries with typical materials noted



While there has been a steady stream of efficiency records reported for many second- and third-generation solar cell technologies over the past few years, no technology has matched the remarkable progress in OPVs. Average power conversion efficiencies are around 4–5%, with some reported exceptions of solar cells with efficiencies as high as 9.2%.[59] Even higher OPV efficiencies can be achieved by fabricating tandem solar cells comprised of multiple active layers with different band gaps to capture a greater fraction of the solar spectrum (Figure 80 (c)). In these devices, high energy photons are absorbed by the first layer, which has the largest band gap, and lower energy photons pass through to the second absorbing layer for capture by a material with a lower band gap (architectures with additional absorbing layers are also possible). Current published and certified record for an OPV cell is held by Mitsubishi Chemical at 10.7% for a tandem device, though even higher efficiencies have been reported.[60] Another notable recent development in OPVs is the introduction of high-performance small molecule absorbers/donors. Conjugated polymers have dominated the field for the last decade, but challenges associated with polymer synthesis such as batch-to-batch variation in performance, have led to a search for small molecules that can rival polymers in devices. In many cases, small molecules are not sufficiently soluble to be processed in solution, and vapor deposition processes are inherently more expensive and, therefore, less attractive. While vapor-deposited small molecule OPVs have made substantial progress

[59] Z. He, C. Zhong, S. Su, M. Xu, H. Wu and Y. Cao, Nature Photon., 2012, 6, 591–595
[60] M. A. Green, K. Emery, Y. Hishikawa, W. Warta and E. D. Dunlop, Prog. Photovoltaics, 2013, 21, 1–11

recently,[61] particular excitement has been generated by reports of solution-processible small molecule OPVs with efficiencies approaching 7%.[62]

Status of OPV industry and challenges for OPVs. With performance of OPV devices entering a realm of potential commercial relevance, attention in the field is beginning to turn to processing methods that are scalable and efficient. Most laboratory-scale devices are fabricated using spin coating of solutions containing toxic solvents on small, rigid glass substrates. Ultimately, one needs a roll-to-roll compatible coating technique, environmentally friendly solution formulations, and mechanically flexible, large-area substrates.[63] While some academic researchers have begun exploring processing of OPVs, several scientific leaders have also begun to explore the economic potential of OPV technology. The leading company in this area for years, and the first to develop a commercially available organic solar cell, was Konarka Technologies. In early 2012, Konarka filed for Chapter 7 bankruptcy protection and is in the process of liquidation, but prior to this culmination, Konarka performed a pivotal role in development of high-throughput roll-to-roll fabrication and marketing of OPVs as a commercial technology. A number of new players have entered the OPV market, including primarily polymer-based Plextronics, Solarmer Energy, and Polyera as well as primarily small molecule-based Mitsubishi Chemical, Heliatek GmbH, and Global Photonic Energy Corporation. In most cases, these companies utilize high-performance organic materials developed in academic laboratories or new materials derived from these, and they typically maintain close relationships with academia. Interestingly, it is often is the case that these companies have set efficiency records with OPVs rather than academic researchers, demonstrating that a focus on optimization is probably most effective in a commercial setting. It remains to be seen if these specific companies will be the ones to bring OPV products to commercial success, but it is clear that the space is becoming increasingly populated and that investors and management in the industry have learned from the fate of Konarka and are adapting their approaches and business models. Regardless, industry will continue to play an important synergistic role with academic research.

Three primary challenges remain for OPVs hindering their commercial application:

- Power conversion efficiency of OPV modules remain lower than any of the commercially available competitors;
- Operational lifetime of OPVs lag far behind those of inorganic products;
- Batch-to-batch variations in organic source materials make consistency of performance difficult.

Efficiency is not the absolute determinant of the value of a PV technology, but a certain minimum efficiency is required even if a panel costs virtually nothing to manufacture because of all the balance of systems and soft costs associated with installing PV power. (Note that balance of systems costs for OPVs are likely to be substantially lower than for

[61] Y.-H. Chen, L.-Y. Lin, C.-W. Lu, F. Lin, Z.-Y. Huang, H.-W. Lin, P.-H. Wang, Y.-H. Liu, K.-T. Wong, J. Wen, D. J. Miller and S. B. Darling, J. Am. Chem. Soc., 2012, 134, 13616–13623
[62] Z. B. Henson, K. Müller and G. C. Bazan, Nat. Chem., 2012, 4, 699–704
[63] R. Sondergaard, M. Hosel, D. Angmo, T. T. Larsen-Olsen and F. C. Krebs, Mater. Today, 2012, 15, 36–49

traditional, racked PV systems because of their light weight and mechanical flexibility, considerably decreasing materials, labor, and overhead costs.) The consensus is that OPVs will continue to improve in performance, but the real challenge at this stage is translating the impressive gains in efficiency seen in laboratory-scale devices to the module scale. The difference between lab cell records and commercial module efficiency is far too large for OPVs. This substantial performance gap must be narrowed if OPVs are to find a place in the energy market beyond a few niche applications. Indeed, a recent economic assessment of OPVs suggests that market competitiveness is achievable with this technology if large-area module efficiencies could reach ~7% with a 5-year device lifetime. Though efficiency captures headlines, device lifetime is at least as important in ascertaining the usefulness of a PV technology. Understanding the degradation of OPV devices is critical for transferring this technology from research labs to the commercial market. Many organic materials currently used in organic solar cells are not air-stable because of photodegradation of semiconducting polymers induced by oxygen and water as well as degradation of electrodes and buffer layers. To increase lifetime, access of oxygen and (especially) water to the active regions of the device is typically limited through encapsulation. Improvements can be accomplished either through superior encapsulation with lower oxygen and water vapor transport rates, or through the use of inherently more stable materials. In the case of polymer-based OPVs, which still represent the vast majority of systems studied, batch-to-batch variations in molecular weight/polydispersity, solubility, and purity can result in different device performance and even in different processing properties. Companies like Plextronics have developed large-batch synthesis of conjugated polymers to lessen the impact of batch variations of this nature, but if polymer-based solar cells are to achieve reliable fabrication consistency, rapid screening of polymer properties will have to be integrated into synthetic or manufacturing facilities to identify suitable materials rapidly and at low cost prior to their use in a production run. Small-molecule OPVs circumvent many of the problems with polymers because of the precise definition of the end products, though purity variations remain an issue for both classes of materials.

With current performance achievements, OPVs are positioned only for niche applications that take advantage of their light weight, mechanical flexibility, tunable color, and low-light performance, such as powering consumer electronics. As efficiencies and lifetimes continue to improve, however, new opportunities emerge. In the relatively near term, OPVs will find applications in third-world, off-grid uses as well as military/emergency and some BIPV functions. Another intriguing mid-term possibility is the implementation of tandem modules in which OPVs serve as the top layer with traditional inorganic cells underneath. In the long term, climate change and other factors demand TWs of energy be supplied by the sun, and – assuming anticipated technological advances are realized – OPVs of the future will have unique advantages for very large-scale power generation because of their scalability as well as their remarkably low energy payback time and carbon emissions.

2.3.4.10 CIGS PV modules

Among the various thin film absorbers, the main low cost materials of current interest are amorphous Si, CdTe and $CuInSe_2$ and its alloys with Ga and/or S. Though amorphous Si:H solar cells have many advantages such as non-toxicity, abundant resources and low temperature/low cost processing, the cell efficiency is comparatively low (10%). They suffer from light induced degradation leading to long term stability issues. CdTe and CIS-based cells are newer additions to the thin film family. The maximum reported efficiency of CdTe cell is 17%. However, the extreme toxicity of Cd and the environmental regulations make them less attractive. Chalcopyrite $CuInSe_2$/$Cu(In_{(1-x)}Ga_x)Se_2$ (CIS/CIGS) cells are conceivably the most promising material in this category with a maximum reported laboratory scale cell efficiency of 20%. They have very high absorption coefficient ($1 \cdot 10^5$/cm). Efficiencies above 17% were reported on flexible metal substrates. The efficiency achieved through flexible polymer substrates was less than 15%. The highest module efficiency reported is 13%. CIS-based cells have demonstrated the excellent long term stability with high radiation resistance and impurity tolerance, which was rationalized in terms of the large non-stoichiometric range. One key issue of concern is the availability of less common elements. Efforts are currently underway to enhance the efficiency to the theoretical maximum (30%) as well as to develop cheaper deposition strategies for the absorber layer. The band gap of CIS is relatively low (1.04 eV); slightly below the range of optimum conversion efficiency of solar cells (1.4–1.5 eV). The band gap can be suitably adjusted to a desired value by alloying with Ga, Al and/or S. The ternary compound $CuInS_2$ has a direct band gap of 1.53 eV. However relatively rapid diffusion of metals and impurity species occur in this phase even at low temperatures. Ga substitution for In is probably the best option for increasing the band gap (in-between 1.04 eV of $CuInSe_2$ and 1.68 eV of $CuGaSe_2$) to a desired value and to achieve an enhanced current conversion efficiency. Among the different CIS-based quaternary compounds investigated ($Cu(InGa)Se_2$, $CuIn(SeS)_2$, $Cu(InAl)Se_2$, $Cu(InGa)S_2$, etc.), CIGS has been found to be the most efficient one till date.

Theoretically, to achieve the optimal band gap and higher cell efficiency, addition of 60–70% Ga is needed. However, when the Ga content was increased to this level, the cell efficiency was inferior. The phenomenon was explained in terms of the film inhomogeneity, leading to band gap fluctuations. Photoluminescence measurements indicated that a higher Ga content in the film led to larger inhomogeneities.

Many experts see in CIGS technology the most promising thin-film application of the coming years. The strong appeal mainly comes from the high efficiency factor. Even today, commercial modules with an efficiency level of 12.5% are being produced, and levels of 20.3% have been achieved at a cell level in the laboratory, meaning that CIGS already has a higher efficiency than conventional polycrystalline technology. No other thin-film technology has proven such high results, and therewith such high potential for improvement. In the mid-term, an increase in efficiency of around 16% in the commercial sector can be calculated. Additionally, the learning curve of the production phase has not yet been brought to an end. CIGS modules have so far been shown to have relatively low production costs even though the step towards mass production in the three figure megawatt level, or even a GW factory has not yet been made. The possibility of low production and system costs combined with high efficiency levels and the aesthetic appeal of the deep black modules also makes this technology particularly attractive for building integrated PV. This is particularly relevant in regard to the strong rooftop installation market in Europe. The modules can also be produced without cadmium by some manufacturers, and although the toxic substance selenium is used, this is only at a very low level.

The appeal of CIGS technology brings an enormous competitive pressure with it. There are currently approximately 40 manufacturers active in this field, but only a few are already producing for the market. Only about a dozen have reached an output of more than a megawatt. The technological leaders and firms in this sector who are nearest to mass production are: Solar Frontier, Würth Solar, Solibro and Honda Soltec. Würth Solar is currently producing the most efficient technology with levels at approximately 12.5%, to which Manz Automation have recently bought the rights of use. As part of a strategic partnership between Würth Solar and Manz Automation, the technological supplier has become, according to their own publications, the only company currently offering a fully operational CIGS module production line which can be used for business.

Thin-film technologies in the roof-top sector have so far been an exception. Due to the limited space on most roofs, highly efficient modules are usually installed so as to create as much electricity as possible on a small area. Crystalline technologies currently have the technological advantage in this sector, and have thus far found the most resonance in the small rooftop systems sector. However, when installers offer thin-film modules, these are usually CIGS technology, because of their high efficiency levels. For the same reason, a-Si and CdTe modules are hardly ever offered for private homes and thus play an insignificant role in this sector.

In the mid- and long-term, it can be expected that CIGS will be able to compete with crystalline technologies. Reasons for this are both the high potentials for an increase in efficiency and the predicted possibility of cost reduction. If CIGS technology begins to be mass produced, an economy of scale should emerge, in which larger factories cause a decrease in production costs. This combination of efficiency, sinking production costs and appealing design is bound to open up considerable possibilities for CIGS technology in the future.

2.3.5 Concentrated PV devices

The Concentrator photovoltaics (CPV) is based on the use of optical devices that increase the light received on the solar cell surface. The idea is simple: optical devices with cheap and easily available technology (lenses and mirrors) are used to concentrate the light on small and high efficient photovoltaic solar cells. The final goal of the CPV systems is to reduce the cost of the electricity produced by means of replacing the cell surface (expensive material) with cheaper optical devices.

It is usual to classify the CPV systems according to the concentration ratio of the solar radiation incident onto the cell. This ratio indicates the number of times that the solar light is concentrated and it is usually known as 'Suns'. According to that description, it can be defined three different CPV systems:[64]

- Low Concentration (LCPV): it refers to those systems that concentrate the light between 1 and 40 times (1–40×), so the LCPV systems have a concentration factor between 1 and 40 suns;
- Medium Concentration (MCPV): these are the systems that concentrate the sunlight between 40 and 300 times (40–300×);
- High Concentration (HCPV): the concentration level of these systems varies between 300 and 2000 suns (300–2000×).

2.3.5.1 Low concentration PV devices

2.3.5.1.1 Non stationary LCPV devices

The tracking flat PV system is one of the methods to reduce the power generation cost. Early on the technological scientific and technological development phase of concentrated photovoltaics it was shown theoretically[65] that for a mid-latitude region, compared to a fixed PV module tilted at an angle equal to the local latitude, the power generation can increase about 41% using two axis tracking. For a one axis tracking PV system, the power increase is 36%. Several approaches to track the sun using a one axis open loop[66], two axis closed loop[67] and two axis open loop[68] tracking have been proposed by many researchers and some of the commercial products has adopted these. There are also many different controllers to implement the control schemes, e.g. PLA[69] (programmable logic array), PC[70] and microprocessor[71]. Another solution toward cost reduction[72] is to use reflector or Fresnel lens[73] to concentrate the solar radiation

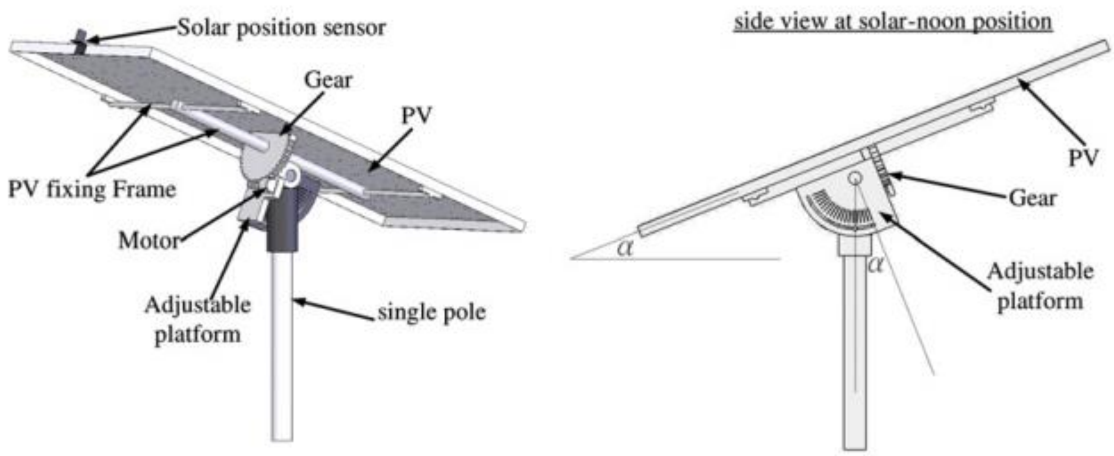
[64] P. Pérez-Higueras, E. Munoz, G. Almonacid, P.G. Vidal, High Concentrator PhotoVoltaics efficiencies: Present status and forecast, Renewable and Sustainable Energy Reviews, Volume 15, Issue 4, May 2011, Pages 1810–1815
[65] Neville RC. Solar energy collector orientation and tracking mode.Solar Energy 1978;20(1):7–11
[66] Kalogirou SA. Design and construction of a one-axis sun-tracking system. Solar Energy 1996;57(6):465–9
[67] Lynch WA, Salameh ZM. Simple electro-optically controlled dual axis sun tracker. Solar Energy 1990;45(2):65–9.
[68] Park K, Lee JH, Kim SH, Kwak YK. Direct tracking control using time-optimal trajectories. Control Eng Practice 1996;4(9): 1231–1240
[69] Abouzeid M. Use of a reluctance stepper motor for solar tracking based on a programmable logic array (PLA) controller. Renew Energy 2001;23:551–60.
[70] Yousef HA. Design and implementation of a fuzzy logic computercontrolled sun tracking system. Proc IEEE Int Symp Ind Electron 1999;3:1030–4.
[71] Koyuncu B, Balasubramanian K. A microprocessor controlled automatic sun tracker. IEEE Trans Consum Electron 1991;37(4): 913–917
[72] Fraas L, McConnell B. High power density photovoltaics – a path to cost-competitive solar electric power. Renew Energy World 2002;5(5): 99–110.
[73] Garboushian V, Roubideaux D, Yoon S. Integrated high-concentration PV near-term alternative for low-cost large-scale solar electric power. Solar Energy Mater Solar Cells 1997;47(1–4):315–23.

incident upon a high efficiency solar cell.[74] It has been shown experimentally that the concentrator PV produces 37% more energy than the flat plate module in a one year comparison in Northern California. The area of PV can be largely reduced if the concentration ratio is high (>100X). However, this requires a high precision two axis sun tracking technology, which is very sophisticated, expensive and less reliable.

The conventional one axis sun tracking system requires continuous tracking using feedback or open loop control. The tracker is usually designed in a large scale in order to mount multiple flat PV modules. This makes the structure very heavy, complicated and not easy to install. It was presented the novel type of LCPV with one axis sun tracking PV module. Every PV module is mounted on an individual sun tracking frame. The one axis tracking mechanism adjusts the PV position only at three fixed angles (three position tracking): morning, noon and afternoon. The tracker is designed in simple structure with low cost.

Figure 81 schematic diagram of the one axis three position tracking mechanism. The mechanism includes a single pole support, a tilt adjustable platform, a PV frame driven by a motor and a solar position sensor. The right side of Figure 81 shows the tilt angle of the tracker, a, at the solar noon position by adjusting the platform. There are three touch switches mounted on the transmission gear of the frame for signal outputting to the control circuit. The PV frame will stop at the touch of the next switch once it is triggered. The designated location of the switch thus determines the stopping angle. Figure 81 shows the stop positions of the tracker

Figure 81: Schematic diagram of one axis three position tracking PV module



2.3.5.1.2 Stationary LCPV devices

Among concentrated solutions for photovoltaics, stationary planar Low Concentration PhotoVoltaic (LCPV) modules, featuring optical concentration ratios lower than 10, are particularly appealing, since they can be made equivalent in shape, weight and size with

[74] P.J. Verlinden et al. One-year comparison of a concentrator module with silicon point-contact solar cell to a fixed flat plate module in Northern California. In: Proceedings of the 16th European photovoltaic solar energy conference, May 1–5, 2000, Glasgow, UK, 2000

standard panels and fully compatible with standard infrastructures of installation. The main potential advantages of LCPV technology can be listed as:

- Module cost reduction, due to lowered active material usage;
- Capex reduction for active material manufacturing; and
- A Balance-Of-the-System (BOS) cost potentially equivalent to that of standard fixed panels,

where the term BOS summarizes all those parts of the plant that are not directly related to the photovoltaic energy conversion, comprising the land, the civil work, the mechanical supports for the panel and the electrical infrastructure made of cables and inverters.

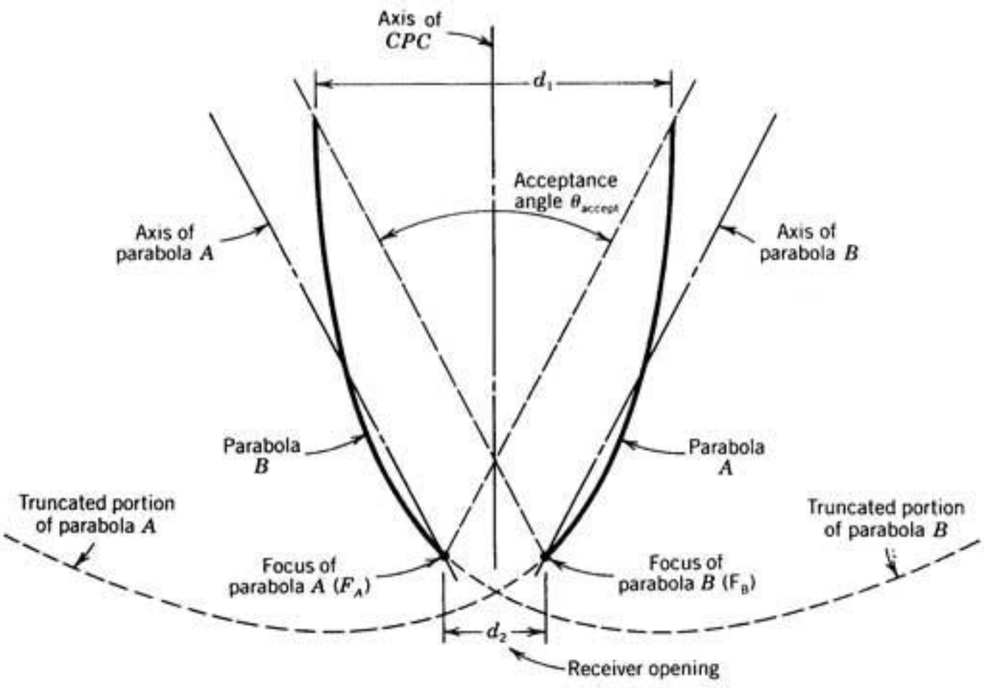
In recent years, the interest for stationary LCPV solutions has somewhat been acknowledged by the scientific community and several technological solutions have been proposed, which primarily make use of silicon cells as the active material. They include among others low-gain compound parabolic concentrators (CPCs) and planar flat concentrators. In turn, flat concentrators may either rely on optical diffusion, and be made of volume scatterers or of dielectric slabs coupled with surface diffusers, or they can include holographic gratings, or they can be luminescent concentrators consisting of dyes dispersed in a transparent waveguide. On the other hand, generally the benefits of concentrated photovoltaic systems are paid in terms of:

- A reduction in panel efficiency, due to unavoidable optical loss of the concentrating set-up;
- A reduction in module energy production due to limited acceptance angle for input solar radiation, if sun tracking is absent; and
- Long term reliability issues of the concentrating optics.

In particular, the economic competitiveness of LCPV systems with respect to standard fixed modules is actually questionable, due to optical concentration loss and limited advantages in terms of silicon usage reduction. In addition, a systematic analysis of the LCPV requirements to be competitive in the photovoltaic solar energy market is missing. To understand the real economic competitiveness of photovoltaic solutions, the best tool to use is the Levelized Cost of Energy (equivalently stated as Levelized Cost of Electricity) (LCoE). It is an aggregate parameter, defined as the ratio between the total panel cost, including construction cost and Operation and Maintenance (O&M), and the total energy production throughout the entire life of the panel. It gives the Levelized cost of produced energy and provides correct means to compare the cost of energy across different technologies.

One of the LCPV technologies which is still in the pre commercial stage comprise the prism coupled compound parabola design (PCCP). This device features a stationary construction with no need to track the Sun. The PCCP, shown in Figure 82, which reaches the theoretical maximum concentration performance.

Figure 82: sLCPV module Prism Coupled Compound Parabola design



The PCCP design has two significant advantages: the reduced aspect ratio and the need to use the prism made of small amount of high refractive index high transparency dielectric material. An additional advantage of the PCCP is the fact there is no presence of high optical power concentration region (hot spot) as in the CPC near the limit input angle. Such hot spots present problems of high current generation in a limited PV cell surface, which reduce the electrical power generation efficiency.

2.3.5.2 Medium to high concentration PV devices

Medium to high concentration photovoltaic (m/hCPV) devices operate under concentration ratios between 40 and 2000 suns. The concentration mechanism is done by lenses or mirrors that either reflect or refract the sunlight on the solar cell surface. Replacing the expensive solar cell materials by cheaper optics offers the opportunity of reducing the costs of the modules. A typical commercial m/hCPV system is composed of concentration modules mounted on two-axis solar trackers, where each module contains several solar cells and each cell has its own optics, typically a point-focus Fresnel lens. Other auxiliary elements are used, such as heat sinks, Secondary Optical Elements (SOEs), bypass diodes and protection elements. Nowadays, these configurations dominate the m/hCPV market and are very promising solutions for the future of photovoltaics.

The main elements that constitute a m/hCPV generator are the solar cells, the receivers, the optical devices and the tracking system. A collection of solar receivers with electrically interconnected cells and with integrated optical devices is known as a m/hCPV module. The main characteristics of these elements are described as follows:

- **Solar cells**. High concentration solar cells have specific characteristics different to those of conventional flat-plate solar cells. The m/hCPV cells are designed to extract more energy under a larger solar radiation. These cells have to be exclusively made of high quality semiconductor materials because of the significance of the conversion efficiency, a factor which is directly related to the quality of the crystal used, in which impurities must be avoided.

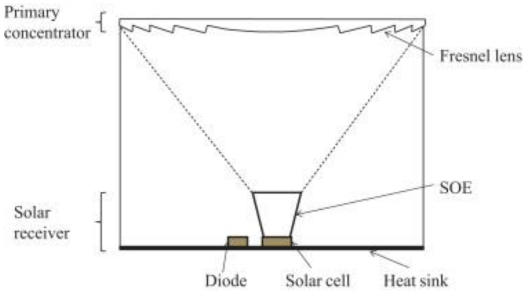
An important characteristic of these solar cells is their enhanced thermal behavior. Under high temperatures, both Si and GaAs cells suffer a significant decrease of performance mainly because of the voltage reduction produced by a temperature increase. Nonetheless, this effect is less accurate at high concentration levels.

Despite the fact that many different types of cells are being tested at laboratory level and although the reported efficiency has increased over 40% for multijunction cells, many of the concentration systems installed nowadays use silicon solar cells, providing efficiencies which hardly exceed 25% under concentration. However, most of the current developments are based on triple-junction cells. These cells can be described as a stack of cells of different compositions with a progressively decreasing bandgap, so that the cell on the top of the stack absorbs higher energy photons than the cell in the middle, and this absorbs higher energy photons than the cell in the bottom.

- **Receivers**. Solar cells have to be mounted on a receiver to extract the generated current and to dissipate and remove the heat resulting from sun power. Current extraction is made by thick wires or ribbons that are soldered to the cells, whereas heat removal is carried out by a heat sink added to the receiver. Materials like copper or aluminum are currently used for heat evacuation. Also, the solar receivers often include a bypass diode connected in parallel with the cell in order to avoid overheating of the cell in non-usual operating conditions such as shading.
- **Optical devices**. The aim of the optical devices used in this technology is to concentrate radiation and to increase the luminous flux on the cells. Optical devices may be simple or consisting of primary and secondary optical element (SOE). Primary optical devices collect direct sun rays. Secondary optical devices receive the light from the primary ones and then change its properties by means of spectral filtering, light homogenization or light direction changing. In this respect, different optical devices are currently used: circular parabolic dishes, parabolic dishes with secondary, square flat Fresnel lenses, square flat Fresnel lenses with secondary, linear flat lenses, linear arched lenses or linear parabolic reflectors.

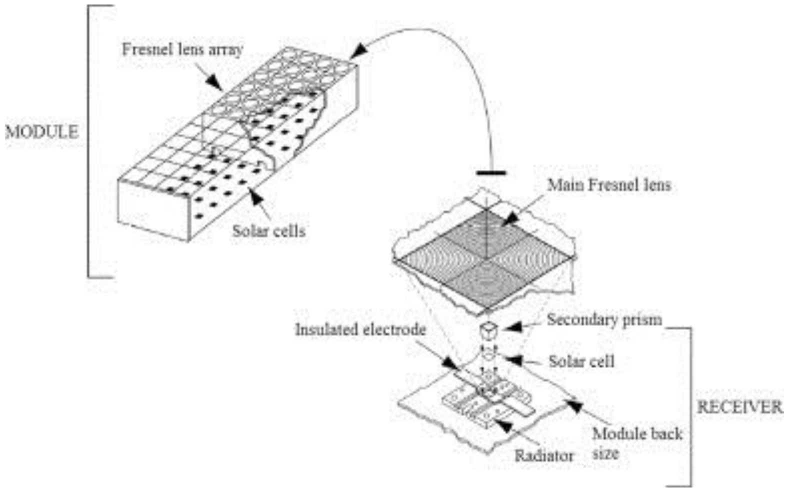
  Most of the systems currently designed are based on Fresnel lenses. This kind of lens reduces the amount of material required to concentrate the light by splitting the lens into a set of concentric annular sections known as Fresnel zones. The use of these zones allows keeping the required curvature without increasing the thickness by means of adding discontinuities between them. Figure 83 shows an example of a solar receiver integrated with point-focus Fresnel lens.

Figure 83: Schematic of a HCPV solar receiver integrated with point-focus Fresnel lens[75]



- **HCPV module** is the smallest, complete, environmentally protected assembly of receivers and optical devices that is able to transform an input of unconcentrated solar radiation. Consequently, a typical HCPV module is made up of a group of cells, primary optics, secondary optics (optional) and housing components such as interconnection and mounting. Figure 84 shows an example of a typical HCPV module and its components.

Figure 84: Schematic of a m/hCPV module based on point-focus Fresnel lenses[75]



- **Tracking system**. Point-focus based m/hCPV modules must be always mounted on two-axis solar trackers, i.e. the modules must be always pointing the solar rays in order for the lenses to be able to focus the radiation on the small solar cell area. This kind of tracking system is more complex than linear tracking or static systems from a mechanical point of view but it presents the advantage of maximizing the solar radiation capture along the daily trajectory.

2.4 Forecast of new PV product market development

2.4.1 Quasi-monocrystalline silicon PV product market development

For now this wafer technology is charakterised by low market acceptance. Due to unmatured technological process, one of the main quasi-mono-crystalline silicon manufacturers Renesola shipped only 11% its total multicrystalline silicon production capacities of quasi monocrystalline silicon modules. JA Solar, shipped only 10% of it's

[75] P. Rodrigo, E.F. Fernández, F. Almonacid, P.J. Pérez-Higueras, Models for the electrical characterization of high concentration photovoltaic cells and modules: A review, Renewable and Sustainable Energy Reviews, Volume 26, October 2013, Pages 752–760

over 1 GW wafer shipments in 2012-Q1.[76] At first sight, the quasi monocrystalline silicon provides value for manufacturing cost and module conversion efficiency combination, but low production capacities testifies, that companies are struggling with the technological issues, thus there are still high uncertaincies regarding market penetration and growth for this technology based products.

2.4.2 CIGS products market development

$Cu(In_{1-x}Ga_x)Se_2$ (CIGS)-based solar cells have emerged as one of the most promising candidates for high-efficiency low-cost thin film solar cells, and high efficiencies of as high as η=~20.0%.[77] Showa Shell Sekiyu, Honda Soltec, and Würth Solar started commercial production from 2007 with their 15–27.5MW/year production facilities. Several other companies also started over 10MW-scale mass production following those three companies. Further improvement in cell and module performance is still desirable, though the best performance for laboratory-scale CIGS cells of η=20.0% is superior to other alternative thin-film solar cells. Further improvement in conversion efficiency will also lead to cost reduction and improved competitiveness in the photovoltaic market. Therefore CIGS based products can be winning technology for TF technologies and will dominate TF products market in the period until 2025.

2.4.3 Dye-sensitised PV product market development

2010-2012, the DSC market has come of age and has moved out of its research and development phase. The performance of DSCs is now comparable with that of amorphous-silicon (a-Si) PV, but with much more potential than a-Si for performance improvements.

In the past, the DSC market has frequently been seen as a subset of the organic PV (OPV) industry. Most superficially, this viewpoint has existed because “pure” OPV and DSC use organic materials. More significantly "pure" OPV and DSC for many years exhibited the same low performance characteristics that relegated both technologies to the same low-end addressable markets. This association made some kind of sense a few years ago, when both “pure” OPV and DSC had very similar performance and commercialization characteristics: OPV seems to be in a permanent R&D phase, and has lower efficiency, while OPV occupies some niches of PV market; DSC has made a considerable improvement in building-integrated PV.[78]

The main issues that DSSC technologies have to solve relate to performance limitations: in lifetime and efficiency. There is a clear handicap in best performance achieved by DSSCs when compared to technologies that have been under development for longer and have achieved much better efficiency levels. On the other hand and on a more

[76] http://solarpvinvestor.com/spvi-news/214-is-quasi-mono-in-a-market-decline. Reviewed on 14-11-2013

[77] Shigeru Niki, Miguel Contreras, Ingrid Repins, Michael Powalla, Katsumi Kushiya, Shogo Ishizuka, Koji Matsubara, CIGS absorbers and processes, Progress in Photovoltaics: Research and Applications, Vol. 18, Issue 6, pages 453–466, September 2010

[78] NanoMarkets. The Coming of Age of the DSC Market. Published: April 13, 2012. Reviewed on 18th January 2013. http://nanomarkets.net/articles/article/the_coming_of_age_of_the_dsc_market

positive note, it's also obvious that the performance gap with amorphous Silicon, one of the incumbent technologies, has closed dramatically in recent years, especially in indoor applications. It is thus, important to identify the best fitting initial applications for DSSCs, as the first ones to target in order to achieve faster commercialization.[79]

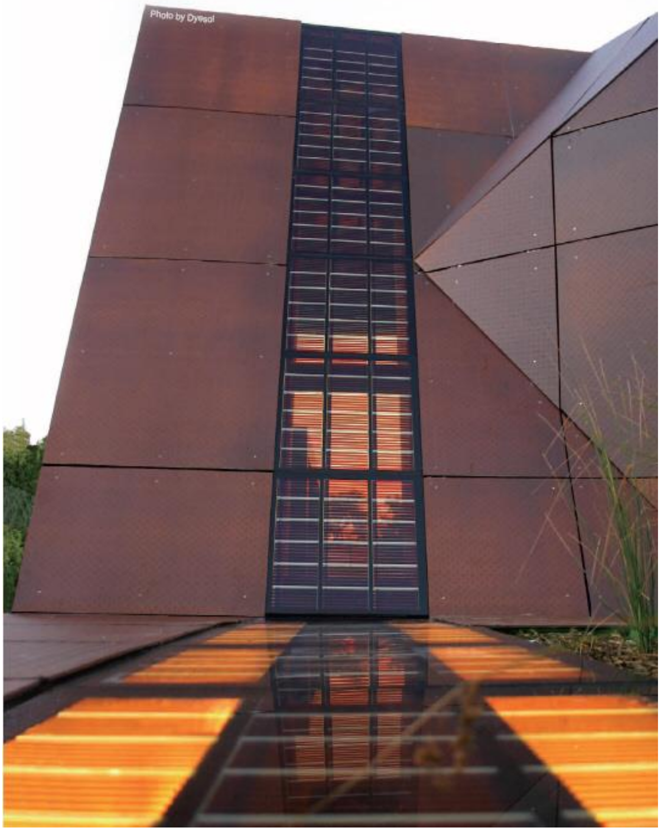
Until this day following companies will open or already have started the commercial production of DSC PV products: 3G Solar, Dyesol, Fujikura, G24 Innovations, Nissha Printing, Oxford Photovoltaics, Samsung SDI, SHARP, Solaronix, SolarPrint, SONY Technology Centre, TiSol.

One of the first DSC PV products manufacturer Dyesol in collaboration with Tata Steel (large steel producer) introduced (joint venture Dye tec Solar) into the market a novel solution for BIPV products, DSC coatings on steel sheets, which can be used in various constructions namely building walls, roofs and etc. Another novel DSC PV product integration example, semi-transparent glass to glass BIPV modules integrated into building walls (Figure 85). Such DSC BIPV products are manufactured in joint venture between Dyesol and Pilkington (glass producer based in USA). Another DSC PV products comprise production of standard flat PV modules, flexible panels for stand-alone and grid connected applications and even DSC solar cells integrated into clothes or backpacks.[80]

[79] H. Zervos. IDTechEx. Dye Sensitized Solar Cells: Technologies, Markets and Players 2012-2023. August 2012

[80] P. Patel. MIT Technology review. Dye-Sensitized Solar to Go. Published In 2009. Reviewed on 18th January, 2013 http://www.technologyreview.com/news/415912/dye-sensitized-solar-to-go/

Figure 85: House of future: DSC semi-transparent BIPV glass to glass module



NanoMarkets estimates that the total market value of DSC modules at the application level will grow from about €30 million in 2012 to more than €370 million by 2015. Then, after building-integrated PV (BIPV) applications for DSC PV take-off, the firm anticipates that the market value will exceed €3.2 billion by 2019. At the same time, the market for DSC materials is expected to grow from a value of almost €10 million in 2012 to more than €1 billion by 2019.

2.5 Areas of PV application

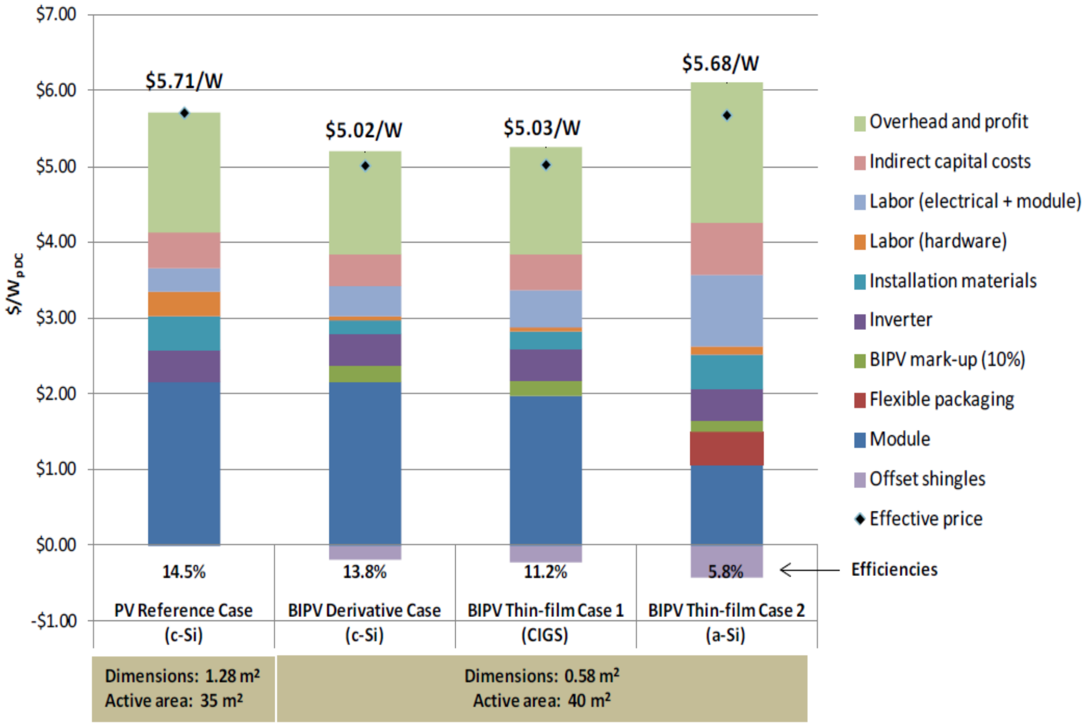
2.5.1 Building integrated PV products

The integration of PV modules into buildings is still struggling due to unsolved standardization and cost problems. The latter is very important as rack-mounted PV systems have lower cost. The Figure 86 shows the comparison of residential rooftop prices for rack-mounted. The listed effective prices account for cost offset as BIPV replaces building materials. The cost calculations[81] showed that BIPV has a potential to achieve lower than rack-mounted PV, but BIPV systems are experiencing serious power output reduction, because such systems usually are in close contact with building, which does not leave any gap for ventilation. Higher operating temperatures results in

[81] T. James *et. al*. National renewable Energy Laboratory. Building-Integrated Photovoltaics (BIPV) in the Residential Sector: An Analysis of Installed Rooftop System Prices. NREL/TP-6A20-53103, Technical Report. November 2011.

decreased overall system conversion efficiency. Other cases showed that on low sloped roofs, BIPV systems tend to soil, which is reducing efficiency as well.[82]

Figure 86: Comparison of prices of PV flat module and three BIPV cases



Especially when the price gap between flat PV and BIPV modules still exists, there are several issues which determine the limitations of BIPV penetration into global market:

1. **The Value for building aesthetics.** Although some believe that integrated PV panels for example into building walls or roof will increase its aesthetics, it is still unclear how this aspect will influence the further BIPV market development. Some market research and reviews have shown that PV installers really care about the general PV devices view and integration into environment.[83] As BIPV is and will be a part of modern architecture, aesthetics will play a major role.
2. **Codes and standards.** The landscape of codes and standards issues is more complex than for flat PV modules, therefore the PV installation figures are still higher. The building integrated devices complie with several groups of requirements which determines the need for different codes and standardizations. Generally the BIPV standards must be derived from buildings codes and standards and from electrochemical codes and standards. As a part of integral building PV devices must comply with mechanical resistance and stability; safety in case of fire; hygiene, health and environment; safety in use;

[82] Schams, B.; TamizhMani, G. "BAPV Modules with Different Air Gaps: Effect of Temperature on Relative Energy Yield and Lifetime." Presented at IEEE's 37th Photovoltaic Specialist Conference (PVC). 2011
[83] Probst, M.M.; Roecker, C. Towards an improved architectural quality of building integrated solar thermal systems (BIST). Solar Energy 81 (2007) 1104–1116.

protection against noise; and energy, economy, heat retention requirements.[84] The process of new standard acquisition has already started although these are not covering all aspects (standards for BIPV modules, inverters, support structures; standards for BIPV systems; installation and maintenance) related to BIPV.

3. **Market segmentation.** BIPV adoption dynamics might be different from those of rack mounted PV, as these are designed for more discrete market opportunities. Although different PV product designs have specific application segments, rack-mountable PV modules are easier adopted than BIPV. These limited BIPV market segmentation possibilities might limit the achievement of the lower cost in comparison to PV.

Until this day BIPV comprised only few niche applications, but it is forecasted that the BIPV market will set to grow by €4 Billion by the end of 2015 (four-fold increase in revenues compared to 2012).[85] Reductions in feed-in tariffs and other support schemes for solar energy have caused massive upheaval throughout the world. Despite the sharp reduction of financial incentives and the ongoing economic troubles in the Eurozone, however, Western Europe remains the largest market for BIPV products. Other notable new markets for BIPV that are likely to emerge through 2017 include Eastern Europe (Lithuania, Serbia, Slovenia, Poland, and Ukraine), Asia Pacific, and South Africa.[86]

2.5.2 Combined PV/solar thermal systems for heating cooling

Since the 90's, solar energy systems in buildings have increasingly been applied and studied. These systems are mainly placed on roofs and are usually used to produce separately electricity and heat through standard flat collectors. However, there are some recent developments of cogeneration systems to produce simultaneously heating and cooling using concentrating solar thermal collectors, installed either on the facade or roof and double-effect absorption chillers, reaching a global higher efficiency and higher operating temperatures. These systems can be used for air-conditioning of buildings during the entire year.

The architectural integration of standard active solar systems in existing urban centres may not be particularly efficient in terms of energy production, especially when they are installed on the facade of the building. However, concentrating systems (CS) applied to solar generation processes could improve remarkably the energy efficiency and can offer advantages compared with conventional thermal collectors, such as: better use of space, ease recycling of constituent materials, flux regulation to achieve variable proper flow conditions, higher levels of power density and thus higher temperature of the fluid, reduction of the hottest parts areas and therefore increasing the overall efficiency of the system (reducing the heat losses), etc. Nevertheless, the viability of building-integrated

[84] B. de Boer. ECN. Regulations and Building codes for BIPV-systems in Europe. Performance BIPV Workshop Nice, 30 October 2008

[85] Nanomarkets. Building-Integrated Photovoltaics Markets. 2012

[86] Pike Research. BIPV and BAPV: Market Drivers and Challenges, Technology Issues, Competitive Landscape, and Global Market Forecasts. 3Q, 2012.

concentrating systems depends on the economic comparison over systems with flat plate or evacuated tube collectors, whose market prices are decreasing from day to day. On the other hand, the major advantage of using CS for cooling is that the higher operation temperatures allow the use of double-effect absorption chillers that are much more energy efficient that the single-effect ones.

There are many developments combining PV and solar thermal collectors due to the useful utilisation of solar spectrum: PV is absorbing irradiation of higher energy while solar collectors are using infrared irradiation for which PV converters are transparent. Unfortunatelly these combined sytems have market penetration difficulties due to higher costs and complicated installation.

Recently with strong decrease in PV prices PV based heating systems are becoming competitive to the solar termal collectors mainly because of easiness of installation and maintenance. There is no need to install heating pipes net in the building to bring heating power to the boiler as well as boiler itself is less expensive comparing with those used for combined heating with solar thermal option.

2.5.3 Charging for local (inside building) lighting/sensing/monitoring devices

PV lighting products can deliver a high quality of service.[87] Moreover, they are safer and more reliable than alternative lighting services such as kerosene lamps, candles or lighting powered by car batteries that must be regularly charged by electricity from the grid. Another important aspect of PV lighting products is their assumed environmental benefit compared to alternative lighting services.

Solar home system (SHS) and LED lighting. Household lighting is a fundamental need, required in the home to extend work and study hours, and allow household tasks and other social activities. The electricity demand in rural regions is mostly dominated by home lighting loads which is insufficient to justify the substantial capital investments required to build electricity generation and transmission infrastructure. Solar photovoltaic SHSs with Light Emitting Diode (LED) lamps are considered to be cost effective and robust decentralized option for rural electrification. A typical SHS consists of a PV module, battery, charge-controller, and end use appliances.

The luminous flux of 100 lm matches a typical lighting requirement for a rural household. A period of 3 h was chosen as it represents a typical time for which light will be daily used. Whereas to meet the Total Energy Access (TEA) minimum standard for lighting, a household must have at least 300 lm of light for a minimum of 4 h per day. A total of 300 lm, equivalent to a 25 W incandescent bulb, can allow sufficient lighting for reading and study, and task lighting in the home.

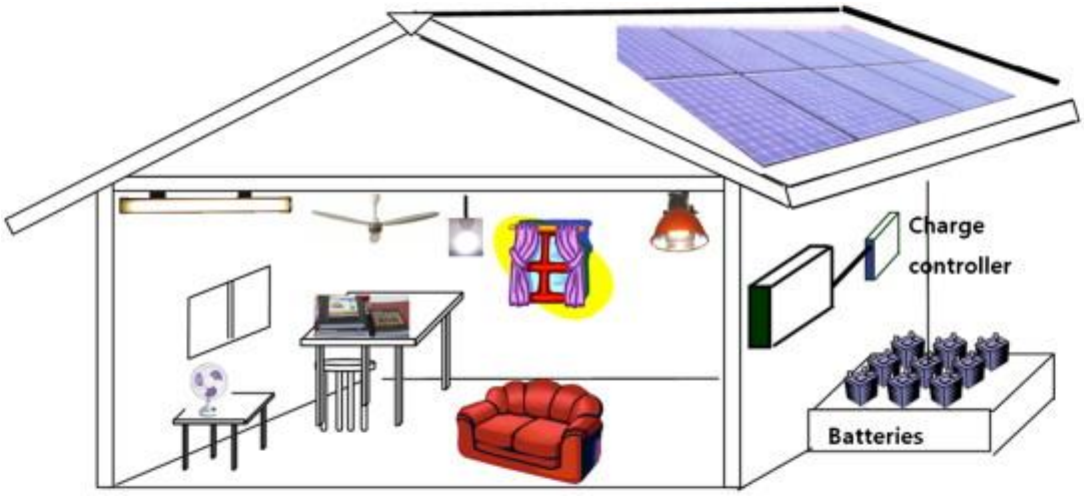
The objective of the 20 W SHS is to provide electricity to households in remote, isolated rural areas. The kit is designed for the poorest of the poor households in rural areas. A typical 20 W SHS which provides only home lighting to small houses/huts consists of a

[87] Bart Durlingera, Angele Reindersa, Marten Toxopeus, A comparative life cycle analysis of low power PV lighting products for rural areas in South East Asia, Renewable Energy, Vol. 41, May 2012, Pages 96–104

PV module, battery, charge-controller, and two 5 W, 12 V DC LED bulbs. The total cost of one complete unit of 20 W SHS including accessories is estimated to be around US$250.00. Usually, DC LED bulbs with E26/E27 base used in SHS vary from 3 to 10 W.

For richer populations who use more energy, buying a SHS is to be an economic choice compared to other options such as diesel/kerosene generator or frequent trips to diesel-powered charging stations for borrowing automobile batteries. SHSs are becoming more cost competitive as diesel fuel costs escalate. Solar solutions provide safe light and save travel time to battery charging station. A standard standalone SHS with a solar panel to convert the sun light into electricity and a battery to store that electricity in order to use it when needed is a way to provide power to off-grid remote places. Figure 87 shows a standalone solar house.

Figure 87: House in rural areas with solar powered Led lighting and fans.



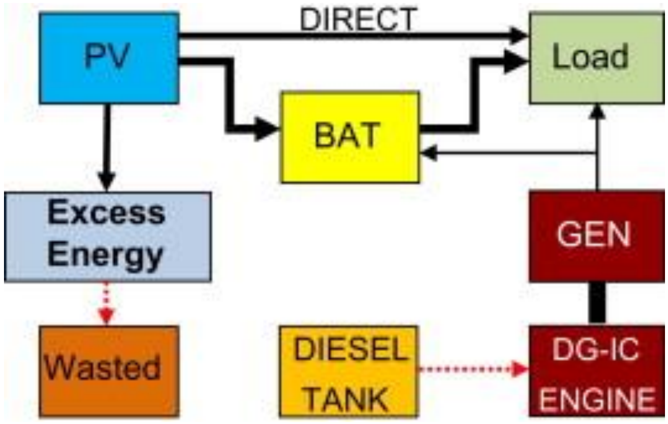
2.5.4 Combined systems with diesel generators

To minimize the loss of load probability in standalone PV systems, conventionally diesel generator (DG) are commonly used as a backup in combination with battery. In such a system peak loads can be met by the DG set together with the stored energy in the battery or the renewable energy converter. The system is sized to reduce the fuel consumption of the diesel generator by 70–90%[88], therefore, relying heavily on the renewable resource.

In a PV-DG hybrid system a PV array is configured in parallel with DG systems to meet the load. Energy flow in a PV-DG hybrid energy supply system is shown in Figure 88.

[88] Arun S. Raj, Prakash C. Ghosh, Standalone PV-diesel system vs. PV-H2 system: An economic analysis, Energy, Vol. 42, Issue 1, June 2012, Pages 270–280

Figure 88: Schematic diagram of energy flow in a PV-DG hybrid system



Diesel generator based systems have low capital cost as the technology is fairly well established. However, such systems are typically oversized, and during the months with high solar insolation (good season), a significant amount of energy is wasted in the system as excess energy.

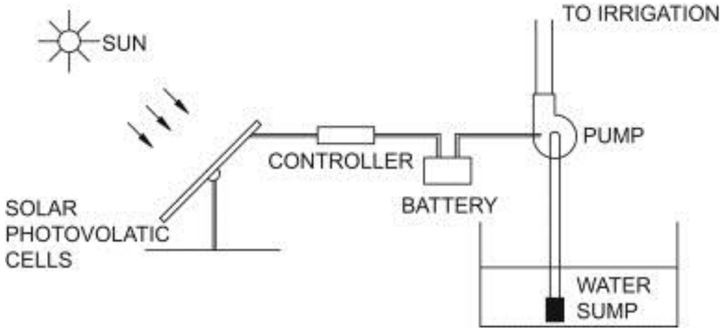
Moreover, diesel based systems cause greenhouse gas emissions and have high operational and maintenance (O&M) cost. They also suffer from lower efficiency at partial load. A battery storage system with minimum capacity is included in the system. The output of DG system is connected to the battery and the load so that it can be operated at full load to avoid the lower energy conversion efficiency at partial load.

2.5.5 PV for other targeted applications

Applications for irrigation. Solar PV based irrigation is not a new concept and there are already a number of such irrigation schemes running. Technologically, it is not a big challenge, as it does not require any highly sophisticated component. However, the main challenge comes from the actual cost of irrigation which is heavily dependent on the irrigation model in the context of the socio-economic condition of rural. As irrigation requirements are quite severe only during the dry months (3-4 months), the overhead costs becomes too high for dedicated irrigation projects. So, it is essential to integrate the Solar PV panels with other energy usage of rural areas to reduce the overhead cost and to make it competitive with diesel based irrigation system.

Solar PV based irrigation systems consist of solar photovoltaic panels, a motor and a pump, which is depicted in Figure 89. Depending on the system design, it requires storage batteries and a charge regulator. The motor is chosen according to the power requirement and the type of current output of the system. If the motor uses alternative current (AC), it is necessary to install a direct current (DC) to AC converter. Battery-less PV irrigation systems are low cost, which requires less maintenance compared to battery powered systems. However, the storage batteries have the advantage of providing consistent performance during lean and off sunshine hours. The addition of a water storage tank in PV systems is more economical than battery storage backup. The use of solar photovoltaic energy is considered to be a primary resource for the countries located in tropical regions, where direct solar radiation may reach up to 1000 W/m^2.

Figure 89: Layout of solar photovoltaic water pumping systems.



Applications for hybrid and electric vehicles. In the European Union, road transport currently accounts for approximately one-quarter of the total final energy consumption and CO_2 emissions. Therefore, the improvement of the energy efficiency for off-road (Figure 90) and on-road transport and the consequent reduction of CO_2 emissions is of particular importance. The PV systems application for transport sector is the most promising solution.

Figure 90: Examples of photovoltaic applications for ships

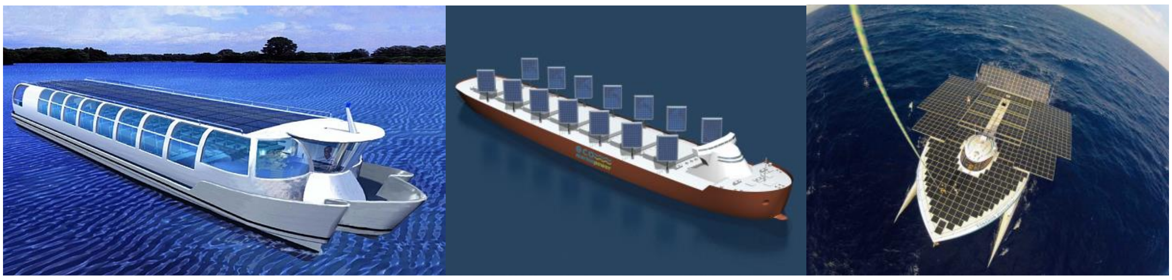
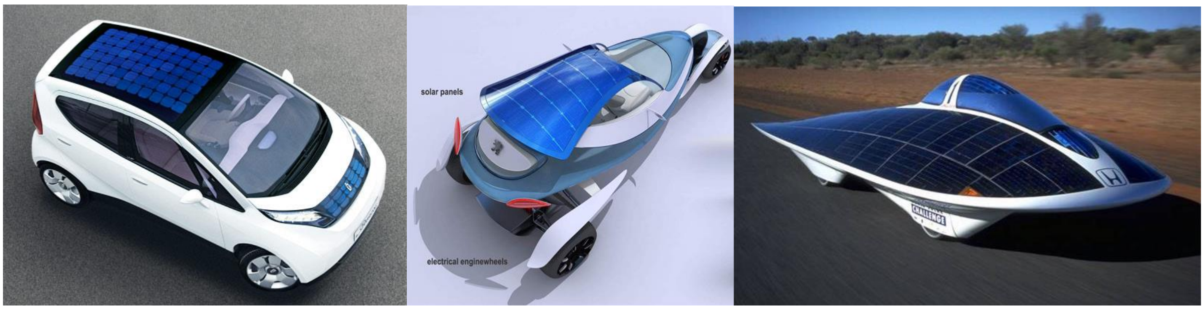


Figure 91: Examples of automotive photovoltaic applications

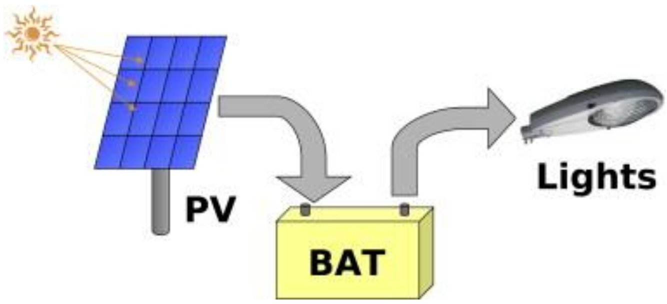


The incorporation of photovoltaic systems on the outer surfaces of electric, plug-in hybrids and hybrid vehicles helps to reduce the overall amount of fuel consumed. In addition, photovoltaic systems are light, noiseless, maintenance-free and work continuously even when the vehicle is not in motion. They can be applied on a large area as the main power module, or on a smaller one as an auxiliary system. This way, the natural energy flow provided by solar radiation is used to replace, at least partially, the need for fossil fuel. Up to now, the only reason for not using photovoltaics was their high cost. However, their price has decreased considerably over the past decade and is expected to decrease even further in the future. The rapid increase in the cost of fossil fuels combined with the aforementioned reduction in the price of photovoltaics will make their use cost-effective in the near future.

The incorporation of PV panels in vehicles has already been realized in solar cars. Solar cars are basically electric cars, in which electricity is provided from the conversion of solar radiation to electric energy through the use of photovoltaic conversion panels. Hybrid electric vehicles (HEVs) on the other hand, use conventional fuel as their source of energy. In hybrid electric vehicles, electrical energy is temporarily stored in the electrochemical storage system and used by the electric motor. This electrical energy is produced by a conventional motor and in part by recovery of kinetic energy when the brakes are used when driving downhill or when stopping. The installation of PV generators in electric or hybrid vehicles can help to conserve energy in the form of fuel in the case of HEV and fuel cell vehicles, or in the form of electrical energy originating from conventional (mostly) power generating plants in the case of electric cars.

Stand alone lighting (street lamps etc.). Nowadays, street lighting is something essential in our society in order to ensure comfort and security. The installation of street lighting in a city involves complex and expensive work. Moreover, to supply the lights, an electrical network is needed. The problem is the same in remote areas where lighting is needed, for instance, on the sides of roads. One solution is to use stand-alone street lighting systems. Such systems are currently sold and are commonly powered by solar cells and batteries to store the energy. The system is presented in Figure 92: PV charges the battery during the day and then it supplies the street lights during the night.

Figure 92: Layout of stend alone lighting system



Monitoring solutions for gas oil pipelines, meteo, surveillance etc. Photovoltaic power generation is a proven method with a vast number of applications across the globe. PV units can be integrated in autonomous or grid-connected systems, covering the electricity demand of various applications. A typical autonomous domestic system, of about 1 kW, may provide electricity for refrigeration, lighting and other low power loads. Similar non-domestic systems can serve loads such as water pumping, telecommunications, etc.

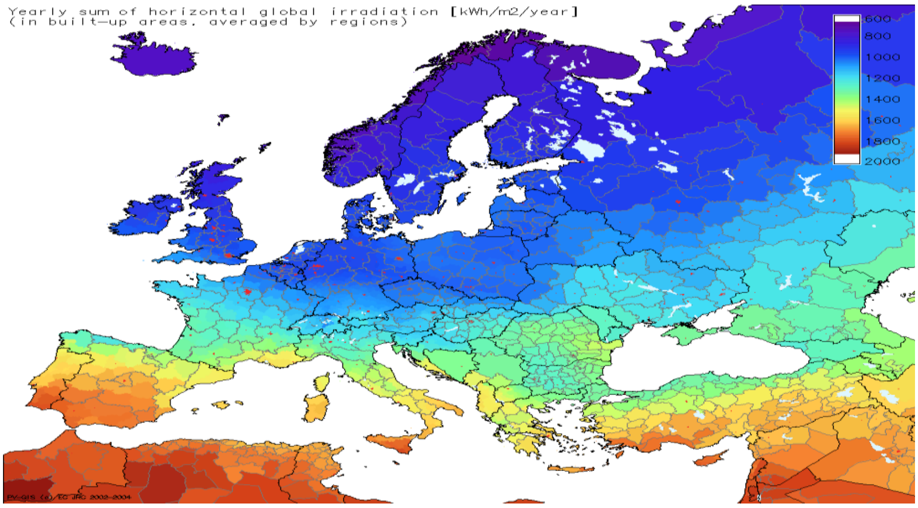
Finalizing short overview of possible PV applications it can be stated that there are unlimited choices where PV based products can be used for energy supply, promising bright future for this technology. We are on the edge of PV becoming cost attractive option for energy supply and having advantages attractive for consumer such as independency from grid, flexibility, scalability, etc. it can be expected booming market for PV applications.

3 LITHUANIAN MARKET OVERVIEW

3.1 Amount of solar energy in Lithuania

Though Lithuania is situated in the latitude of 54^0-56^0 North, the results of the scientific research show that the amount of solar radiation can fully meet the energy needs of the country. The geographical location of Lithuania allows expecting the similar solar energy consumption effect as in Denmark and Germany (Figure 93).

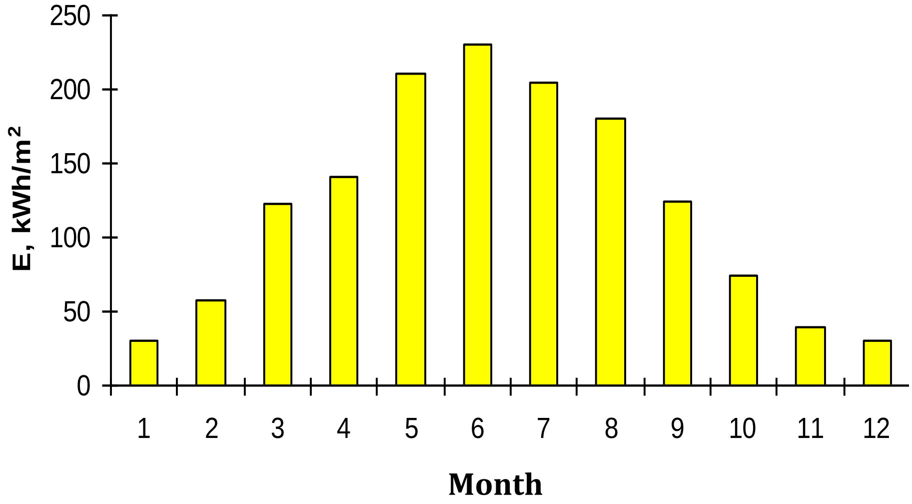
Figure 93: Seasonal shift in solar energy in Lithuania



The territory of Lithuania covers the area of 65 200 km^2. Annually from 926 kWh/m^2 per year (Biržai) to 1042 kWh/m^2 per year (Nida) of solar radiation energy reaches one square meter of horizontal surface. On average, this falling energy comprises ~1000 kWh/m^2 per year in Lithuania. With the 15% efficiency of solar cells, it is possible to acquire $2.25 \cdot 10^{10}$ kWh/per year[89] from the power-stations situated on the roofs. Presently, the Lithuanian energy capacities allow to produce $2.27 \cdot 10^{10}$ kWh/per year. Thus, the capacity of photovoltaic power-stations installed on all the roofs of the houses would be equal to that produced by Lithuanian common energy power-stations. Solar radiation energy falling to the surface of Earth changes depending on the season of the year, time of the day as well as meteorological conditions (Figure 94). The energy falling during November, December, January equals only to 10% of the energy falling during May, June or July. During the night the energy almost equals zero, on the cloudy day it comprises only few per cents of the energy falling on the bright day. Photovoltaic as the only permanent energy source may be exploited only when the possibility to accumulate it is available, thus covering the lack of the energy caused by seasonal, daily or meteorological shifts.

[89] Lietuvos nacionalinė saulės programa 2000-2005, koordinatorius habil. dr. Stepas Janušonis.

Figure 94: Annual solar energy incident upon horizontal surface, (kWh/m²)

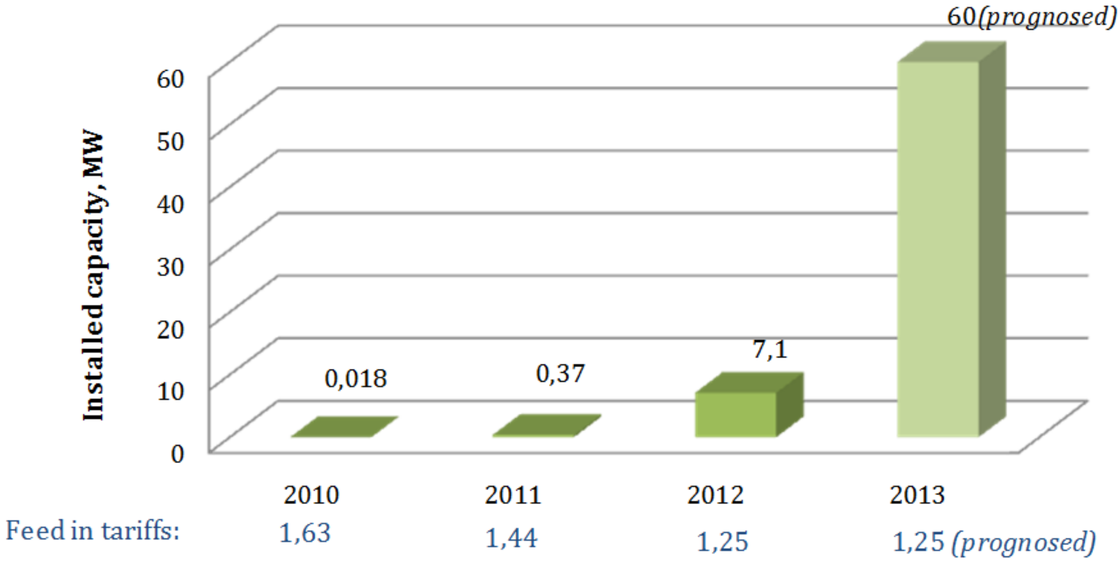


3.2 Photovoltaic installations in Lithuania

This chapter will be dedicated to the overview of local photovoltaic installation market in Lithuania. The separate Study V on "State of the art analysis of Lithuanian PV technology cluster and potential for its development" is under preparation and is dedicated to detailed analysis of PV potential development in Lithuania form the research and development and manufacturing points of view.

Photovoltaics (PV) are basically not highly exploited in Lithuania. Firstly it is attributed to the sufficiently distributed electricity allocation infrastructure as well as high potential of traditional means for electricity generation. For this reason, PV exploitation is limited to the installation of local power-stations for the provision of energy to the mobile appliances as well as demonstration power-stations for educational purposes. Until 2010 in Lithuania only small photovoltaics market existed for training tools, supply sources of electronic equipment as well as photovoltaic modules intended for recreation and tourism. During the last two years the demand of autonomous photovoltaic power stations had steadily growing due to quite high feed-intarfis (Figure 95).

Figure 95: Lithuanian market overview in 2010-2012 and prognosis for 2013



The majority of these power stations are installed as the powerplants up to 30kW, or also in the posts of road monitoring, magistral gas pipes as well as security and alarm systems, in the remote houses, newly built resorts or some of the garden plots.

Demonstrational-training power stations for universities and high schools should be mentioned separately:

- The most powerful of them is installed in Vilnius Gediminas Technical University in 2001, the nominal power of its photovoltaic modules is 0.6 kWp;
- In 2003 a solar mico power station of 0.2 kWp was installed in Alanta technology and business school;
- Solar mico power station with the efficiency of 0.2 kWp was installed in Technology centre of renewable energy sources of Kaunas Technology University in which its efficiency was increased to 0.32 kWp in 2004;
- Solar mico power station with the efficiency of 0.15 kWp was installed in Šiauliai University in 2004;
- In addition, various training tools were created and distributed to high schools: micro power stations of 50 Wp to basic schools, stands of laboratory works, modules of 1-2 Wp are distributed to students during Physics classes, etc. In high schools modules of 25-100 W (0.5-2m2 area) photovoltaic modules are installed in well seen places – above the entrances or on the window sills in classes. Relatively cheap (the whole set costs 1000-3000 LTL, installation included) these power stations usually supply energy to emergency lighting system or other small efficiency receptor. However, their main function is to be an every day seen example of photovoltaics exploitation for students.

4 CONCLUSIONS

Conclusions drawn from this study are based on information on PV products market dynamics, understanding of the tendencies of the growth of production capacities for particular PV value chain products, availability of innovations and technologies flow ensuring growth of quality and competitiveness of the separate products as well as acceptance by different markets of these technological products.

Conclusion 1: Despite recent slowdown further steady growth of PV market is expected for the timeframe under consideration as well as available products costs reductions are expected to follow along the learning curve

Conclusion 1 is based on the following:

Increasing demand for PV	Reducing demand for PV
(1) Existing production capacities are demonstrating clear prospects to benefit from economy of scale to follow cost reduction trend	(1) Phasing out incentives for PV installations are hindering further market development in the matured for PV markets like EU
(2) Technological development of existing products on all value chain segments is ensuring steady improvements of PV products in terms of efficiency and further costs reduction	(2) Fossil alternatives on cost competitive price are becoming available in short term frame
(3) PV is becoming cost competitive energy generation source in wide geographical area	(3) Other RES are demonstrating better performance and cost efficiency comparing to PV

Conclusion 2: In most advanced market segments like EU strong growth of sales of today niche products (BAPV/BIPV) can be expected while for growing markets in Sun Belt countries main stream products will stay in dominant position. Therefore EU based producers should more focus on introduction of the new BAPV or BIPV products

Conclusion 2 is based on the following:

Growth of the share of the BIPV products	Increasing demand for mainstream PV products
(1) Policy driven measures for energy generation and energy saving measures in EU construction sector are pushing toward PV integration into building environment and reducing investments into power plants installations.	(1) Main markets for PV are expected to shift from EU and other developed countries to the developing countries of Sun Belt geographical area.
(2) Building area for PV large power plants is becoming increasingly scarcely available in EU	(3) There are no limitations for PV plants building space in growing Sun Belt markets.
(4) In BIPV and BAPV market PV systems are tailored according installation place and of small scale, therefore less pressure from top tier producers can be expected creating advantageous position for local producers	(5) In Sun Belt countries the most important issue in energy sector is scarcity of electricity and PV is already providing good alternative to the large conventional power plants with no need for huge investment into power plant and grid. PV is providing good possibilities for local communities to get reliable access to the electricity in the areas without strong grid and on low level of investment.
(6) In BIPV market TF technologies have competitive position due to better visual	(7) In Sun Belt area most of the countries belongs to the developing world where price of the products

Growth of the share of the BIPV products	Increasing demand for mainstream PV products
appearance and better acceptance by architects of these products	is first option of choice creating better position for top tier producers offering best prices.

Conclusion 3: There is low probability that mainstream c-Si technology based products will be replaced by competing technologies in the timeframe under consideration although both TF and CPV products can significantly interfere into market redistribution especially in new Sun Belt growing markets

Conclusion 3 is based on the following:

c-Si based PV products are keeping leading market position	Growing market share for competitive PV technology products
(1) Mainstream c-Si products have huge technological advantage because of its maturity, reliability and durability	(1) In opening Sun Belt markets operating conditions are more favorable for TF and CPV products which are demonstrating lower temperature dependency of performance especially in higher temperatures of operation
(2) Existing production capacities for c-si PV products are the only means to fulfill growing demand for PV installations	(3) TF products especially CIGS are demonstrating steady improvements in efficiency without increased complexity
(4) There are no prerequisites available for large scale investments into alternative PV technologies production capacities	(5) CPV products are undergoing significant cost reductions due to the innovations first of all in introduction of industrial solutions for the assembling for the CPV systems

Conclusion 4: Market growth for PV products based applications is strongly dependent on complementary technologies products availability like other RES or storage and is particularly dependent on introduction of cost competitive storage products in both developed as well as in emerging PV markets. In markets with high penetration of PV grid, stability issue is becoming of primary importance and can be solved only by means of integration with other RES (like wind), introduction of local storage capacities and introduction of smart grid concepts in the operation of the grid. In emerging markets of Sun Belt countries in the presence of the weak grid or no grid situation distributed generation by PV is directly dependent on integration with other power generation and/or storage capacities

Conclusion 4 is based on the following:

Issues stimulating PV applications market growth	Issues limiting PV applications market growth
(1) In high PV penetration markets further PV installations growth can be ensured only through complex energy generation systems contributing to grid stability issues.	(1) Products for local storage implementation on small PV installations level are still immature and costly
(2) In developing energy markets RES and especially PV are providing feasible solution for diesel based systems	(3) PV based applications are still not attractive in terms of cost effectiveness and operation to replace existing diesel based systems in developing countries
(4) Growing diversification of PV based applications for cost effective local energy generation	(5) To compete with available solutions PV based applications must demonstrate not only better cost effectiveness but comply with requirements for safety, standards etc.