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Review Article

Thin Film Photovoltaics: Markets and Industry

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Since 2000, total PV production increased almost by two orders of magnitude, with a compound annual growth rate of over 52%. The most rapid growth in annual cell and module production over the last five years could be observed in Asia, where China and Taiwan together now account for about 60% of worldwide production. Between 2005 and 2009, thin film production capacity and volume increased more than the overall industry but did not keep up in 2010 and 2011 due to the rapid price decline for solar modules. Prices for photovoltaic electricity generation systems have more than halved over the last five years making the technology affordable to an ever-increasing number of customers worldwide. With worldwide over 60 GW cumulative installed photovoltaic electricity generation capacity installed in November 2011, photovoltaics still is a small contributor to the electricity supply, and another 10 to 15 years of sustained and aggressive growth will be required for photovoltaic solar electricity to become one of the main providers of electricity. To achieve this, a continuous improvement of the current solar cell technologies will be necessary.

1. Introduction

Photovoltaics has enjoyed extraordinary growth during the last decade with overall growth rates above 50% per annum, indicating that further increase of production facilities is an attractive investment. The last World Energy Outlook released by the International Energy Agency (IEA) in November 2011 indicates that more and more renewable energy and in particular solar energy will be needed and used in the coming decades to ensure a stable and secure energy supply as well as limit the effects of energy-induced climate change [1].

On the one hand the IEA stressed an urgent need to accelerate actions to tackle climate changes as 80% of the total energy-related CO_2 emissions allowed under the 450 ppm scenario for 2035 are already "locked in" by the existing capital stock (power plants, buildings, factories, etc.), but on the other, the IEA only forecasts an increase of non-hydrorenewables in power generation from 3% in 2009 to 15% in 2035, which is far below the renewable energy potential.

Due to the current financial and economic constraints, the introduction of renewable energy sources and photovoltaic electricity generation systems is often depicted as a too expensive energy option. This is a short-sighted view as it does not take into account that all those renewable energy generation technologies that do not require fuels, for example, solar, wind, and so forth, reduce the price volatility risk and enhance the predictability of power generation cost.

There are several studies that examine the difficult issue of quantifying the effect of the inclusion of RES in an energy portfolio and the reduction in the portfolio energy price. This is in addition to the employment benefits and the economic benefits of avoided fuel costs and external costs (GHG), money which could be spent within the economy and used for local wealth creation [7].

Production data for the global cell production in 2010 is about 24 GW (Figure 1), which is about the double compared to 2009. (Solar cell production capacities mean (i) in the case of wafer silicon-based solar cells only the cells; (ii) in the case of thin films, the complete integrated module; (iii) only those companies that actually produce the active circuit (solar cell) are counted; (iv) companies that purchase these circuits and make cells are not counted.) For 2011 a further increase to about 30 GW is expected. The significant uncertainty in the data for 2011 is due to the very competitive market environment, as well as the fact that some companies

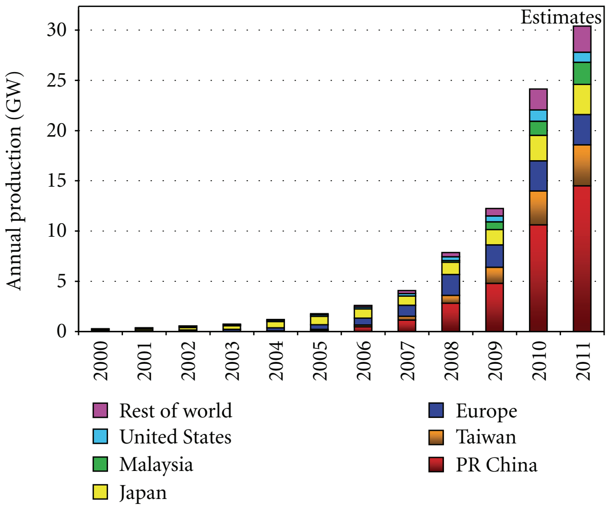

Figure 1: Worldwide PV production from 2000 to 2011. (data source: PV News [2], Photon International [3], and own analysis).

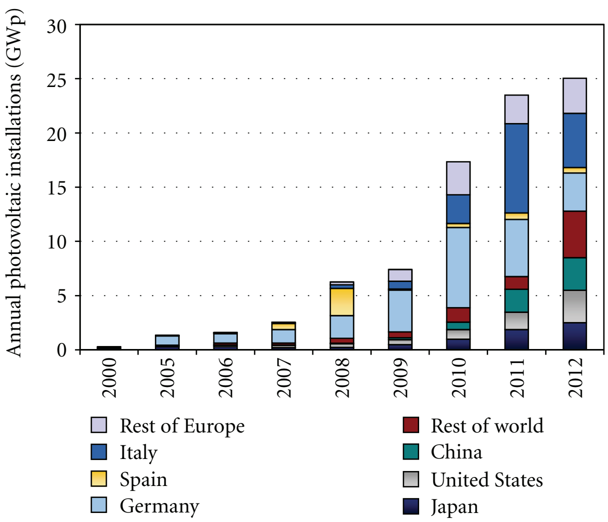

Figure 2: Annual photovoltaic installations from 2000 to 2012. 2011 and 2012 are still estimates. (data source: Bank Sarasin [4], EPIA [5], EurObserv'ER [6], and own analysis).

report shipment figures, others report sales, and again others report production figures. The continuation of the difficult economic situation worldwide as well as a fierce competition and a production capacity that is more than twice the actual market led to a decreased willingness to report confidential company data. The previous tight silicon supply situation reversed due to massive production expansions as well as the economic situation. This led to a price decrease on the spot market from the 2008 peak of around 500 $/kg to below 30 $/kg at the end of 2011.

More than 80% of the current production uses wafer-based crystalline silicon technology. A major advantage of this technology is that complete production lines can be bought, installed, and up and producing within a relatively short time frame. This predictable production start-up scenario constitutes a low-risk placement with calculable return on investments. However, the temporary shortage in silicon feedstock and the market entry of companies offering turn-key production lines for thin film solar cells led to a massive expansion of investments into thin film capacities between 2005 and 2010.

Since 2000, total PV production increased by two orders of magnitude, with a compound annual growth rate (CAGR) of 53%. The most rapid growth in annual production over the last five years could be observed in Asia, where China and Taiwan together now account for more than 60% of world-wide production.

The change of the market from a supply-restricted to a demand-driven market and the resulting overcapacity for solar modules have resulted in a dramatic price reduction of PV systems of more than 50% over the last four years. Average prices for grid-connected PV systems were reported with 2,540 $/kWp (1,880 €/kWp) for residential and 2,350 $/kWp (1,740 €/kWp) for commercial systems at the beginning of December 2011 [8].

2. Markets

Market predictions for the 2011 PV market vary between 21.9 GW and 24 GW with a consensus value in the 23 GW range (Figure 2). For 2012 analyst expectations vary between 20.5 GW and 27 GW. Despite these moderate growth forecasts, massive capacity increases are still ongoing or announced, and if all of them are realised, the world-wide production capacity for solar cells will exceed 65 GW at the end of 2011 and 85 GW at the end of 2012. This indicates that even with the optimistic market growth expectations, the planned capacity increases are way above the market growth. The consequences are either low utilisation rates or the build-up of high inventories resulting in a continued price pressure in an oversupplied market. Such a development will accelerate the consolidation of the photovoltaics industry and spur more mergers and acquisitions.

With a cumulative installed capacity of over 46 GW, the European Union is leading in PV installations with a little more than 70% of the total worldwide 63 GW of solar photovoltaic electricity generation capacity at the end of 2011 (Figure 3).

In 2012, the European market share of new installations is expected to drop from about 70% to 50% due to the rapid growing markets in Asia and North America. This development reflects the fact that the rapid cost reduction during the last few years is opening more and more markets worldwide, easing the dependency of the PV industry from a few very strong markets.

Asia and Pacific Region. The Asia and Pacific region shows an increasing trend in photovoltaic electricity system installations. There are a number of reasons for this development, ranging from declining system prices, heightened awareness, favourable policies, and the sustained use of solar power for rural electrification projects. Countries such as Australia, China, India, Indonesia, Japan, Malaysia, Repuplic of Korea, Taiwan, Thailand, The Philippines and Vietnam show a very positive upward trend, thanks to increasing governmental

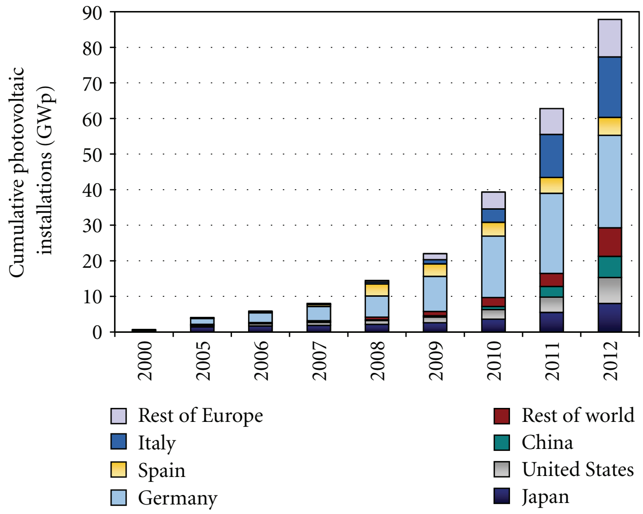

Figure 3: Cumulative photovoltaic installations from 2000 to 2012. 2011 and 2012 are still estimates. (data source: Bank Sarasin [4], EPIA [5], EurObserv'ER [6] and own analysis).

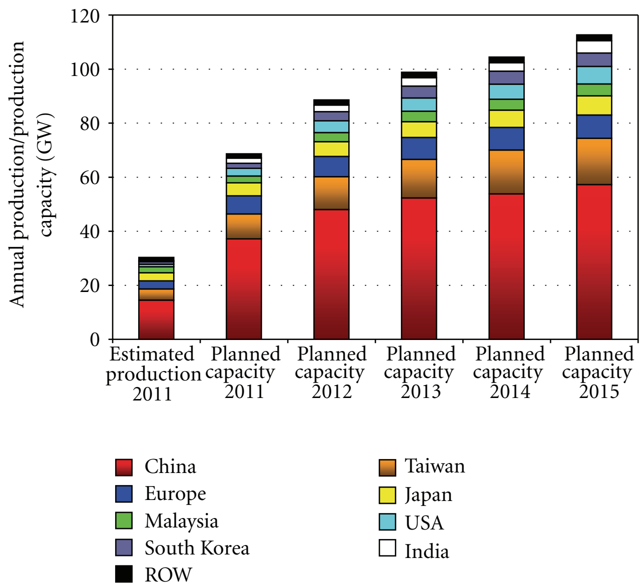

Figure 4: Actual and planned PV production capacities.

commitment towards the promotion of solar energy and the creation of sustainable cities.

The introduction or expansion of feed-in tariffs is expected to be an additional big stimulant for on-grid solar PV system installations for both distributed and centralised solar power plants in countries such as Australia, Japan, Malaysia, Thailand, Taiwan, and Republic of Korea.

In 2010 about 2.5 GW of new PV electricity generation systems was installed in the region. The largest market was Japan with 990 MW followed by China with 560 MW and Australia with 380 MW. For 2011 a market increase to about 5 GW is expected, driven by the major market growth in China (∼2 GW), India, Japan, Malaysia, and Thailand. Market expectations for the region range between 7 and 8 GW in 2012.

The Asian Development Bank (ADB) launched an Asian Solar Energy Initiative (ASEI) in 2010, which should lead to the installation of 3 GW of solar power by 2012 [9]. In their report, ADB states: "*Overall, ASEI aims to create a virtuous cycle of solar energy investments in the region, toward achieving grid parity, so that ADB developing member countries optimally benefit from this clean, inexhaustible energy resource.*"

European Union. Market conditions for photovoltaics differ substantially from country to country. This is due to different energy policies and public support programmes for renewable energies and especially photovoltaics, as well as the varying grades of liberalisation of domestic electricity markets. After a tenfold increase of solar photovoltaic electricity generation capacity between 2001 and 2008, the newly installed capacity more than quadrupled in the last three years to exceed 46 GW cumulative installed capacity at the end of 2011 [10, 11]. For 2012 market expectations vary between 11 and 13 GW of new installations.

The legal framework for the overall increase of renewable energy sources was set with the Directive 2009/28/EC, and in their National Renewable Energy Action Plans (NREAPs), 26 Member States have set specific photovoltaic solar energy targets, adding up to 84.5 GW in 2020. However, since the submission of the NREAPs in 2010 a number of positive signs have emerged for PV. In Italy, the 4th *Conto Energia* was enacted in the first half of 2011 and it limits the support for PV installations until 2017 or 23 GW whatever is reached earlier. In August 2011 Greece announced the "*Helios*" project, which aims to install up to 10 GW of PV electricity systems on public land by 2020. These developments indicate that the targets set in the NREAPs should be seen as the guaranteed minimum and not the overall goal.

In 2011 Italy overtook Germany as the biggest market with an expected new connected capacity of 8.2 GW versus 5.2 GW, respectively. The market growth in these two countries is directly correlated to the introduction of the Renewable Energy Sources Act or "*Erneuerbare Energien Gesetz*" (EEG) in Germany in 2000 and the "*Conto Energia*" in Italy in 2005.

North America. In 2010, Canada more than tripled its cumulative installed PV capacity to about 420 MW, with 300 MW new installed systems. For 2011 a further increase of the market from 350 to 400 MW is estimated. This development is driven by the introduction of a feed-in tariff in the province of Ontario in 2009.

With close to 900 MW of new installed PV capacity, the USA reached a cumulative PV capacity of 2.5 GW at the end of 2010. Utility PV installations more than tripled compared to 2009 and reached 242 MW in 2010. The top ten states—California, New Jersey, Nevada, Arizona, Colorado, Pennsylvania, New Mexico, Florida, North Carolina, and Texas accounted for 85% of the US grid-connected PV market [12]. For 2011 an increase of the US market to 1.6 GW is estimated.

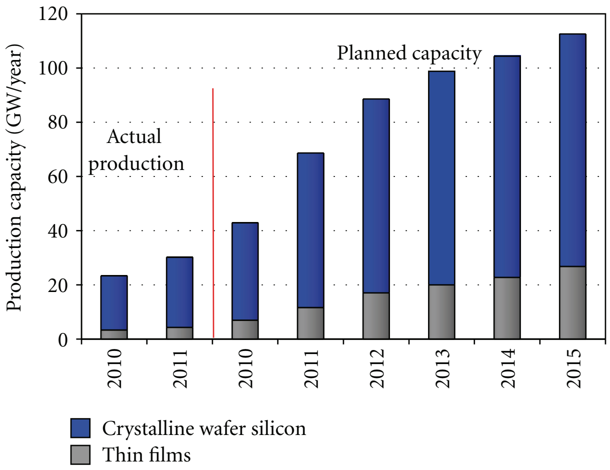

Figure 5: Actual and planned PV production capacities of thin film and crystalline silicon-based solar modules.

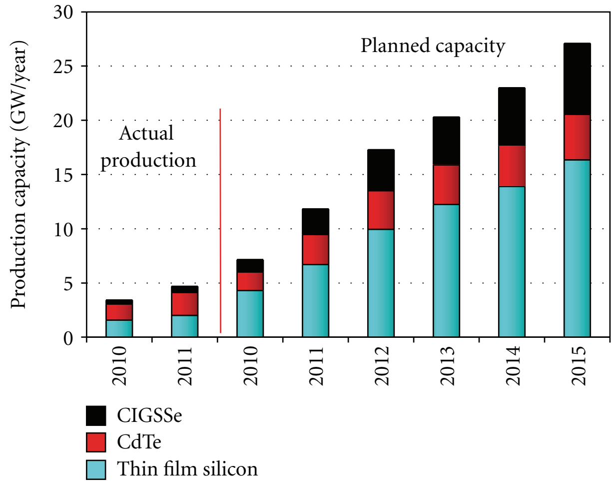

Figure 6: Actual production and planned capacities of the different thin film technologies.

PV projects with Power Purchase Agreements (PPAs), with a total capacity of 6.1 GW, are already under contract and to be completed by 2014 [13]. If one adds that 10.5 GW of projects, which are already publicly announced, but PPAs have yet to be signed, this makes the total "pipeline" more than 16.6 GW.

Many state and federal policies and programmes exist and one of the most comprehensive databases about the different support schemes in the USA is maintained by the Solar Centre of the State University of North Carolina. The Database of State Incentives for Renewable Energy (DSIRE) is a comprehensive source of information on state, local, utility, and selected federal incentives that promote renewable energy. All the different support schemes are described therein and it is highly recommended to visit the DSIRE website (http://www.dsireusa.org/) and the corresponding interactive tables and maps for details.

The 2012 market expectations for Canada and the USA together vary between 3.5 and 5 GW.

3. Thin Film Photovoltaic Industry

Thin film photovoltaics was always an integral part of the industry. Back in 1994 about 80 companies with a total production capacity of 130 MW existed worldwide and their activities ranged from research to production of solar cells. About half of them were actually manufacturing and other 29 companies were involved in module production only. Out of the solar cell companies, 41 companies used crystalline silicon (72 MW capacity), 2 ribbon silicon (1 MW capacity), 19 amorphous silicon (46 MW capacity), 3 CdTe (11 MW capacity), 5 CIS (research only), and 10 companies other concepts like III–V concentrator cells or spherical cells.

Since then the world wide production capacity of solar cells has increased about 500 times exceeding 68 GW in 2011 with thin films accounting for 11.5 GW or 17%.

The reported future production capacities are based on a survey of more than 300 companies worldwide with a cut-off date at the beginning of December 2011. Despite the fact that a significant number of players delayed or cancelled their expansion plans and some companies had to seize operations due to bankruptcy, the number of new entrants into the field, notably large semiconductor or energy related companies overcompensated this. The announced production capacities increased again in 2011. It is important to note that production capacities are often announced, taking into account different operation models such as number of shifts and operating hours per year. In addition the announcements of the increase in production capacity do not always specify when the capacity will be fully ramped up and operational. This method has of course the setback that (a) not all companies announce their capacity increases in advance and (b) that in times of financial tightening, the announcements of the scale back of expansion plans are often delayed in order not to upset financial markets. Therefore, the capacity figures just give a trend but do not represent final numbers.

If all these ambitious plans can be realised by 2015, China will have about 50.8% of the world-wide production capacity of 112 GW, followed by Taiwan (15.2%), Europe (7.6%), and Japan (6.3%) (Figure 4).

In 2005 production of thin film solar cells reached for the first time more than 100 MW per annum. The first 100 MW thin-film factories became operational in 2007, followed by the first 1 GW factory in 2010. Between 2005 and 2010, the Compound Annual Growth Rate (CAGR) of thin-film solar cell production was above the overall industry, driven by the temporary shortage in silicon feedstock and the market entry of companies offering turnkey production lines for thin-film solar cells. Despite the fact that in production capacity terms, the market share of thin films is still increasing, the pace has slowed down considerably because the vast majority of new production capacity announcements over the last two years were for wafer-based silicon technologies.

In 2011, more than 200 companies were involved in thin-film solar cell activities, ranging from basic R&D activities to major manufacturing activities and over 150 of them

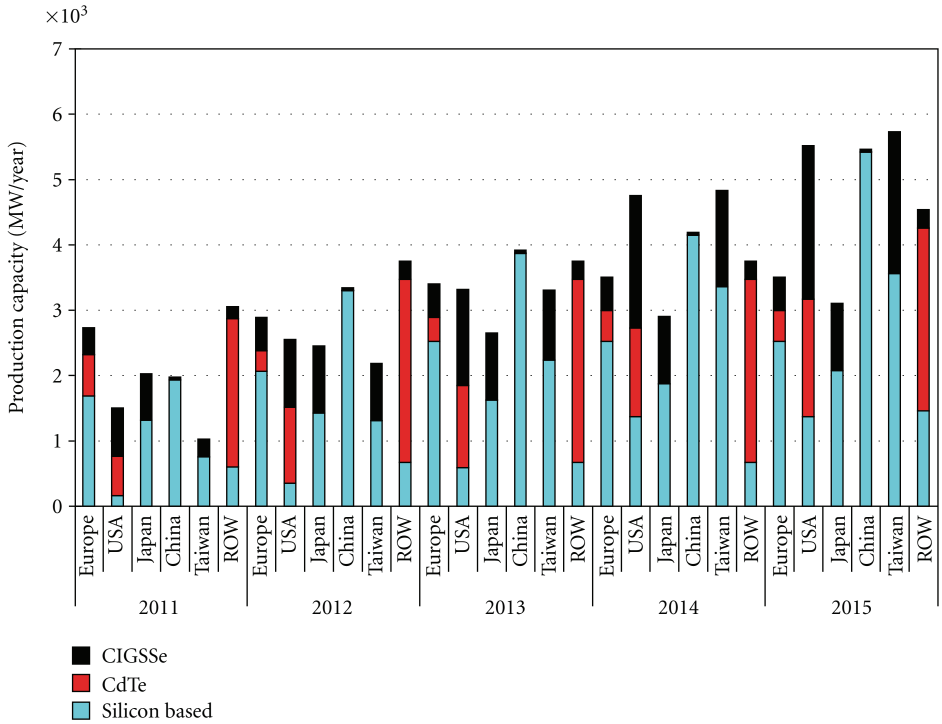

Figure 7: Projected thin film PV production capacities. Regional distribution of the different technologies.

have announced the start or increase of production. If all expansion plans are realised in time, thin-film production capacity could be around 17 GW, or 19% of the total 88 GW, in 2012 and about 27 GW, or 24%, in 2015 of a total of 112 GW (Figure 5).

In August 2007, when the first survey was presented at the 22nd EUPVSEC in Milano, it was found that in 2006 just 21 companies had produced thin film solar modules, which were available in the market with quantities above 1 MW. Since then the number has more than tripled to 65. However, the production quantities are in general still quite small. Out of the over 120 companies, with announced production plans, about 40% produced 10 MW or more and only 5% produced more than 100 MW in 2011.

More than 70 companies are silicon based and use either amorphous silicon or an amorphous/microcrystalline silicon structure (Figure 6). Thirty-six companies announced using $Cu(In,Ga)(Se,S)_2$ as absorber material for their thin-film solar modules, whereas nine companies use CdTe and eight companies go for dye and other materials.

Despite the fact that the majority of companies use thin film silicon structure, the dominating thin film technology in the market in 2011 is CdTe with about 2.1 GW followed by thin film silicon with 2 GW and CIGSSe with 0.6 GW. In terms of projected capacity increases, thin film silicon is leading followed by CIGSSe and CdTe.

The technology as well as the company distribution varies significantly from region to region (Figure 7).

This regional distribution reflects on the one hand the scientific knowledge base concerning the different thin film technologies and also the investment options and availability of human resources. This last issue is a very crucial one for the future development of photovoltaics and thin film photovoltaics in particular. All these new thin film factories will need not only qualified operators and process engineers but also scientists with a profound knowledge of the respective materials in order to improve the guaranteed start-up processes and secure the competitiveness of the companies for the years to come. Compared to the silicon wafer-based PV technology, the different thin film technologies still have a significant number of fundamental material problems to solve in order to unlock the full efficiency and cost saving potential of the different technologies.

The change of the market from a supply-restricted to a demand-driven market and the build-up overcapacity for solar modules have resulted in a dramatic price reduction of more than 50% over the last three years. Sepecifically companies in their start-up and expansion phase, with limited financial resources and restricted access to capital, are struggling in the current market environment. This situation is believed to continue for at least the next few years and put further pressure on the reduction of the average selling prices (ASP). The recent financial crisis added pressure as it resulted in higher government bond yields, and ASPs have to decline even faster than previously expected to allow for higher project internal rate of returns (IRRs). On the other hand, the rapidly declining module and system prices open new markets, which offer the perspectives for further growth of the industry—at least for those companies with the capability to expand and reduce their costs at the same pace.

4. Conclusion

The increase of conventional energy prices has increased the investment attention for renewable energies and in particular photovoltaics significantly. Since 2006 the investments and growth in thin film photovoltaics have surpassed the already high growth rates of the whole photovoltaics industry but have recently slowed due to technology and financial reasons.

Thin film solar cells still offer the possibility of reducing the manufacturing costs considerably; however, considering the increasing maturity of wafer-based production technologies, observed learning curves, and recent cost reductions, newcomers have to enter the game at already very competitive levels. In addition, the entry ticket, that is, factory size for thin film manufacturers into the market, has increased from a 20 MW factory in 2006 to a minimum of 100 MW in 2011 and is still growing with the increasing market volume.

Thin film technologies still need a lot of research over a wide range of issues, ranging from improvement of the understanding of basic material properties to advanced production technologies and the possible market perspectives. To tackle these problems, a long-term vision for photovoltaics and long-term research are needed.

However, there is no "winning technology" and a viable variety of technology options have to be ensured. To focus on any single technology option now could be a road block in the future. Public research funding structures should take into account that different technologies are at different development stages and need different kind of support measures.

In order to realise high production volumes for PV we must now look towards already available high-throughput, high-yield production technologies analysing if and how they can be utilised for PV in the future. This is especially important for thin film solar cell materials, that have only a limited backing by other industries, such as that provided by the microelectronic industry, in the development of production technologies for silicon solar cells. In addition, there are a number of research issues common to all thin film technologies which have to be solved. No single solar cell technology can neither satisfy the world-wide demand nor all the different wishes consumers have for the appearance or performance of PV systems.

Disclaimer

The opinion given in this paper is based on the current information available to the author and does not reflect the opinion of the European Commission.

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