Energy Sector Economic Report

Economic Analysis: Nanotechnology for Photovoltaics

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Executive summary

Solar photovoltaic (PV) technology may be used in several types of applications: grid-connected and off-grid systems as well as consumer electronics. Grid-connected solutions have been the engine for solar PV growth over the last decade, and it accounts for the biggest share of the market. A growing interest for building integrated PV (BIPV) is also recognised and nanotechnology is key when producing flexible thin film products for buildings.

PV is still an early-stage technology with several barriers slowing the technology´s transition to market. Cost competitiveness, system integration with infrastructure and other renewable energy sources, supply chain, market deployment and policy framework with feed-in tariffs are important factors affecting the commercialisation of PV. The effects of nanotechnology can be seen on solar photovoltaic´s price and in the shorter value chain of thin film produced PV. On the application level, the functional requirements of solar photovoltaics are efficiency, durability, easy installation, light weight and disposability.

Global solar photovoltaic installations increased in 2009 reaching 6.43 GW, with annual production of 9.6 GW (regardless of the down turn). The share of nanotechnology-enabled thin film technology increased sharply. It was slightly below 20% in 2009 and the market was dominated by crystalline silicon wafer based technology. Most of the European companies producing solar cells and modules utilizing nanotechnology - now or in a near future - seem to focus on a-si. In addition CIS, CIGS or DSSC PV technologies are the focus of several European companies, as indicated by research carried out by the ObservatoryNano-project. 60 to 75% of the European companies in this study were small or medium sized. 90% of the companies focused only on solar photovoltaic. Germany was the location for most of the companies.

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1. Market description of Solar Photovoltaics

1.1. Short application description

Solar PV technology can be used in several types of applications: grid-connected systems, off-grid systems, and consumer goods.

Grid-connected

Electricity grid connected solar power plants are capable of generating electricity from several hundred kilowatts to several megawatts. Industrial and home installations may be used to satisfy local electricity demand, and to supply additional power at times of peak demand. Grid connectivity also enables excess local electricity production to be supplied to the power grid, although this also requires billing and metering mechanisms and a device to convert the current. A number of companies have invested in the production of solar power plants. Grid-connected solar replaces other sources of electricity generation; typically coal or gas-fired power stations.[1]

Grid-connected solar PV has been the engine of solar growth over the last decade, and accounts for a very high proportion of all solar cells sold. The quantities involved render this a large-scale, manufacturing intensive business. Many of the larger companies in this space, such as Sharp or Kyocera, have experience in mass production of glass or displays, and have applied this experience to the production of crystalline silicon PV.

Off-grid systems

Off-grid systems are generally smaller scale than grid-connected PV. Off-grid solar PV may be used to provide power in places which are not connected to the electricity grid, in developing countries or in rural areas of developed countries. Electrifying rural areas is not only an economic opportunity, and also has wider societal benefits. A significant application is the use of off-grid solar to power utilities, such as cell towers for mobile telephone networks. A combination of the power requirement of telecom base stations, and their location on high ground, make off-grid solar PV an attractive power source. Similarly, solar PV cells may be used to power street lighting, traffic lights, and signage. This application area reduces the cost and complexity of connecting these utilities to the electricity grid.[1]

Consumer goods

The most ubiquitous application of solar PV is their use to replace batteries as a power source for portable devices such as calculators and watches. This application area currently accounts for a very small proportion of the total global PV market. Despite their ubiquity, these are a small, commoditised component of a low cost device, and therefore the value is low.[1]

1.1.1. Drivers and barriers

PV is still an early-stage technology so there are several barriers which slow the technology's transition to market. The high price seems to be most prominent factor. PV plants have a higher investment cost than competing technologies, but lower operating cost and no fuel price risk. Other barriers are the market power of incumbent energy firm and valuation methods that favour large-scale power plants. The cost disadvantage is influenced by subsidies. The Swiss University of St. Gallen´s Institute for Economy and the Environment reported in 2009 that duration of administrative process was the most important attribute encouraging PV project developers. Almost as important was also the level of Feed-In Tariffs, as seen from the Figure 1.[2]

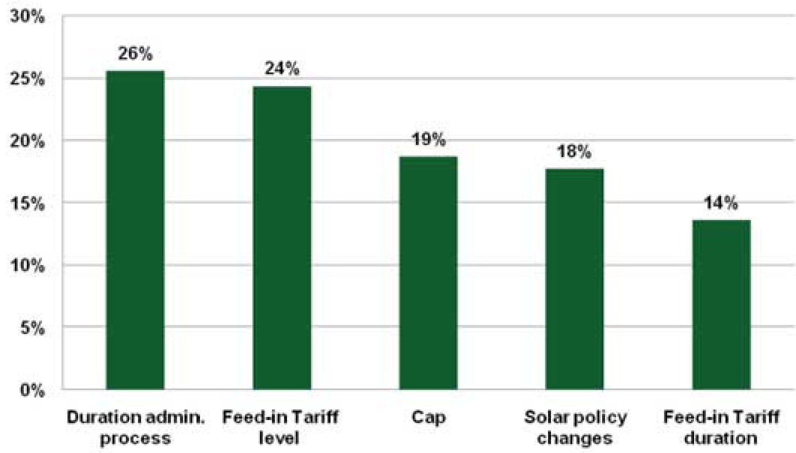

Figure 1. Relative importance of policy attributes by Swiss University of St. Gallen´s Institute for Economy and the Environment research [2].

According to the EPIA report "Set For 2020 - Solar Photovoltaic Electricity", the potential of PV deployment depends on six independent framework conditions. These framework conditions are: system integration, cost competitiveness, market deployment, policy framework, interaction with other renewable energy sources and the supply chain.[3]

System integration

Daily and seasonal variation affects the generation of solar energy and thus requires flexibility of grid management. That is achieved by better coordinated long-term planning of investments in new generation capacities across the European electricity market. However, system integration to the infrastructure and evolution of the generation mix will limit market penetration of new energy technologies.[3]

Cost competitiveness

Increased market penetration of PV will reduce the price level and make investments competitive in Europe. This enables market-driven growth in the near to mid-term without Feed-in Tariffs. The first step is technology development to enable price reduction at system level. Extensive R&D investment and continued support of PV market development is required for price reduction.[3]

Market deployment

The development of innovative products to meet diverse customers needs, certification for safety, and reliability as well as availability of appropriate financing solutions is key to enable successful PV deployment. [3]

Policy framework

Feed-In Tariffs are the best support, especially when they are sustainable, not unduly generous and develop with the growing market share of PV.[3] At least 11 EU member states offer subsidies for solar power including instruments such as feed in tariffs, investment grants and subsidies, tax credits, and beneficial credit terms. These supports are available to utilities, companies and individual households[4]. A cautionary note, in 2009 some solar manufacturers have complained that subsidies which offer tax rebates are no longer effective, as companies are not making a profit on which to pay tax in the first place.

Integration with other renewable energy sources

PV is essential component of the EU´s 20/20/20 objective. PV and wind with grid connection has a common interest.[3]

Supply chain

The PV supply chain is expected to maintain a global multi-gigawatt production capacity in the coming years. Key challenges for the chain are: the availability of silicon feedstock and commodity materials, cell and module capacities, and the availability of professionals. Therefore education is an important to maintain a leading PV industry position in Europe.[3]

1.1.2. Functional requirements and impacts of nanotechnology

Nanotechnology-based solutions may be used to improve the functional requirements of solar photovoltaics and to speed competitive PV-applications market entry. The impact of nanotechnology may be to lower the cost of solar PV by reducing material requirements or by introducing more efficient manufacturing methods. It may also increase the efficiency of semiconductor materials and enable novel applications of solar PV technology, such as integration with building materials or even clothing. Regardless of the technology used, solar PV has the following functional requirements[5]:

Effectiveness

PV cell must provide enough electrical energy to offset the costs of its production, installation and use. Currently the highest efficiencies are obtained by concentrator PV cells, which are capable of generating conversion efficiencies of around 40% (a European record of 39,7% was achieved by Fraunhofer ISE in 2008)[6]. Efficiencies achieved by other technology approaches are shown in

Table **1**.

Table 1. Comparison of Efficiency Levels Achieved by Solar PV Technologies[7,8]

Technology	Highest Recorded Efficiency
Concentrator PV	40%
Crystalline Silicon	25%
Thin Film – CIGS	19%
Thin Film - CdTe	16%
Thin Film - aSi	12%
Dye sensitized	11%
Organic PV	5%

For example carbon nanotubes might be used in photovoltaic cells to make more efficient next-generation solar cells[9]. Using roll to roll nanoimprint lithography the solar cells could also be produced cheaply[10]. Use of nanocrystals may also give a potentially high efficiency[5].

Durability & lifetime

Clearly one of the most important factors in calculating the life-cycle cost of PV cells is how its efficiency will change over time and what is lifetime. The target lifetime for a PV cell is at least 20 years, in a temperature range of -40 ^{o}C to 85 ^{o}C[11] and many manufactures issue warrantees to this effect. Durability is a particular issue with organic approaches; degradation of conducting polymers is a well-studied phenomenon.

Easy installation & lightweight

The easier the installation is more potentially the PV application win market acceptance. The lighter the PV cell is, the more numerous locations in which they can be installed. A potential application of DSSC is their use as windows, given that their structure may render them partially translucent[12]. PV coatings may be also applied for example to the surface of roof material in the same way that corrosion-resistant coating.[13]

Disposable

Given that solar PV is sold as an environmentally-friendly product, it is important that cells can be disposed of safely at the end of their useful life. This mitigates against the use of polluting heavy metals, or at least places a burden on the manufacturer to ensure that safe disposal methods exist.[14]

1.1.3. Nanotechnology impacts on value chain

Silicon supply has been the PV industry bottleneck since 2005 and that has enabled the PV Thin Film industry to grow[31]. However, silicon supply is no longer the bottleneck as the price has fallen closer to spot price, so silicon solar panel producers are able to sell their products below $2 per watt. The price of silicon panels was narrowing to the price of cadmium-telluride panels in 2009.[15]

Competitive price levels and production with low manufacturing cost per kWh are the targets in the PV market. This target is being reached by investing in larger manufacturing processes and equipment and materials suppliers' partnerships. As seen from Figure 3 and Figure 4, crystalline silicon technology has many steps in the value chain and several players are typically needed, whereas one producer can handle the whole value chain in one factory using thin film technology. Innovation of thin film production equipment and materials are the key parameters when moving towards thin film PV production, according to the Yole Développement Photovoltaic Report.[16]

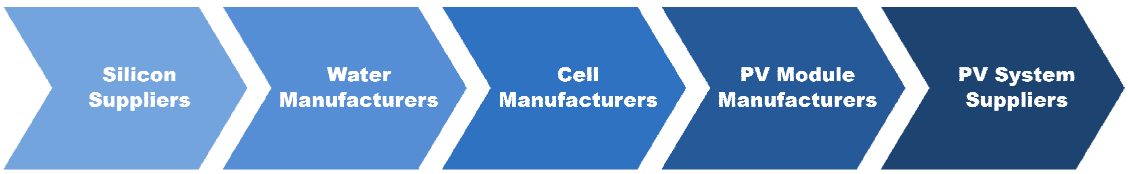

Figure 2. Value chain for crystalline silicon solar cells.

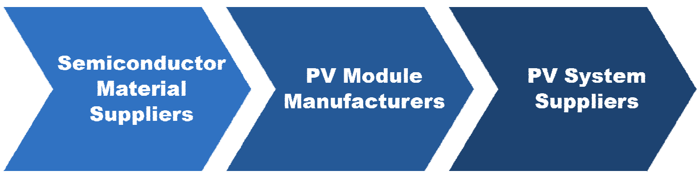

Figure 3. Value chain for thin film cells.

Several factors will impact the extent to which nanotechnology-based approaches become price competitive with crystalline silicon; cost of materials, cost of production, and efficiency.[17] Dye-sensitized solar cells do provide an opportunity for bulk chemical manufacturers to enter the PV market, supplying titanium dioxide and the dye itself. It is unlikely that they would be able to appropriate much value from this, as the titanium dioxide market is somewhat commoditized.

PV coatings would change the role of the cell manufacturer. In the case the value is likely to be in the coating machinery, which would then be installed in existing steel plants, for example. In the case of thin film PV the value chain is likely to consist of the chemical supplier, the equipment manufacturer and the material manufacturer, who could offer PV-integrated materials for the differentiated product.

1.1.4. Product and company examples

This is a listing of some innovative companies using thin film and other nanotechnology-based approaches to PV production or products. The adoption potential and market penetration of PV technologies was evaluated by questionnaire and interviews and those are therefore company specific.

Amorphous silicon is a one of the well developed thin film technology. It is potentially cheaper than crystalline silicon or other thin film technologies, although it´s less efficient (4% - 8% stabilized module efficiency). It's advantage is based on the lower material cost and cheaper and more scalable manufacturing processes.[18]

VHT-Technologies (Flexcell) is a good example of the thin film Amorphous silicon PV products market penetration. The first PV consumer products were launched in 2003 and the product range was enlarged in 2008 with flexible building integrated solutions. Alexandre Closset, CEO of VHT-Technologies argued that, "Convincing a customer with a new technology and its advantages was a major barrier, when coming to the market with new products. Competition from China is increasing and it brings tight price competition." Closset also described the advantages of amorphous silicon technology; "Flexible building integrated solutions utilizing a-si *thin film technology benefits from lighter weight and improved temperature performance compared with crystalline silicon. PV modules with a-si technology produce more power in hot surroundings, whereas it is opposite for products with crystalline silicon technology."*

Name:	**VHF-Technologies SA (Flexcell)**
URL:	http://www.flexcell.com
Used technology:	Thin film Amorphous silicon deposition to flexible plastic substrate instead
Investment:	25 MW production line
Description:	Flexcell was established in 2000 to commercialise work carried out at the Institute of Micro Technology in Neuchâtel. The company is now a subsidiary of Q-Cells

Flexible building integrated solutions

Flexcell makes flexible PV modules an integral part of the various sized and shaped building component. Applications are lightweight and easy to install. Efficiency is 5%.

BIPV solution from Flexcell

CIS, copper indium selenide, achieved greater than 14% efficiency. However, manufacturing costs of CIS solar cells are high, when compared with amorphous silicon solar cells.[19]

Bernhard Dimmler, CEO of Wuerth Elektronik Research GmbH, pointed out that "market adoption of our CIS modules is good, but we are selling the module together with a complete, grid connected PV system. The potential efficiency is for sure the biggest advantage of CIS technology. The current average efficiency will be increased in the near future, with efficiencies already reached at laboratory scale. The biggest opportunities for CIS modules compared to conventional c-Si are a lower temperature coefficient, higher low light behaviour, much higher flexibility in module design, and a favourable cost structure with higher production volumes, *especially in the future." Dimmler continued: "Surely there are still barriers to overcome especially with further designs for BIPV (building integrated PV), in addition to existing varieties we are already offering. An additional barrier is set by the proposal to change the German feed-in tariff, as well as our scaling velocity and innovation potential, which are not rapid enough to compete easily in the market. The major barriers when coming to the market with CIS modules are new materials, new products, and a shortage of references. It was necessary to build a good sales channel."*

Dimmler emphasized the importance of nanotechnology: "I think it could become a very important technology for thin films".

Name:	**Würth Solar**
URL:	www.wuerth-solar.de
Used technology:	Thin film CIS
Investment:	In 2008 expansion to 30MW production capacity
Description:	Würth Solar was the first company worldwide to begin large-scale production of GeneCIS solar modules in its specially-built CISfab solar factory in Schwäbisch Hall in autumn 2006 – setting new benchmarks in the industry.

GeneCIS modules

GeneCIS modules generate relatively high yields even in high temperatures that can occur in European latitudes in early summer or in scattered light.

GeneCIS modules area efficiency is at the moment max. 14%

GeneCIS modules by Wûrth Solar

CIGS are currently the most efficient thin film technology. Efficiency is not however as good as crystalline silicon solar cells, but they are substantially cheaper than crystalline due to potentially lower production and material costs. CIGS has also very strong light absorption and therefore thinner layer of material is needed than to achieve the same absorption as crystalline silicon PV. In addition, smaller amounts of toxic cadmium are used in CIGS than in CdTe cells.[20]

Name:	**Q-Cells SE (Solibro)**
URL:	http://cigs.q-cells-moduls.com
Used technology:	Thin Film CIGS
Investment:	Q-Cells shares from thin film subsidiaries Solibro (100%), Calyxo 93%, Sunfilm 50%, Flexcell 58,11% (Year 2009 figures)
Description:	CiGS modules produced in Q-Cells´s subsidiary Solibro´s factory are the world's highest efficiency (12%) thin-film solar modules. Good performance in low and oblique light and positive power sorting result in excellent energy yields. First CIGS modules were manufactured in 2008 and the production capacity was expanded in 2009.

CIGS modules

Q-Cells' CIGS modules are distinguished by the world's highest efficiency (12%) for thin-film solar modules. Their long-term stability is also proven in quality tests. Glass-glass composite SL1 PV module is self-cleaning and cost-efficient without frame.

SL1 modules by Q-Cells

CdTe is the other technology penetrated well to the market especially by the USA companies. However potential emissions of cadmium have concerned the communities. It has been shown that Cd compounds cannot be emitted during normal use of PV modules. Environmental emissions to environment would occur only after decommissioning, if modules ended up in municipal waste-incinerators. Recycling completely resolves these problems.[21] CdTe semiconductors, like a-si, are less susceptible to cell temperature variations than traditional crystalline semiconductors and therefore the modules produce more electricity in hot areas.

GaAs, gallium arsenide is also known as single crystalline thin film. It is a high cost and high efficiency (>32% for triple junction)solar cell. These solar cells have taken over from silicon as the cell type most commonly used in satellite applications. Many solar cars also utilize GaAs. Gallium arsenide's toxic and carcinogenic properties are drawbacks of the technology. [22]

Morten Schaldemose, CEO of SunFlake A/S, remarked that successful results have been published from GaAs technology and that the first products will be on the market within a few years. The advantages of the technology are high efficiency and a beneficial band gap when comparing to silicon and other thin film technologies. Uniform crystalline structure growth is one of the biggest barriers to overcome with the technology. Concentrating solar power (CPV) in high irradiance areas and other applications where space is limited are maybe the most significant threats for GaAs applications. Nanotechnology can be seen as an enabler of CPV and other new applications.

Name:	**SunFlake A/S**
URL:	http://www.sunflake.dk
Used technology:	GaAs
Description:	SunFlake is among the very first companies to use nanostructures as the only active element in a solar cell. The prospect of achieving record high conversion efficiencies combined with a reduction in fabrication cost gives advantage on the market. Households in rural areas around the world with no stable energy supply, as well as future high-tech mobile phones can benefit from this technology.

Dye-sensitized cells (DSSC) are cheaper to manufacture than other thin film technologies and they can be printed quickly on flexible surfaces. Special benefits over other thin-film solar technologies are that dye-based cells work well at wide angles, are longer lasting and they work more efficiently in indoor light.[23] These solar cells may have a small niche in the market right now. Professor Michael McGehee, at Stanford University said on Technology Review (11/2009), that "in the future we may see this technology compete with the more traditional thin-film solar technologies based on amorphous silicon, cadmium telluride, and cadmium indium gallium arsenide if the combination of efficiency, cost, and durability improves."

"Solaronix´s current DSSC technology is ready for indoor and some outdoor industrial uses and ongoing qualifications are in progress for building applications as well. In the next 2 years, efficiencies will be increased to ca. 8 – 9 %, while we estimate that the production costs will be less than 0.5 € /Wp, thanks to the fully automatic "all printed" concept we pursue", told Toby Meyer, CEO from Solaronix SA.

Name:	**SOLARONIX SA**
URL:	http://www.solaronix.com
Used technology:	Dye-sensitized solar cell modules (DSSC)
Investment:	New facilities with 30 cm wide "all printed" module production test line, chemicals production up scaling for industrial supplies.
Description:	Solaronix, located in Aubonne Switzerland, was established end 1993, and is the leading provider for all the specialty products related to the DSSC field, such as sensitizers (with ruthenium and pure organic), nano-titania pastes for all printing methods, ionic liquid electrolytes, etc.

The DSSC MIM's

The DSSC MIM's are manufactured from a few cm^2 up to 30 x 30 cm with the actual equipments. The current efficiency is 6 to 7 %.

The monolithically integrated modules (MIM) are made by screen printing of all the active layers. The modules contain 34 cells, delivering ca 250 mA and 18 V when lit at one sun.

Monolithically integrated module (MIM) by Solaronix SA

Organic solar cells' optical absorption coefficient is high, but the main disadvantages associated with then are low efficiency, low stability and low strength compared to inorganic photovoltaic cells.[24]

One company indicated that they had a prototype already available and high adoption potential for the products is seen.

Name:	**Solar Press**
URL:	http://www.solar-press.com/home
Used technology:	Organic
Description:	A newly formed company for the commercialisation of Organic Photovoltaics (OPV). An international and multidisciplinary partnership of scientific pioneers in plastic electronics and materials processing is collaborating with Solar Press in accelerating OPV technology innovation for commercial use. The company has been set up to rapidly deliver a series of solar powered commercial applications, based on OPV, for mass production and usage worldwide. Solar Press is initially focusing on the delivery of solar modules for off-grid applications at unbeatable prices.

Quantum dots

"Quantum-dot solar power could boost output in cheap photovoltaics", expresses Arthur Nozik in Technology Review 2007.[25]

1.2. Solar Photovoltaic market

This chapter considers the current market for solar PV, and assesses the proportion which is currently accounted by nanotechnology.

1.2.1. Technologies market penetration

Photovoltaic global figures indicated that annual installations (GW) increased over 100% from 2007 to 2008, as seen in

Table **1**. The global photovoltaic market was estimated to decrease by 17% in 2009 and small companies were predicted to be worst affected by the financial crisis. Acquisition of smaller companies by the large players assesses to give them greater control over the solar market in the future[26]. However global solar photovoltaic installations increased in 2009 despite of downturn and reached 6.43GW, according to a new report from Solarbuzz published in 2010[27]. Displaybank reported that total global solar cell production was 9.6GW in 2009[28].

The subsidy models pioneered in Japan and Germany have spread many countries and the positive influences are showing up in increasing the domestic market take-up of PV. PV market was predicted to double and achieve US$48 billion size after the five years, reported Intertech Pira in 2009.[29] Table 2 shows that the EPIA and Greenpeace forecasted PV global market size reach 139 billion € by 2020. The prediction was made before the downturn.

Table 2. Global PV-market figures and predictions for the 2009 and 2020[30, 31]

	2007	**2008**	**2009**	**2020***
PV annual installations, GW	2,4	5,6	6,8	56
PV accumulated capacity, GW	9,2	15		278
Electricity production, TWh	10			362
Grid-connection consumers, million	5,5			198
Off-grid connection consumers, million	14			757
Employment potential, thousands	119			2 343
Market value,€ billion/annum	13			139

**Advanced scenario for 2020 is based on the assumption that additional support mechanisms will lead to dynamic worldwide growth and the prediction is made before the year 2009 downturn by EPIA and Greenpeace.*

The EPIA projected in 2009 that thin film solar PV will have a production capacity of 4 GW by 2010 and 9 GW by 2013, accounting for about 25% of the global total (Figure 4)[31]. Assuming that market share and production capacity are directly linked, this implies that the market share of nanotechnology-enabled approaches are growing by 15 percentage points during the period 2007 to 2013. Displaybank, announced in 2010 that share of thin film solar cells market increased and represented 19.8% of globally produced solar cells in 2009[28].

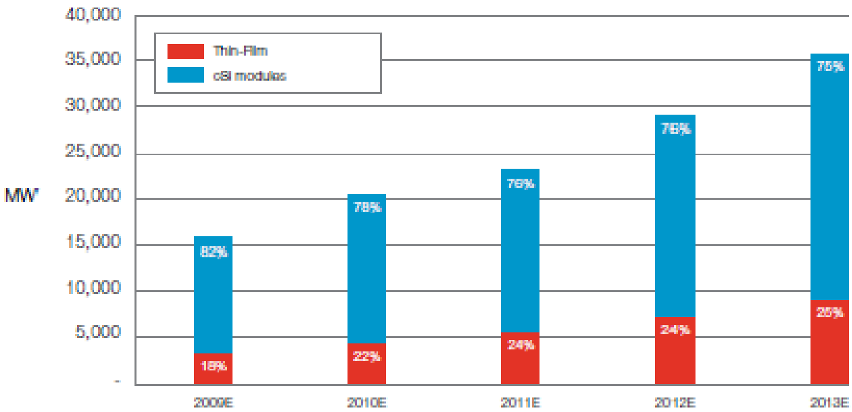

Figure 4. Production capacity outlook – Crystalline technologies vs. Thin film (nanotechnology-enabled production)[31]

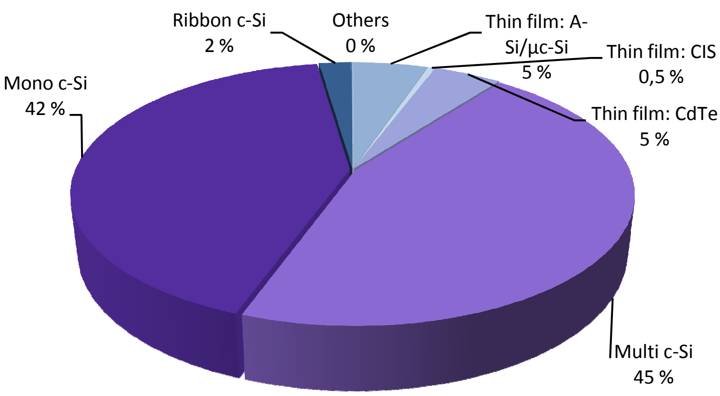

Figure 5. Market shares of solar PV technologies in 2007, Photon International[30]

In 2007 the share of thin film technology was only 10% and was split to a-Si and CdTe, whereas CIS was just entering the market with 0,5% share, as shown in Figure 5. It is interesting to note that in the beginning of 2010 the amount of European nanotechnology based solar photovoltaic cell and module producers concentrating to CdTe technology is smaller than companies focusing on CIS/CIGS technology, as seen from Figure 6. At the moment there are on the market a few large USA-based companies and at least 5 others entering the market in the near future, whereas the focus of European companies seems to be in other competitive technologies which are coming to the market in near future. One reason might be that in European Union is more cautious about the toxicity of cadmium and cadmium compounds.

Figure 6 is based on the ObservatoryNano-project research carried out in 2010 by evaluating European companies who indicate that they currently produce nanotechnology-enabled solar photovoltaics, or plan to do so in the near future. Adoption potential of the products was estimated with scale 1 to 4, where 1 indicates novel technology with difficulties for market adoption and 4 refer to major breakthroughs. For market penetration 0 refers to products in an R&D phase, 3 that are starting production and 5 are mature products in which the product has been on the market for at least 2 years.

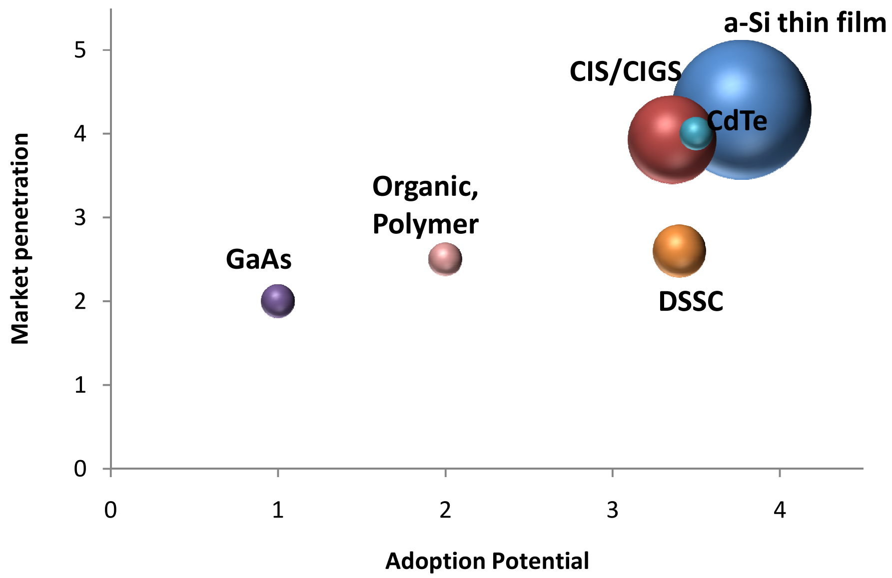

Figure 6. European companies currently producing nanotechnology-based solar photovoltaics or companies planning to enter the market in near future. The size of bubble indicates the amount of companies. (*Adoption potential and market penetration are estimates is based on internet research done by ObservatoryNano-project in 2010.)*

1.2.2. Applications market share

The market share of grid-connected solar PV applications has increased dramatically since 2004 and it has become dominant (Figure 7). High feed-in tariffs supports the trend. Other trends recognised in 2008 were growing interest to building-integrated PV (BIPV) and utility scale over 200 kW solar PV. [32] The trend towards building integrated systems will increase the role of nanotechnology as well.

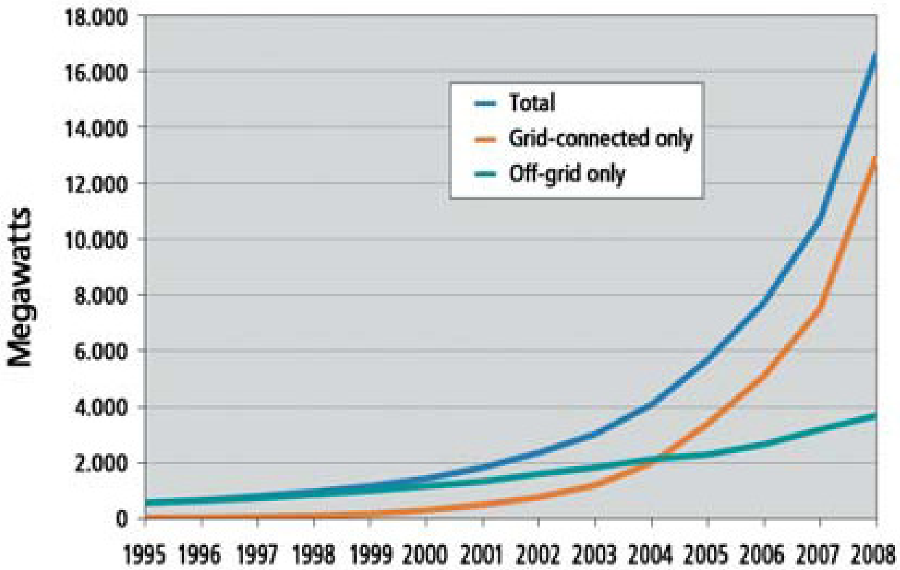

Figure 7. Solar PV, Existing World Capacity, 1995-2008[32]

Off-grid applications have potential, especially for electricity production in rural areas in developing countries. Small home systems and power for summer cottages also belong to this category. The benefits of nanotechnology are seen also in the innovative consumer good – sector.

1.2.3. Geographical spread of activities

Europe is leading the solar PV market. In 2008 it´s share was over 65% of the Global cumulative PV installed capacity, with Japan and US following behind. The intensive increase in 2008 was mainly due to the development of the Spanish market representing 45% of the Global market.[31]

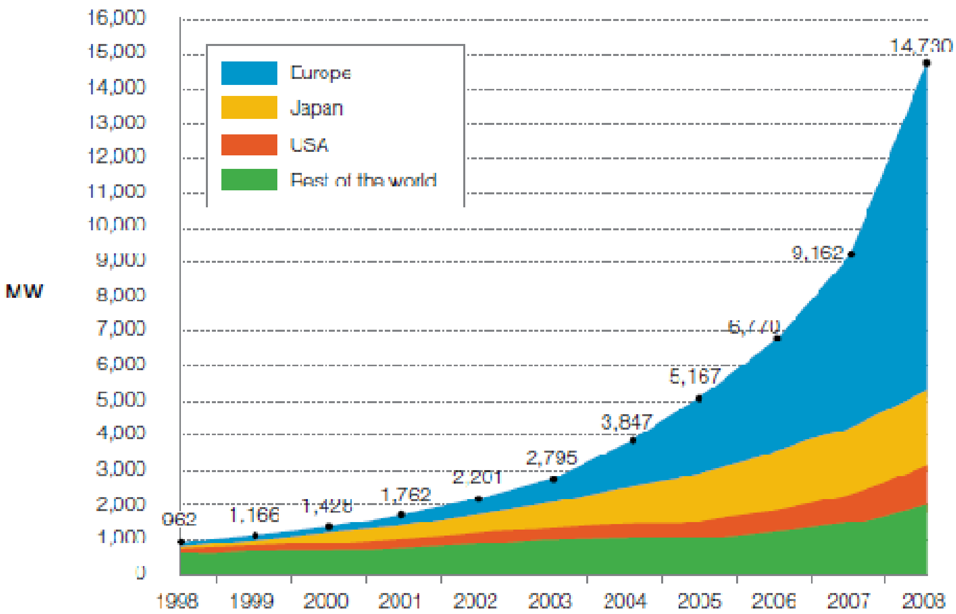

Figure 8. Development of Global cumulative PV power installed per Region [31]

The EPIA evaluated that Germany will take the market leader position again due to the Spanish cap which has been set at 500MW for 2009 - 2011. This is supported by that fact that it is the most mature market with FIT schemes, financing opportunities, high potential for future development and skilled PV companies. The United States is predicted to be one of the top markets also in future, because of its support schemes. Japan’s growing market size is based on ambitious objectives, and PV technology is well-established and widely integrated in buildings.[31]

Nanotechnology will enable solar PV integration to building materials. According to the Pira studies, thin film and flexible PV growth will start from Europe (especially from Germany) and the US in the short to medium term, whereas Japan, China and Asia will adapt the technology strongly in the medium term. Sales to Africa and other developing nations are predicted to increase in the long term, when organic flexible products are fully viable.[33]

Table 3. Solar Photovoltaic production location in 2007[30]

Production location, %	
China	29
Japan	22
Germany	20
Taiwan	11
Rest of Europe	7
Others	11

China led solar photovoltaic production with 29% share followed by Japan and Germany in 2007, Table 3. China and Japan has kept the leader position in 2008 as well[34] The European Commission´s Joint Research Centre report suggests that China's share is predicted to increase and reach 32% by 2012[35].

1.2.4. Solar Photovoltaic business in Europe

Research carried for this study indicated that the number of European companies producing solar photovoltaic cells and modules utilizing nanotechnology now or in the near future is about 60. 75% of these companies are small or medium sized, and almost 90% of the companies focused only on solar photovoltaic. Most of the companies are located in Germany where the share of small and medium size companies was slightly below 60%. A more specific size distribution of the companies in diverse countries is presented in Figure 6 and a company list is presented in appendix 1.

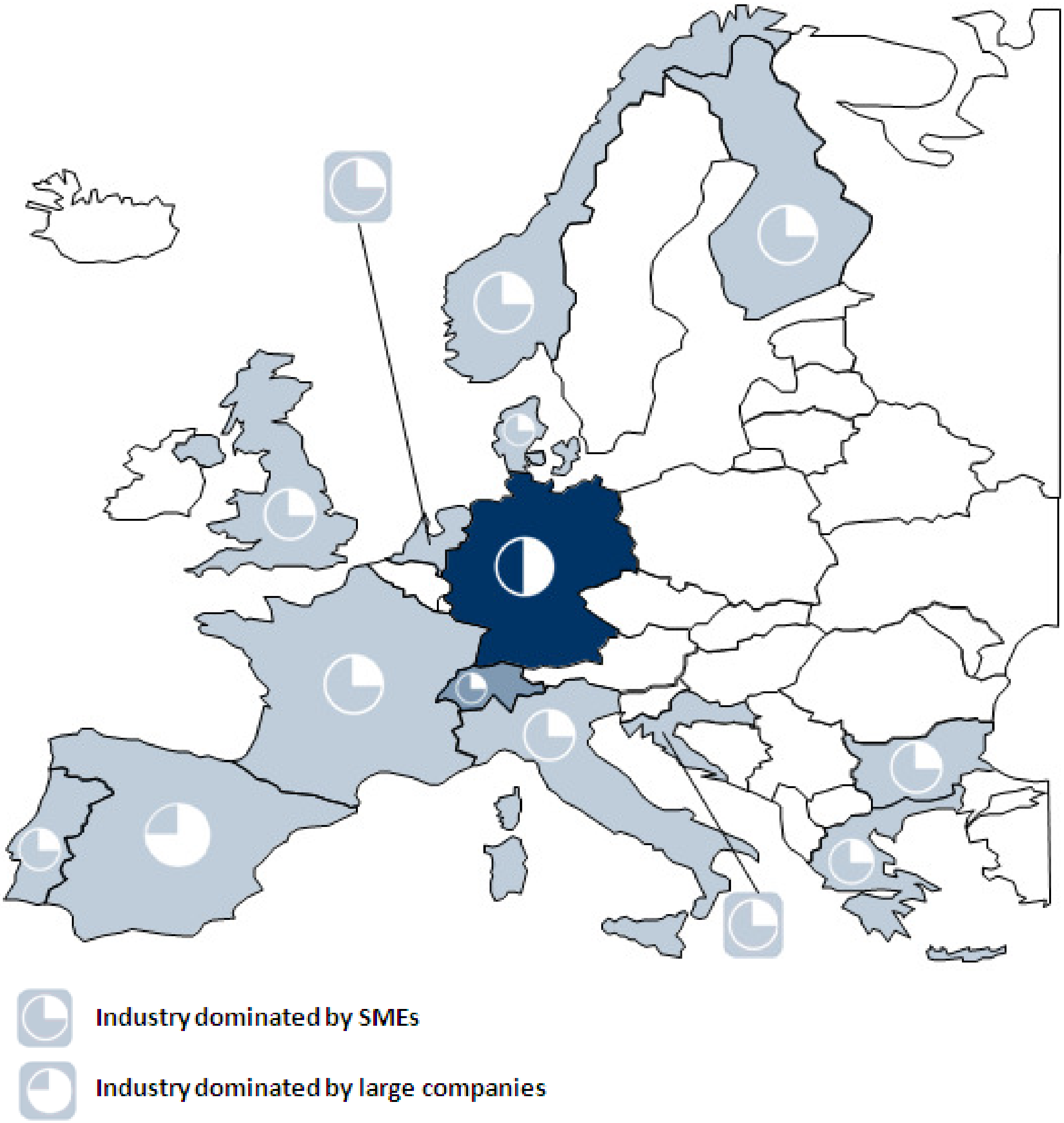

Figure 9. European companies producing now or in near future nanotechnology based solar photovoltaic cells/modules. The darker the colour, more companies located on that country. SME: under 250 employee. *(Amount of companies is based on research carried out by ObservatoryNano-project in 2010.)*

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1.3. References

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Expert interviews for Solar PV Market report, March 2010

Dr. Bernhard Dimmler, *CEO, Wuerth Elektronik Research GmbH*

Mr. Alexandre Closset*, CEO, VHF-Technologies SA (Flexcell), Switzerland*

Dr. Claude Levy-Clement*, Emeritus Research Director, CNRS, France*

Dr. Toby Meyer, *CEO, SOLARONIX SA, Switzerland*

Dr. Morten Schaldemose*, CEO, SunFlake A/S, Denmark*

Dr. Christian Simon*, Research Manager, SINTEF, Norway*

Appendix 1:

List of European Companies indicating in internet to produce nanotechnology based solar photovoltaic now or in future. (Internet search done in beginning of 2010.) See Appendix 2; http://www.observatorynano.eu/project/filesystem/files/EconomicAnalysis_Photovoltaics_Appendix1.pdf