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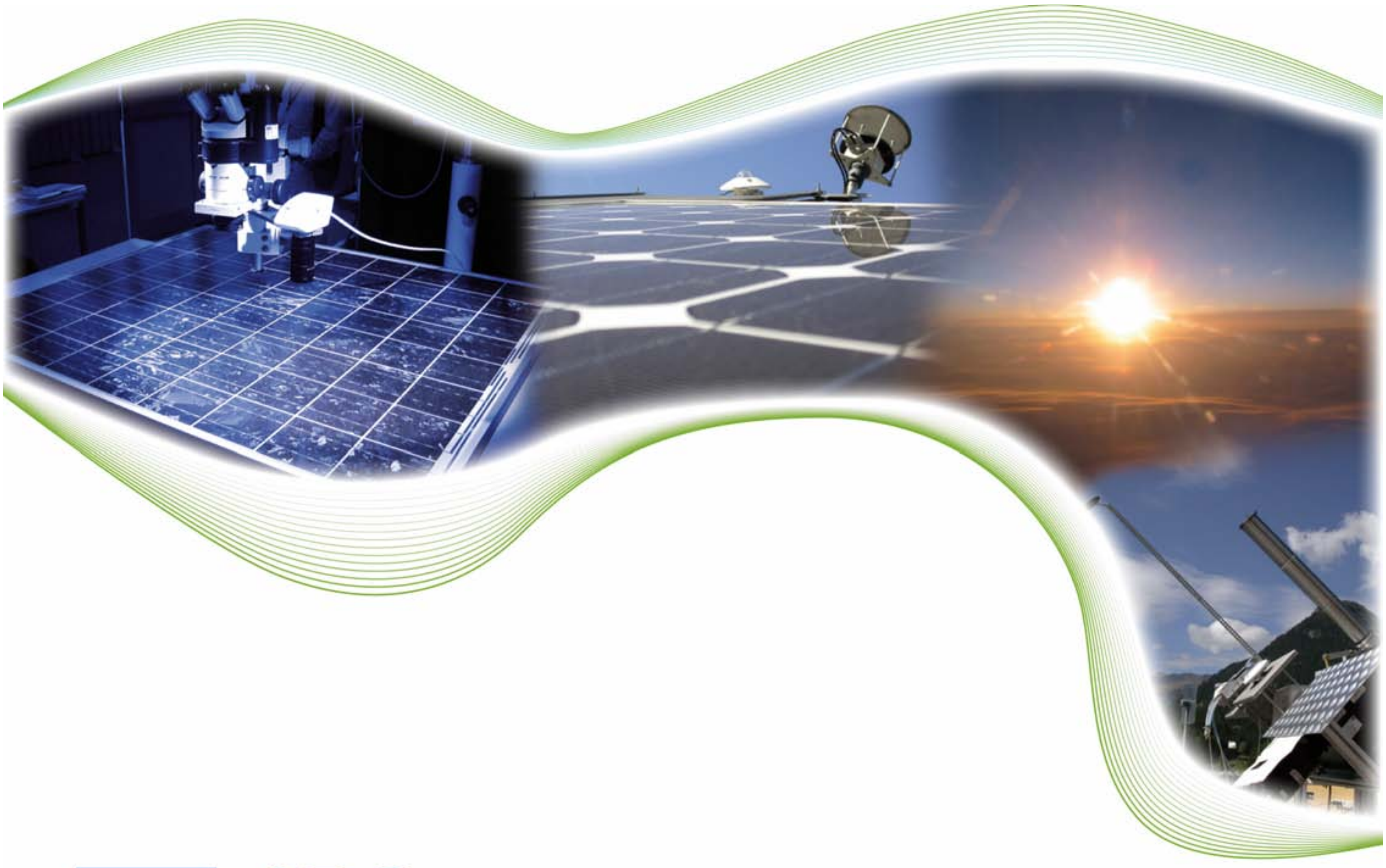
PV STATUS REPORT 2008



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PV Status Report 2008

Research, Solar Cell Production and Market Implementation of Photovoltaics

September 2008

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Front cover: Artwork by Jennifer Rundle & Robert Houghton

PREFACE

Spiking oil prices at $ 147 per barrel in July 2008 and speculations when the oil price will exceed $ 200 per barrel have already become a reality. The current dive in oil prices due to the volatility of the financial markets and fears of an economic slowdown have highlighted our strong dependence on oil and have shifted the focus to more abundant fossil energy resources like gas and coal. However, the *Gas Crisis* at the beginning of 2006 and interruptions of the gas supply in the summer of 2008 due to "*maintenance*" has demonstrated that Europe is still highly vulnerable with respect to its total energy supply. A possible solution is the diversification of supply countries as well as the diversification of energy sources including renewable energies and Photovoltaics.

In March 2007 the European Council endorsed the binding target of a 20% share of renewable energies in the overall EU energy consumption by 2020. Now the question in the European Union is no longer – *What can renewable energies contribute to the European energy supply?* – **but** – *How can we realise the growth of renewable energy production?*

The motivation behind the Council Decision is the need to stabilise atmospheric greenhouse gases in the 450 to 550 ppmv range which leads to the necessity to decarbonise our energy supply.

Photovoltaics is a key technology option to realise such a shift. The solar resources in Europe and world wide are abundant and can't be monopolised by one country. Regardless for what reasons and how fast the oil price and energy prices will increase in the future, Photovoltaics and other renewable energies are the only ones to offer a reduction of prices rather than an increase in the future.

In 2007, the Photovoltaic industry production grew by over 60% reaching a worldwide production volume of 4 GWp of Photovoltaic modules and has become a € 14 billion business. Yearly growth rates over the last five years were in average more than 40%, which makes Photovoltaics one of the fastest growing industries at present. Business analysts predict the market volume to increase to € 40 billion in 2010 and expect lower prices for consumers. The trend that thin film Photovoltaics grew faster than the overall PV market continued in 2007.

The Seventh Edition of the "PV Status Report" tries to give an overview about the current activities regarding Research, Manufacturing and Market Implementation. I am aware that not every country and development is treated with the same attention, but this would go beyond the scope of this report. Nevertheless, I hope that this report will provide a useful overview about the situation worldwide. The opinion given in this report is based on the current information available to the author, and does not reflect the opinion of the European Commission.

Ispra, September 2008

Arnulf Jäger-Waldau
European Commission
Joint Research Centre; Renewable Energies Unit

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1. INTRODUCTION

Production data for the global cell production in 2007 vary quite significantly between 3,733 MW [Pho 2008] and 4,279 MW [Pvn 2008]. The high end of the data published by Photon International includes a number of estimated production data as indicated in their statistics. PV News, on the other hand, did not list a number of Chinese and Taiwanese manufacturers. According to our own data, collected from various companies and colleagues and then compared to the PV News and Photon 2007 production, data led to an estimate of 4,022 MW (Fig. 1). Despite the still tight silicon supply situation the production grew more than 50%.

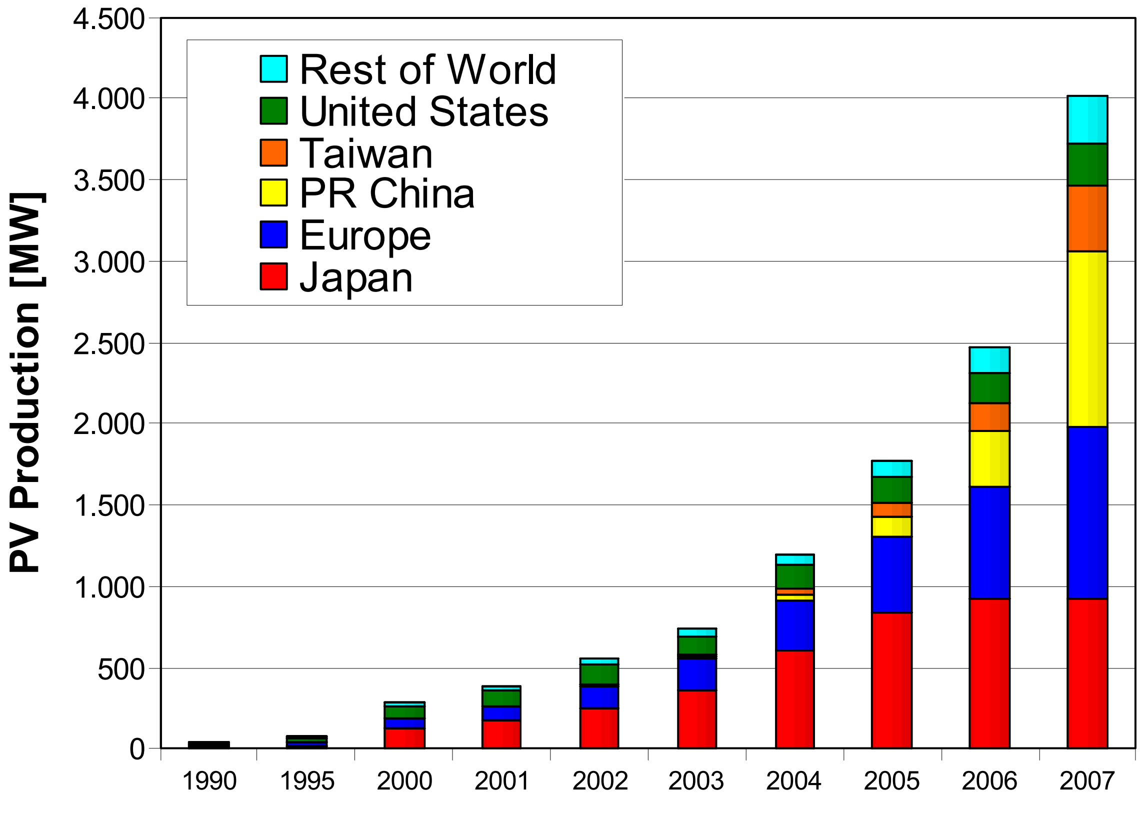

Fig. 1: World PV Cell/Module Production from 1990 to 2007
(data source: PV News [Pvn 2008], Photon International [Pho 2008] and own analysis

Since 2003, total PV production grew in average by almost 50%, whereas the thin film segment – starting from a very low level – grew in average by over 80% and reached 400 MW or 10% of total PV production in 2007. The high growth rate of thin film production and the increase of the total production share indicate that the thin film technology is gaining more and more acceptance. A thin film market share of 25 to 30% in 2010 seems not to be unrealistic. This takes into account the fact that more and more PV manufacturers are diversifying their production portfolio. It should be noted that the current thin film market leader First Solar will reach an annual production capacity of more than 1 GW by 2010. Sharp (Japan), Showa Shell Sekiyu (Japan) and Best Solar (PRC) announced they would build thin film factories with at least 1 GW capacity to be operational in 2010 [Bes 2008, Sha 2007] and 2011 [Sho 2008] respectively. In addition, a number of other thin film manufacturers are aiming at 500 MW production capacities in that time frame.

Public traded companies manufacturing solar products, or offering related services, are attracting a growing number of private and institutional investors. Worldwide, more than US $148 billion (€[1] 102 billion) in new funding entered the renewable energy and energy efficiency sectors in 2007, up 60% from 2006, even as the credit crunch began to put stress on the financial markets toward the end of the year. Investments in solar power grew most rapidly, reaching US $28.6 billion (€ 19.7 billion) or 19% of new capital with average annual growth rates of more than 250% since 2004. This development is driven by the emergence of larger project financings. Another interesting figure is the growth of venture capital from US $1.4 billion (€ 0.97 billion) in 2006 to US $3.2 billion (€ 2.2 billion) in 2007.

The number of consulting companies and financial institutions offering market studies and investment opportunities has considerably increased in the last few years and business analysts are very confident, that despite raising interest rates, the Photovoltaics sector is in a healthy condition. Notwithstanding the quite massive stock price adjustments in the first half of 2008 and the stock market sell out in September 2008 as a result of the financial turmoil the total market capitalisation of the 30 PPVX[2] (Photon Pholtovoltaic stock index) companies[3] was with € 55 billion about the same at the end of September 2008 than in 2007.

Market predictions for the 2010 PV market vary between 6 GW (Navigant conservative scenario), 7 to 8 GW (EPIA, Bank Sarasin, LBBW) and 17 GW (Photon Consulting). Massive capacity increases are underway or announced and if all of them are realised, the worldwide production capacity for solar cells would exceed 35 GW at the end of in 2010. This indicates that even with the most optimistic market growth expectations, the planned capacity increases are way above the market growth. The consequence would be a quite low utilisation rate and consequently a shift from the demand-driven markets of the last years to an oversupplied market which will increase the pressure on the margins. Such a development could accelerate the consolidation of the Photovoltaics industry and spur more mergers and acquisitions.

The current solar cell technologies are well established and provide a reliable product, with sufficient efficiency and energy output for at least 20 years of lifetime. This reliability, the

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1 Exchange rate: 1 € = 1.45 US$

2 The PPVX is a non commercial financial index published by the solar magazine "Photon" and "Öko-Invest". The index started on 1 August 2001 with 1000 points and 11 companies and is calculated weekly using the Euro as reference currency. Only companies which made more than 50% of their sales in the previous year with PV products or services are included [Pho 2007].

3 Please note that the composition of the index changes as new companies are added and others have to leave the index.

increasing potential of electricity interruption from grid overloads, as well as the rise of electricity prices from conventional energy sources, add to the attractiveness of Photovoltaic systems.

About 90% of the current production uses wafer-based crystalline silicon technology. Up to now the main advantage of this technology was that complete production lines could be bought, installed and be up and producing within a relatively short time-frame. This predictable production start-up scenario constitutes a low-risk placement with high expectations for return on investments. However, the ongoing 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. WTC, a consulting company based in Munich, Germany, has identified more than 130 companies which are involved in the thin film solar cell production process ranging from R&D activities to major manufacturing plants.

The ongoing shortage in silicon feedstock, the relative slow response of the established silicon producers and the accelerated expansion of production capacities led to the market entry of new potential silicon producers. The following developments can be observed at the moment:

- Silicon producers are in the process of increasing their production capacities, which will ease the pressure on the supply side within the next years. This indicates that they have recognised PV as a fully fledged industry that provides a stable business segment for the silicon industry, as opposed to being strongly dependent on the demand cycles of the microelectronics industry.
- New silicon producers enter the market and are in the process of finalising their business plans or are already constructing new production facilities.
- PV companies accelerate the move to thinner silicon wafers and higher efficient solar cells in order to save on the silicon demand per Wp.
- Significant expansions of thin film production capacities of existing manufacturers are under way and a large number of new manufacturers try to enter the market to supply the growing demand for PV modules. Compared to 2006, thin film shipments increased by more than 100% to 402 MW in 2007. If all currently announced thin film production capacities are realised, more than 10 GW production capacity could be reached by 2010. This is an increase of more than 60% compared to the announcements made at the same time last year.

Projected silicon production capacities available for solar in 2010 vary between 99,500 metric tons [Pvn 2008a] and 245,000 metric tons [EuP 2008]. The possible solar cell production will in addition depend on the material use per Wp. Material consumption could decrease from the current 10 g/Wp down to 8 g/Wp, but this might not be achieved by all manufacturers.

Similar to learning curves in other technology areas, new products will enter the market, enabling further cost reduction. Equally competitive technologies are amorphous/micromorph Silicon, CdTe and $Cu(In,Ga)(S,Se)_2$ thin films. In addition, Dye-cells are getting ready to enter the market as well. The growth of these technologies is accelerated by the positive development of the PV market as a whole. It is interesting to note that not only new players are entering into thin film production, but also established silicon-based PV cell manufacturers diversify into thin film PV.

It can be concluded that in order to maintain the extremely high growth rate of the Photovoltaic industry, different pathways have to be pursued at the same time:

- Drastic increase of solar grade silicon production capacities;
- Accelerated reduction of material consumption per silicon solar cell and Wp, e.g. higher efficiencies, thinner wafers, less wafering losses, etc.;
- Accelerated introduction of thin film solar cell technologies into the market and capacity growth rates above the normal trend.

Further cost reduction will depend not only on the scale-up benefits, but also on the cost of the encapsulation system, if module efficiency remains limited to below 15%, stimulating strong demand for very low area-proportional costs.

2. THE WORLD MARKET

The Photovoltaic world market grew in terms of production by more than 60% in 2007 to approximately 4 GW. The market for installed systems also grew more than 60% to reach 2,825 MW, as reported by various consultancies. One could guess that this represents mostly the grid connected Photovoltaic market. To what extent the off-grid and consumer product markets are included is unclear. The difference of roughly 1,200 MW could therefore be explained as a combination of unaccounted off-grid installations (ca 150 MW off-grid rural, ca 100 MW communication/signals, ca 80 MW off-grid commercial), consumer products (ca. 100 MW) and cells/modules in stock.

Like in the last years, Germany was the largest single market with 1,100 MW, followed by Spain with 341 MW, Japan with 210 MW and the US with 205 MW [Ikk 2008, Sys 2008, She 2008, Tec 2008]. The Photovoltaic Energy Barometer reported that Europe had a cumulative installed PV system capacity of 4.7 GW in 2007.

Despite the fact that the European PV production grew again by almost 60% and reached 1040 MW, the size of the German market and the rapid increase of the Spanish market to almost 341 MW did not change the role of Europe as a net importer of solar cells and/or modules. The ongoing capacity expansions might change this in the future.

The Japanese market saw a further decline to 210 MW of new installations, 36% lower than in 2006. The decrease of new installed capacity is mainly explained with the completion of the Residential PV System Dissemination Programme in FY 2005, not so much because of the financial incentive of ¥20,000 per kWp, but because this was perceived as lack of political support. In addition there are three more aspects which are worth looking at.

First, due to societal changes and economic conditions, the detached-house market in Japan, the major market for residential systems is experiencing a downward trend. Second, the strong demand for solar modules outside of Japan and the strong Euro make it more attractive for Japanese companies to export their products and vica versa make it less interesting for foreign companies to export to Japan. Third, in 2007 the silicon shortage led to a lower solar cell production at the Japanese market leader Sharp. This, and the fact that European customers generally secure their shipments through long-term supply contracts might have led to a shortage of solar modules in Japan. An indication for this theory is the fact that Sekisui Homes – one of the leading manufacturers of detached homes in Japan – who until recently was only installing Sharp solar systems is now also offering systems from other companies.

At the end of 2007 total cumulative installed capacity in 2007 stands at 1.9 GW, almost 3 GW short of the original 4.8 GW goal for 2010 [Ikk 2008]. Due to the marginal increase of Japanese solar cell production in 2007, the world market share of Photovoltaic devices manufactured in Japan further decreased from 36.9% to 23%. The number of Japanese companies amongst the *Top Ten* decreased to three, followed by two from PRChina (Fig. 2).

Sharp Corporation changed place with Q-cells as the number one cell manufacturer, closely followed by Suntech from China. This development could be behind the announcement of Mr. Toshishige Hamano, Corporate Senior Executive Director and Group General Manager of the Solar Systems Group during his Keynote presentation on the occasion of the 1st International Photovoltaic Power Generation Expo in Tokyo on 27 February 2008 to increase Sharp's thin film production capacity beyond the original foreseen 1 GW to 6 GW after 2012.

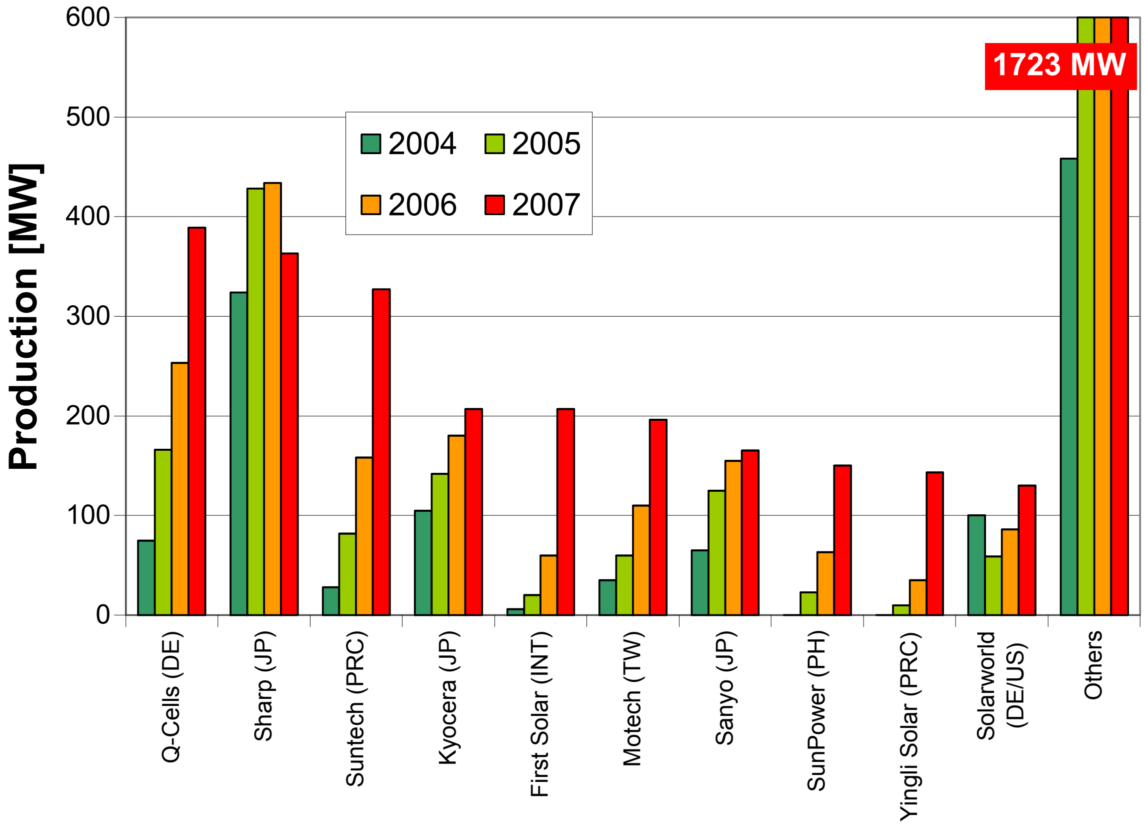

Fig. 2: Top 10 Photovoltaic companies in 2006 (total shipments in 2006: 2520 MW) [Pvn 2007]

The fourth largest market was the USA with 205 MW of PV installations, 152 MW grid-connected [She 2008]. California and New Jersey account for almost 70% of the US grid-connected PV market. Despite new Federal States emerging as markets in 2007, 90% of the total US market remains still in just five States. It is of interest to note, that the trend toward more non-residential installation continues, due to the more generous Federal Investment Tax incentives for commercial installations. After more than a year of political debate the U.S. Senate finally voted to extend the tax credits for solar and other renewable energies on 23 September 2008. On 3 October 2008, following weeks of contentious negotiations between the House and Senate, Congress approved, and the President signed into law the *"Energy Improvement and Extension Act of 2008"* as part of H.R. 1424, the *"Emergency Economic Stabilization Act of 2008"*.

There is no single market for PV in the United States, but a conglomeration of regional markets and special applications for which PV offers the most cost-effective solution. In 2005 the cumulative installed capacity of grid-connected PV systems surpassed that of off-grid systems. Since 2002 the grid-connected market has been growing much faster, thanks to a wide range of “buy-down” programmes, sponsored either by States or utilities.

The rapid expansion of solar cell manufacturing capacities and production volume in the Peoples Republic of China and Taiwan is not yet reflected in a significant size of the respective home markets. For 2007, the estimates of the Chinese and Taiwanese PV market are in the order of 10 to 20 MW each. As a result, more than 98% of the Chinese and Taiwanese PV production is exported.

Another noteworthy development is the fact that the market share of the ten largest PV manufacturers together further decreased from 80% in 2004 to 57% in 2007. This development is explained by the fact that an increasing number of solar cell manufacturers are entering the market. The most rapid expansion of production capacities can be observed at the moment in China and Taiwan, but other countries like India, Malaysia and South Korea are following the example to attract investment in the solar sector.

The announced increases of production capacities[4] again accelerated in 2007 and the first half of 2008 (Fig. 3).

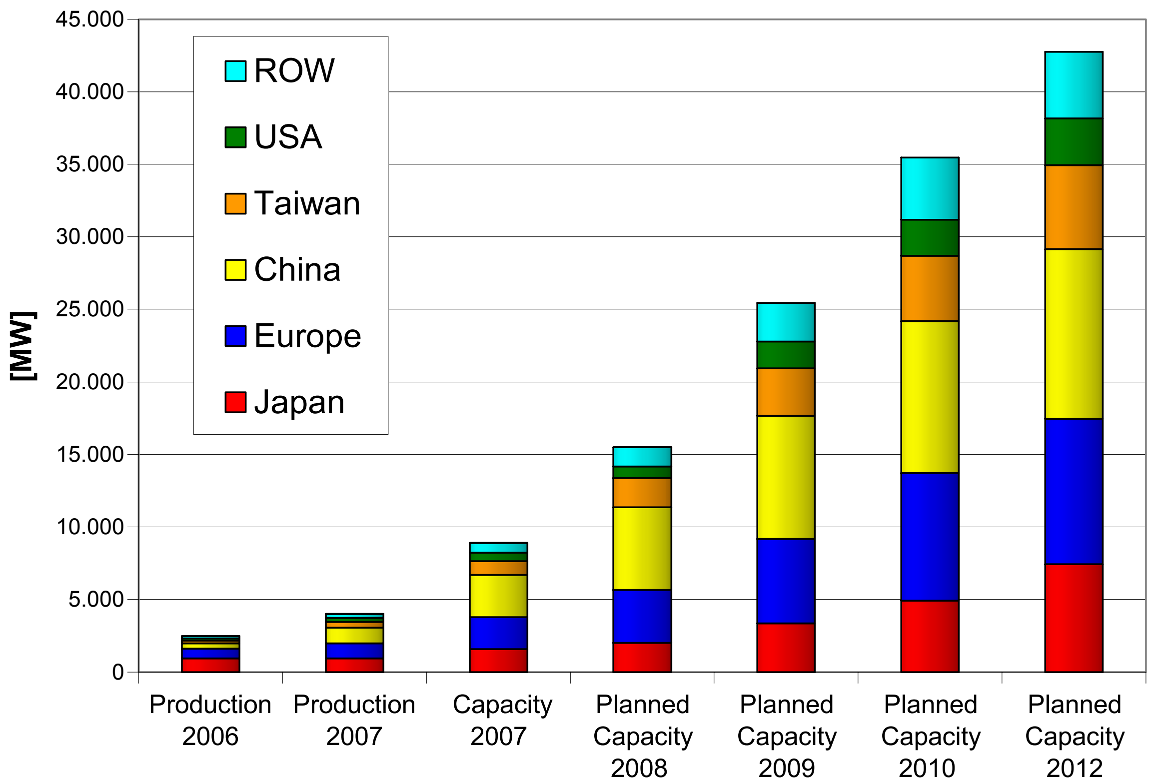

Fig. 3: Worldwide PV Production 2006/7 and planned production capacity increases

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[4] The figures are based on a survey of company statements and press releases of more than 200 companies worldwide with a cut off date at the end of July 2008.

If all these ambitious plans can be realised, China will account for about 27% of the worldwide production capacity of 42.8 GW, followed by Europe with 23%, Japan with 17% and Taiwan with 14% (Fig. 3).

It has to be noted that the assessment of all the capacity increases is rather difficult, as it is affected by the following uncertainties. The announcements of the increase in production capacity in Europe, the US or China, often lack the information about completion date compared to Japan. Because of the Japanese mentality, where it is felt that a public announcement reflects a commitment, the moral pressure to meet a given time target is higher in Japan than elsewhere where delays are more acceptable. Not all companies announce their capacity increases in advance. Therefore, this report does not take into account increases which are not communicated.

Announcements of completion of a capacity increase frequently refer to the installation of the equipment only. It does not mean that the production line is really fully operational. This means, especially with new technologies, that there can be some time delay between installation of the production line and real sales of solar cells. In addition, the production capacities are often announced, taking into account different operation models, e.g. maximum capacity (4 shifts 365 days/year), whereas others are only quoting capacity under real operation conditions. Production capacities are not equal to sales and therefore there is always a noticeable difference between the two figures, which cannot be avoided.

Should the announced increases be realised, total production capacities in 2012 could then stand at 42.8 GW, of which 15 GW could be thin films (Fig: 4).

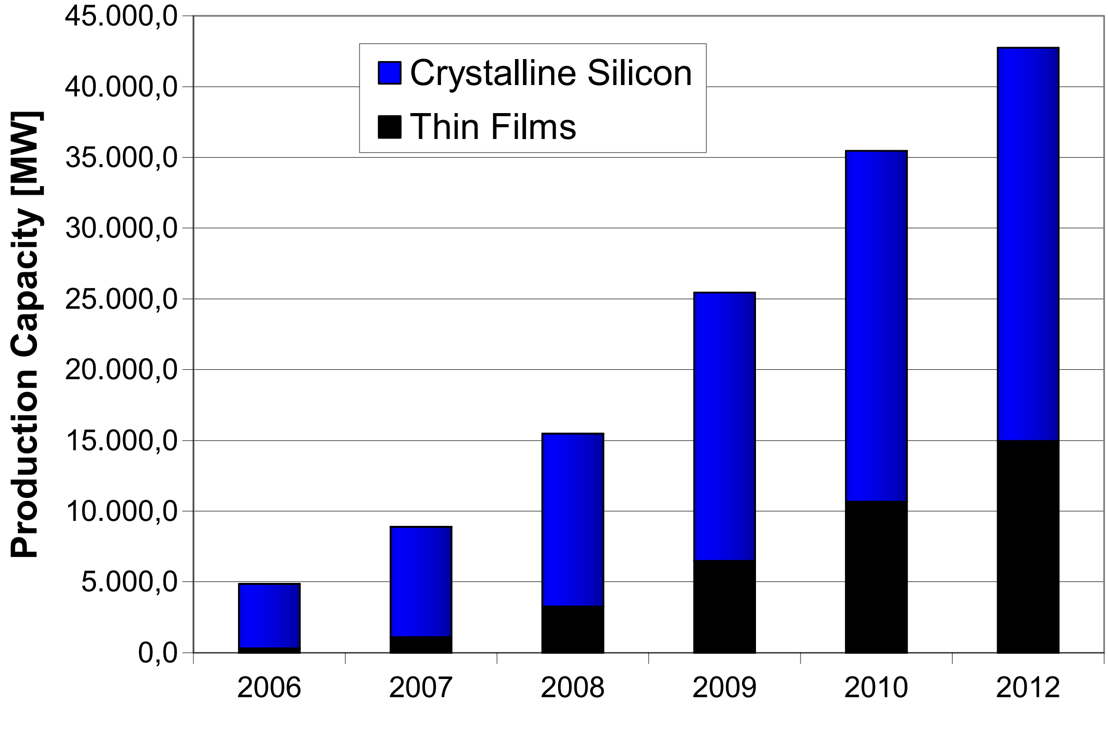

Fig. 4: PV Production Capacities 2006/7 and planned production capacity increases.

However, one should bear in mind that out of the ca. 100 companies, which have announced their intention to increase their production capacity or start up production in the field of thin films, only one fourth have actually already produced thin film modules on a commercial scale.

For 2010, roughly 10.5 GW of thin film production capacities are announced, an increase of almost 4 GW compared to the 2009 figures. Considering that at the end of year 2009 capacity could eventually be transformed into production, First Solar and Sharp together would contribute with about 1.5 to 2 GW, whereas the other existing producers would add about the same capacity. For that reason, 3.5 GW production in 2010 are considered as quite certain, another 1 GW as possible. For the remaining 2 GW there is a high uncertainty as to whether or not it can be realised in the time-frame given.

Despite the fact that only limited comparisons between the different world regions are possible, the planned cell production capacities portray some very interesting developments.

First, the technology as well as the company distribution, varies significantly from region to region (Fig. 5). 40 companies are located in Europe, 27 in China, 19 in the US, 12 in Taiwan, 8 in Japan and 10 elsewhere. The majority of 82 companies is silicon based. The reason is probably that in the meantime there is a number of companies offering complete production lines for amorphous and/or micromorph silicon. 19 companies will use Cu(In,Ga)(Se,S)$_2$ as absorber material for their thin-film solar modules, whereas 7 companies will use CdTe and 5 companies go for Dye & other materials.

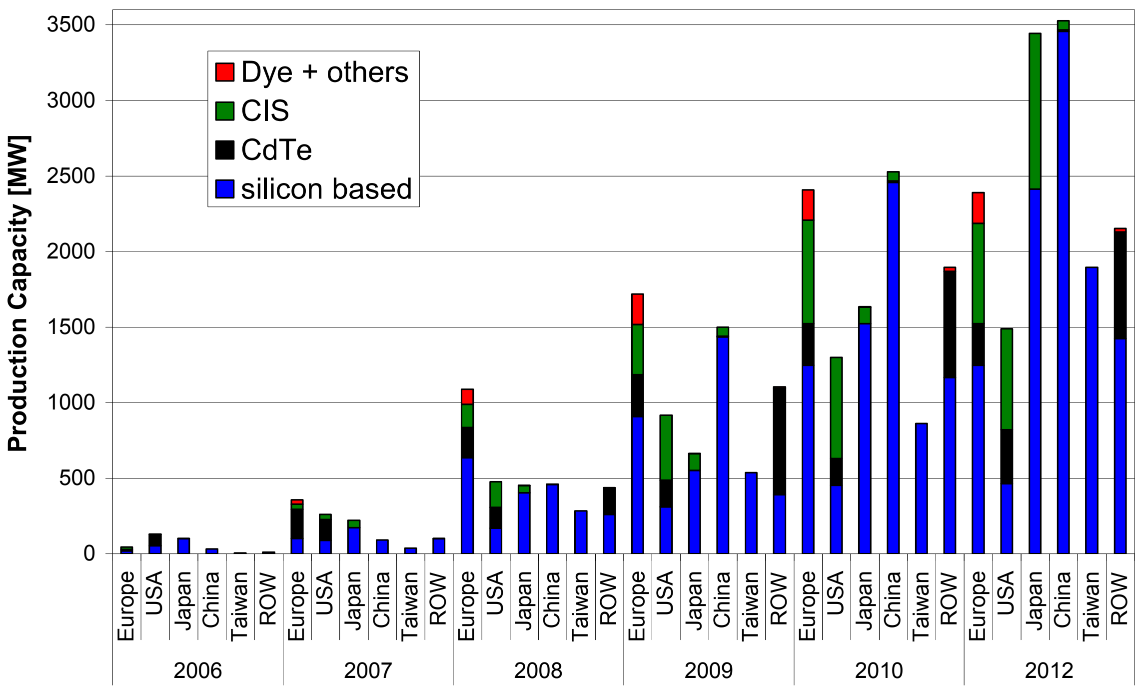

Fig. 5: Regional and technology distribution of the thin film production capacity increases.

In the case of the more optimistic silicon feedstock expansions to 115,000 metric tons available for the solar industry and a material consumption decrease to 8 g/Wp, about 20 GW of solar cells could theoretically then be produced annually (14.25 GW silicon based and 6 GW thin films). This would be twice as much as the current optimistic market predictions forecast. Another important factor is the actual utilisation rate of the production capacities. For 2007 the overall capacity utilisation of the solar cell industry with respect to shipments was given with 58% by Navigant Consulting [Min 2008]. This is different from the utilisation rate with respect to production, as shipments were given with 3061 MW by Navigant. According to this, the US had a utilisation rate of 64%, Japan 63% and Europe of 61%. A number of analysts predict that the utilisation rate will further decrease in 2008 and 2009 before it might increase gain in 2010.

Second, 10 companies are aiming at total production capacity in the order of 1GW or more, whereas another 19 aim at 500 MW or more. The majority of these super factories are planned in China (6)) followed by Europe, Taiwan and Japan with five each.

This leads to a third observation. If the large increase in production capacity is realised in China, the share on the world market would increase from 11.9% in 2005 to about 27% in 2012. This production capacity would be much more than the 500 MW of cumulative installed solar systems in the People's Republic of China by 2010, as planned in the "Eleventh Five-Year Plan" (2006 – 2010). It is obvious that the solar cell manufacturers in China intend to continue the high export rate (98% in 2007) of their production to the growing markets in Europe, the US and developing countries.

In response to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report *"Climate Change 2007"*, the European Council endorsed during its Council Meeting in Brussels on 8/9 March 2007 a binding target of a 20% share of renewable energies in the overall EU energy consumption by 2020 and a 10% binding minimum target to be achieved by all Member States for the share of Biofuels in overall EU transport petrol and diesel consumption [CEU 2007].

During the 23rd European Phtovoltaic Solar Energy Conference and Exhibition from 1 to 5 September 2008, Anton Milner, Director of EPIA, presented the new vision of the European Photovoltaic Industry Association for 2020. According to his presentation, 6 to 12% of European electricity should then be generated with Photovoltaic systems. This would correspond to 210 to 420 TWh of electricity or 175 to 350 GWp installed capacity of Photovoltaic electricity systems. To realise this new vision, around 170 GW to 345 GW of new capacity have to be installed between 2008 and 2020. Installations of new Photovoltaic systems would have to increase from around 1.6 GW per annum in 2007 to 3.3 – 4 GW per annum in 2010 and 40 – 90 GW per annum in 2020. This corresponds to a CAGR (Compound Annual Growth Rate) of 28% to 37% over the next 13 years.

This would be a dramatic change from the development of the last years. Since the introduction of the German Feed-in Law in 1999, more than 80% of European PV systems were installed in Germany. The Spanish PV market grew from 14.5 MW in 2005, to 340 MW in 2007, and it is expected that in 2008 it will be above 1 GW according to info given by the Spanish National Energy Commission. However, the prospects for 2009 are not as bright as the Spanish Government introduced a cap of 500 MW on the yearly installations which is well below the 2008 installation figure. Since 1999, European PV production has grown on average by 50% per annum and reached about 1040 MW in 2007. The European market share rose during the same time from 20% to 25%, whereas the Chinese from 0% to 25%. On the contrary, the US share decreased due to a weak home market. By 2005 the Japanese market share had increased and stabilised around 50 ± 3%, but decreased sharply to 37% in 2006 and 24% in 2007.

The European PV industry has to continue its high growth over the next years in order to maintain that level and to contribute to the new EPIA vision. This will, however, only be possible if reliable and long term political frame conditions – not to be changed each year – are in place in Europe to enable a return on investment for the PV industry and the final consumer. One of the crucial issues is an agreement on an easy and priority access of renewable electricity to the grid all over Europe and preferably worldwide. The design of subsequent monetary support mechanisms like feed-in tariffs, tax incentives or direct investment subsidies, should then to be designed in a way that they enable the necessary capital investment and take into account the cost and market developments.

Besides this political issue, a continuous improvement of the solar cell and system technology is required. This leads to the search for new developments with respect to material use and consumption, device design, reliability and production technologies, as well as new concepts to increase overall efficiency.

Such developments are of particular interest in view of the strategic importance of solar cell production as a key technology in the 21st century, as well as for the electrification of developing countries and the fulfilment of Kyoto Targets.

The Standing Committee of the National People's Congress of China endorsed the Renewable Energy Law on 28 February 2005. At the same time as the law was passed, the Chinese Government set a target for renewable energy to contribute 10% of the country's gross energy consumption by 2020, a huge increase from the current 1%. The Renewable Energy Law went into effect on 1 January 2006, but no specific rate was set for electricity from Photovoltaic installations. The 2006 Report on the Development of the Photovoltaic Industry in China by the National Development and Reform Commission (NDRC), the Global Environment Facility (GEF) and World Bank (WB), estimates a market of 130 MW in 2010 [NDR 2006]. The report states that the imbalance between solar cell production and domestic market development *impedes not only the sustainable development of energy sources in China, but also the healthy development of the PV industry.*

A growing number of States in the US are emerging as markets where electricity from PV can be considered competitive with electricity from the grid, if different incentives are taken into account. The 2005 Energy Bill shows results but the current tax credits for renewable electricity will expire at the end of 2008 and so far the House of Representatives, the Senate and the White House could not agree on a prolongation beyond 2008.

The 2005 Energy Bill together with the Californian “Million Roof Initiative” (SB1), and the other initiatives by individual States, increase the demand for Photovoltaic solar systems in the USA, and the prolongation of the Federal Tax Incentives should help to continue this trend.

A new and emerging market is South Korea. At the end of 2006 the cumulative installed capacity of Photovoltaic electricity systems was only in the range of 25 MW. In 2007 about 45 MW were installed and for 2008 the market is estimated to be in the range of 75 to 80 MW. The driver for this development is the Government's goal to increase the share of New and Renewable Energy Sources (NRES) to 5% by 2011. For Photovoltaics, a goal of 1.3 GW cumulative installed Photovoltaic electricity generation capacity by 2012 and 4 GW by 2020 was set. To realise these target, South Korea had introduced an attractive feed-in tariff for 15 years along with investment grants up to 60%. From October 2008 to 2011 new feed-in tariffs are valid (Table 1).

Table 1: Korean Feed-in Tariffs [Yoo 2008]
Fixed Price in Korean Won/kWh (€[5]/kWh

Until 30 Sept. 2009	Period	< 30 kW	> 30 kW			
	15 years	711.25 (€ 0.44)	677.38 (€ 0.42)			
1 Oct. 2008 – 2009	Period	< 30 kW	30 – 200 kW	200 kW – 1 MW	1 MW – 3 MW	> 3MW
	15 years	646.96 (0.40)	620.41 (0.39)	590.87 (0.37)	561.33 (0.35)	472.7 (0.30)
	20 years	589.64 (0.37)	562.84 (0.35)	536.04 (0.34)	509.24 (0.32)	428.83 (0.27)

From 2012 on it is planned to substitute the tariffs by a Renewable Portfolio Standard. In the new tariff scheme it is possible to choose between 15 years guarantee and a higher kWh price and a 20 years guarantee and a somewhat lower kWh price. The previous 100 MW cap was increased to 500 MW and if it is not reached in 2009 the fixed prices applicable for new systems in 2010 will be announced later. However, the cumulative installed capacity at the end of 2007 was 78 MW. In January 2008, 46 MW of installed capacity was under the cap scheme and more than 560 MW were already under planning or construction. The Korean Government aims to equip 100,000 houses and 70,000 public/commercial buildings with PV systems by 2012. An interesting aspect is that some of the larger projects will qualify for

[5] Exchange rate: 1 € = 1600 KRW

Clean Development Mechanism (CDM) credits, allowing for trading of Certified Emission Reductions (CER) under the Kyoto Protocol.

On 1 July 2008, Prime Minister Manmohan Singh unveiled India's first National Action Plan to on Climate Change. To cope with the challenges of Climate Change India identified eight National Missions aimed to develop and use new technologies. The use of solar energy with Photovoltaics and Concentrating Solar Power (CSP) is described in the National Solar Mission (NSM). The actions for Photovoltaics in the National Solar Mission call for R&D collaboration, technology transfer and capacity building. The NSM aims to create a local Photovoltaic Industry and market. The comprehensive missions documents will be developed and institutionalised via several ministries and should be ready by December 2008.

At the end of 2007, most of Photovoltaic applications in India were off-grid, accounting for 560,000 solar lanterns, 342,000 solar home systems, 54,700 solar street lights and almost 7,000 water pumping systems. Grid connected were 33 solar Photovoltaic systems with a total capacity of approximately 2 MWp. For its eleventh Five Year Plan (2008 -2012) India has set a target to install 50 MW grid-connected Photovoltaic systems supported by the Ministry of New and Renewable Energy with an investment subsidy and power purchase programme. Contrary to these moderate installation plans, Indian PV companies expect the PV market in India to grow to 1 – 2 GW by 2010.

3. JAPAN

The long-term Japanese PV research and development programmes, as well as the measures for market implementation which started in 1994, have ensured that Japan has become a leading PV nation worldwide. The principles of Japan's Energy Policy are the **3E**s:

- Security of Japanese **E**nergy Supply (Alternatives to oil)
- **E**conomic Efficiency (Market mechanisms)
- Harmony with **E**nvironment (Cutting CO_2 emissions on line with the Kyoto Targets)

3.1 Policy to Introduce New Energies in Japan

In earlier Status Reports, the main differences between the Japanese and European reasons for the introduction of renewable energies, as well as the history, were already described [Jäg 2004]. The current basic energy policy is based on market principles, but seeks to ensure a stable supply and environmentally-friendly production and consumption of energy at the same time [MET 2006]. The justification for the promotion of New Energies is spelled out in the goals supporting this policy:

- Promoting energy conservation measures;
- Developing and introducing diverse sources of energy;
- Ensuring a stable supply of oil;
- Basing the energy market on market principles.

At the current stage, new energy is still considered as having problems regarding economic viability and level of output. However, it has few environmental restrictions and is an environmentally friendly form of energy. The scarcity of natural conventional energy resources in Japan, the current status of mid/long term supply of oil and the risks for a stable energy supply for Japan, as well as the need to address global environmental problems, such as reducing emissions of greenhouse gases like CO_2, increase the need to accelerate the advancement of implementation of new energy. Therefore, the Japanese Government is tackling this problem by promoting implementation through the assistance of technological development of low cost/high efficiency equipment and installation of new energy facilities. The following laws and measures were implemented to ensure this:

1. **'Basic Guidelines for New Energy Introduction'**

The 'Basic Guidelines' were set by the 'Council of Ministers for the Promotion of Comprehensive Energy Measures' in December 1994, based on a Cabinet Decision in September 1994. An important reason for the introduction of new energies is stipulated in the Chapter about Photovoltaics: 'The international market'. There is a fundamental difference in the attitude of implementing renewables between Japan and Europe. The Japanese policy not only has the advantage of being much more market-oriented, but also has a major aim in the policy guidelines: "The establishment of a prospering market". These expectations are also expressed by the long-term goals, which already in 1994 made a commitment for the next fifteen years until the year 2010. This long-term policy and commitment constitute an enormous advantage, as industry can rely on such a long-term programme and plan their individual industry policy as well. Hitherto, in Europe, most of the national, as well as European Community programmes, clearly lack such long-term policy commitments!

2. Law Concerning the Promotion of Development and the Introduction of Oil Alternative Energy (Alternative Energy Law)

The Alternative Energy Law (enacted in 1980 and amended in 1992) came into force to provide a legal framework for the development and implementation of oil alternative energies in order to secure a stable and appropriate supply of energy. In addition to the determination and public announcements of oil alternative energy targets, it employs various measures through New Energy and Industrial Technology Development Organisations.

3. Long-term Energy Supply/Demand Outlook

The "Long-term Energy Supply/Demand Outlook" was determined from the viewpoint of advancing the promotion of implementation of non-fossil energy, such as New Energy and Nuclear Power, etc. It represents efforts aimed at stabilising the supply of energy and further improving energy consumption efficiency. This forecast was revised in June 1998, based on the targeted reduction of carbon-dioxide emissions of Japan for 2010, decided at the COP3 in December 1997. Additionally, the “Long-term Energy Supply/Demand Outlook” was revised in July 2001 to represent the desired energy supply and demand figures in the future.

4. “Law Concerning Special Measures for Promotion of New Energy Use, etc. (New Energy Law)”

The “Law Concerning Special Measures for Promotion of New Energy Use, etc., (New Energy Law)” was enacted in April 1997 to accelerate the advancement of the introduction of New Energy, aiming to achieve its targets by 2010. This Law, while clarifying the role of each area for the overall advancement of New Energy usage, provides the financial support measures for utilities that use New Energy. In January 2002, an amendment was made to Article 1 of the Act for the "New Energy Use, etc." section of this Law so that Biomass Energy and Cool Energy could be added.

Also in September 1997, based on this Law, a fundamental policy for basic matters concerning measures for each area that the public, utilities and governments should consider, was determined.

5. Renewable Portfolio Standard

The Japanese RPS market went into effect on 1 April 2003, based on the "Special Measures Law Concerning the Use of New Energy by Electric Utilities". The goal is to increase the total usage of New Energy up to 12.2 TWh by 2010 or 1.35% of the electricity. Under this scheme the National Government requires each electric power company to use a certain amount of electricity, depending on its electricity sales, generated from new energies.

The power companies can select the most advantageous way for them from the following options:

- Self-generation of new energy
- Purchasing of new energy from others
- Subrogation of the obligation to another company

6. Science and Technology Policy 2006

At its 56th session on 14 June 2006, the Japanese Council for "Science and Technology Policy", chaired by the then Prime Minister Koizumi, passed the "Third Science and Technology Basic Plan" (FY 2006 to 2010) [GoJ 2006]. During these five years the Government wanted to spend ¥ 25 trillion (ca. € 172 billion[6]) for Science & Technology to strengthen international competitiveness and developing the Human Resources. In total, 273 important measures were identified. Amongst the 14 measures of strategic importance selected in the energy area, the further technical development of Photovoltaic systems will be promoted under the theme: "Technology for innovative efficiency improvement and cost reduction to disseminate Photovoltaic power generation to the world".

7. Low Carbon Technology Plan

During the 75th Session of the Council for Science and Technology Policy on 19 May 2008, the “Low Carbon Technology Plan” was approved [CST 2008]. Within this Plan, Photovoltaic electricity generation is regarded as one of the key technologies to enhance the efficiency of reducing GHG emissions.

8. Fukuda Vision

On 9 June 2008, then Prime Minister Yasuo Fukuda released his "vision" for creating a low-carbon society in preparation of the summit of the Group of Eight industrialized nations in Toyako, Hokkaido. Photovoltaic electricity systems are included as one of the key components and it aims to install PV on 70% of all newly build homes by 2020.

The policy drivers in Japan can be summarised by the following bullet points given by METI:

- Contribution to securing a stable energy supply as an oil alternative energy;
- Clean energy with a small burden on the environment;
- Contribution to new industry and job creation;
- Advantage of creating a decentralised energy system;
- Contribution of load levelling for electric power (effect reducing energy peaks).

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6 Exchange rate used: 145 ¥ = 1 €

3.2 Implementation of Photovoltaics

The Japanese residential implementation programme for Photovoltaics, which ended in October 2005 was the longest running. It started with the “Monitoring Programme for Residential PV systems” from 94 to 96, followed by the “Programme for the Development of the Infrastructure for the Introduction of Residential PV Systems”, which has been running since 1997. During this period, the average price for 1 kWp in the residential sector fell from 2 million ¥/kWp in 1994 to 670,000 ¥/kWp in 2004. With the end of the "Residential PV System Dissemination Programme" in October 2005, the price data base of the New Energy Foundation (NEF) was no longer continued.

The Residential PV System Dissemination Programme has been leading the expansion of Japan's PV market for 12 years. In 2006, 88.5%, or 254 MW of the new installations were grid-connected residential systems, bringing the accumulated power of solar systems under the Japanese PV Residential Programme to 1,617 MW, out of 1,709 MW total installed PV capacity at the end of FY 2006 [Mat 2007]. However, in FY 2007 the Japanese market declined to 210 MW of new installations, 36% lower than in 2006. At the end of 2007, total cumulative installed capacity in 2007 was 1.9 GW, almost 3 GW short of the original 4.8 GW goal for 2010 [Ikk 2008].

In general, the end of the Residential PV System Dissemination Programme in FY 2005 is given as a reason for the decrease of new installations, but not so much because of the financial incentive of ¥ 20,000 per kWp, but because this was perceived as lack of political support. Additional reasons are:

First, that due to societal changes and economic conditions, the detached house market in Japan, the major market for residential systems, is experiencing a downward trend.

Second, the strong demand for solar modules outside of Japan and the strong Euro make it more attractive for Japanese companies to export their products and visa versa make it less interesting for foreign companies to import into Japan.

Third, in 2007 the silicon shortage led to a lower solar cell production at the Japanese market leader Sharp. This and the fact that European customers generally secure their shipments through long term supply contracts might have led to a shortage of solar modules in Japan. An indication for this theory is the fact that Sekisui Homes – one of the leading manufacturers of detached homes in Japan – who until recently was only installing Sharp solar systems is now also offering systems from other companies.

In order to stimulate the home market and to realise the "Fukuda Vision" METI announced at the end of August 2008 that they want to reinstate an investment subsidy for residential Photovoltaic systems in FY 2009 and that they have submitted a budget request 23.8 billion ¥[7] (164 million €). A decision is expected at the end of November 2008.

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7 Exchange rate used: 145 ¥ = 1 €

The new measures to revitalise the Japanese market as well as METI's “Vision for New Energy Business” (June 2004) and the "New National Energy Strategy" (June 2006) confirm the political support for renewable energies.

This strategy aims to develop an independent and sustainable new energy business and various support measures for PV are explicitly mentioned. The key elements are:

1) Strategic promotion of technological developments as a driving force for competitiveness:
   - Promotion of technological development to overcome high costs;
   - Development of PV systems to facilitate grid-connection and creation of the environment for its implementation.
2) Accelerated demand creation:
   - Develop a range of support measures besides subsidies;
   - Support to create new business models.
3) Enhancement of competitiveness to establish a sustainable PV industry:
   - Establishment of standards, codes and an accreditation system to contribute to the availability of human resources, as well as securing performance, quality and safety;
   - Enhancement of the awareness for Photovoltaic systems;
   - Promotion of international co-operation.

The key elements are industry-policy targeted and the aim is to create viable, independent and sustainable new energy businesses. This includes the whole chain from raw material production, cell, module and BOS component manufacturing to the establishment of business opportunities in overseas markets. The strong focus on the establishment of international standards should help to transfer the new Japanese business models worldwide. The strategy was implemented in the revised “PV Roadmap towards 2030” (Fig. 6), which was drafted by NEDO, METI, PVTEC[8] and JPEA[9].

The number of Japanese Ministries working on support measures to install PV systems has expanded from METI to the Ministry of the Environment (MOE), the Ministry of Land, Infrastructure and Transport (MLIT) and the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF).

In addition to the measures taken by the National Government, over 300 local authorities have introduced measures to promote the installation of PV systems. One of the largest programmes was announced by the Tokyo Metropolitan Government which plans to support the installation of 1 GW of PV systems at 40,000 households in FY2009 and 2010. The Federation of Electric Power Companies of Japan (FEPC) announced that they intend to install PV plants with a cumulative installed capacity of 10 GW by 2020 [Ikk 2008].

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[8] Phtovoltaic Power Generation Technology Research Association

[9] Japan Photovoltaic Energy Association

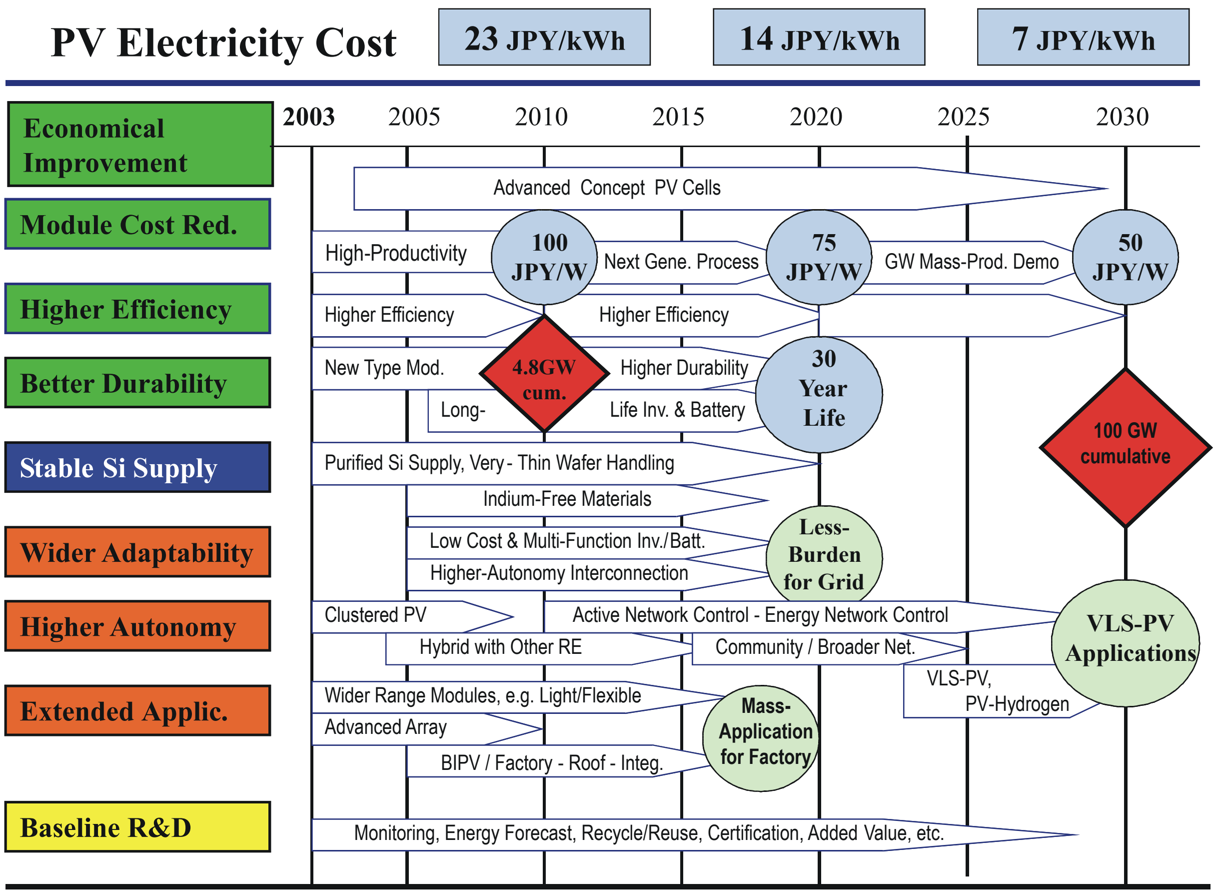

Fig. 6: Japanese Roadmap for PV R&D and market implementation [Kur 2004]

3.3 NEDO PV Programme

In Japan, the Independent Governmental Entity New Energy Development Organisation (NEDO) is responsible for the Research Programme for Renewable Energies. The current programmes for Photovoltaics in the frame of Energy and Environment Technologies Development Projects has three main pillars [NED 2007]:

- New Energy Technology Development
- Introduction and Dissemination of New Energy and Energy Conservation
- International Projects

One of the dominant priorities, besides the future increase in PV production, is obviously the cost reduction of solar cells and PV systems. In addition to these activities, there are programmes on future technology (in and outside NEDO) where participation of Japanese institutes or companies occurs by invitation only. For the participation of non-Japanese partners there are "future development projects" and the NEDO Joint Research Programme, mainly dealing with non-applied research topics.

Within the **New Energy Technology Development** Programme there are projects on Photovoltaic technology specific issues, problems of grid-connected systems, as well as public solicitation.

♦ **Field Test Projects on Photovoltaic Power Generation**
FY2007 - FY2014 (Installation work to be completed in FY2010)

To further promote the introduction of PV systems, it is considered essential to install them at public facilities, residential housing complexes, and in the industrial sector, such as at factories. The potential of such installations is comparable to that of the detached home market. Medium- and large-scale PV systems are being adopted more slowly than detached home systems even though costs have been substantially reduced and their effectiveness as power generation devices has been verified. Systems employing new modules or other innovations will be verified through joint research activities (partly covered by technology research subsidies). Operating data is being analysed, evaluated, and published with the objective of encouraging further cost reductions and system performance improvements. NEDO and joint researchers each bear 50% of the costs.

♦ **Research and Development of Next-generation PV System Technologies**
FY2006 - FY2009

To play an important role in energy generation in the future, the cost-effectiveness, performance, function, applicability, and usability of Photovoltaic systems must be drastically improved to facilitate the promotion and dissemination of solar power generation. Given this, medium- to long-term innovative technological development efforts beyond simple extensions of currently available technologies are underway. More specifically, the following research and development themes are being undertaken:

- **Technologies to improve the efficiency of CIS thin-film solar cells and elemental technologies to form solar cells on lightweight substrates.**
  Target efficiencies:
  18% for sub-module area of 100 cm^2
  16% for sub-module area of 900 cm^2
  16% for sub-module area of 100 cm^2 on a light-weight substrate
- **Technologies to enable higher productivity and to improve the efficiency of thin-film silicon solar cells.**
  High Productivity Targets:
  1) μc-Si thin films with large area (4m^2)
  deposition rate > 2.5 nm/s and single junction cell efficiency > 8%
  2) μc-Si thin films 100 cm^2 substrates
  deposition rate > 10 nm/s and single junction cell efficiency > 8%
  3) Thin film silicon etching rate: 20 nm/s
  High Efficiency:
  15% for module area of 1000 cm^2 with (film deposition rate: 2.5 nm/s)
- **Technologies to enable highly efficient, modular, and durable dye-sensitized solar cells**.
  High efficiency of 15% for small area (1cm^2) cells
  Durability of modules wit target efficiency of 8% (900 cm^2)
- **Technologies and associated processes to produce highly efficient next-generation ultra-thin crystalline silicon solar cells.**
  Development of production technology for crystalline silicon solar cells with a

Monocrystalline: 100-μm substrate thickness, 125 × 125 mm^2 and 21% efficiency
Polycrystalline: 100-μm substrate thickness, 150 × 150 mm^2 and 18% efficiency

- **Technologies to improve the efficiency and durability of organic thin-film solar cells.**
  Target efficiency of 7% for small area (1 cm^2) cells
  Relative efficiency degradation ≤ 10% after 100 hours of exposure to air and direct light
- **Search for next-generation technologies that would enable significant cost reductions, improved performance, and extend the usable life of solar power generation systems.**

♦ **Research and Development on Innovative Solar Cells**
FY2008 - FY2014 (peer review after 3rd year)

The objective of this project is to improve drastically the conversion efficiency of solar cells using new and innovative concepts. Tokyo University and AIST Tsukuba in collaboration with the Tokyo Institute of Technology were selected in July 2008 as Centres of excellence (CoE) to carry out the tasks. The following research topics were selected and are open for international collaboration:

- **Post-silicon Solar Cells for Ultra-high Efficiencies**
  (1) Super high-efficiency concentrator multi-junction solar cells
  (2) High efficiency quantum structure tandem solar cells and their manufacturing technologies
  (3) Ultra-high efficiency solar cells based on quantum dots and super lattice
  (4) Ultra-high efficiency multiple junction solar cells with hybrid materials
- **Thin Film Full Spectrum Solar Cells with low concentration ratios**
  (1) Band-gap control of nano dots/ multi-exiton/ band-gap engineering of strained Ge/ novel Si-based and amorphous alloy thin films/ thin film materials design
  (2) Si-based thin film concentrators/ wide band-gap Si based thin films/ multi-cell interface junction/ Chalcopyrite based thin film concentrators on metal substrates/ optical design/ CdTe thin film concentrators
  (3) Surface plasmons/ p-type TCO/ full-spectrum TCO/ grapheme transparent conductive film
- **Exploring Novel Thin Film Multi-junction Solar Cells with Highly-ordered Structure**
  (1) Highly-ordered plane poly-silane/ ordered nano-crystalline Si-materials/ Ge-based narrow band-gap materials/ heterojunction devices
  (2) Wide band-gap chalcogenide-based materials/ solar cells using novel wide band-gap material/ Oxynitride-based wide band-gap materials/ Oxide-based wide band-gap materials/ CIGSSe-based tandem-type solar cells
  (3) Novel concept solar cells using nano-Si, nano-carbon and single-crystalline organic semiconductors/ novel concept solar cells using correlated materials/ novel concept solar cells using nano-materials with controlled structure
  (4) Mechanical stacking-techniques/ highly efficient light-trapping techniques/ improved transparent conduction oxides films using preparation techniques for improved glass substrates

♦ **Research and Development of Common Fundamental Technologies for Photovoltaic Generation Systems**
FY2006 - FY2009

To facilitate the dissemination of Photovoltaic generation systems in the future, it is essential to develop and incorporate commonly-used fundamental technologies and to reduce the cost of solar cells. For this purpose, the following research and development activities are currently ongoing:

- **Development of new solar cell evaluation technologies**
  To increase the number of installations, methods to evaluate the performance and reliability of solar cell modules and solar generation systems are being developed.
- **Development of Photovoltaic environmental technologies**
  Studies are being conducted under a variety of environmental conditions and guidelines for Photovoltaic (PV) generation systems. The development of technologies related to solar cell recycling and the development of life-cycle assessment (LCA) evaluation methods for PV generation are also being carried out.
- **Study on Photovoltaic generation technology development trends**
  Research and development trends, future development directions, and the analysis and evaluation of the state of PV generation abroad are being tracked.

♦ **Verification of Grid Stabilization with Large-scale PV Power Generation Systems**
FY2006 - FY2010

It is expected that large-scale Photovoltaic (PV) generation systems will be increasingly disseminated. When a number of such large-scale PV systems are connected to power grids, there is a concern that the fluctuating output inherent to PV systems could affect the voltage and frequency of power on utility power grids, and result in restrictions that limit the dissemination and practical application of PV systems. To investigate this problem, the following work will be carried out:

- Development and verification of the effectiveness of various technologies required when large-scale PV systems are connected to power grids, including voltage fluctuation suppression technology, frequency (output) fluctuation suppression technology, large-scale PV output control technology to enable scheduled operations, and harmonic suppression technology. Large PV power conditioners capable of stabilising grids will also be developed.
- Development of simulation methods to apply to the above research topics, which will also be useful for studying specific conditions in preparation for future large-scale PV system installations.

♦ **Project to Support Innovative New Energy Technology Ventures**
FY2006 - FY2011

The purpose of this project is to promote the technological development of fields related to untapped energies, including new sources/technologies such as (1) Photovoltaic power generation, (2) Biomass, (3) fuel cells and batteries, (4) wind power generation and unutilised energy sources. More specifically, the project aims to make full use of the promising technological seeds that are held by venture companies and other organisations, to identify new technologies that can boost efforts to introduce and popularise new energy systems by 2010 and beyond through creating and expanding new businesses, and to launch new venture companies.

The **Introduction and Dissemination of New Energy and Energy Conservation** Programme consists of various promotional and awareness campaign projects.

- ♦ **Project for Promoting the Local Introduction of New Energy**
  FY1998 - open

This project is designed to accelerate the introduction of the New Energy Facility Introduction Project and the New Energy Introduction Promotion/Dissemination Project, which are implemented by local governments. The facility introduction project subsidizes local governments for up to 50% of equipment/facility introduction costs and up to 20 million yen for dissemination.

Non-profit organisations are also eligible for support under the New Energy Facility Introduction Project if they introduce effective new energy utilisation systems at the local level. To disseminate non-profit organisations' efforts nationally in order to accelerate the dissemination of new energy, projects can be subsidised at up to 50% of the cost.

The **International Projects** mainly focus on neighbouring Asian developing countries to promote technological development.

- ♦ **International Co-operative Demonstration Project Utilising Photovoltaic Power Generation Systems**
  FY1992 – open

The technological development necessary for the practical application and dissemination of Photovoltaic power generation systems cannot be achieved without the efficient promotion of system improvements including system reliability verification and demonstration, as well as cost reductions. NEDO conducts the International Co-operative Demonstration Project Utilising Photovoltaic Power Generation Systems with developing countries whose natural conditions and distinctive social systems are rarely seen in Japan.

- **Demonstrative Research Project on Integrated Control Technology for Large-scale Photovoltaic Systems** (High-capacity PV + Capacitor + Integrated control)
  Country of Implementation: China (Qinghai)
  FY2006 - FY2009
  Substantial efforts are being made to increase the capacity of Photovoltaic power generation systems. There is, however, a concern that the short-term output fluctuations of Photovoltaic power generation systems can cause voltage variations and degrade electric power quality.
  In this project, the stabilisation of power supplies through the use of electric double-layered capacitors will be verified. Besides being able to compensate for output

variations in general, electric double-layered capacitors rapidly respond to instantaneous voltage variations, are easily serviceable, and have less environmental impact when disposed of.
Other points to be verified in this project include failure response technology to be applied during power system failures or other incidents, as well as other space- and equipment-saving measures required when system capacity increases significantly.
The site for this demonstrative project is the Xining National Economic and Technological Development Area in Xining City, Qinghai Province, China.

- **Development of Design Support Tools for Photovoltaic Power Generation Systems**
  FY2006 - FY2009
  By utilising the data and knowledge obtained through NEDO's international co-operative demonstration projects, including those related to Photovoltaic power generation systems, highly reliable design support tools will be developed reflecting the field results in order to improve the accuracy and accelerate design efforts regarding the capacity, output, and economic efficiency of Photovoltaic power generation systems.
- **Support Project to Improve Maintenance Skills for Application to Photovoltaic Power Generation Systems**
  FY2006 - FY2009
  In order to further raise the technological knowledge level and to popularise the use of reusable energies through the use of technologies such as Photovoltaic generation systems, it is necessary to obtain sufficient knowledge of the methods and techniques to enable the efficient use, maintenance and management of the systems. Presently, however, education and training systems to systematically provide information on reusable energies are not widely available in most Asian countries.
  To address this situation, NEDO, using results and knowledge obtained through international co-operative demonstration projects, will help other Asian countries implement education and training for selected engineering managers. These individuals will then become master trainers in their home countries. NEDO will prepare textbooks and training curriculum for the participating countries, and implement education and training courses to be delivered by the master trainers to trainers and students in their own countries.
  The School of Renewable Energy Technology (SERT) at Naresuan University in Thailand serves as the centre for this project. SERT was chosen in part because of its efforts to develop renewable energy education programmes, including a curriculum on Photovoltaic power generation systems.

3.4 Japanese Market Situation

Japanese Photovoltaic production has rapidly increased following the development of roof-type technologies and the introduction of the subsidy system "Programme for the Development of Infrastructure for the Introduction of Residential PV Systems" in 1997. After the end of the Residential Market Implementation Programme which was widely received as a slowing political support, the Japanese market has decreased from about 290 MW in 2005 to 210 MW in 2007. Despite the fact that PV systems have developed into additional added value for existing or new houses, the downward trend of the detached house market in Japan, which is due to societal changes and economic conditions, had a negative effect on the PV market. The strong Euro and higher prices for modules outside Japan as well as the silicon shortage for some companies have added towards this trend.

After 30 years of PV development under the different NEDO programmes, 11 Japanese PV manufacturing companies have manufactured solar cells in 2007 [Ikk 2008] and produced approx. 23% (931 MWp) of the solar cells worldwide in 2007. The production reduction of Sharp, due to silicon shortage was only compensated partly by the other manufacturers and because the overall Japanese production grew only marginally from 2006 to 2007, Japanese manufacturers lost overall market shares due to the worldwide production growth of 60%.

All Japanese solar cell manufacturers have announced massive increases of production capacities for 2010 onwards, signalling the expectations for a continuation of the high growth rates of the world market. If the announced capacity increases are realised, production capacity in Japan would increase from 1.5 GW in 2007 to 3.5 GW in 2010 and around 7 GW in 2012.

The total cumulative installed capacity in 2007 was 1.9 GW, almost 3 GW short of the original 4.8 GW goal for 2010 [Ikk 2008]. In order to revitalise the Japanese home market, METI announced, at the end of August 2008 that they have submitted a budget request of 23.8 billion ¥[10] (164 million €) for an investment subsidy for residential Photovoltaic systems in FY 2009.

So far, the majority of PV systems were installed on residential houses. At the end of FY 2007, about 1.6 GWp, out of the total 1.9 GWp installed were on residential buildings. It is interesting to note that the number of real roof integrated houses is rather small, despite the fact that such solutions are readily available. One of the reasons for this is that people investing in PV systems want to "exhibit" them in order to show their environmental consciousness and lifestyle.

In June 2006 the Japanese Photovoltaic Energy Association published its vision on the "Future of the Photovoltaics Industry in Japan" in response to METI's "New National Energy

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[10] Exchange rate used: 145 ¥ = 1 €

Strategy" in June 2006 [Ikk 2006]. This vision paper was a revision of the 2002 version, taking into account the significant increase of the world PV market, as well as soaring crude oil and energy prices. The figures given in this vision for the expected domestic market of 1.18 GW for 2010 were still in view of the cumulative installed capacity target of 4.8 GW for 2010 and 100 GW in 2030. However, new scenarios within NEDO expect a domestic market of just 1 GW in 2030, which would reduce the total installed capacity to 30 GW. Contrary to that, the *Fukuda Vision* calls for a total installed capacity of 14 GW in 2020 and 50 GW in 2030.

A new roadmap is currently under development at NEDO and according to information given by the director of grid connected power systems, Mr. Satoshi Morozumi, it will probably be available in March 2009 [Pho 2008a].

In an interview with Photon International during the PV Japan 2008 Fair in Tokyo (30 July – 1 August 2008), Junichi Honda, Manager of the Japan Photovoltaic Energy Association (JPEA), expressed his view, that in his opinion the domestic market should be in the range of 35 to 40% of the Japanese actual production. This would be close to JPEA's 2006 vision figures and it has to be seen if the market stimulus by a new residential PV programme is sufficient to realise it. But even if the new programme is approved, the capacity of all installed PV systems in Japan will be in the range of 3 GW in 2010 (Fig. 7).

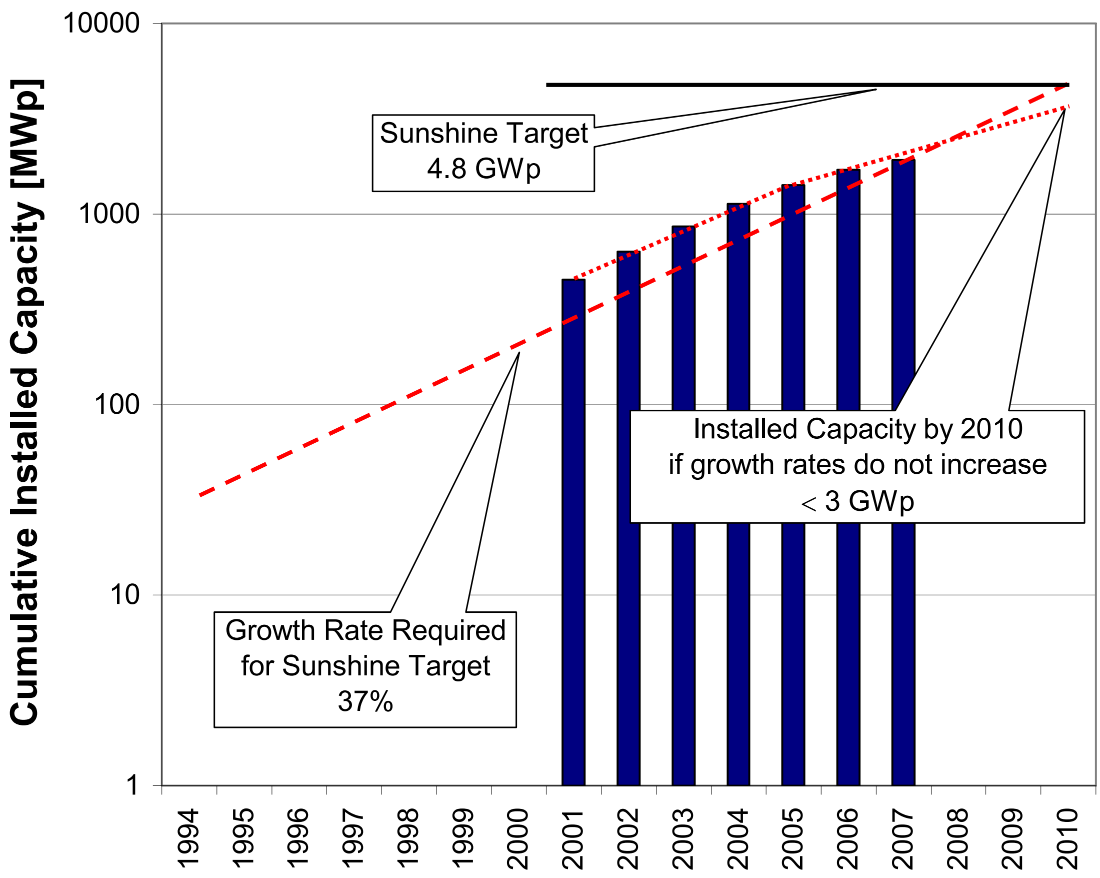

Fig. 7: Sunshine Target and current trends

A special condition of the Japanese PV industry is the fact that most of the production capacities are limited to a few large companies, which bundle the whole, or at least large portions, of the PV value chain inside their own company, i.e. the solar cell, module, BOS components and sometimes even the installation and maintenance of the PV systems are offered from the same company. This development is fostered by the special situation of the Japanese construction market. The average lifetime of a residential home is 25 to 35 years and corresponds well with the lifetime of solar modules. A lot of houses are either prefabricated or construction companies use standardised building components, favourable for the integration of solar modules. This advantage was recognised by the solar cell manufacturers and they have either bought housing or construction companies, or forged strategic alliances with such companies.

3.5 Solar Companies

In the following chapter, most of the market players in Japan are briefly described. This listing does not claim to be complete, especially due to the fact that the availability of information or data for some companies was very fragmentary.

3.5.1 Kaneka Solartech

Kaneka has been involved in the development of amorphous solar cells for over 25 years. Initially this was aimed at the consumer electronics market, but overall R&D, as well as business strategy, was changed in 1993 when Kaneka decided to move into the power module market for residential and industrial applications.

Currently Kaneka produces a-Si and amorphous/microcrystalline silicon modules for rooftop application and built-in roofing types for the Japanese, as well as export markets. The built-in roofing types were developed for the Japanese housing market in co-operation with Quarter-House and Kubota and are either shingle type modules or larger roofing elements. In 2006 the company opened a module factory in Olomouc, Czech Republic, where the capacity will be increased to 30 MW in 2008. In FY2008 the total production capacity will be expanded to 70 MWp/year, with a further expansion to 130 MW planned for 2010 [Kan 2008]. In FY 2007 production was 40 MW [Pvn 2008].

3.5.2 Kyocera Corporation

In 2007, Kyocera had a production of 207 MW and is also marketing systems that both generate electricity through solar cells and exploit heat from the sun for other purposes, such as heating water. The Sakura Factory, Chiba Prefecture, is involved in everything from R&D and system planning to construction and servicing and the Shiga factory, Shiga Prefecture, is active in R&D, as well as the manufacturing of solar cells, modules, equipment parts, and devices, which exploit heat. Like other Japanese manufacturers, Kyocera is planning to increase its current capacity of 240 MW to more than 500 MW by 2010 [Kyo 2007].

The growing markets in developing countries are of major interest to the company. Therefore, Kyocera set up a joint venture with the Tianjin Yiqing Group (10% share) in Tianjin, China, to produce PV modules for the local market [Kyo 2003]. The factory started operation in October 2003 and was expanded to 40 MW in 2004. A second module factory with 36 MW production capacity in Tijuana, Mexico, started production in December 2004 [Kyo 2004]. In order to supply the growing European market, Kyocera decided to build a third module assembly plant in Kadan, Czech Republic, which started operation in 2005, with a production capacity of 60 MW annually [Ikk 2006a].

In 1975 Kyocera began with research on solar cells. The Shiga Yohkaichi Factory was established in 1980 and R&D and manufacturing of solar cells and products started with mass production of multicrystalline silicon solar cells in 1982. In 1993 Kyocera achieved a 19.5 % world record efficiency with single-crystal silicon solar cells (10 cm^2). In the same year Kyocera started as the first Japanese company to sell home PV generation systems.

3.5.3 Mitsubishi Electric

In 1974 research and development of Photovoltaic modules was initiated. In 1976 Mitsubishi Electric established its space satellite business and 1986 saw the beginning of a public and industrial systems business. One of the largest PV systems in Japan was delivered in 1993 to Miyako Island in the Okinawa Prefecture (750 kWp). With the start of the NEDO Residential Programme, Mitubishi Electric got involved in the residential PV market in 1996. The Iida factory, Nagano Prefecture, was established in 1998 where cells and modules were manufactured. Today this plant is used for cell production and the modules are manufactured in Nakatsugawa, Gifu Prefecture, and Nagaokakyo, Kyoto Prefecture. Production capacity from October 2008 on will be 220 MW [Mit 2008] and production in FY2007 was 121 MW [Pvn 2008].

3.5.4 Mitsubishi Heavy Industries

Mitsubishi Heavy Industries (MHI) started their pilot plant production in 2001, because solar energy has attracted increasing attention as an environment-friendly form of energy. In 2007 MHI produced 16 MW of amorphous silicon solar cells and in 2008 a total production capacity of 128 MW should become operational [Ikk 2008].

The plasma CVD deposition used by MHI allows rapid deposition on large size glass and flexible substrates (roll-to-roll). MHI has stabilised the a-Si single-junction efficiency at 8%, starting with 10% initial efficiency. The degradation process lasts for approximately 3 to 4 months, before the stabilised efficiency is reached. Long-time outdoor exposure tests performed at JQA showed that the stabilised efficiency does not change and that the lifetime expectancy can be rated at 20 to 25 years. Mitsubishi is currently working on improving the efficiency to 12% by using a microcrystalline/a-Si structure in the future. Another feature of the Mitsubishi modules is their high voltage. The modules are produced with either 50V or 100V and power ratings between 24 and 100Wp.

3.5.5 SANYO Electric Company

Sanyo commenced R&D for a-Si solar cells in 1975. 1980 marked the beginning of Sanyo’s a-Si solar cell mass productions for consumer applications. Ten years later in 1990 research on the HIT (Heterojunction with Intrinsic Thin Layer) structure was started. In 1992 Dr. Kuwano (former president of SANYO) installed the first residential PV system at his private home. Amorphous Silicon modules for power use became available from SANYO in 1993 and in 1997 the mass production of HIT solar cells started. In 2007 Sanyo had a production of 165 MW solar cells. The latest expansion plans foresee focus on the solar business and a rapid expansion from 260 MW in FY 2007 to 650 MW in 2010 [San 2007].

At the end of 2002, Sanyo announced the start of module production outside Japan. The company now has a HIT PV module production (12 MW/a) at SANYO Energy S.A. de C.V.’s Monterrey, Mexico and it joined Sharp and Kyocera to set up module manufacturing plants in Europe. 2005 it opened its module manufacturing plant in Dorog, Hungary, and the production capacity was increased to 100MW in 2008 [San 2008].

Sanyo has set a world record for the efficiency of the HIT solar cell with 22% under laboratory conditions [San 2007a]. The HIT structure offers the possibility to produce double-sided solar cells, which offer the advantage to collect scattered light on the rear side of the solar cell and can therefore increase the performance by up to 30% compared to one-sided HIT modules in the case of vertical installation.

Sanyo works closely with Daiwa House to promote the HIT power roofing tile. The advantages are the lower weight (50%) compared to a conventional roof tile. Like other big Japanese solar companies Sanyo offers the complete PV systems manufactured by its own factories.

Solar Ark Project: The "Solar Ark", a large scale solar power generation system (630 kWp) at SANYO's Gifu facility was completed in December 2001 and is a symbol of solar energy well known in the whole of Japan. The Solar Ark was built in the image of an Ark embarking into the 21st century, powered by solar energy (Fig. 8).

The Ark's total length measures 315 metres, its highest point measuring 37.1 metres, making it the largest single-structure solar installation in the world. In the meantime, it has become one of the symbols of Photovoltaics. Placed underneath the Ark is the "Solar Lab", a Solar Energy Museum opened in 2002. The main activities are:

- Cultivating children’s awareness in Science and Ecology.
- Releasing information from the standpoint of benefiting mankind and the environment.
- Regional contribution, such as support for the development of Eco-Town.
- Creation of new ideas through various activities.

Fig. 8: Sanyo’s Solar Ark (Picture: courtesy of Sanyo)

3.5.6 Sharp Corporation

Sharp started to develop solar cells in 1959 and succeeded in mass-producing them in 1963. Since its products were mounted on "Ume", Japan's first commercial-use artificial satellite, in 1974, Sharp has been the only Japanese maker to produce silicon solar cells for use in space. Another milestone was achieved in 1980, with the release of electronic calculators equipped with single-crystal solar cells. Sharp aims to become a “Zero Global Warming Impact Company by 2010” as the World’s Top Manufacturer of Solar Cells.

In FY 2007 Sharp had a production capacity of 710 MWp/year [Sha 2007a] and produced 363 MW [Pvn 2008]. An enhanced production line (15 MW) for new large format thin-film polycrystalline solar cells went into operation in September 2005, which is expanded to 160 MW in FY2008. The newly developed “Thin-Film Crystalline Tandem Cell” consists of an upper amorphous silicon solar cell and a lower crystalline thin-film silicon solar cell [Sha 2004]. The thin-films can either be manufactured as see-through (illuminating PV module “Lumiwall”, integrating light emitting diodes) or non see-through modules. After the announcement that their triple-junction thin film solar cell, with an increased module efficiency of 10%, would go into mass production in May 2007 [Sha 2007b], the company announced the construction of a 1 GW thin-film plant by 2010 [Sha 2007]. During the 1st International Photovoltaic Power Generation Expo in Tokyo on 27 February 2008, Sharp announced to increase thin film production capacity beyond the original foreseen 1 GW to 6 GW after 2012.

Together with Daido Steel and Daido Metal, Sharp developed a super high-efficiency Compound Solar Cell used for low cost solar concentrator modules and tracking systems within a NEDO research project. The InGaP/InGaAs/Ge solar cell has an efficiency of 36% under 700 X concentration. The tracking system has a size of $3.8 \times 4.8\ m^2$ and the system output is 2,922 W. According to a press release from September 2007, the system is now available [Sha 2007c].

The company has close collaboration with major Japanese housing companies and offers complete PV systems with all components made within the company (Fig. 9). At the moment, the residential PV market is the driving force for the capacity expansion, but Sharp considers future growth in the industrial sector as well. Sharp thus plans to offer the installation and service of large PV systems (in the range of a few hundred kWp) for industrial clients.

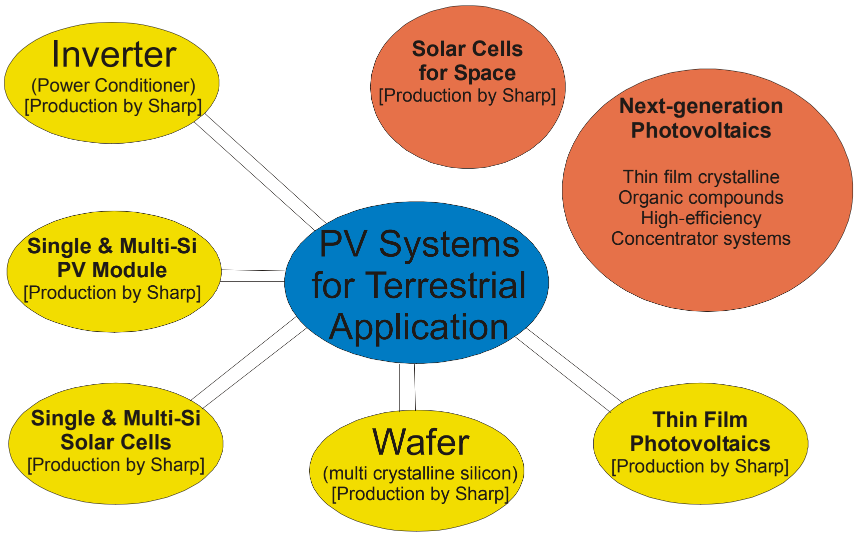

Fig. 9: Development concept of Sharp

In addition to the solar cell factory at the Katsuragi Plant, Nara Prefecture, Sharp has five module factories and has established the Toyama factory to produce silicon. Three of the module factories are outside Japan, one in Memphis, Tennessee, USA with 70 MW capacity, one in Wrexham, UK, with 220 MW capacity and one in Nakornpathom, Thailand.

3.5.7 Showa Shell Sekiyu:

In 1986 Showa started to import small modules for traffic signals, and started module production in Japan, co-operatively with Siemens (now Solar World). The company developed CIS solar cells and completed the construction of the first factory with 20 MW capacity in October 2006. Commercial production started in FY 2007. In August 2007 the company announced the construction of a second factory with a production capacity of 60 MW to be fully operational in 2009 [Sho 2007]. In July 2008 the company announced to open a research centre *"to strengthen research on CIS solar powered cell technology, and to start a collaborative research on mass production technology of the solar modules with Ulvac, Inc."* [Sho 2008]. The aim of this project is to start a new plant in 2011 with a capacity of 1 GW.

3.5.8 Additional Solar Cell Companies

- **Clean Venture 21:** Clean Venture 21 Corporation was founded in 2001 as a privately held solar company and develops spherical Silicon solar cells. In 2006 CV21 opened its first production facility in Kyoto. The company claims that the cells have 12% efficiency and that the costs should be only one fifth of a conventional silicon cell due to the significantly reduced silicon use. CV21 entered into an exclusive sale agreement with FujiPream Corporation in December 2005. According to RTS Corporation, the company has a production capacity of 12 MW for spherical silicon solar cells [Ikk 2008].

- **Fuji Electric Systems Co. Ltd.**: In 1993 Fuji Electric started its activities in amorphous thin film technology. The company developed amorphous-silicon thin film solar cells in the framework of a NEDO contract. The cells, which use a plastic film substrate less than 0.1mm thick, are light, inexpensive to manufacture and easily processed into large surface areas. In 2005 Fuji announced the construction of a factory with an initial capacity of 12 MW to be expanded to 40 MW in 2009 [Fuj 2007].

- **Hitachi:** Tokyo-based Hitachi Ltd. had a production capacity for its bi-facial crystalline solar cell of 10 MW/a, but sold it to Space Energy Corporation in April 2008. In addition, Hitachi developed a dye-sensitized solar cell with 9.3% efficiency according to the company.

- **Honda Soltec Co. Ltd.:** Honda R&D Co. Ltd. developed a CIGS thin-film module with a power output of 112W. To commercialise the product, Honda Soltec Co. Ltd, was established on 1 December 2006. Since June 2007, the company sells 125 W modules produced by Honda Engineering Co. Ltd. and announced that the mass production at the Kumamoto Plant with an annual capacity of 27.5 MW started its production in November 2007 [Hon 2007].

- **Kyosemi Corporation** was founded in 1980 and is a research and development-oriented optoelectronic company. The company developed a proprietary spherical solar cell and in 2004 registered the trademark Sphelar®.

- **Matsushita Ecology Systems**: National/Panasonic produces a colourable Photovoltaic cell (PV) and module especially for commercial use. Applications are building roofs, wall mountings and glass windows. They design and select the most suitable products, and supply individual solar modules or cells. In addition, Matsushita is involved in research of CIGS thin film modules.

- **Space Energy Corporation**: The company was established in April 1995 under the name Metal Reclaim Corporation and produces wafers. In April 2008 the company bought Hitachi's bi-facial solar cell and module manufacturing facility and started to set up a factory in Nagano with an initial capacity of 3.5 MW to be expanded to 7 MW in 2009.

3.5.9 Kobelco (Kobe Steel)

In April 1999, Kobe Steel's Engineering Company formed an agreement with Germany's Angewandte Solarenergie - ASE GmbH that enables Kobe Steel to market ASE's (now

Schott-Solar) Photovoltaic systems in Japan. Kobe Steel is focusing on selling mid- to large-size systems for industrial and public facilities. By 2010, it aims to acquire a 10% share of the domestic market.

Since the beginning of 2002, Kobelco has been supplying Misawa Homes Co., Ltd., with Photovoltaic module systems for its houses. Owing to rising demand, they began manufacturing the modules in November 2001 at the Takasago Works in Hyogo, Japan.

3.5.10 MSK Corporation

MSK Corporation was founded in 1967 as an import/export company for electrical parts. Already in 1981 MSK began with sales of solar cells and in 1984 opened a Photovoltaic module factory in the Nagano Prefecture. In 1992 they concluded a distribution agreement with Solarex (now BP Solar) and at the beginning of the Japanese Residential Dissemination Programme in 1994, MSK developed the roof material "Just Roof", together with Misawa Homes, and started sales of residential PV systems.

In August 2006, Suntech Power (PRC) announced the first step of its acquisition of MSK. Suntech acquired a two third equity interest in MSK for \$ 107 million (€ 73.86 million) in cash [Msk 2006]. The second step to acquire the remaining shares was closed in June 2008 [Sun 2008].

3.5.11 YOKASOL

After the takeover of MSK by Suntech Power, employees of MSK's Fukuoka Plant bought the plant and set it up as a new company named YOKASOL. The company manufactures mono- and polycrystalline silicon modules.

3.5.12 Daiwa House

Since August 1998, Daiwa House has been selling "Whole-Roof Solar Energy System" attached to single-family houses. This system, which is a unique type that comes already fixed to the steel roofing material, uses thin-film solar cells made from amorphous materials.

3.5.13 Misawa Homes

In 1990, Misawa Homes Co. Ltd., one of the biggest housing companies in Japan, started research activities to utilise PV as roofing material. In October 1992 they built the first model of the "Eco Energy House" with a PV roof-top system in the suburbs of Tokyo. 2003/4 Misawa Homes built "Hills Garden Kiyota", a 503-home residential community in Kiyota, Hokkaido. The homes are all equipped with solar Photovoltaic systems, with a total electrical generation capacity of 1,500kw, the world's largest in terms of electricity generated by a residential development at that time [Mis 2005].

3.5.14 Sekisui Heim

Sekisui Heim is a housing division of the Sekisui Chemical Company, which was founded in 1947. Sekisui Chemical was the first to develop plastic moulds in Japan. Its current annual revenue base is $1.35 billion, 50 percent of which comes from Sekisui Heim. In 1971, Sekisui Chemical created the Heim Division to build modular houses. Sekisui Heim, currently the fourth largest house builder in Japan, builds about 15,000 houses per year.

In January 2003 Sekisui introduced the "zero-cost-electricity-system" [Jap 2003]. The basic specification of the "utility charges zero dwelling house" are:

1) Use of "creative energy" = solar Photovoltaic electricity generation system;
2) Utilisation of "energy saving" = heat pump and the building frame responsive to the next-generation energy saving standard;
3) Management for "effective operation" = the total electrification by using the electricity in the middle of night.

In its 2008 annual report Sekisui stated that they have already sold some 60,000 units with Photovoltaic electricity systems.

3.5.15 PanaHome Corporation

PanaHome Corporation was established in 1963 to support the Matsushita Group's housing business. On 1 October 2002, the 28 principal subsidiaries of the PanaHome Group merged to form PanaHome. Designating detached housing, asset management, and home remodelling are the three core businesses of the company. In line with this, PanaHome offers Eco-Life Homes that are "friendly to people and the environment". As a part of this initiative, in July 2003 PanaHome launched the sale of energy-conservation homes equipped with solar power generation systems and other energy saving features.

Matsushita Electric Industrial Co., Ltd., has strengthened its capital alliance with Matsushita Electric Works, Ltd., creating a new comprehensive co-operative framework for the Matsushita Group for the 21st century. As a part of this new Group framework, PanaHome was turned into a consolidated subsidiary of Matsushita Electric Industrial on 1 April 2004.

PanaHome is offering environment-friendly Eco-Life Homes to reduce the volume of CO_2 emissions generated in everyday living, through the use of a solar power generation system, an all-electric system, and the Eco-Life ventilation system.

3.5.16 Tokuyama Corporation

Tokuyama is a chemical company involved in the manufacturing of solar-grade silicon, the base material for solar cells. The company is one of the world's leading polysilicon manufacturers and produces roughly 16% of the global supply of electronics and solar grade silicon. In 2007 Tokuyama had an annual production of 5,400 tons and is planning to expand this to 6,900 tons by 2009 and 8,200 tons by 2010 [Pvn 2008a].

A verification plant for the vapour to liquid-deposition process (VLD method) of Polycrystalline silicon for solar cells has been completed in December 2005 [Tok 2006]. According to the company, steady progress has been made with the verification tests of this process, which allows a more effective manufacturing of polycrystalline silicon for solar cells.

Tokuyama has decided to form a joint venture with Mitsui Chemicals, a leading supplier of silane gas [Tok 2008]. The reason for this is the increased demand for silane gas due to the rapid expansion of amorphous/ microcrystalline thin film solar cell manufacturing capacities.

3.5.17 Additional Silicon Producers

- **JFE Steel Corporation:** JFE Steel began to produce silicon ingots in 2001. To stabilise their supplies of feedstock, it began to investigate techniques for producing SOG silicon in-house from metallic silicon as an alternative to polysilicon. Prototypes created with 100% metallic silicon have achieved the same high conversion efficiency as conventional polysilicon units. The company built a commercial plant with a capacity of 100 tons/year and has also begun designing a plant to mass produce the material [Jfe 2006]. According to PV News the production should reach 150 tons in 2010 [Pvn 2008a].

- **Japan Solar Silicon:** JSS was founded in January 2007 as a joint venture between Chisso Corporation, Nippon Mining Holdings and Toho Titanium. At the moment the company operates a pilot plant and plans to start the construction of a commercial plant in the second half of 2009.

- **M.Setek:** Manufacturer of semiconductor equipment and monocrystalline silicon wafers. The company has two plants in Japan (Sendai, Kouchi) and two in the PRC, Hebei Lang Fang Songgong Semiconductor Co. Ltd. (Beijing) and Hebei Ningjin Songgong Semiconductor Co. Ltd. (Ningjin). In April 2007 polysilicon production started at the Soma Factory in Fukushima Prefecture. According to PV News the current production is 1,350 tons and will be increased to 6,850 tons in 2010 [Pvn 2008a].

- **Mitsubishi Materials Corporation (MMC):** The company was established in 1950 and is one of the world's largest diversified materials corporations. MMC produces polysilicon for the semiconductor and Photovoltaic industry. Current production is about 3,300 tons [Pvn 2008a]. The polysilicon is produced by their affiliates *Mitsubishi Polycrystalline Silicon Corp.* and *Mitsubishi Polycrystalline Silicon America Corp.*

- **NS Solar Material Co., Ltd.:** This is a joint venture between Nippon Steel Materials and Sharp Corporation and was established in June 2006. Production was planned with 480 tons/year and start of operation was scheduled for October 2007.

- **OSAKA Titanium Technologies Co. Ltd.** is a manufacturer of Titanium and Silicon. The first step of the capacity increase from 900 tons to 1,300 tons was completed in May 2007 [Sum 2007]. The second increase to 1,400 tons/year should be completed in October 2008. In addition, a new plant with 2,200 tons will be constructed and should become operational in 2011.

4. PEOPLE'S REPUBLIC OF CHINA

The production of solar cells and the announcements of planned new production capacities in the People's Republic of China, as well as Taiwan, have sky-rocketed since 2001. Production rose from just 3 MW in 2001 to 124 MW in 2005 and 1070 MW in 2007. For 2008 capacity increases to 5.7 GW are announced, whereas the figure stands at 10.5 GW for 2010. In parallel, China is aiming to build up its own polysilicon production capacity. The numbers given for 2007 production capacity vary quite significantly from 1,225 [Pvn 2008a] to 4,550 [Cui 2007] and 8,900 [Yol 2008]. The same is true for 2010 figures: 29,050 [Pvn 2008a] to 84,500 [Cui 2007]. However, despite the discrepancies, it is clear that there is a strong drive to build up an own silicon feedstock supply industry. This development has to be seen in the light of the PRC's strategy to diversify its energy supply system and overcome the existing energy shortage.

Why is this of particular interest? During the China Development Forum 2003, it was highlighted that China's primary energy demand will reach 2.3 billion toe in 2020 or 253% of the 2000 consumption if business-as-usual (BAU) occurs [Fuq 2003]. Under such a scenario the electricity demand would be 4,200 TWh by 2020 (Fig. 10).

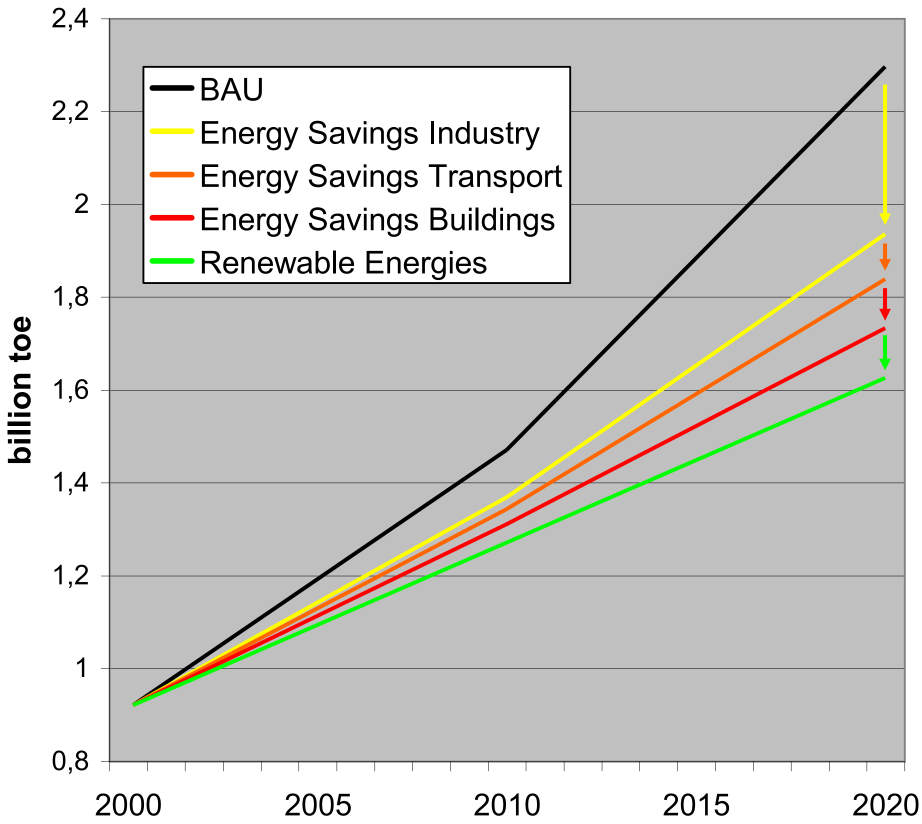

Fig. 10: Scenarios of PRC's fossil energy demand up until 2020 for different scenarios [Fuq 2003]

This development presents a reason to press for additional government policies supporting the introduction of energy efficiency measures and renewable energy sources. With the proposed measures, fossil energy demand would still grow, though considerably slower than in the case of BAU.

In the National Outlines for Medium and Long-term Planning for Scientific and Technological Development (2006-2020) solar energy is listed as a priority theme.

New and renewable energy technologies: to develop low-cost, large-scale renewable energy development and utilisation technologies, large-scale wind power generation equipment; to develop technology of Photovoltaic cells with high cost-effect ratio and its utilisation; to develop solar power generation technology and study integration of solar powered building; to develop technologies of fuel cells, hydropower, biomass energy, hydrogen energy, geothermal energy, ocean energy, biogas, etc.

Also the National Medium and Long Term Renewable Energy Development Plan has listed solar Photovoltaic power generation as an important developing point. Within the National Basic Research Programme of China, the so-called 973 Programme, there is an additional topic on "Basic research of mass hydrogen production using solar energy".

With the support from national ministries and commissions, the top efficiency of China's current lab PV cell is 21%, commercialised PV components and normal commercialised cells respectively have an efficiency of 14 – 15% and 10 – 13%. China has reduced the production cost of solar PV cells and the price of solar cells has gradually declined from the 40 RMB/Wp (4.40 €/Wp)[11] in 2000 to 33 RMB/Wp (3.62 €/Wp) in 2003 and to 27 RMB/Wp (2.57 €/Wp)[12] in 2004, which is not only crucial to the growth and maturity of China's domestic solar energy market but also significant in connection with the international PV market. It is estimated that by 2010, the electricity generation cost with solar PV systems will decline to some 1 RMB/kWh (0.089 €/kWh)[13], reaching or approaching the cost price of routine power generation.

4.1 PV Resources and Utilisation

The PRC's continental solar power potential is estimated at 1,680 billion toe (equivalent to 19,536,000 TWh) per year [CDF 2003]. One percent of China's continental area, with 15% transformation efficiency, could supply 29,304 TWh of solar energy. That is 189% of the worldwide electricity consumption in 2001.

The Standing Committee of the National People's Congress of China endorsed the Renewable Energy Law on 28 February 2005. Although the Renewable Energy Law went into effect on 1 January 2006, the impact on Photovoltaic installations in China is however

[11] Exchange rate 2003: 1 RMB = 0.11 €

[12] Exchange rate 2004: 1 RMB = 0.095 €

[13] Exchange rate 2008: 1 RMB = 0.089 €

still limited, due to the fact that no tariff has yet been set for PV. The main features of the Law are listed below:

- Energy Authorities of the State Council are responsible for implementing and managing renewable energy development, including resource surveys;
- The government budget establishes a renewable energy development fund to support R&D and resource assessment;
- The government encourages and supports various types of grid-connected renewable energy power generation;
- Grid enterprises shall purchase the power produced with renewable energy within the coverage of their power grid, and provide gird-connection service;
- The grid-connection price of renewable energy power generation shall be determined by the price authorities, and the excess shall be shared in the power selling price within the coverage of the grid;
- The Law became effective in January 2006.

During the China Renewable Energy Development Strategy Workshop 2005 Wang Sicheng, from the National Development and Reform Commission's Energy Institute, presented the "Strategic Status of Photovoltaics in China" [Sic 2005]. The national target for the accumulated capacity of PV systems set in the "Eleventh Five-Year Plan" (2006 – 2010) is 500 MW in 2010. The predictions of the PV Market in China for 2020 were rather optimistic. The accumulated installed capacity was given as 30 GW and includes 12 GW in the frame of the Chinese Large-Scale PV Development Plan, a project which should start in 2010. However, the actual growth of PV installations is far below the required figures. Therefore, the 2007 China Solar PV Report authored by the China Renewable Energy Industry Association, Greenpeace China, European PV Industry Association, and WWF, reduced the market predictions to 300 MW cumulative installed capacity in 2010 [Chi 2007]. For 2020 two scenarios are given. The low target scenario predicts 1.8 GW in line with the current government policy, whereas a high target of 10 GW would be possible if strong support mechanisms were to be introduced (Fig. 11).

For 2006, installation costs for free-fields system in China were quoted as 50 Yuan/KWp (4.7 €/KWp) and the aim is to reduce this to 37 Yuan/KWp (3.5 €/KWp) in 2010 [Sic 2005, Chi 2007]. 2006 installation costs for independent PV village systems in China were quoted as 70 Yuan/KWp (6.6 €/KWp) and the aim is to reduce this to 52 Yuan/KWp (4.9 €/KWp) in 2010.

For the Olympic Summer Games in Beijing in 2008, a concept of Green Olympics was developed, in line with the idea of sustainable development. All the seven main Olympic stadiums are equipped with Photovoltaic solar systems with a cumulative capacity of 480 kWp. Ninety percent of the lighting outside the stadiums, as well as the entire hot water supply for the Olympic Village, was powered by solar energy. In addition, the main stadiums received power from Beijing's first wind farm.

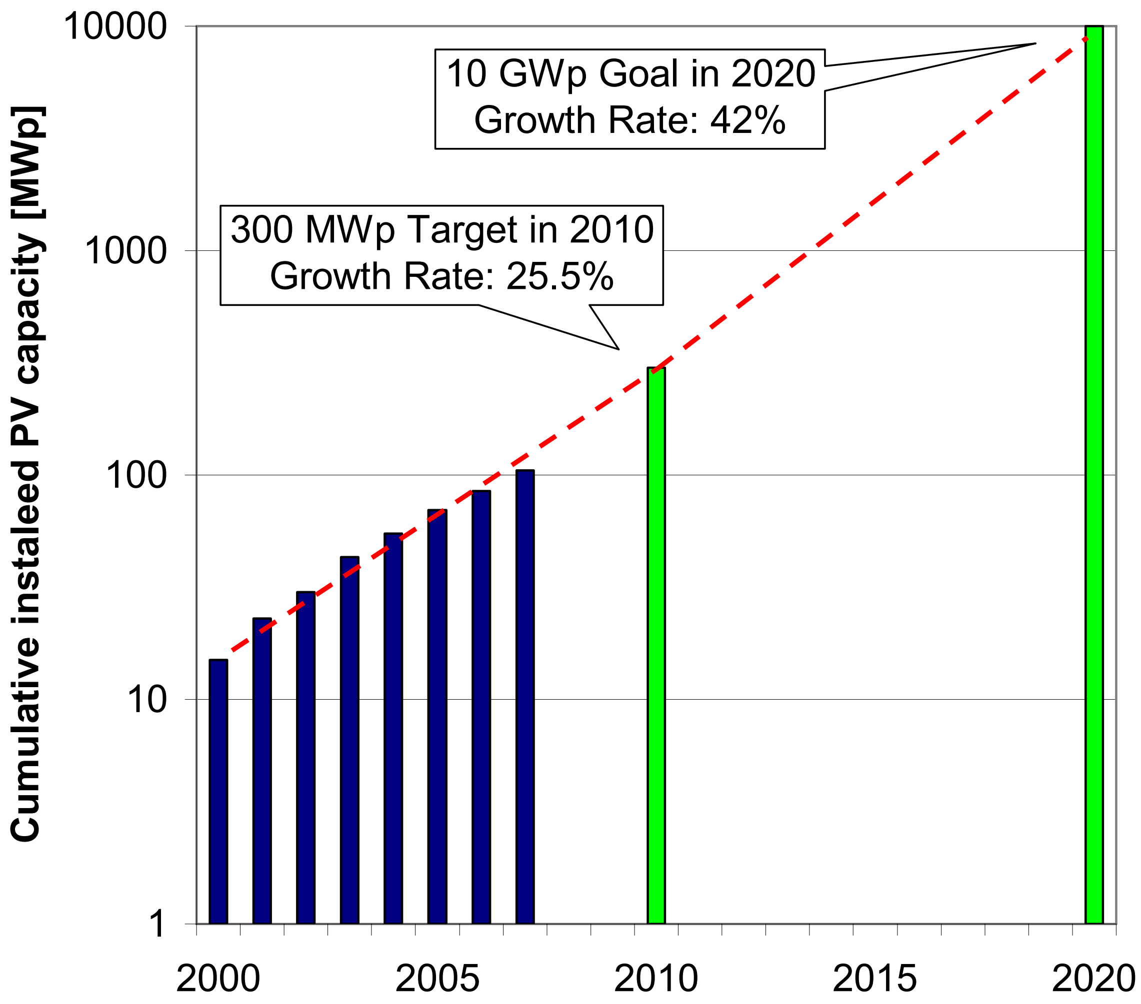

Fig. 11: Cumulative installed Photovoltaic capacities and targets for 2010 and 2020 in PRC

The World Bank and the Global Environment Facility provide assistance to the Government of China with the implementation of the Renewable Energy Programme during the 10th and 11th Five Year Plans. To this end, the China Renewable Energy Scale-up Programme (CRESP) was set up. CRESP is managed by the Project Management Office (PMO), which is institutionally placed in the National Development and Planning Commission (NDRC). The Renewable Energy Scale-up Programme supports the Government in implementing its RE strategy. It is the largest such project supported by the World Bank and GEF in recent years. Over its lifetime, the project is expected to induce an increased capacity of renewable electricity of more than 20 GW, reduce carbon emissions by about 800 million tons, totally suspend particulate emissions by more than 800 million tons, sulphur oxide emissions by more than 30 million tons, and nitrogen oxide emissions by more than 6 million tons.

In June 2005 the World Bank's Board of Executive Directors approved a loan of US$ 87 million to China to finance the Renewable Energy Scale-up Programme, supplemented by a grant of US$ 40.22 million from the Global Environment Facility (GEF)

[Chi 2005]. The project's objective is to expand renewable electricity supply in China efficiently, cost effectively and on a large scale.

Already in the spring of 2004, the World Bank approved a loan and Global Environment Facility (GEF) grant to China for the Renewable Energy Development Project (REDP), which includes a large Photovoltaic market development component and a Photovoltaic technology improvement component. Both components are managed by the REDP Project Management Office (PMO) of the National Development and Reform Commission.

The PV Market Development (PV) Component will provide assistance to Photovoltaic system companies to market, sell, and maintain an estimated 300,000 – 400,000 systems in remote rural areas of China's North Western Provinces. This programme partly supports PV system companies providing electricity services using PV or PV/wind hybrid systems in households or community facilities in Qinghai, Gansu, Inner Mongolia, Xinjiang, Sichuan and Xizang and adjacent counties (in total about 10 MWp of PV). System components, such as modules, controllers, inverters, batteries and DC lights, sold under the project must be certified to meet project standards. The Project supports strengthening the capacity of a Chinese module testing laboratory to obtain ISO/IEC17025 and IECEE-PV accreditation for testing modules under the new national standard GB9535-1998 (equivalent to IEC61215-1993). To date there is no test facility in China yet that has the capacity to carry out certified tests on PV modules according to IEC61215-1993/GB9535-1998.

The 11th 5-year plan (2006 to 2010), which was approved in October 2005, puts more emphasis on energy conservation and energy diversification. It states: *"Efficiency of resources will be enhanced significantly, and energy consumption per unit GDP will be about 20 percent lower than that at end of the 10th Five-Year Plan period"*. One of the measures is to accelerate the use of renewable energies and during the 1st Phase of the Village Programme around € 3.2 billion is earmarked for solar energy projects. It is planned to install about 250 MW of Photovoltaic systems to help to give electricity to the 2 million households which still have no access to electricity. The programme should then be continued in the next 5 year plan. In addition, about 50 MW roof top and BIPV systems should be supported, as well as a 20 MW demonstration plant in the Gobi Desert. In total 320 MW should be installed with the support of this programme.

In October 2005, the Shanghai Municipal Government endorsed the "100,000 Solar Roof Project", which is expected to lead to the installation of 70 MW of Photovoltaic solar electricity capacity by 2010, and 360 MW or an annual production of 432 GWh, once completed.

On 1 November 2006 a new law on energy-efficient construction, in order to promote the use of solar power to supply hot water and generate electricity, took effect in the city of Shenzhen [Chi 2006]. Projects which are unable to use solar power will require special permission from the government, otherwise they cannot be put on the market. By 2010, the Shenzhen Construction Bureau expects that 50% of the new buildings will install solar water heating systems and 20% of new buildings will use Photovoltaic electricity generation systems.

China Strategies LLC reported in their February 2008 Newsletter that the China Electric Power Investment Group Co. will invest 5 billion Yuan to construct a 1 GW Photovoltaic solar cell project in Xian, Shaanxi Province. The China Electric Power Investment Group Co. also is planning on pursuing a multicrystalline solar project in the city of Xining in Qinghai Province.

4.2 Solar Companies

In the following chapter, some of the major market players in the PRC are briefly described. This listing is far from being complete, due to the fact that more than 50 solar cell and more than 300 solar module companies exist in China. In addition, availability of information or data for some companies is very fragmentary.

4.2.1 Canadian Solar Inc.

Canadian Solar Inc. was founded in Canada in 2001 and was listed on NASDAQ in November 2006. CSI has established six wholly-owned manufacturing subsidiaries in China, manufacturing ingot /wafer (planned production in mid 2008), solar cells and solar modules. According to the company, 150MW of additional cell capacity will be commissioned before the end of the third quarter 2008 and another 150MW by the end of 2008, bringing the total internal cell capacity to 400MW. For 2007 a cell production of 23 MW was reported [She 2008a].

4.2.2 Changzhou EGing Photovoltaic Technology Co. Ltd.

The company was founded in 2003 and works along the complete Photovoltaic industry value chain from the production of mono-crystalline furnace, quartz crucible, 5-8 inch mono-crystalline silicon ingots supporting equipment of squaring and wire sawing, mono-crystalline silicon wafers, solar cells, and solar modules. According to the company, it has a production capacity of 250 MW of cells and modules. For 2007 a production of 30 MW was reported [She 2008a].

4.2.3 China Sunergy (formerly CEEG Nanjing PV-Tech Co. Ltd.)

China Sunergy was established as CEEG Nanjing PV-Tech Co. (NJPV), a joint venture between the Chinese Electrical Equipment Group in Jiangsu and the Australian Photovoltaic Research Centre in 2004. China Sunergy went public in May 2007. According to the company, the production capacity at the end of 2007 was 192 MW and the current increase will put it to 320 MW at the end of 2008. In 2007, production was 78 MW [Pvn 2008].

4.2.4 JA Solar Holding Co. Ltd.

JingAo Solar Co. Ltd. Was established in May 2005 by the Hebei Jinglong Industry and Commerce Group Co. Ltd., the Australia Solar Energy Development Pty. Ltd. and Australia PV Science and Engineering Company. Commercial operation started in April 2006 and the company went public on 7 February 2007. According to the company the production capacity will increase from 175 MW at the end of 2007 to 500 to 600 MW at the end of 2008. For 2007 the company reported a production of 133.5 MW.

4.2.5 Jetion Holdings Ltd.

The group was founded in December 2004, went public in 2007 and manufactures solar cells and modules. According to the company, production capacity is 100 MW for solar cells and 50 MW for modules. For 2007 the company reported a production of 35 MW solar cells.

4.2.6 NingBo Solar Electric Power Co. Ltd.

The company is part of China PuTian Group since 2003. According to company information Ningbo has imported solar cell and module producing and assembling lines from America and Japan. Current production capacity is given with 75 MW and for 2007 a production of 45 MW was reported [Se 2008a].

4.2.7 Shanghai Solar Energy Science & Technology Co.

SSEC produces mono-crystalline and multi-crystalline solar cells. According to the company, current production capacity is 80 MWp and it is planned to increase it to 100 MW by 2010. Production volume in 2007 was 15 MW [She 2008a].

4.2.8 Shanghai Topsolar Green Energy Ltd.

Shanghai Topsolar Green Energy Co., Ltd is a joint stock company established by Shanghai Electric Group Holding Co., Ltd, Shanghai Jiao Da NanYang Co. Ltd, and Shanghai Zhenglong Technology Investment Co. Ltd. Production volume in 2007 was reported as 25 MW [She 2008a].

4.2.9 ShanShan Ulica Science & Technology Co. Ltd.

ShanShan Ulica Science & Technology Co.,Ltd, was founded in August 2005 as a joint venture between the ShanShan Group and Shanghai Ulica Solar Company. It is planned to increase the current production capacity from 20 MW to 100MW, but no date is set for it. For 2007 a production of 18 MW was reported [She 2008a].

4.2.10 Shenzhen Topray Solar Co.Ltd.

The company was founded in 2002 and manufactures solar cells, solar chargers, solar lights, solar garden products and solar power systems, as well as solar charge controllers, solar fountain pumps and solar fan caps. For 2008 the company reported production capacities of 50 MW for dual junction amorphous silicon solar cells and 30 MW for mono and poly crystalline solar cells. For 2007 a production of 25 MW was reported [She 2008a].

4.2.11 Solarfun Power Holdings

Solarfun was established in 2004 by the electricity metre manufacturer Lingyang Electronics. The first production line was completed at the end of 2004 and commercial production started in November 2005. The company went public in December 2006 and reported the completion of their production capacity expansion to 360 MW in the second quarter of 2008. For 2009 a further 120 MW expansion is planned. For 2007 a production of 78 MW was reported by the company.

4.2.12 Suntech Power Co. Ltd.

Suntech Power Co. Ltd. is located in Wuxi. It was founded in January 2001 by Dr. Zhengrong Shi and went public in December 2005. Suntech specialises in the design, development, manufacturing and sale of Photovoltaic cells, modules and systems. In 2007 Suntech had a production of 327 MW and held 3rd place in the Top-10 list. The annual production capacity of Suntech Power was 660 MW at the end of the second quarter and is on track to increase to 1 GW by the end of 2008 and aims for 2 GW in 2010 [Sun 2007]. The takeover of the Japanese PV module manufacturer MSK was completed in June 2008. The company has a commitment to become the "lowest cost per watt" provider of PV solutions to customers worldwide.

4.2.13 Trina Solar Ltd, PRC

Trina Solar was founded in 1997 and went public in December 2006. The company has integrated product lines, from ingots to wafers and modules. In December 2005 a 30 MW mono-crystalline silicon wafer product line went into operation. According to the company the production capacity was 150 MW at the end of 2007. Solar cell production for 2007 was reported with 40 MW [She 2008a].

4.2.14 Yingli Green Energy Holding Company Ltd.

Yingli Green Energy went public on 8 June 2007. The main operating subsidiary, Baoding Tianwei Yingli New Energy Resources Co. Ltd., is located in the Baoding National High-New Tech Industrial Development Zone. The company deals with the whole set from solar wafers, cell manufacturing and module production. On 29 April 2006 the groundbreaking ceremony was held for Yingli's 3rd phase enlargement project, which aimed for production capacities of 500 MW for wafers, solar cells and modules at the end of 2008 [Yin 2006]. The investment includes a Photovoltaic System Research Centre and a Professional Training Centre as well. The first stage of this expansion to 200 MW was finished in July 2007 and the company reports that the expansion to 400 MW at the end of 2008 and 600 MW at the end of 2009 are on track. The financial statement for 2007 stated shipments of 142.5 MW.

4.2.15 Wuxi Shangpin Solar Energy Science & Technology Co. Ltd.

It is a UK invested company which specialises in R&D, manufacturing and sales of crystalline silicon solar cells, modules and PV powered products. According to the company, the first 25 MW production line was put into operation in April 2007. For 2007 a production of 10 MW was reported [She 2008a].

4.2.16 Yunnan Tianda Photovoltaic Co. Ltd.

Yunnan Tianda Photovoltaic Co. is one of the oldest companies which make, design, sell and install solar modules and PV systems in China and was founded in 1977 as Yunnan Semi-Conductor Device Factory. In 2005, the production capacity of solar cells was extended to 35MW and the production of 5 inch solar cells started. 2006 the capacity was increased to 60MW and in 2007 the production capacity of solar cells was extended to 100MW. For 2007 a production of 10 MW is reported [She 2008a].

4.2.17 Additional Solar Cell Companies in People's Republic of China

- **Aide Solar** (Jiangsu Aide Solar Energy Technology Co. Ltd.) was founded in 2003 and formed a joint venture with the Taiwanese Panjit Group in November 2007. The company has a mono solar cells production line with 40 MW capacity and increased their solar modules production capacity to 150 MW in 2008.

- **Astronergy** (Chint Solar Energy Science & Technology Co. Ltd.) was established as a member of the Chint Group in October 2006. The first production line of 25 MW for crystalline silicon cells and modules was installed in May 2007 and an increase of the production capacity to 100 MW was finished in July 2008. The company not only plans to reach 380 MW production capacity by 2010 but to "*become the world's leading thin film PV producer*". On 3 July 2008 Oerlikon Solar announced that Chint Solar purchased a micromorph® R&D line and first phase production equipment with plans to build the production capacity up to 180 MWp in 2010.

- **Bengbu Polar Beam Co. Ltd.** is a joint venture between Bengbu Construction Investment Co. Ltd., two other Chinese partner companies and US-based Polar Beam Technologies Inc. [Enf 2006]. Production of amorphous silicon solar cells was planned to start in May 2007 with approximately 2 MWp capacity and plans to boost capacity to 10 MWp in 2008.

- **Best Solar Hi-Tech Co. Ltd.** was set up by LDK Solar's founder and CEO Xiaofeng Peng and started operations in February 2008. The company aims to produce amorphous/ microcrystalline silicon thin film modules and has contracted AMAT for the equipment. The groundbreaking for their "Site 1 in JinagSu SuZhou took place in February 2008. With an investment of $2.5 billion $ it has a design capacity of 1 GW to be realised in three phases. It is planned to start solar cell production by the end of 2008. At their second site in JiangXi NanChang also with a design capacity of 1 GW, groundbreaking took place in June 2008. Production start is scheduled there for the 1st quarter of 2009.

- **ENN Solar Energy** (part of XinAo Group) was set up in the Langfang Economic and Technological Development Zone in 2007. In November 2007 ENN Solar Energy signed a contract with AMAT for a SunFab Thin Film production line to produce ultra-large 5.7m^2 (GEN 8.5) solar modules. The 50 MW line is planned to be the first phase of an expected 500 MW capacity plant .

- **Nantong Qiangsheng Photovoltaic Technology Co. Ltd.** (QS Solar, Shanghai, China) started the production of amorphous silicon thin-film solar with their new 25 MW production line in January 2008. The company announced that it would add two more production lines in 2008, bringing the total production capacity to 75 MW. The company plans to increase production capacity within the next three years to 500 MW. Company representatives said they expect that in two years the price of thin-film solar cells will reach 1 yuan (14 cents), far below the current price of 4-5 yuan (55-70 cents) for conventional Photovoltaic cells.

- **Shanghai Chaori Solar Energy Science & Technology Co. Ltd**. was established in June 2003. Production capacity was 15 MW in 2007 and the company plans to increase it to 40 MW in 2008.

- **Solar EnerTech Corp.** is incorporated in the USA, but its factory is based in Shanghai, China. Solar EnerTech has established a manufacturing and research facility in Shanghai's Jinqiao Modern Science and Technology Park. According to the company the current production capacity is 25 MW of solar cells and it is planned to double it to 50 MW by the end of 2008.

- **TaiZhou Sopray Solar Co. Ltd.** was established in 2005 as a joint venture between Taizhou Luqiao Huanneng Lights Factory and Mr. Michael Ming. According to the company the annual output capacity of mono- and poly-crystalline solar cells is 100MW with plans to double to 200 MW in 2009.

- **Zhejiang Sunflower Light Energy Science & Technology Co. Ltd. (Sunowe)** was funded by Hong Kong YauChong International Investment Group Co. Ltd. founded in 2004 in the Shaoxing in Zhejiang. In a first phase it is planned to ramp up the annual production capacity to 100MW. According to the company 75 MW are already operational.

4.2.18 LDK Solar Co. Ltd.

Jianxi LDK Solar Hi-Tech Co. Ltd. was set up by the Liouxin Group, which had 12,000 employees in 2005. The Liouxin Group makes personal protective equipment, power tools and elevators. With the formation of LDK Solar, the company is diversifying into solar energy products. LDK Solar went public in May 2007. According to the company the production capacity for solar wafers at the end of the first Quarter 2008 was 580 MW. Further expansion plans are to ramp the production up to 1.2 GW by the end of 2008, 2.2 GW in 2009 and 3.2 GW in 2010. In September 2007 the company announced that the capacity of their new Trichlorosilane (TCS) plant at its Xinyu, Jiangxi headquarters will raise their polysilicon capacity to 7,000 tons by the end of 2008 and 16,000 tons by the end of 2009.

4.2.19 ReneSola Ltd.

ReneSola, previously known as Zhejiang Yuhui Solar Energy Source Co. Ltd, was listed on London's AIM stock market on 8 August 2006. ReneSola's factories are based in China, but the company is registered in the British Virgin Islands. ReneSola is recycling silicon to make the wafers. Wafer production capacity at the end of 2007 was 165 MW monocrystalline and 160 MW multicrystalline. According to the company, the expansion of capacities to 645 MW at the end of 2008 are on track.

On May 14, 2008 ReneSola announced that it had increased the planned annual polysilicon manufacturing capacity to 3,000 tonnes at the wholly-owned facility in Meishan, Sichuan Province, China [Ren 2008]. Construction of this facility is on track, with completion expected in early 2009. The facility is expected to be operational in the first half of 2009.

4.2.20 Solar Silicon Companies in the People's Republic of China

- **CSG Holding Co. Ltd.,** a Chinese glass producer is building up the complete silicon wafer based Photovoltaics valuechain. *Yichang CSG Polysilicon Co. Ltd*. was established in 2006 and is locatedin Xiaoting Distict, Yichang City, Hubei Province. This polysilicon project is divided into three stages with unified planning of 4500 to 5000 tons per year of high-pure polysilicon. The first stage with 1500 tons/year has been started on 22nd October 2006 and was expected to be commissioned at the end of June 2008. Dongguan CSG Solar Glass Co. Ltd., was founded in October 2005 and is now operating two production lines for solar glass. An additional sub-company "*CSG PVTECH CO. LTD*" was founded in February of 2006, which started the pilot production of solar cells on a 25 MW line in June 2007. The main products are silicon solar cells and modules with a planned capacity of 450MW by 2010.

- **EMEI Semiconductor Material Factory** is located in Chengdu and produces and markets semiconductor material silicon. For 2007 a production of 160 tons poly-silicon feedstock was reported and the production capacity for 2008 was given with 1500 tons [She 2008a].

- **GCL Silicon Holdings. Inc.** was founded in March 2006. The company started the construction of their Xuzhou polysilicon plant (Jiangsu Zhongneng Polysilicon Technology Development Co. Ltd.) in July 2006. Phase I has a designated annual production capacity of 1,500 tons and the first shipments were made in October 2007. Phase II with additional 1,500 tons started commercial operation in July 2008. Construction for Phase III with 10,500 tons was started in December 2007 and a further expansion to 24,000 tons is planned to be finished in 2010.

In August 2008 a joint-venture Taixing Zhongneng (Far East) Silicon Co. Ltd. started pilot production of trichlorsilane. Phase I will be 20,000 tons to be expanded to 60,000 tons in the future.

- **Jinglong Industry and Commerce Group Co. Ltd.** mainly produces monocrystalline silicon ingots and wafers but also produces graphite products, quartz crucible and chemical products. Jinglong produce mono-crystalline silicon mainly for the semiconductor industry, but also for solar cells. At present, Jinglong has an annual capacity of more than 2,600 tons and 80 million wafers. The company plans to increase their production capacity to 5,000 tons in 2010.

- **Leshan Ledian Tianwei Silicone Science and Technology Co. Ltd.**, is a joint venture formally set up in January 2008 by Baoding Tianwei Baobian Electric Co. Ltd. and Leshan Electric Power Co. Ltd. The company will build a polycrystalline facility at Leshan of Sichuan province, with a capacity of 3000 t/a.

- **Leshan Yongxiang Silicon Co. Ltd.** was established in July 2006 and is a subsidiary of Sichuan Yongxiang Co. Ltd. The company operates a 5000 tons/ year production of of trichlorosilane. In July 2007 the construction of a polysilicon plant with 1,000 tons/year capacity started with the total investment of 5 billion Yuan. A further expansion 10,000 tons/year polycrystalline silicon is planned. Production capacity in June 2008 is given with 800 tons [Sch 2008].

- **Luoyang Monocrystalline Silicon Co. Ltd**. is a state-owned company. The products of the company are: polycrystalline silicon (annual output 300 tons), monocrystalline silicon (annual output 15 tons), organosilicon γ1 (annual output 165 t), and 6-inch silicon polished wafer (annual output 2 million pieces).

- **Luoyang China Silicon High-Tech Co. Ltd.** is one of the largest silicon raw material suppliers and silicon purification companies in China and had a production of 520 tons of multi-crystal silicon in 2007 and plans to finalise the increase of their production capacity to 2000 tons in 2008 [She 2008a].

- **Luoyang Zhonggui Material Co. Ltd.** The company is a joint venture of American MEMC Company and the Chinese Sijia Semiconductor Company. The main products are multi-crystal silicon, single-crystal silicon and organic silicon. The production capacity is 500 tons and it is planned to increase it to 2000 tons [Sch 2008].

- **Sichuan Xinguang Silicon Technology Co. Ltd.** constructed a production plant for silicon material and began commercial operation in February 2007. For 2007 production of 230 tons and for 2008 production capacity of 1,500 tons are reported [She 2008a].

- **JiangSu Shunda Group Corporation** is based in Yangzhou. As a high-technology company it focuses on the Photovoltaic market and produces polysilicon, mono-crystalline ingots, and wafers. For 2006 the capacity was given with 480 tons [Ron 2006]. An expansion to 1,500 tons is planned, but the time of operation differs according to the source: 1,500 tons capacity in 2008 [She 2008a], start of operation with 1,500 tons in 2009 [Sch 2008].

- **Xi'an Lijing Electronic Technology Co. Ltd.** was founded in December1997 and is located in the "Western Silicon Valley" Xi'an High-tech Development Zone New Industrial Park. According to the company, production capacity is currently over 100 tons of mono-crystalline silicon and it plans to increase it to 500 tons.

In addition, there are a considerable number of smaller and start-up companies along the whole value chain. However, information is still very fragmented and due to the rapid development quickly goes out of date. In the meantime, an increasing number of consultancies are providing market analysis and study tours. The PRC's long-term energy plan calls for a considerable strengthening of the solar industry and all aspects from silicon production, wafering, cell and module manufacturing and distribution are covered. In January 2004 the Ministry of Science and Technology published a solar energy exploitation plan for the next five years, in order to promote the development of Photovoltaic technology and industry.

Chinese manufacturers are expected to export their products as Chinese PV production will grow much faster than the market. In China Photovoltaics is discussed at the level of a strategic industry policy for the future.

5. TAIWAN

In 2002 the *Renewable Energy Development Plan* was approved by the Executive Yuan and it calls for 10% or more of Taiwan's total electricity generation by 2010. This plan has led to concerted efforts by all levels of the government, as well as the general public, to develop renewable energy and to aggressively adopt its use. In 2004 Taiwan enacted "*Measures for Subsidising Photovoltaic Demonstration Systems*" as part of its National Development Plan by 2008. This programme provides subsidies that cover up to 50 percent of the installation costs for Photovoltaic systems.

The current support scheme foresees a maximum investment subsidy of NT$ 150,000/kWp (3,225 €/kWp), but only up to 50% of installation costs. Administration Agencies, public schools and hospitals, suitable for demonstration projects, are eligible for 100 % investment subsidies for systems under 10 kWp. In addition for all renewable energies, NT$ 2/kWh (0.043 €/kWh) are paid to approved applicants for 10 years, and this can be extended up to 20 years. Other support measures for renewable energies are a 13% tax credit for investment in energy conservation, as well as renewable energy utilisation equipment, a 2-year accelerated deprecation and low interest loans.

The Solar Energy Development Project has a number of long-term goals. It is planned that a total of 7.5 million residents should utilise solar energy by 2030. Industrial and commercial use should be about half that of residential use. Public utilities are expected to have the same solar power generating capacity as the industrial and commercial sectors, and independent solar power generating systems will be set up in mountains and on offshore islands. The aim is that in 2020, the island's solar power generating capacity should reach 4.5 GW.

At the end of 2006 the total installed capacity of solar Photovoltaic systems was 1.3 MW, including emergency and disaster prevention systems in remote areas and offshore islands. In 2006, the Bureau of Energy subsidised Taipei County and Hualien County to carry out the Solar City Project (II), with a total capacity of 440 kW. The Bureau also initiated the Solar Top Project, subsidising the National Museum of Taiwan History, National Museum of Marine Biology and Aquarium, Kaohsiung City True Love Wharf, and Liu Dui Hakka Cultural Park, to carry out the Project with a total capacity of 440 kW. In addition, the Bureau worked with the Ministry of Education to promote the Solar Campus Project, providing subsidies to 40 schools for installing solar Photovoltaic systems.

In July 2008, the Cabinet in Taiwan decided to designate solar energy and light emitting diodes (LED) as two industries to actively develop in the near future. The government was planning to encourage households to install solar panels to generate power and to replace existing public lighting with LED lamps to save electricity.

It is estimated that the two above-industries may generate production value exceeding NT$1 trillion by 2015. So, to actively promote the two industries, Economics Minister Yin

Chi-ming recently led a delegation to Japan to solicit Japanese manufacturers to invest in Taiwan to help develop green industries on the island.

To promote the solar energy industry the government intends to subsidise manufacturers engaging in R&D and will offer incentives to consumers that use solar energy. With the help of official programmes material suppliers are going to expand operations and increase investments in the field. In addition, about a dozen manufacturers expressed the intention to invest in fabricating thin films for solar cells and eight of them will set up their own plants to process the products. Moreover, the Industrial Technology Research Institute (ITRI), a government-backed research organisation, is going to import advanced foreign technology for local manufacturers. The solar energy industry may see its output reach NT$ 450 billion by 2015.

The Executive Yuan (the Cabinet) passed the "programme for coping with economic slowdown and bolstering the economy" on 11 September 2008. The package covers a total of 41 measures and includes the promotion of solar energy. From 2008 to 2009, the government will set aside NT$1 billion for subsidies to consumers who buy solar-power systems. The government plans to subsidise half of the installation cost for solar devices, and households which install solar Photovoltaic electricity systems would be offered a favourable electricity rate of NT$2.1 per kilowatt.

5.1 Solar Companies

In the following chapter, some of the market players in Taiwan are briefly described. This listing does not claim to be complete, especially due to the fact that the availability of information or data for some companies was fragmentary.

5.1.1 DelSolar Co. Ltd.

DelSolar was established as a subsidiary of Delta Electronics in 2004 and went public in November 2007. DelSolar has a strategic co-operation with the Industrial Technology Research Institute (ITRI). DelSolar had a production capacity of 100 MW at the end of 2007 and produced 45 MW in 2007 [Pvn 2008]. The company has plans to expand the production capacity to 600 MW with no date set.

5.1.2 E-TON Solartech Co. Ltd.

E-Ton Solartech was founded in 2001 and produced 72 MW in 2007 [Pvn 2008]. At the end of 2007 the production capacity was 200 MW per annum and a capacity increase to 320 MW should be realised at the end of 2008.

5.1.3 Gintech Energy Corporation

Gintech was established in August 2005 and went public in December 2006. In 2007 the company increased its production capacity to 210 MW and had a production of 55 MW [Pvn 20087]. The company plans to expand their capacity to 660 MW at the end of 2008 and to 1.4 GW in 2010.

5.1.4 Motech Solar

Motech Solar is a wholly-owned subsidiary of Motech Industries Inc., located in the Tainan Science Industrial Park. The company started its mass production of polycrystalline solar cells at the end of 2000 with an annual production capacity of 3.5 MW. The production increased from 3.5 MW in 2001 to 176 MW in 2007. With this output, Motec Solar was No. 6 of the top 10 list for 2007. Current production capacity is around 320 MW. In August 2007, Motech Solar's Research and Development Department was upgraded to Research and Development Centre (R&D Centre), with the aim not only to improve the present production processes for wafer and cell production, but to develop next generation solar cell technologies [Mot 2007].

5.1.5 Neo Solar Power Corporation

The company was founded in 2005 by PowerChip Semiconductor, Taiwan's largest DRAM company and went public in October 2007. The current production capacity of silicon solar cells is 210 MW and a further expansion to 510 MW in 2009 and 660 MW in 2010 is already planned. For 2009 the company plans to start thin film production with an initial production capacity of 30 to 60 MW.

5.1.6 Additional Taiwanese Companies

- **Auria Solar Co**. was founded in October 2007 as a joint venture between E-Ton Solar, Lite-On Technology Corp, Hermes-Epitek Corp. and MiTAC-SYNNEX Group to manufacture thin-film solar cells. The company has chosen Oerlikon as equipment supplier and plans to produce amorphous/micromorph silicon thin films. The first factory will have a capacity of 60 MW and pilot production is planned for the end of 2008. Further expansion plans aim for 500 MW in 2012.

- **BeyondPV Co. Ltd**'s main shareholder is optical film maker Efun Technology and plans to produce amorphous/microcrystalline silicon thin film modules. The company is expected to complete their equipment installation in the fourth quarter of 2008, and annual capacity will reach 40MWp by 2010, to be ramped up to 80MWp by 2011, and 350MWp by 2014, according to the parent company.

- **Big Sun Energy Technology Incorporation** was founded in 2006 and started its solar cell production in the 3rd Quarter of 2007 [Dig 2007]. According to the company the production capacity in 2007 was 30 MW and it is planned to increase this to 60 MW in 2008.

- **Chi Mei Energy Corp.** is a subsidiary of Chi Mei Optoelectronics (CMO), a world leader in the production of TFT-LCD (Thin Film Transistor Liquid Crystal Display) panels for a wide range of application. Chi Mei Energy was established in Januray 2008 and plans to complete their equipment installation in Q4, 2008 and start mass production in Q1, 2009 with 50MW annual capacity. After 2009, Chi Mei Energy plans an aggressive capacity expansion to the GW scale.

- **Ever Energy Co. Ltd**. was established in October 2005 by a group of investors. In early 2007, Ever Energy signed a contract with Centrotherm AG, Germany, to purchase equipment with 90MW capacity for the initial phase of a 180MW facility. In October 2007 the company started to build the factory.

- **Formosun Technology Corporation** was established in 2005 as a trading company of solar cell materials and products. In 2006 they decided to start the production of amorphous silicon thin-film modules with production equipment from EPV (NJ), USA. According to the company, series production started in May 2008 and it is planned to increase the current capacity of 6 MW to 18 MW in 2009.

- **Green Energy Technology (GET)** is a subsidiary of the Tatung Group of companies in Taiwan. GET's Initial capacity in May 2005 was 25 – 30 MW wafers with 13 furnaces, band saws, and wire saws. An additional 7 furnaces were installed in July 2006, boosting annual capacity to 40 – 50 MW. In 2008, GET has expanded to 80 furnaces and has now an annual capacity of up to 200 MW wafer production. In June 2007 the company signed a contract with Applied Materials to deliver a fully-integrated thin film solar cell production line with a nominal rated capacity of 40 MW [App 2007]. The systems are scheduled to be shipped and installed during the first half of 2008 with production expected later that year.

- **Higher Way Electronic Co. Ltd.** is an IC application design company established in 1991, which manufactures GaAs and silicon solar cells. The focus is mainly on consumer products.

- **Kenmos Photovoltaic** was founded as a joint venture of Kenmos Technology Co. Ltd., NanoPV Corporation and a Taiwanese equipment manufacturer in September 2007. Kenmos PV is building up a 10 MW amorphous silicon thin film production capacity and plans to start mass production at the end of 2008. The capacity will then be gradually expanded to 200 MW within 3 years.

- **Millennium Communication Co. Ltd.** manufacures III–V compound material solar cells like GaAs, InGaP single junction and GaAs/InGaP tandem solar cells with up to 25% efficiency.

- **Mosel Vitelic Inc.:** The Group's principal activities are the design, research, development, manufacturing and sale of integrated circuits and related spare parts. As part of a five-year transformation project, the company moved into the solar cell business in 2006. According to the company, current production capacity is 60 MW. The groundbreaking for a further expansion with 200 MW capacity took place in May 2008. Mosel also plans to develop thin-film solar cell production from its own technology and to expand their production capacity to 1.5 GW by 2014.

- **Nexpower Technology Corporation** was formed by United Microelectronics Corporation (UMC) in 2005. UMC is one of the worldwide IC foundry providers. In addition to crystalline silicon solar cells, Nexpower is dedicated to silicon thin-film Photovoltaics technology and commercial applications, by building up a new manufacturing facility in Hsin Chu, Taiwan with an annual production capacity of 25MW in 2008. The next expansion plans are to increase manufacturing capacity to 100MW by the end of 2010. The company contracted ULVAC, Japan, for the production equipment [Ulv 2007].

- **Powercom Co. Ltd**. was founded in 1987, as a provider of power protection products. In 2007 the company installed a 30MW silicon solar cell production line. A future capacity increase to 90MW is planned.

- **Solartech Energy Corp. (Solartech)** was founded in June 2005. Solartech has a production capacity of 60 MW and plans to expand it from 60 MW to 180 MW in 2008. Further expansion plans aim at a capacity beyond 1 GW per year by 2014.

- **Sunner Solar Corporation** was founded in Taoyuan, Taiwan in June 2007. The company plans to start series production of thin film amorphous silicon modules in the second half of 2008 with 25 MW capacity. The company then plans to expand to 120 MW by 2010.

- **Sunwell Solar Corporation,** a subsidiary of CMC Magnetics Corporation, Taiwan's top compact disc maker, contracted a 46 MW thin-film PV production plant with Oerlikon Solar. The plant started production at the beginning of September 2008. According to Oerlikon, Sunwell has placed a follow up order of 180 MW and plans to start production in 2009 [Oer 2008].

- **Topco Scientific,** is a semiconductor company and Taiwan's largest distributor of silicon wafers. In 2005 the company started to produce wafers for solar cells from reclaimed semiconductor material. In 2006 the company announced that it would stop the manufacturing of silicon solar cells and move to thin-film solar cells.

- **Top Green Energy Technologies Inc**. was established in January 2006 by Powercom. The company produces silicon solar cells and now plans to move into polysilicon production [Dig 2008].

- **United Printed Circuit Board (UPCB)** started the construction of its first solar cell factory at the high-tech industrial park in Yilan County of Eastern Taiwan in August 2007. The first stage is a 30 MW multi-crystalline silicon line from Centrotherm, Germany. According to the company, production will increase from the current 30 MW to 90 MW in 2009, 180 MW in 2010 and 270 MW in 2011.

6. THE UNITED STATES

In 2007, the USA was the fourth largest market with 205 MW of PV installations, 152 MW grid connected [She 2008]. Again, California and New Jersey accounted for almost 70% of the US grid-connected PV market. In 2007 the cumulative installed capacity was around 810 MW (476 MW grid connected). Production grew by 22% to 266 MW, mainly driven by the production increase of thin film manufacturers *First Solar* (CdTe) and United Solar (a-Si). The US market share in the thin film market is around 43% and much higher than the overall market share of 7%.

First Solar is continuing to expand its CdTe thin film production capacity and plans to have 720 MW fully operational by the end of 2008 and more than 1.1 GW in 2009 [Fir 2008]. United Solar has decided to expand its production capacity to 300 MW by 2010 and 1 GW in 2012 [Ecd 2008]. After the acquisition of the manufacturing assets of Shell Solar in 2006, SolarWorld AG acquired the Komatsu silicon wafer production facility in Hillsboro (OR) in 2007 and started to convert it into a wafer and solar cell manufacturing plant with up to 500 MW capacity. The new Hillsboro facility will come on line in the autumn 2008 and ramp up is foreseen for 2009. Evergreen Solar is ramping up production as well and announced that they have secured enough silicon to increase production to 850 MW in 2012 [Eve 2008].

After years of political deadlock and negotiations concerning the support of renewable energies in the USA, things started to move in 2005. The main breakthrough was reached, when the 2005 Energy Bill was passed by the Senate on 29 July 2005 and signed by President Bush on 8 August 2005. The Bill's main support mechanisms are:

- Increase of the permanent 10 percent business energy credit for solar to 30% for two years. Eligible technologies include Photovoltaics, solar water heaters, concentrating solar power, and solar hybrid lighting. The credit reverts back to the permanent 10 percent level after two years.
- Establish a 30 percent residential energy credit for solar for two years. For residential systems, the tax credit is capped at $2,000.

The tax credits for renewable energy sources were limited until the end of 2008 and after more than a year of political debate the US Senate finally voted to extend the tax credits for solar and other renewable energies on 23 September 2008. The "Energy Improvement and Extension Act 2008" still has to be approved by the House of Representatives, but different to former attempts, the White House has already agreed to sign it.

The second milestone was the final approval of the Californian "Million Solar Roofs Plan" or Senate Bill 1 (SB1) by the Californian Senate on 14 August 2006 and the signature by Governor Schwarzenegger on 21 August 2006. The Governor's Office expects that the plan will lead to one million solar roofs with at least 3 GW installed Photovoltaic electricity generating capacity in 2018.

Already in January 2006, the California Public Utilities Commission (CPUC) put the major piece of the plan into effect when it created the 10-year, \$ 2.9 billion (€ 2.32 billion) "California Solar Initiative" to offer rebates on solar Photovoltaic systems. However, because the CPUC only has authority over investor-owned utilities, the rebates were funded by the customers of those utilities and only available to those customers. SB 1 expanded the programme to municipal utilities such as the Sacramento Municipal Utility District and the Los Angeles Department of Power and Water and allows the total cost of the programme to increase to as much as \$ 3.35 billion (€ 2.39 billion). It also increases the cap on the number of utility customers that can sell their excess solar power generation back to the utility. That number was previously capped at 0.5 % of the utility's customers, but is now capped at 2.5 % of the customers. Starting in 2011, SB 1 requires developments of more than 50 new single-family homes to offer solar energy systems as an option. It is believed that these Bills, together with other initiatives by individual States, will increase the demand for Photovoltaic solar systems in the USA by large.

Despite the increase of grid-connected Photovoltaic system installations during the last years, with growth rates of around 30%, much still needs to be done to reach the targets of the “One Million Roofs” Initiative (Fig. 12).

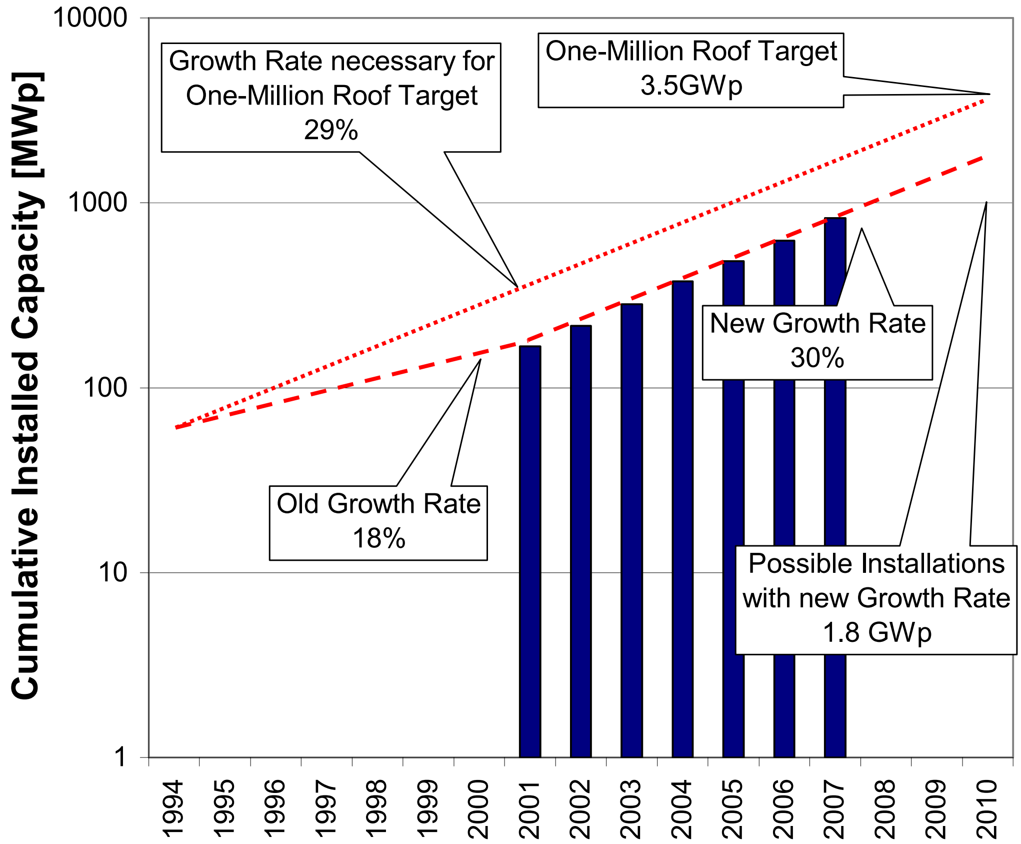

Fig. 12: One Million Roofs Target growth rate and new estimates based on 2004 to 2007 installations.

Figure 13 shows the nation-wide figures for electricity prices in May 2008 which increased in average by 6.1% from 10.77 ct/kWh to 11.43 ct/kWh. Taking these figures as a base, the US market for grid connected systems can be classified into four categories where, according to local electricity costs net-metering and market incentives, a listed turn key price for a PV system allows for competitive PV electricity production.

Best markets: (red) above 6 \$/Wp; 10 States: California, Connecticut, Colorado, Delaware, Hawaii, Nevada, New Jersey, New York, Rhode Island, Texas	Emerging markets: (green) between 2.5 \$/Wp and 4 \$/Wp; 8 States Alaska, Georgia, Maryland, Minnesota, Montana, New Hampshire, New Mexico, Oklahoma
Cost effective markets: (orange) between 4 \$/Wp and 6 \$/Wp; 9 States + DC Arizona, Florida, Maine, Massachusetts, Illinois, Ohio, Oregon, Utah, Vermont, Washington DC	Significant incentives needed: (blue) below 2.5 \$/Wp; 23 States

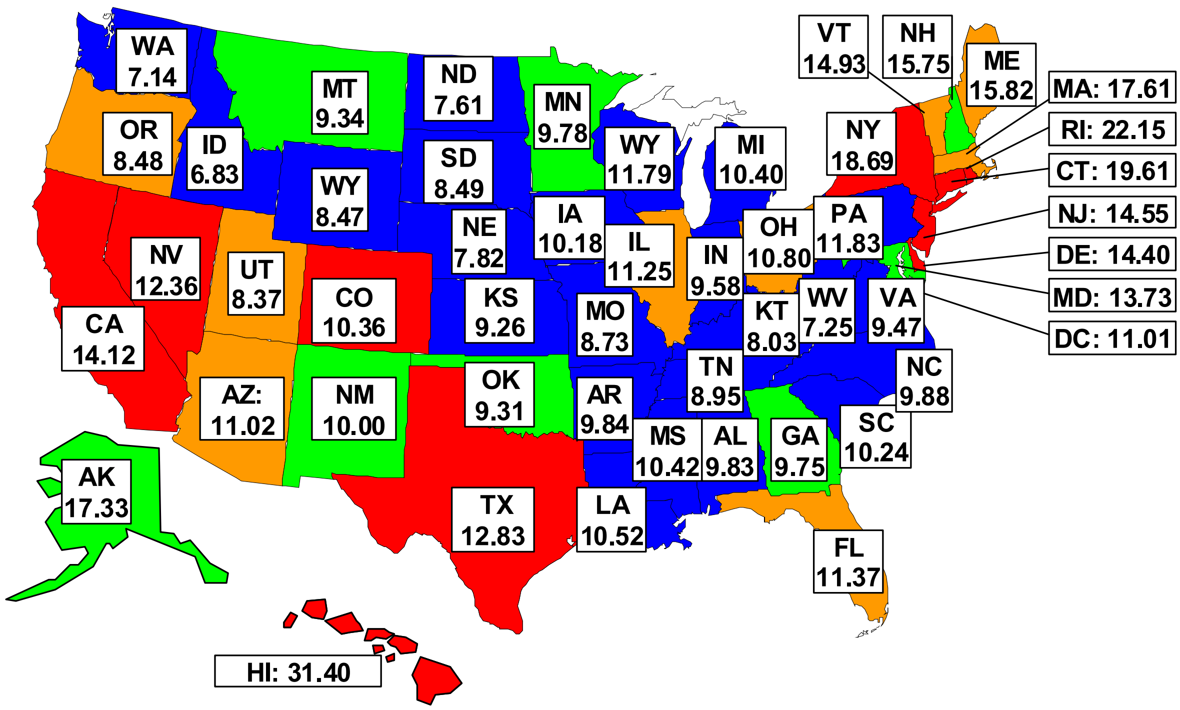

Fig. 13: Average residential electricity prices (¢/kWh) for May 2008 [Eia 2008].

Although the majority of US States are in the category in which significant incentives are required, one quarter of the US population lives in the five best market States for PV. In those States, PV is cost-effective at an installed cost of \$ 6/Wp (assuming long-term financing as in a mortgage). These five States also belong to those with the highest economic potentials.

The Energy Bill, the California SB 1 and other State Programmes are helping to accelerate the implementation of solar electricity. Whether or not the current support measures are sufficient to stimulate the necessary growth in US installations still has to be seen.

In September 2004, the US Photovoltaic Industry published their PV Roadmap through to 2030 and beyond “Our Solar Power Future” [Sei 2004]. The main goal of this Roadmap is: “Solar provides half of all new US electricity generation by 2025”. The Industry Association advocated effective policies sustained over time to increase solar power production and implementation in the US. Recommended actions were split into two sections:

Market Expansion

- Enact a residential and commercial tax credit that augments current state and federal support. The first 10 kW installed would receive a 50% tax credit capped at $ 3 per watt. Any amount above 10 kW would be eligible for a 30% tax credit capped at $ 2 per watt. Decreasing the caps by 5% per year will encourage a steady decline in prices and ease the transition to a market without tax credits.
- Modify the wind tax credit for solar so that it can be used together with the existing 10% investment tax credit.
- Establish uniform net metering and interconnection standards to give solar power owners simple, equitable access to the grid and fair compensation.
- Boost Federal Government procurement of solar power to $ 100 million per year to build public-sector markets for solar power.
- Support state public benefit charge programmes and other state initiatives to advance solar power and build strategic alliances with public and private organisations to expand solar markets.

Research and Development

- Increase R&D investment to $ 250 million per year by 2010.
- Strengthen investments in crystalline silicon, thin film, and balance-of-systems components, as well as new system concepts that are critical to the industry now – reducing the gap between their current cost and performance and their technical potential.
- Support higher-risk, longer-term R&D for all system components that can leap-frog beyond today’s technology to new levels of performance and reduce installed system costs.
- Enhance funding for facilities and equipment at centres of excellence, universities, national labs (Sandia National Laboratories and the National Renewable Energy Laboratory) – as well as the Science and Technology Facility at NREL – to shorten by 50% the time between lab discoveries and industry use in manufacturing and products.
- Grow partnerships among industry, universities, and national laboratories to advance PV manufacturing and product technologies.

6.1 Incentives supporting PV

Due to the political situation in the US, there are no uniform implementation incentives for Photovoltaics. The "One Million Solar Roof" Initiative signed by President Clinton in 1997 lacks a dedicated budget and the Department of Energy (DoE) can only support measures for the removal of market barriers or the development of local promotion programmes. The goal of the Initiative is practical and market-driven: to facilitate the sale and installation of one million "solar roofs" by 2010. Eligible technologies include Photovoltaics (PV), solar water heating, transpired solar collectors, solar space heating and cooling and pool heating.

After years of political negotiations, the Federal 2005 Energy Bill went into effect. The main incentive is the increase of the permanent 10 percent business energy credit for solar to 30% for two years. After that, the credit reverts back to the permanent 10 percent level after two years (2008). In addition, it established a 30 percent residential energy credit for solar for two years. For residential systems, the tax credit is capped at $2,000. The extension of the tax credits until 2016 was finally approved by the U.S. Senate in September 2008.

The Californian SB 1 went into force on 8 August 2006 and the California Public Utilities Commission (PUC) adopted performance-based incentives for the California Solar Initiative on 24 August 2006. Since 1 January 2007, the PUC offers performance-based incentives for solar energy systems greater than 100 KWp in size, installed in businesses and other large facilities. For systems smaller than 100 KWp, incentives for residential and small businesses will be based on each system's estimated future performance. Both mechanisms reward the selection and proper installation of high quality solar systems. This decision implements the first phase of the California Solar Initiative, which was adopted by the PUC in January 2006. The goal of the Solar Initiative is to increase the amount of installed solar capacity in California by 3,000 MW by 2017.

From 1 January 2007, residential and small commercial systems receive incentives of $ 2.50 per watt and will be eligible for additional federal tax credits. Government and non-profit organisations will receive $ 3.25 per watt to compensate for their lack of access to the federal tax credit. For systems larger than 100 KWp, incentive payments over the first five years of operation will be $ 0.39/kWh of output for taxable entities and $ 0.50/kWh of output for government/non-profit organisations.

Many State and Federal policies and programmes have been adopted to encourage the development of markets for PV and other renewable technologies. These consist of direct legislative mandates (such as renewable content requirements) and financial incentives[14] (such as tax credits). Financial incentives typically involve appropriations or other public

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[14] DOE has defined a financial incentive as one that: (1) transfers economic resources by the Government to the buyer or seller of goods or a service that has the effect of reducing the price paid or increasing the price received; (2) reduces the cost of producing the goods or service; and/or (3) creates or expands a market for producers [Gie 2000].

funding, whereas direct mandates typically do not. In both cases, these programmes provide important market development support for PV. The types of incentives are described below. Amongst them, investment rebates, loans and grants are the most commonly used – at least 39 States, in all regions of the country, have such programmes in place. Most common mechanisms are:

- personal tax exemptions (Federal Gov., 19 States + Puerto Rico)
- corporate tax exemptions (Federal Gov., 24 States)
- sales tax exemptions for renewable investments (23 States + Puerto Rico)
- property tax exemptions (32 States + Puerto Rico)
- buy-down programmes (18 States + Virgin Islands, 193 utilities, 7 local)
- loan programmes and grants (Federal Gov., 35 States + DC + Virgin Islands; 56 utilities, 22 local, 11 private)
- industry support and production incentives (Federal Gov ., 21 States, 23 Utilities)

One of the most comprehensive databases about the different support schemes in the US 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 [Dsi 2008]. All different support schemes are described there and it is highly recommended to visit the DSIRE web-site http://www.dsireusa.org/ and the corresponding interactive tables and maps for more details.

Table 2: Financial Incentives for Renewable Energy [DSIRE]

State/Territory	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Bonds	Production Incentive*
Federal Gov.	3	4				2	3			1
Alabama	1-S				3-U	1-S	1-S, 1-U			1-U
Alaska						1-S	2-S			1-U
Arizona	3-S	1-S	1-S	2-S	6-U		2-U			
Arkansas										
California				1-S	5-S, 35-U, 1-L	1-L	1-U, 2-S, 2-L			1-S, 2-U
Colorado			1-S, 1-L	2-S	7-U, 3-L	1-L, 1-P	3-U, 1-L	1-S		
Connecticut			1-S	1-S	2-S	4-S	2-S	2-S		1-P
Delaware					1-S	2-S				
Florida		2-S	1-S	1-S	1-S, 7-U, 2-L	1-S	1-U			1-U
Georgia	1-S	1-S	1-S		3-U		3-U			1-U
Hawaii	1-S	1-S			2-U		1-S, 2-U, 1-L	1-S	1-L	
Idaho	1-S		1-S	1-S	2-U	2-P	1-S		1-S	1-P
Illinois				2-S	1-S	2-S, 1-P		1-S		
Indiana				1-S	1-S, 25-U	1-S				
Iowa	1-S	1-S	1-S	3-S	6-U	1-S	2-S			
Kansas				1-S			1-S			
Kentucky	1-S	2-S	1-S		5-U		1-P, 2-U			1-U

State/Territory	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Bonds	Production Incentive*
Louisiana	1-S	1-S		1-S			1-S			
Maine					1-S	1-S	1-S			
Maryland	2-S	2-S	2-S	4-S, 3-L	3-S, 1-L		2-S			
Massachusetts	2-S	3-S	1-S	1-S	2-S, 2-U	3-S	1-S, 1-U	2-S		1-P
Michigan				1-S	1-U	4-S		2-S		
Minnesota			2-S	1-S	2-S, 9-U	2-U	5-S, 1-U			1-S, 1-U
Mississippi					4-U		1-S			1-U
Missouri		1-S			6-U		1-S, 1-U			
Montana	3-S	1-S		3-S	2-U	2-P, 1-U	1-S	2-S		1-P
Nebraska			1-S		2-U		1-S			
Nevada				3-S	1-S					
New Hampshire				1-S	3-U		1-S			
New Jersey			1-S		4-S, 1-U		1-S, 1-U			1-S
New Mexico	3-S	3-S	2-S					1-S	1-S	1-U
New York	2-S	1-S	1-S	2-S, 1-L	5-S, 3-U	2-S	2-S	2-S		1-S
North Carolina	1-S	1-S	1-S	2-S			1-S	1-S		1-U, 1-P
North Dakota	1-S	1-S		2-S			1-U			
Ohio		1-S	1-S	1-S, 1-L	6-U	2-S				1-S
Oklahoma		1-S					3-S, 1-U	1-S		
Oregon	1-S	1-S		1-S	3-S, 12-U	2-P, 1-S	1-S, 7-U	1-S		1-P, 1-U
Pennsylvania				1-S		3-S, 3-L	1-S, 5-L, 1-U			
Rhode Island	1-S	1-S	1-S	2-S	1-U					1-P
South Carolina	1-S	2-S	1-S		1-S, 2-U	1-S	1-S, 4-U			1-S
South Dakota				3-S	1-U		2-U			
Tennessee				1-S		1-S	1-S			1-U
Texas		1-S		1-S	7-U		1-S	1-S		
Utah	1-S	1-S	1-S		5-U					
Vermont		1-S	1-S	1-S	1-S	1-S, 1-U	1-S			2-U
Virginia				1-S				1-S		1-U
Washington			1-S		12-U	2-P, 1-L	9-U	1-S		1-S, 3-U, 1-P
West Virginia		1-S		1-S						
Wisconsin				1-S	2-S, 2-U	1-S, 1-U		1-S		42-U
Wyoming			1-S		1-S, 1-U					
D.C.						1-S				
Palau										
Guam										
Puerto Rico	1-S		1-S	1-S						
Virgin Islands					1-S	1-S				
N. Mariana Isl.										
American Samoa										
Totals	**32**	**36**	**28**	**56**	**228**	**58**	**100**	**21**	**3**	**39**

S = State/Territory **L** = Local **U** = Utility **P** = Private

Source: North Carolina Solar Centre, North Carolina State University research based on information in the Database of State Incentives for Renewable Energy (DSIRE) (2007). http://www.dsireusa.org

* In addition, some private renewable energy credit (REC) marketers provide production-based incentives to renewable energy project owners.
For more info see: http://www.eere.energy.gov/greenpower/markets/certificates.shtml?page=2

A study by B.J. Rabe for the Pew Centre on Global Climate Change looks into the expanding role of US State Renewable Portfolio Standards [Rab 2006]. One of the key messages is: *States are compelled to enact or expand RPSs for multiple reasons, and greenhouse gas emissions may or may not be central factors in prompting adoption.* ***Instead, States consistently anticipate significant economic development benefits from promoting renewables, particularly given the promise of developing home-grown energy sources that could lead to instate job creation****. In turn, States are also attracted to RPSs by the* ***prospect of greater reliability of electricity supply in coming decades*** *and the prospect of reducing conventional air pollutants through a shift toward expanded use of renewables.*

Table 3: Incentives for Renewable Energy - Rules, Regulations & Policies [DSIRE]

State / Territory	PBF	Disclosure	RPS	Net Metering	Interconnection	Extension Analysis	Contractor License	Equipment Certification	Access Laws	Construction & Design Standards	Green Power Purchase	Required Green Power
Alabama												
Alaska									1-S			
Arizona			1-S	3-U	1-U	1-S	1-S	1-S	1-S	3-S, 2-L	1-L	
Arkansas				1-S	1-S					1-S		
California	1-S	1-S	1-S	1-S	1-S		1-S		2-S, 8-L	1-S, 6-L	4-L	
Colorado	1-L	1-S	1-S, 1-L	1-S	1-S	1-S			1-S, 2-L	2-S, 5-L	2-L	1-S
Connecticut	1-S	1-S	1-S	1-S	1-S		1-S			1-S	1-S, 1-L	
Delaware	2-S, 1-U	1-S	1-S	1-S	1-S							2-U
Florida		1-S	1-U	1-S, 7-U	1-S		1-S	1-S	1-S 1-L	1-S		
Georgia				1-S	1-S				1-S			
Hawaii			1-S	1-S	1-S		1-S		1-S	2-S		
Idaho				3-U					1-S			
Illinois	1-S	1-S	1-S	1-S	1-S						1-S, 1-L	
Indiana				1-S	1-S				1-S	1-S	1-S	
Iowa		1-S	1-S	1-S	1-S				1-S			1-S
Kansas									1-S	1-L		
Kentucky				1-S					1-S			
Louisiana				1-S, 1-L	1-S							
Maine	1-S	1-S	1-S	1-S					1-S	1-S	1-S	
Maryland		1-S	1-S	1-S	1-S				1-S	3-S	1-S, 2-L	
Massachusetts	1-S	1-S	1-S	1-S	1-S				1-S	2-S	1-S, 1-L	
Michigan	1-S	1-S	1-U	1-S	1-S		1-S			2-S, 1-L	3-L	
Minnesota	1-S	1-S	2-S	1-S	1-S			1-S	1-S	1-S		1-S
Mississippi												
Missouri			1-S 1-L	1-S	1-S				1-S	1-S		
Montana	1-S		1-S	1-S, 1-U	1-S				1-S			1-S
Nebraska				1-U					1-S			
Nevada		1-S	1-S	1-S	1-S		1-S		1-S	2-S		
New Hamp.			1-S	1-S	1-S				1-S	1-L		

State / Territory	PBF	Disclosure	RPS	Net Metering	Interconnection	Extension Analysis	Contractor License	Equipment Certification	Access Laws	Construction & Design Standards	Green Power Purchase	Required Green Power
New Jersey	1-S	1-S	1-S	1-S	1-S				2-S	2-S		
New Mexico			1-S	1-S 1-U	1-S	1-S			1-S	1-S		1-S
New York	1-S	1-S	1-S 1-U	1-S	1-S				1-S	1-S 1-L	1-S 1-L	
N. Carolina			1-S	1-S	1-S				1-S, 1-L	1-S, 7-L		
North Dakota			1-S	1-S					1-S			
Ohio	1-S	1-S	1-S	1-S, 1-U	1-S				1-S	1-S		
Oklahoma				1-S						1-S		
Oregon	1-S	1-S	1-S	1-S, 1-U	1-S		1-S		1-S, 2-L	1-S 1-L	1-L	1-S
Pennsylvania	1-S	1-S	1-S	1-S	1-S					1-S	1-S, 1-L	
Rhode Island	1-S	1-S	1-S	1-S					1-S	1-S	1-S	
S. Carolina				2-U	1-S					1-S	1-L	
South Dakota			1-S							1-S		
Tennessee									1-S			
Texas		1-S	1-S, 1-L 1-U	1-S, 1-U	1-S	1-S				2-S, 6-L	3-L	
Utah			1-S	1-S, 3-U	1-S		1-S		1-S	1-L	1-L	
Vermont	1-S		1-S	1-S	1-S							1-S
Virginia		1-S	1-S	1-S	1-S				21-S	1-S, 1-L	1-L	
Washington		1-S	1-S	1-S, 1-U	1-S				1-S	1-S 1-L	2-L	1-S
West Virginia				1-S								
Wisconsin	1-S		1-S	1-S	1-S		1-L		1-S, 1-L	1-S	1-S, 1-L	
Wyoming				1-S	1-S							
D.C	1-S	1-S	1-S	1-S	1-S					1-S		
Palau												
Guam			1-S	1-S						1-S		
Puerto Rico				1-S				1-S				
Virgin Islands				1-S					1-S			
N. Mariana Isl.												
Amer. Samoa												
Totals	21	23	42	70	38	4	10	4	53	79	38	10

S = State/Territory **L** = Local **U** = Utility

Source: North Carolina Solar Centre, North Carolina State University research based on information in the Database of State Incentives for Renewable Energy (DSIRE) (2007). http://www.dsireusa.org

In September 2008, 26 States, the District of Columbia and Guam had Renewable Portfolio Standards, six additional States have State Goals and in two additional States utilities have agreed on a RPS (Fig. 14). 13 State RPS include minimum solar or customer sited RE requirements and in 3 States there is an increased credit for solar electricity.

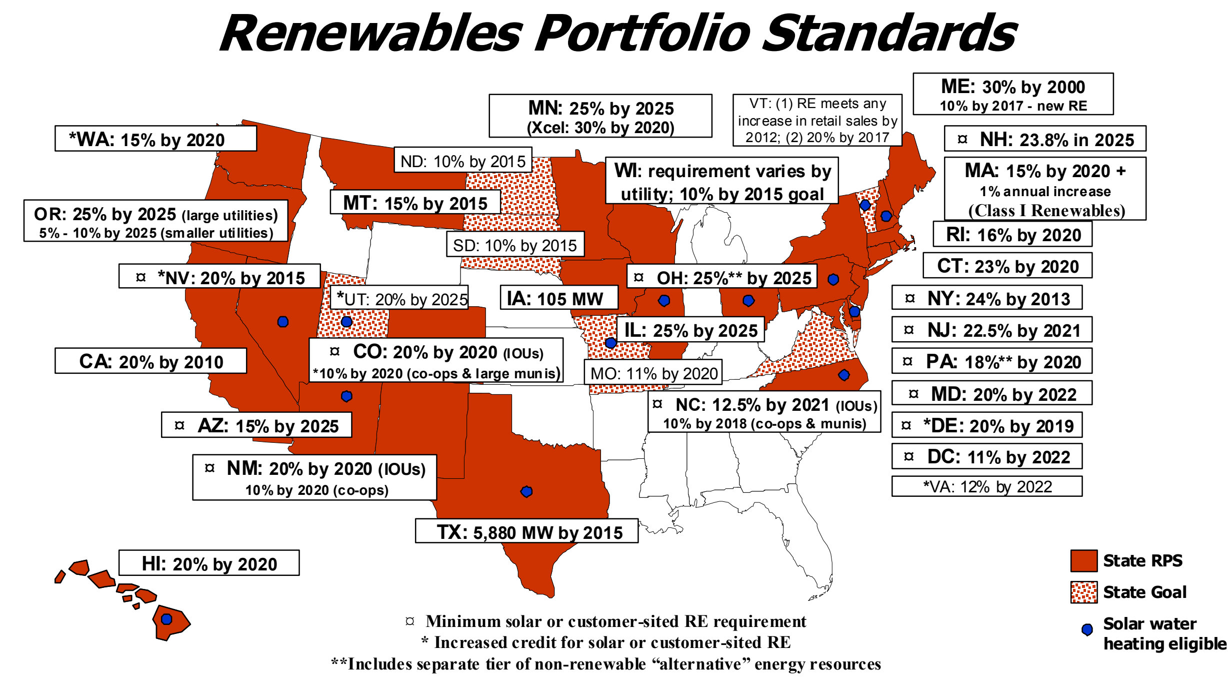

Fig. 14: States with Renewable Portfolio Standards in the US (September 2008); Figure © DSIRE [Dsi 2008].

Another very important measure for Photovoltaics is the grid access. In September 2008, 44 US States + Washington DC had implemented measures for the net-metering of electricity produced by PV (Fig. 15).

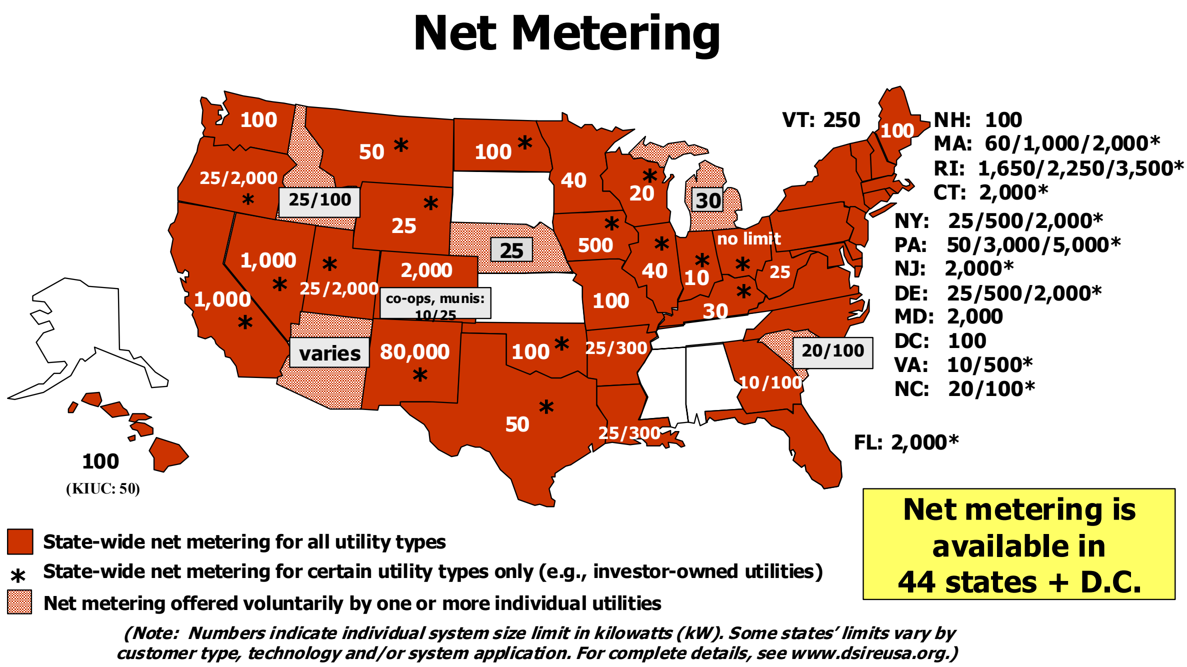

Fig. 15: States with Net-metering in the US (September 2008) and upper limits; Figure © DSIRE [Dsi 2008].

The Union of Concerned Scientists predicts that State RPS and Renewable Energy Funds could lead to 25,900 MW of new renewable production capacity by 2017 (Fig. 16).

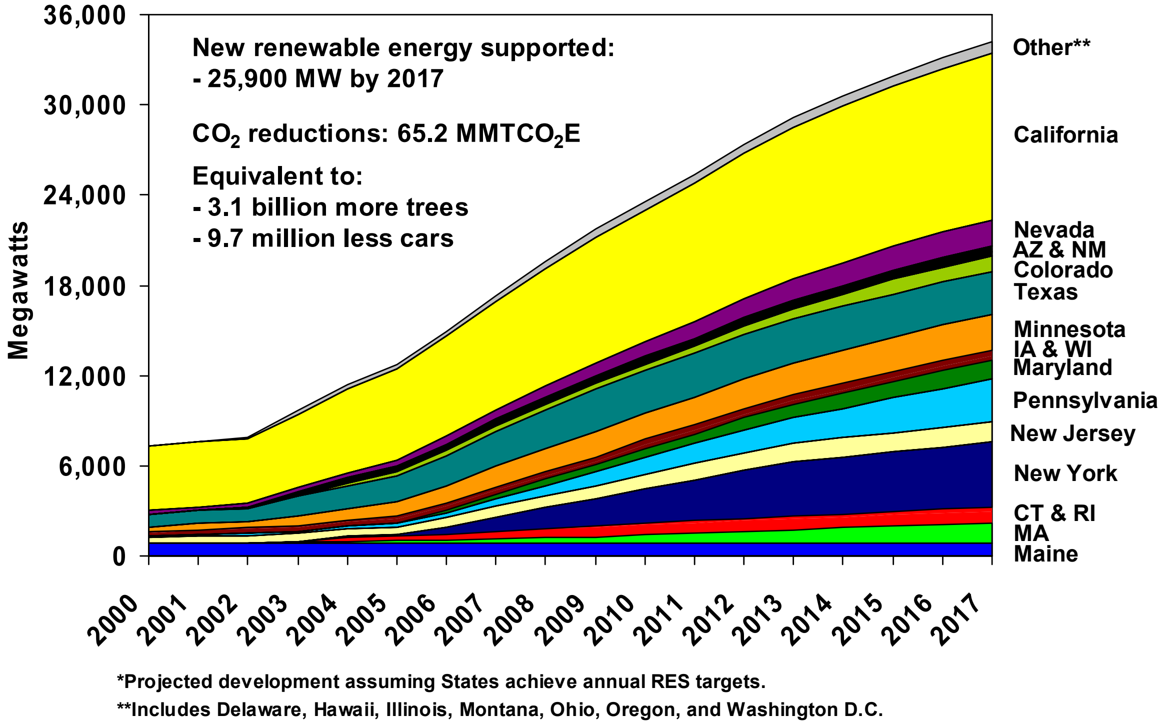

Fig. 16: Prediction of new Renewables from State Standards and Renewable Energy Funds Figure © Union of Concerned Scientists [Uni 2005]

This would be a two-fold increase over total 1997 US levels (excluding hydro). Most of these capacities will be wind, but Photovoltaic electricity is seen more and more as an option as well. Therefore, it is interesting that the Colorado RPS has a specific target for solar electricity. The RPS laws in California and New York create the two largest markets for new renewable energy growth. Wisconsin, Iowa, Minnesota and Texas have already seen significant developments, e.g. Wisconsin utilities have already acquired enough renewable electricity to meet their target through 2005.

In December 2007, Ken Zweibel, James Mason and Vasilis Fthenakis published their vision "A Solar Grand Plan" for the U.S. in Scientific America [Zwe 2007]. The paper describes, how Photovoltaic technology could provide almost 3,000 GW of power by 2050. According to the authors, solar must become competitive at the mass-production level in a first phase from now until 2020. In order realise this, about 84 GW of Photovoltaics and concentrated solar power plants would have to be built by 2020. In parallel it would be necessary to lay the foundation of the necessary High Voltage Direct Current (HVDC) transmission system.

The realisation of such a plan would drastically change the market situation as well as the production and technology base in the U.S.

6.2 Solar Energy Technologies Programme

The National Renewable Energy Laboratory (NREL) supports the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE) "Solar Energy Technologies Programme". NREL's National Centre for Photovoltaics (NCPV) conducts research to support the U.S. Department of Energy's goal to reduce the average cost of all grid-connected PV systems from 6.25 $/W to 3.30 $/W for end users.

DOE's "Solar Energy Technologies Programme" runs from 2008 to 2012 [DOE 2008] and covers both Photovoltaic Electricity generation and Concentrated Solar Thermal Electricity. The vision of the Solar Energy Technologies Programme is that:

- Inexpensive solar energy will become available for all Americans,
- Millions of homes and commercial buildings across the nation will use solar technology to provide all or much of their energy needs, and
- Solar energy will constitute a significant portion of the Nation's energy production.

This vision directly supports the goal of the President's Advanced Energy Initiative: "Changing the way we power our homes and businesses."[15]

The major solar energy programme activities include:

- **Photovoltaics Research and Development (R&D)** to achieve improvements with impact in the cost, reliability, and performance of devices, components, and systems.
- **Concentrating Solar Power R&D** to develop and improve utility-scale power systems and to create and demonstrate effective storage technologies.
- **Market Transformation** to reduce market barriers through non-R&D activities, including infrastructure development and deployment assistance.
- **Partnerships with Other Programmes** to effectively accelerate the commercialisation of solar energy systems and to integrate results of basic research results from other government programmes into solar program R&D activities.

The 2008-2012 timeframe emphasizes the following areas:

1. Fully incorporating concentrating solar power (CSP) efforts into the Solar America Initiative (SAI).
2. Improving storage technologies for both CSP and PV technologies.
3. Better integrating solar technologies into the electric grid, in both distributed and centralised generation applications.
4. Eliminating city and state level technical and regulatory barriers to solar technology deployment.

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[15] "Advanced Energy Initiative." The White House National Economic Council. Washington, DC. February 2006.

5. Improving the ability of DOE and its laboratories and partners to quickly and effectively transfer R&D concepts from basic to applied science and then to the marketplace.
6. Exploring and developing the next generation of PV technologies that will reach consumers beyond the SAI timeframe (post-2015).
7. Assisting U.S. industry in regaining its leadership role in the global solar marketplace.
8. Promoting increased understanding of environmental and organisational safety across all Solar Program activities by all participants.

The Solar Programme goals support the DOE 2006 Strategic Plan [DOE 2006], which identified five strategic themes amongst them *energy security,* which is a key driver of the Solar Programme activities supported by the DOE. In addition, the Programme supports the research and development provisions and broad energy goals outlined in the National Energy Policy, EPAct 2005, and the Energy Independence and Security Act (EISA). In both acts, Congress expressed strong support for decreasing dependence on foreign energy sources and decreasing the cost of renewable energy generation and delivery. Support from Congress and state governments and the availability of financial incentives are important for achieving the Solar Programme goals.

The Solar Programme lists economic targets for PV (Table 4), which were determined by an analysis of key markets. They were set based on assessments of the Levelised Costs of Energy (LCOE) for solar technologies to be competitive in these markets.

According to the Solar Programme, the residential and commercial price targets are based on current retail electricity prices and take into consideration EIA's rather optimistic projection that electricity prices will remain fairly constant (in real terms) through 2025. With these assumptions, the Programme predicts that meeting the solar market cost goals will result in 5-10 GW of PV installed by 2015 and 70-100 GW by 2030 in the U.S.

Table 4: Solar Programme Cost Targets

Market Sector	Current U.S. Market Price Range for Conventional Electricity(¢/kWh)	Levelised Cost of Energy (¢/kWh)		
		Benchmark	Target	
		2005	2010	2015
Utility	4.0-7.6 3.5-20.7 [b]	13-22	13-18	5-7
Commercial [a]	5.4-15.0 [c] 5.5-28.5 [d]	16-22	9-12	6-8
Residential	5.8-16.7 [c] 6.8-31.4 [d]	23-32	13-18	8-10

a) In many commercial applications, utility costs are tax deductible. In these cases, the cost of solar energy should be compared to the effective market price, considering tax effects.
b) Day-ahead market on ICE platform representing approximately 70% of next day trading activity [Eia 2008].
c) Electricity costs cited in the Solar Programme.
d) Electricity costs in May 2008 [Eia 2008].

6.2.1 *Photovoltaic Technology Roadmaps*

Ten Photovoltaic technology roadmaps were developed in 2007 by staff at NREL, Sandia National Laboratories, DOE, and experts from universities and private industry [DOE 2008a]. This work was done, in part, to support activities within the Solar America Initiative. These technology roadmaps summarise the current status and future goals for the specific technologies. The Roadmaps for Intermediate-Band PV, Multiple-Exciton-Generation PV and Nano-Architecture PV are still in a draft stage.

6.2.1.1 Wafer-Silicon PV

R&D for wafer based silicon Photovoltaics is currently focused on achieving the necessary cost reduction through the following topics:

- Reduced materials cost, particularly the silicon substrate
- Increased conversion efficiency
- Improved manufacturing processes and higher throughput
- Improved reliability (reduced wafer breakage, tighter performance distributions)

Table 5:Wafer-Silicon Technology [DOE 2008]

Parameter	**Present Status (2007)**	**Future Goal (2015)**
Polysilicon costs	45–60 \$/kg	20 \$/kg
Wire sawing costs	0.25 \$/W	0.15 \$/W
Wafer size	~250 cm^2	~400 cm^2
Wafer thickness	200–250 µm	120 µm
Volume manufacturing	100–200 MW/yr plants	500 MW/yr plants
Automation	Partial	Complete
Efficiency, best lab cells	25%	27%
Efficiency, commercial modules	12%–18%	15%–21%
Module manufacturing cost	2 \$/W (at 30 \$/kg Si FS)	1 \$/W

6.2.1.2 Film-Silicon PV

The roadmap highlights the following pathways to advance the technology to advance:

1. For a-SI:H, cells dramatically reduce area-costs and moderately increase efficiency.
2. Despite the fact that c-Si film technologies still lack the efficiencies of wafer-based silicon, a high-risk/high-payoff pathway uses c-Si films fabricated on one of several candidates of inexpensive substrates such as glass, glass-ceramics, metallurgical-grade Si, or stainless steel. This wafer-replacement approach has the potential to raise efficiencies to levels competitive with polysilicon-wafer technology, while maintaining the low-cost structure of a-SI:H thin-film manufacturing.

Table 6:a-Si-Based Thin-Film Technology Performance [DOE 2008]

Parameter	**Present Status (2007)** (costs are estimated)	**Future Goal (2015)**
Production volume	100 MW/yr	>5 GW/yr
Capital equipment cost	1–2 $/W @ plant capacity	0.7 $/W @ plant capacity
Substrate cost	12–20 $\$/m^2$	4 $\$/m^2$
Module manufacturing cost for a-Si	125–200 $\$/m^2$	0.45–0.70 $/W or 70 $\$/m^2$ @ 10%–15% efficiency
Stabilised efficiency, best a-Si lab cells	13%	15%
Stabilised efficiency, commercial a-Si modules	5%–8%	10%–13%
Reliability of a-Si panels	~1%/yr degradation	1%/yr degradation

Table 7:c-Si Film Technology Performance [DOE 2008]

Parameter	**Present Status (2007)** (costs are estimated)	**Future Goal (2015)**
Production volume	<1 MW/yr	1 GW/yr
Capital equipment cost	2–3 $/W @ plant capacity	0.7 $/W @ plant capacity
Substrate cost	26 $\$/m^2$	10 $\$/m^2$
Module manufacturing cost for waferless silicon	Not available	0.50 $/W or 65 $\$/m^2$ @ 13% efficiency
Efficiency, best supported-film c-Si lab cells	10%	16%–18%
Efficiency, best supported-film c-Si modules	5%–6%	13%–16%
Reliability of Si-film panels	? ? %/yr degradation	1%/yr degradation

6.2.1.3 Concentrator PV

In order to reduce the cell costs, which are a substantial fraction of the total system cost of CPV, a variety of approaches to reduce the cost are available: reduction of epitaxy costs; reduction of substrate costs via recycling and reuse; increased use of automation in processing and testing, combined with transition to a larger substrate diameter; improved yield; and increased solar concentration.

Little information is available regarding long-term cell reliability under concentration, especially for III-V cells. Factors specific to CPV reliability include the high-flux, high-current, high-temperature operating environment encountered by the cells; weathering and other degradation of the optical elements; the bonding of concentrating optics to the solar cell; and the operation of the mechanical parts of the trackers.

Table 8: Concentrating PV Technology Performance [DOE 2008]

Parameter	Present Status (2007)	Future Goal (2015)
$/W installed cost	7–10 $/W	< 2 $/W
¢/kWh	> 30 ¢/kWh	< 7 ¢/kWh
System reliability – IEC qual. spec.	5 years	20 years
Commercial system efficiency	17%	29%–36%
Champion device efficiency	40.7% (III-V); 26.8% (Si)	48% (III-V); 28% (Si)
Commercial device efficiency	35 – 37% (III-V); 20 – 26% (Si)	42% (III-V) ;22 – 26% (Si)
Optical efficiency	75%–85%	80%–90%
III-V cell cost	10–15 $/cm^2	3–5 $/cm^2

6.2.1.4 CdTe PV

Enhanced open-circuit voltage (V_{oc}) with some improvements from short-circuit current density (J_{sc}) in thin-film CdTe devices will most likely be the pathway to higher cell and module efficiency. Factors limiting fill factor (FF) have to be analysed and evaluated to improve solar cell and module performance. The CdTe deposition processes have the distinct advantage of rapidly transferring the material needed to compose the cells, but it also limits the ability to introduce and control constituents to modify the electro-optical properties of the materials.

The reliability of the current glass-glass encapsulated thin-film CdTe modules appears to be comparable to conventional Si-based technology. As new technologies are added to boost efficiency, tests are needed to ensure that reliability is not sacrificed. Environmental, safety, and health (ES&H) continues to be an important aspect of the technology development and should be constantly updated and studied. Efforts should be made to increase public awareness of the perceived cadmium issue.

Table 9: Cadmium Telluride Technology Performance [DOE 2008]

Parameter	Present Status (2007)	Future Goal (2015)
Commercial module efficiency	>9%	13%
Champion device efficiency	16.5%	18%–20%
Module cost	1.21 $/W	0.70 $/W
$/W installed system cost	4–5 $/W	2 $/W
LCOE	18–22 ¢/kWh	7–8 ¢/kWh
Overall process yield	90%	95%
Identify relevant degradation mechanisms and develop appropriate ALTs for device and mini-modules	1.2% per year	0.75% per year

6.2.1.5 CIGS PV

A primary challenge for CIGS is to provide the science and technology needed to close the gap in efficiency between the entry-level prototype products and champion devices. A second challenge is to discover and qualify new materials and device schemes that can enhance performance, absorber band-gap and voltage, material usage, stability, yield, and process simplicity.

Issues including device sensitivity to water vapour, the commercially limited availability of indium, and enhancing processing approaches to improve commercial module efficiency, are all significant challenges for CIGS. Building-integrated products may provide an entry channel for the technologies, taking advantage of the demonstrated capability to manufacture flexible modules and the potential to conform the film PV to building-material geometries.

Overall, the following issues need to be addressed:

- Enhance module efficiency,
- Improve module manufacturing processes,
- Discover alternative approaches and new materials
- Assess and interact.

Table 10: CIGS Technology Performance [DOE 2008]

Parameter	Present Status (2007)	Future Goal (2015)
Commercial module efficiency	5%–11%	10%–15%
Champion device efficiency	19.5%	21%–23%
Module cost	Not established, estimated < 2 $/W	~ 1 $/W
$/W installed system cost	5–12 $/W	3 $/W
Reliability goal	0% to 6% annual degradation in pilot arrays	<1% annual power loss for commercial product
Overall process yield	Not available	> 95%
New manufacturing methods	Pilot Flexible "roll-to-roll" manufacturing (initially packaged as a glass to glass laminate)	Develop new encapsulation schemes and appropriate accelerated life testing for flexible and rigid modules
Deposition rate and cell thickness	5 µm/h, 1.25–3 µm CIGS absorber thickness	30–40 µm/h <1 µm CIGS absorber thickness

6.2.1.6 Organic PV

The primary challenge for OPV is to increase the efficiency and reliability. The limitations to efficiency are generally understood, but a rigorous fundamental understanding is lacking. Issues related to device degradation, such as photo-oxidation, interfacial instability and de-lamination, inter-diffusion, and morphology changes are poorly understood. Development of more complex device designs, such as multi-junction devices or inclusion of more exotic third-generation mechanisms into the OPV design, may be necessary to push efficiencies to competitive levels or to enable substantially higher efficiencies. The long-range goal of OPV is large-scale power generation. But as the technology develops, the potential for low-cost and flexible form-factors may enable other applications in the short term.

Table 11: OPV Technology Performance [DOE 2008]

Parameter	Present Status (2007)	Future Goal (2015)
Champion device efficiency	5.2%	12%
Cell degradation	< 5% per 1000 h, research-scale	< 2% per 1000 h, module
Material figure-of-merit efficiency. Identification of candidate materials whose fundamental properties, such as optical absorption, band structure, and carrier mobility, allow for high theoretically attainable efficiencies.	Some material sets with improved figure-of-merit efficiencies exist.	Identification and synthesis of multiple donor-acceptor materials that meet all the fundamental requirements to achieve the Shockley-Queisser limit.

6.2.1.7 Sensitised Solar Cells

Although the stability and light-conversion mechanisms are currently inadequately understood, it can be said that (1) there is no expected limitation on material, (2) stable 10%-efficient modules are certainly within reach, and (3) the energy-payback period should be significantly shorter than other PV technologies. Demonstrated levels of efficiency and degradation have inspired investment, and several companies are working toward commercialising this technology. To reach the 2015 targets, further advance in the fundamental understanding of the factors that govern cell performance and stability is essential.

Table 12: Sensitised Solar Cells Technology Performance [DOE 2008]

Parameter	Present Status (2007)	Future Goal (2015)
Champion device efficiency	11%	16%
Laboratory cell degradation	<5% after stress at 80°C for 1000h in dark or after light-soaking for 1000 h @ 1 sun at 60°C	<5% after stress at 85°C for 3000 h in the dark or after light-soaking for 3000 h @ 1 sun at 60°C
Module efficiency	5–7%	10%
Outdoor module degradation	<15% in 4 yrs	<15% in 10 yrs
Identification of key degradation mechanisms	Degradation mechanisms are controversial	Primary degradation mechanisms identified

6.2.1.8 Intermediate-Band PV

This roadmap addresses intermediate-band (IB) solar cell technology which currently is in a concept stage. The main challenge is to experimentally prove the concept, because so far, an increase in cell efficiency due to the presence of an IB has not been experimentally demonstrated. The reason for this is that a suitable materials system, with the required properties, has yet to be discovered.

Table 13: Intermediate-Band PV [DOE 2008a]

Parameter	Present Status (2007)	Future Goal (2015)
Understand the material design needed to implement the IB concept.	The importance of choosing a materials system with the IB at optimal energy is understood, but a method to avoid harmful non-radiative recombination is lacking.	By **2010,** identify the material requirements needed to demonstrate added efficiency from excitation through the IB.
Identify a materials system: new compound (e.g., GaPTi); new alloy (e.g., ZnMnOTe); quantum dot array, with the required properties to demonstrate an IB cell with an efficiency greater than the present record efficiency for a single-junction solar cell.	Not accomplished	Demonstrate an IB cell with an efficiency that exceeds the present record efficiency for a single-junction solar cell (~25%).
Champion device efficiency (1 sun)	Not accomplished	>25%
Champion device efficiency (under concentration)	Not accomplished	>30%
Cost target (assuming a single-junction single-crystal IB cell with an efficiency of 40% under concentration can be fabricated with a similar cost to a single-junction crystalline Si cell.)	Not accomplished	5–7 ¢/kWh
Cost target (assuming a single-junction IB cell with an efficiency of >20% can be fabricated by a low-cost route similar to CIGS thin films.)	Not accomplished	7–10 ¢/kWh

6.2.1.9 Multiple-Exciton-Generation PV [DOE 2008a]

This roadmap addresses the development of solar cells based on inorganic semiconductor nanocrystals (NCs) – such as spherical quantum dots (QDs), quantum rods (QRs), or quantum wires (QWs) – focusing on their potential to improve upon bulk semiconductor cell efficiencies by efficient multiple-exciton generation (MEG). The generation of multiple excitons (i.e., electron-hole pairs) for each absorbed photon of sufficient energy raises the thermodynamically attainable power conversion efficiency of a single-junction Photovoltaic (PV) solar cell from 33.7% to 44.4%. Semiconductor NCs are produced at much lower temperatures than their bulk counterparts, enabling significantly lower production cost. Several possible implementations of semiconductor NC-based solar cell devices may be realised.

The current state of this technology is in the fundamental and exploratory research phase, and is focused on:

- Pursuing an experimental and theoretical understanding of the MEG mechanism—i.e., how NCs enhance charge-carrier pair production for high photon energies.
- Materials selection and characterisation.
- Efficient charge separation for photocurrent collection from MEG-active NCs.

Table 14: Multiple-Exciton-Generation PV [DOE 2008a]

Parameter	**Present Status (2007)**	**Future Goal (2015)**
MEG quantum yield at $h\nu = 2.5 \times E_g$	105% – 110%	180%
IPCE at $h\nu > 2E_g$	45%	>100%
Champion NC solar cell efficiency	1%–3%	25%
AM1.5 photocurrent density at Voc = 1.0 eV	~1 mA/cm^2	36 mA/cm^2
Carrier mobility (DC value for coupled NC array)	~1 $cm^2/(V \cdot s)$	100 $cm^2/(V \cdot s)$

6.2.1.10 Nano-Architecture PV

This roadmap addresses nano-architecture solar cells that use nanowires, nanotubes, and nanocrystals, including single-component, core-shell, embedded nanowires or nanocrystals, either as absorbers or transporters.

These technologies are mostly in the stage of concept proposal or proof-of-principle device demonstration, although few have reached the stage of offering decent efficiency (although still not comparable to the more mature technologies, e.g., Si, CdTe, and CIGS).

Table 15: Nano-Architecture PV [DOE 2008a]

Parameter	**Present Status (2007)**	**Future Goal (2015)**
Concept; Proof-of-principle device	Either with only concept proposals or proof-of-principle devices	By 2010, the material systems that could, in principle, offer the desirable material properties should be identified; the proof-of-principle solar cells should be demonstrated
Materials; Device structures; Efficiency	Materials might not have the desirable properties; Device structures are not optimised; Efficiency < 3%	By 2015, the most-promising device structures and materials should be identified; the target efficiency of 15% should be achieved in the laboratory; the compatibility with thin-film and/or CPV technologies should be assessed

6.2.2 Solar Technology Research Plan

The U.S. strategy for overcoming the challenges and barriers to massive manufacturing, sales, and installation of PV technology is to achieve challenging targets throughout the development pipeline. Multiple technologies are being pursued that are at differing stages of maturity. With an effective combination of the talents in industry, university, and national laboratories, the needed cost, performance and reliability goals should be achieved. Specific PV R&D efforts toward achieving these goals include:

1. PV Systems & Module Development
2. PV Materials & Cell Technologies
3. Testing & Evaluation
4. Grid / Building Integration

The R&D activities are divided into the following three categories:

6.2.2.1 New Devices and Processes

These research and development activities address the development of novel Photovoltaic or concentrating solar power devices or processes with potentially significant performance or cost advantages. In April 2007, DOE made a call for projects on "*Next Generation Photovoltaic Devices and Processes*" to develop innovative Photovoltaic cells and/or processes by 2015. Potential areas of interest included, but were not limited to, the following:

- Photovoltaic devices-organic, crystalline, non-single-crystal devices, photoelectro-chemical, advanced multijunction, low-dimensional structures, optimised interfaces, transport properties, and cross-cutting issues
- Hybrid PV concepts-hydrogen generation, powered electrochromics, and storage
- Manufacturing-low-cost techniques, environmental/recycling issues, and novel manufacturing processes.

The PV device and manufacturing process research activities in this area are expected to produce prototype PV cells and/or processes by 2015, with full commercialisation by 2020-2030. 25 *Next Generation PV* projects stared at the end of 2007.

6.2.2.2 Prototype Components and Systems

The Solar America Initiative's research in component and system prototypes emphasizes development of prototype components and systems produced at pilot-scale. The demonstration of cost, reliability, or performance advantages is required.

The proposed research will target the following:

- Development of component prototype design with full functionality and complete "look and feel" of commercial products

- Accelerated and qualifications testing to improve component design and gain early insight into reliability issues
- Complete proof of concept for all new manufacturing processes in pilot-scale operations
- Lab testing to provide data for systems integration and optimisation
- Evaluate component costing based on pilot production processes.

The financing tool for this task is called Photovoltaic Incubator funding. The funding structure for this solicitation is intended to be flexible and cyclical. The performance period of each project is 18 months, with the possibility of project termination after a DOE stage gate review at month nine. The projects have been structured so that companies will receive their funding from DOE only upon successful delivery of pre-specified samples of new hardware. This approach will allow early-stage companies to focus on demonstration of technology, while assuring that taxpayers get the best value for their investment in these projects.

In September 2008, the DOE announced the second round of winners for its Photovoltaic (PV) Incubator funding opportunity. The projects focus on developing prototype PV components and systems and barriers to entry for 2010 commercialisation. The result of the first round was announced in June 2007.

The PV Incubator awards target research and development of PV systems and component prototypes with full functionality, produced in pilot-scale operations. Prototype technologies are expected to have already completed proof-of-concept for new manufacturing processes, either through contractor equipment, the NREL Process Development and Integration Laboratory facilities, or other appropriate facilities. Goals of these projects are:

- Explore the commercial potential of new manufacturing processes and products
- Foster innovation and growth in the domestic PV industry
- Establish an efficient and cyclic funding opportunity
- Expand and diversify domestic "market-ready" PV technologies

6.2.2.3 Systems Development and Manufacturing

These R&D activities are intended for collaboration and partnership among industry and university researchers on components and systems that are ready for mass production and capable of delivering electricity at Solar America Initiative target costs.

This research is divided into two areas:

1) **Technology Pathway Partnerships** – Activities focused on research and development (R&D) of concentrating solar power (CSP) and Photovoltaic (PV) component and system design that is ready for mass production and capable of delivering energy at target costs.

The teams selected for the Technology Pathway Partnerships include companies, laboratories, universities, and non-profit organisations to accelerate the drive toward commercialization of U.S.-produced Photovoltaic (PV) systems. These partnerships comprise more than 50 companies, 14 universities, 3 non-profit organisations, and 2 national laboratories. The current project phase focuses on projects for the development, testing, demonstration, validation, and interconnection of new PV components, systems, and manufacturing equipment. The current goals are:

- Bring better products to market and enable new applications
- Foster the development of the domestic PV industry
- Impact the U.S. energy economy with results

2) University Process and Product Development Support – Targeted materials science and process engineering research by universities in support of industry-led teams who are developing new CSP and PV systems for commercialisation by 2010 to 2015.

This project part focuses on University-led system development and manufacturing research that emphasises direct, near-term improvements in PV products and development processes by universities in support of the Solar America Initiative goals. The goals are to leverage university understanding and experience improving PV products and process development.

In addition, the Solar America Initiative's **Market Transformation activities** address barriers to commercialisation of solar energy technologies.

6.3 Very High Efficiency Solar Cell Programme

In 2005 the US Defence Advanced Research Projects Agency initiated the Very High Efficiency Solar Cell (VHESC) Programme to develop 50% efficient solar cells over the next years. The aim of the Programme is to reduce the average load of 20 pounds (ca 9 kg) that an average soldier has to carry to power the portable technology gadgets used.

The initial phase which started in November 2005 was co-ordinated by the University of Delaware. Partners in this phase included BP Solar, Blue Square Energy, Energy Focus, Emcore and SAIC. Key research contributors included the University of Delaware, National Renewable Energy Laboratory, Georgia Institute of Technology, Purdue University, University of Rochester, Massachusetts Institute of Technology, University of California Santa Barbara, Optical Research Associates and the Australian National University.

During the initial phase the co-design of optics and solar cell architectures enabling ultra-high efficiency and low cost manufacture was investigated. The relevant topics were:

- **Lateral solar cell architecture** – this expands material choice (no lattice/current mismatch), increases performance
- **Substrate is high performance, low-cost silicon solar cell independently-contacted vertical solar cell architecture**
  - expands material choice

- monolithic structure with low materials and fabrication costs
- no tunnel junctions

- **Low cost multijunction solar cell**
  - New structures based on existing high efficiency materials
  - Parallel paths and materials for high, mid and low energy photons
- **High performance substrate, low-cost silicon solar cell**
- **Quantum dot solar cells**
  – optimised solar cell structures selective energy contacts
  – closely spaced QD arrays

In July 2007 DARPA announced the start of the second phase of the programme by funding the newly formed DuPont-University of Delaware VHESC Consortium to transition the lab-scale work to an engineering and manufacturing prototype model. For this purpose, DARPA awarded the consortium $ 12.2 million as part of a three-year, multi-phase programme that could total up to $ 100 million. DuPont is managing the consortium of proposed companies and scientific institutions dedicated to the optimisation of the VHESC solar cells for efficiency and cost.

6.4 The US PV-Industry Roadmap

To meet the challenge of the expanding PV markets the US-based PV industry has developed a PV Roadmap as a guide for building their industry in 2001 and updated it in 2004 [Sol 2001, Sei 2004]. In 2001 the main issues were concerned with ensuring US technology ownership and implementing a sound commercialisation strategy that should yield significant benefits at minimal cost. To do so they call for "reasonable and consistent co-investment by our industry and government in research and technology development". Despite the high investments needed, the environmental and direct economic benefits, together with the additional energy security, will by far exceed the investments.

In the 2004 update the US Industry states that their original analysis on cost reduction and market development was right, but that the necessary investments to achieve the goals were not made in the US but in Japan and Germany. It is highlighted that California is one of the shining stars in the US regarding PV implementation. The success there cannot substitute a national commitment to develop the markets. The conclusion drawn is: "Effective policies sustained over time increase solar power production, make markets grow dramatically, improve technology and reduce costs."

In the 2004 update, the industry showed two scenarios. The first one, Business as Usual and the more ambiguous "Roadmap" scenario, where the target figures are increased compared to 2001. Under the Roadmap scenario, PV should provide half of all new US electricity generation by 2025 and produce approximately 7% of the national electricity compared to 1% in the BAU case. Within the next 25 years the PV Industry expects to employ more than 260,000 people (59,000 in case of BAU) in the US. To reach these goals the PV Industry argues that market leadership has to be reclaimed and technology ownership has to be maintained. The following measures are supposed to do so, by the American PV Industry in their Roadmap.

Reclaim Market Leadership

- **Create Incentives for Market Leadership** – Implement tax credits for residential and commercial installations that augment current state and federal support. The first 10 kWp installed should receive a 50% tax credit capped at $ 3 per watt. Any amount above 10 kWp would be eligible for a 30% tax credit capped at $ 2 per watt. Decreasing the caps by 5% per year will encourage a steady decline in prices and ease the transition to a market without tax credits. The wind production tax credit for solar power should also be expanded in a manner that allows it to be used in combination with the existing 10% tax credit for businesses that install solar power equipment.
- **Establish Uniform Net Metering and Interconnection Standards** to give solar power owners everywhere the right to simple, equitable access to the grid and fair compensation for the value of the solar power they supply.
- **Boost Government Procurement** of solar power to $ 100 million per year by allowing 20-year Power Purchase Agreements and by appropriating funds for Federal Agencies to install solar energy. Leaders should dedicate appropriations for green solar power purchases and direct agencies to use solar power equipment where it can increase energy security and emergency preparedness for the largest electricity consumers in the United States – Federal and State Governments.
- **Support and Reinforce State and Local Efforts to Advance Solar Power** by designing federal incentives to lever existing state solar support and encourage other States to adopt solar policies that open new markets, increase sales volume, and help consumers, utilities, and communities benefit from solar electricity.
- **Increase the DOE Solar R&D Budget to $250 Million Per Year by 2010** to leverage our R&D excellence and thus build solar markets by balanced programmes on current crystalline silicon and thin films, manufacturing, reliability, and next-generation PV technologies. Solar power research has helped reduce their costs by nearly 50% in a decade and is essential to make it broadly competitive in the next decade. DOE and its national laboratories should validate solar system performance to reassure financial institutions and help reduce the cost of capital for the solar industry. The programme should lead in higher-risk research, advancing potentially disruptive (“leapfrog”) technologies and processes.

Maintain Technology Ownership

The foundation of successful technology is excellent research and development. The US industry recognises that to reduce solar power system costs, increase the energy delivered from its components and systems, and enhance its manufacturing efficiency (i.e., throughput and yield), the following investments in balanced federal R&D are essential:

- **Foster technologies that exist now or are near commercialisation, which are critical to our current US industry** – This includes crystalline silicon and thin films, as well as balance-of-systems components. This focus will decrease the gaps between where these manufactured technologies are now and what they can realistically achieve, helping to ensure that we meet the Roadmap's technical goals over the next 10 years.
- **Position the United States to own the coming generations of solar power technologies** – Investing in R&D for higher-risk, longer-term technology will provide options to leap-frog beyond today's technology to new levels of performance and reduced costs. This R&D includes developing new materials that push current technologies to the next performance level, discovering and demonstrating new devices with ultra-high efficiencies (e.g., nanotechnology approaches, multiple-junction and layered devices), and developing devices with ultra-low costs (e.g., organic or plastic solar cells, ultra-thin films). Investments must also stimulate the next generation of fully integrated solar energy systems. This includes modules and balance-of-systems components, including novel and "smart" electronics, optics, integration, architecture-based energy, storage, hydrogen production, and advanced power electronics.
- **Enhance support for existing centres of excellence, national labs and NREL's Science and Technology Facility** – This is critical to improve crystalline silicon and thin films. These centres help to shorten the time between laboratory discovery and industry use by at least 50%, significantly accelerating the transfer of innovation to the market-place. They also provide rapid response to overcome manufacturing issues and barriers identified by industry.
- **Continue to develop programmes and partnerships among industry, universities, and national laboratories** – Partnerships in PV manufacturing R&D and thin-film development have produced unprecedented cost sharing, research collaboration, and publishing a model for research that should be expanded and strengthened. The previous roadmap identified the doubling of the Federal R&D investment as a critical strategy for success. This did not occur, and global competition has advanced and threatens to knock the US out of research leadership. To reverse this trend, the United States are called to gradually increase its annual R&D investment to $ 250 million by 2010. This moderate investment will accelerate the current US industry's technology strength in capturing near-term markets and will ensure that the United States owns and manufactures the solar products that will serve future generations.

Compared to the 2001 scenario, the new update emphasises the importance of a strong home market in order to develop the local industry in the long term. This is in contrast to the earlier assumption that US PV-Industry Roadmap could depend on 70% export rate of their annual production. A strong home market like in Japan, where it accelerated the expansion of production capacities, is still missing in the United States. This might be one of the reasons why it lost its market leader position, held for many years, and is now at fourth place behind Japan, Europe and China.

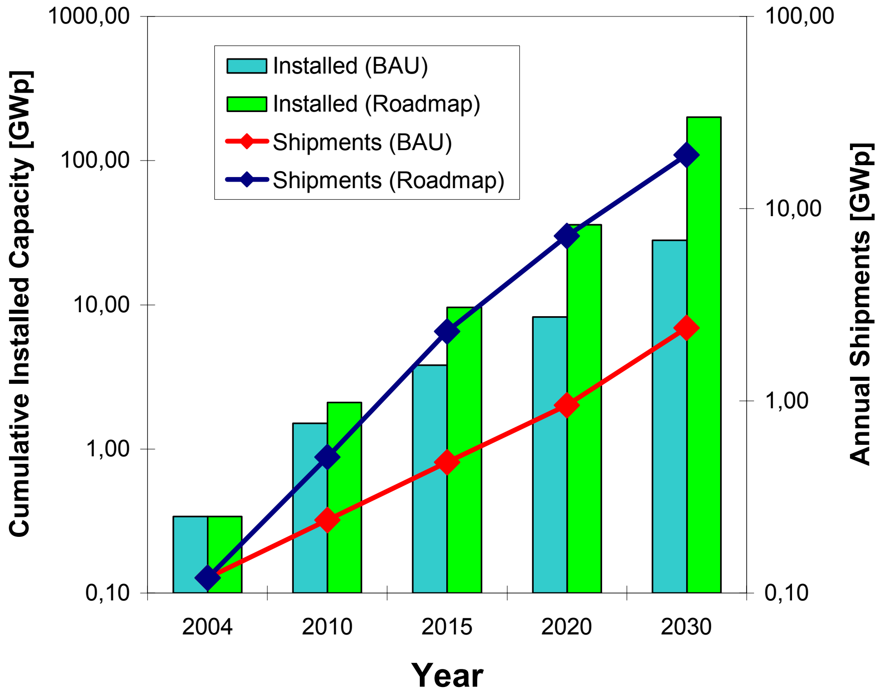

Fig. 17: US PV-Industry Roadmap [Sei 2004]

6.5 Solar Companies

In the following chapter most of the current cell manufacturers in the US are described briefly. This listing does not claim to be complete, especially due to the fact that for some companies, information or data were very fragmented. Data were collected from the companies' web-sites. A lot of start-up companies are missing due to sparse and sometimes contradictory information.

6.5.1 BP Solar

BP Solar has its headquarters in Linthicum, MD, and has various factories worldwide. In number of sales, BP Solar moved from third place in 2004, with 85 MW to number 13 in 2007 with 102 MW. BP Solar has 5 solar cell plants located in Madrid, Spain (Tres Cantos: 12 MW, c-Si Saturn solar cells), Sydney-Homebush Bay, Australia (33 MW, mc-Si and c-Si Saturn solar cells), Bangalore, India (14 MW, mc-Si), and Frederick, Maryland (26 MW mc-Si). BP Solar operates joint ventures in India, Malaysia, Saudi Arabia, South Africa, Thailand and Indonesia. According to the company production capacity in 2007 was 228 MW with an additional 700 MW under construction.

The production capacity at the Homebush Bay Plant, Australia is 50 MW. In 2007, BP also announced the expansion of production capacities. The current plan is 150 MW at the

Frederick Plant, but with space for further enlargements of the manufacturing capacity to 400+ MW in its casting, sizing, and wafering processes [Bps 2007]. Construction is slated for completion by the end of 2009.

At the inauguration of a new 36MW solar Photovoltaic (PV) production line in March 2007, the board of Tata BP Solar confirmed that this represents another step towards realising the designed potential of the 300MW plant [Bps 2007a]. This brings the production capacity to 50 MW. The next phase of the expansion will see an additional 128MW of cell manufacturing capacity added during 2007-8.

In Spain a phase 1 expansion at the Tres Cantos site from the current 55 MW to 300 MW was announced in March 2007 [Bps 2007b].

6.5.2 Evergreen Solar

Evergreen Solar, founded in 1994, develops, manufactures and sells solar power products, primarily solar panels. The company serves three markets: wireless power, rural electrification and grid-connected applications. The company uses its String Ribbon wafer production to produce distinctive products, to reduce manufacturing costs through lower materials use and streamlined processes, and to manufacture internationally for global market penetration. Production in 2007 was 16.4 MW [Pvn 2008]. According to the company, the first 80 MW phase of their new facility in Devens was opened in June 2008, with the second 80 MW planned to become operational in 2009. The company has announced that it has secured enough silicon feedstock to grow to 850 MW production in 2012.

Evergreen Solar has a joint venture *"EverQ"* with Q-cells, Germany, and Renewable Energy Corporation ASA (REC), Norway in Thalheim, Germany, which is located approximately 80 miles from Berlin. In June 2007 the second production line started operation, bringing the total capacity of EverQ to 90 MW and plans to increase its production capacity to approximately 300MW by 2010 [Eve 2007].

6.5.3 First Solar LLC.

First Solar LLC, is one of the companies worldwide to produce CdTe-Thin Film modules. First Solar has developed a solar module product platform that is manufactured using a unique and proprietary Vapour Transport Deposition (VTD) process. The VTD process optimises the cost and production through-put of thin film PV modules. The process deposits semiconductor material while the glass remains in motion, completing deposition of stable, non-soluble compound semiconductor materials.

First Solar is continuing to expand its CdTe thin film production capacity massively. The latest announcement was made in August 2008 to bring their manufacturing facility in Perrysburg to the same four line configuration standard as the others [Fst 2008a]. The company has currently four manufacturing plants in Perrysburg (U.S.A.), Frankfurt/Oder

(Germany) and two in Kulim (Malaysia), which will have a combined capacity of 720 MW at the end of 2008. In 2009 two additional plants are planned to become operational in Kulim, bringing the capacity to 1,104 MW, and the expansion in Perrysburg will then bring it to 1,152 MW in 2010. In 2007 the company produced 207 MW [Pvn 2008] and currently sets the production cost benchmark with 1.09 \$/Wp (0.78 €/Wp) in the second quarter of 2008.

6.5.4 Global Solar Energy Inc.

GSE is located in Tucson and was established in 1996. In 2006, German module manufacturer, SOLON AG, acquired a 19% stake in Global Solar Energy Inc. The remaining 81% are owned by a European venture capital investor. The company is producing thin-film Photovoltaic CIGS solar cells for use in solar products as well as installing and managing large solar Photovoltaic systems. According to the company, the new 40 MW plant was opened in March 2008 and the company is on track to open their 35 MW plant in Germany in the autumn of 2008. With plans to expand production capacity by an additional 100 MW in 2009, GSE aims for 175 MW production capacity in 2010 [Gse 2008]. In 2007, 4 MW production was reported [Pvn 2008].

6.5.5 United Solar Systems

United Solar Systems Corp. is a subsidiary of Energy Conversion Devices, Inc. (ECD). The first 25 MW manufacturing facility of the flexible a-Si triple junction solar cell is located in Auburn Hills (MI) and was inaugurated in 2002. The plant is fully automated and allows simultaneous processing of six rolls of stainless steel, each 1 ½ miles long, during deposition of the a-Si layers.

United Solar has decided to expand its production capacity to 300 MW by 2010 and 1 GW in 2012 [Ecd 2008]. The current nameplate capacity in Auburn Hills is quoted with 58 MW and in Greenville, Michigan 120 MW. Additional expansion is planned in China where a joint venture with Tianjin Jinneng Investment Company (TJIC) will build a 30 MW module plant in Tianjin. Production in 2007 increased to 48 MW [Pvn 2008].

6.5.6 SunPower Corporation

SunPower was founded in 1988 by Richard Swanson and Robert Lorenzini to commercialise proprietary high-efficiency silicon solar cell technology. The company went public in November 2005. SunPower designs and manufactures high-performance silicon solar cells, based on an interdigitated rear-contact design for commercial use. The initial products, introduced in 1992, were high-concentration solar cells with an efficiency of 26%. SunPower also manufactures a 22% efficient solar cell called Pegasus that is designed for non-concentrating applications.

SunPower conducts its main R&D activity in Sunnyvale, California and has its cell manufacturing plant outside of Manila in the Philippines. Fab. No 1 has a nameplate capacity of 108 MW. Fab. No 2 was dedicated in July 2007 and once finished at the end of 2008 should have a capacity of 300 MW. According to the 2nd Quarter 2008 results, the company started site preparation for a 1 GW solar cell factory in Malaysia [Sun 2008a]. Production in 2007 was quoted with 150 MW [Pvn 2008].

6.5.7 Additional Solar Cell Companies

- **Ascent Solar Technologies Incorporated** was established in 2005 to manufacture CIGS thin film solar modules with a roll to roll process. According to the company it is on track to commence full scale production on their 1.5 MW pilot line by the end of 2008. A 30 MW production line is planned to be completed in 2009 and for 2012 the company plans to increase production capacity to 110 MW.

- **AVA Solar, Inc.** was founded in 2007 to commercialise the manufacturing of cadmium telluride (CdTe) thin-film Photovoltaic modules. The company's initial pre-production system is under construction and pilot production (3 MW) should start in 2008.

- **DayStar Technologies** was founded in 1997 and conducted an Initial Public Offering in February of 2004. Products are: *LightFoil*™ and *TerraFoil*™ thin film solar cells based on CIGS. In addition, DayStar has its patented ConcentraTIR™ (Total Internal Reflection) PV module which has been designed to incorporate a variety of cell material components, including wafer-Si, Spheral Si, thin-film CIGS and a-Si.

- **GE Energy** acquired the US business assets of AstroPower in March 2004 for about $ 19 million [Gee 2004]. GE Energy (www.gepower.com) is one of the world's leading suppliers of power generation and energy delivery technology based in Atlanta (GA). AstroPower began as a division of Astrosystems Inc., founded in 1983 as an outgrowth of semiconductor work initiated at the University of Delaware. In 1989, the company was incorporated in Delaware. The company went bankrupt in 2003 and sales dropped from 29.7 MW in 2002 to 17 MW in 2003 and GE Energy sales recovered to 22 MW in 2006. For 2007 no significant production was reported. In June 2008, GE Energy became the largest shareholder in the thin-film solar start-up company PrimeStar Solar.

- **Miasolé** was formed in 2001 and produces flexible CIGS solar cells on a continuous, roll-to-roll production line. The company has installed two 20MW production lines in its Santa Clara facility. In July 2008 the company announced that NREL has measured their modules based on their flexible cells encapsulated in a glass/glass construction with more than 10% efficiency [Mia 2008].

- **Nanosolar** was founded in 2001 and is based in Palo Alto. It is a privately held company with financial-backing of private-technology-investors. According to the company, Nanosolar developed nanotechnology and high-yield high-throughput process technology for a proven thin-film solar device technology based on GIGS. The company made headlines when it announced on 21 June 2006 that it has secured $ 100 million in funding and intends to build a 430 MW thin-film factory [Nan 2006].

- **Power Films Inc.** was founded in 1988 to develop and manufacture thin film silicon solar cells. The company announced in its 2008 first half year report that it continues to make progress with its strategic objective of achieving 10 MW production capacity by the end of 2009 and 24 MW of capacity by the end of 2010.

6.5.8 AE Polysilicon

AE Polysilicon was founded in 2006 to manufacture polysilicon for the solar industry. On 19 February 2008 the company broke ground on its production facility at its site at the Keystone Industrial Port Complex (KIPC) in Fairless Hills (PA). The initial 1,800 ton facility is scheduled to start test production in late 2008 and commercial production in 2009.

6.5.9 Hemlock Semiconductor Corporation

Hemlock Semiconductor Corporation is based in Hemlock, Michigan. The corporation is a joint venture of Dow Corning Corporation (63.25 %) and two Japanese firms, Shin-Etsu Handotai Company, Ltd. (24.5 %) and Mitsubishi Materials Corporation (12.25 %). The company is the leading provider of polycrystalline silicon and other silicon-based products used in the semiconductor and solar industry.

In 2007 the company had an annual production capacity of 10,000 tons of polycrystalline silicon and an expansion of the Hemlock site is underway to increase capacity to 14,500 tons in 2008 and 19,000 tons in 2009.

6.5.10 Hoku Scientific, Inc.

Hoku Scientific is a material science company founded in 2001 and based in Kapolei, Hawaii. The company has three business units: Hoku Fuel Cells, Hoku Solar and Hoku Materials.

In September 2008 Hoku Materials announced that they hade adjusted their planning for the polysilicon manufacturing plant located in Pocatello (ID) to 3,500 tons in order to meet customer demand [Hok 2008]. Reactor demonstration is currently planned for the first quarter of 2009 and the plant should become operational at full capacity in 2010.

6.5.11 MEMC Electronic Materials Inc.

MEMC Electronic Materials Inc. has its headquartered in St. Peters, Missouri. It started operations in 1959 and the company's products are Semiconductor-grade Wafers, Granular Polysilicon, Ultra-high purity Silane, Trichlorosilane (TCS), Silicon Tetraflouride (SiF4), Sodium Aluminum Tetraflouride (SAF). MEMC's production for 2007 is reported with 5,125 tons and increased their production capacity to more than 6,000 tons [Pvn 2008a, Mem 2008]. The company plans to increase capacity further to 8,000 tons at the end of 2008 and 15,000 tons in 2010.

7. THE EUROPEAN UNION

The political structure of the European Union with now 27 Member States is quite diverse and there is no unified approach towards renewable energies yet. However, during the European Council Meeting in Brussels on 8/9 March 2007, the Council endorsed a binding target of a 20% share of renewable energies in the overall EU energy consumption by 2020 and a 10% binding minimum target to be achieved by all Member States for the share of Biofuels in overall EU transport petrol and diesel consumption [CEU 2007].

In order to meet the new targets, the European Council called for an overall coherent framework for renewable energies which could be established on the basis of a Commission proposal in 2008 for a new comprehensive Directive on the use of all renewable energy resources [EC 2008]. It was decided that this proposal should be in line with other Community legislation and could contain provisions as regards:

- Member States' overall national targets;
- National Action Plans containing sectoral targets and measures to meet them; and
- Criteria and provisions to ensure sustainable production and use of Bioenergy and to avoid conflicts between different uses of biomass.

This Decision exceeds the targets set within the White Paper “Energy for the Future: Renewable Sources of Energy” [EC 1997] and the Green Paper “Towards a European Strategy for the Security of Energy Supply” [EC 2000]. The goals were that renewable energies should provide 12% of the total and 21% of electric energy in the European Union by 2010, in order to meet the obligations of CO_2-reductions pledged in the Kyoto Protocol and to lower the dependence on energy imports.

For this purpose, targets were set in the European Renewable Grid Directive [EC 2001]. Indicative targets for the share of Electricity from Renewable Energy Sources (RES-E) were set for each Member State (Fig. 18 and 19). However, Member States have the freedom to choose the kind of support schemes (measures and incentives) by which they wish to achieve the targets. The Member States are obliged to report on the progress of implementation and success of the chosen methods, every two years. The Directive also regulates grid access and obliges Member States to ensure a non discriminatory treatment of electricity generated by renewable energies.

The EU15 Member States adopted national targets in line with the reference values listed in Annex I of the Directive; the 12 New Member States have also committed to national targets in their Accession Treaties in April 2003 and April 2005. Consequently, these national targets are, on the whole, also sufficiently ambitious to achieve the EU-27 target of a 21% RES-E share by 2010.

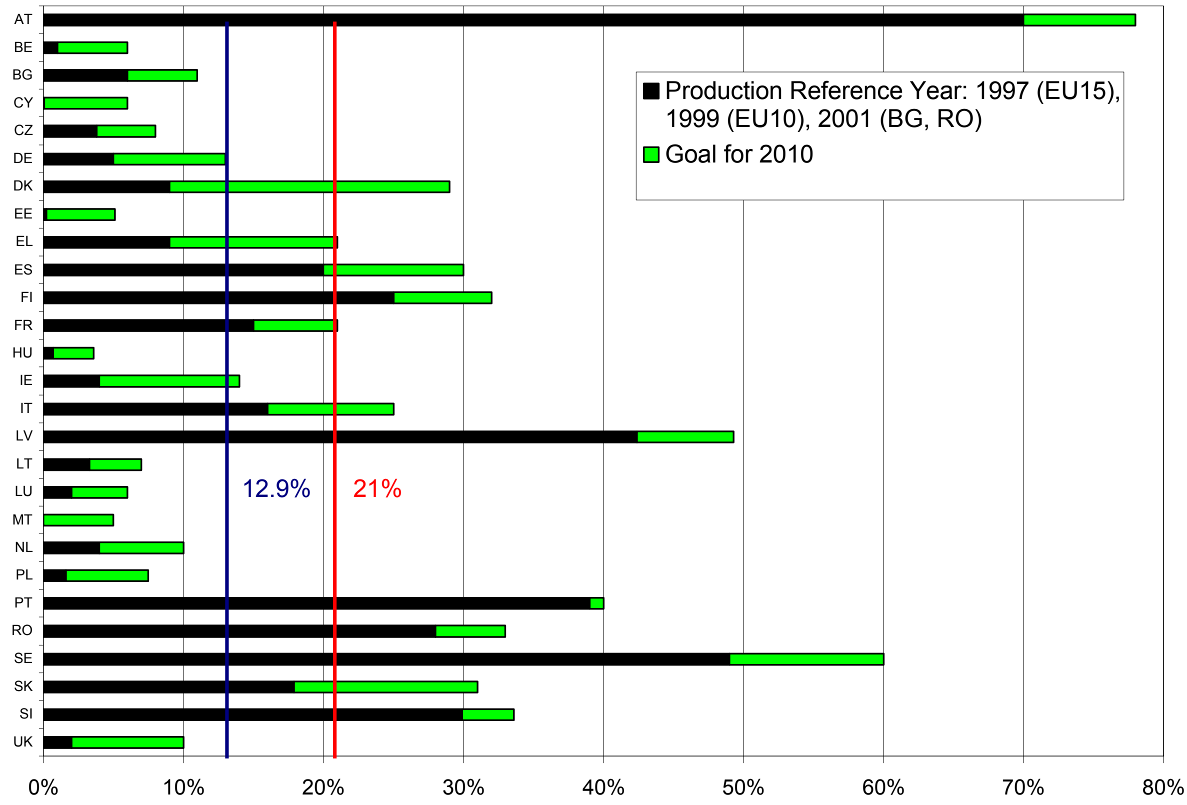

Fig. 18: Share of renewable energies of total European Union electricity production

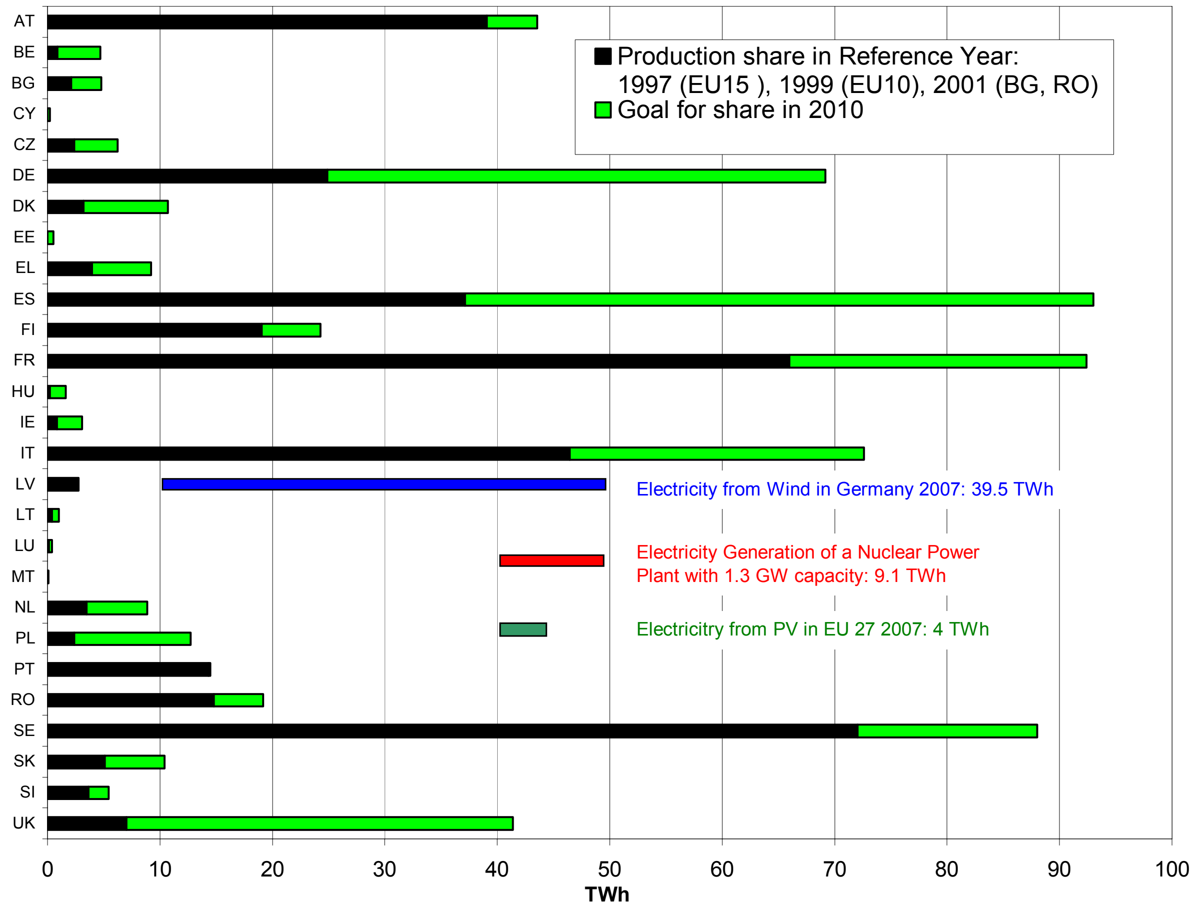

Fig. 19: Electricity generation in TWh from renewable energies in the European Union

The target for the cumulative Photovoltaic systems capacity installed in the European Union by 2010 was 3,000 MW, or a 100-fold increase of the capacity in 1995. Electricity generation from these PV systems would then be in the order of 2.4 to 3.5 TWh, depending under which climatic conditions these systems are installed.

A first monitoring communication on this Directive showed that many Member States are behind in implementing their own targets and thus the overall EU-goal [EC 2004]. It revealed the status of non-achievement for some RE-Technologies, and substantial differences in compliance with the national targets between the Member States. The interpretation was underpinned by a first Commission-staff working document including country profiles [EC 2004a].

In the autumn of 2005, the Commission presented a second report on the Directive containing experiences gained with the application and co-existence of the different mechanisms [EC 2005]. The report concluded that it is too early to harmonise the support schemes for renewable electricity and that a co-ordinated approach should be followed in order to reach the 2010 targets.

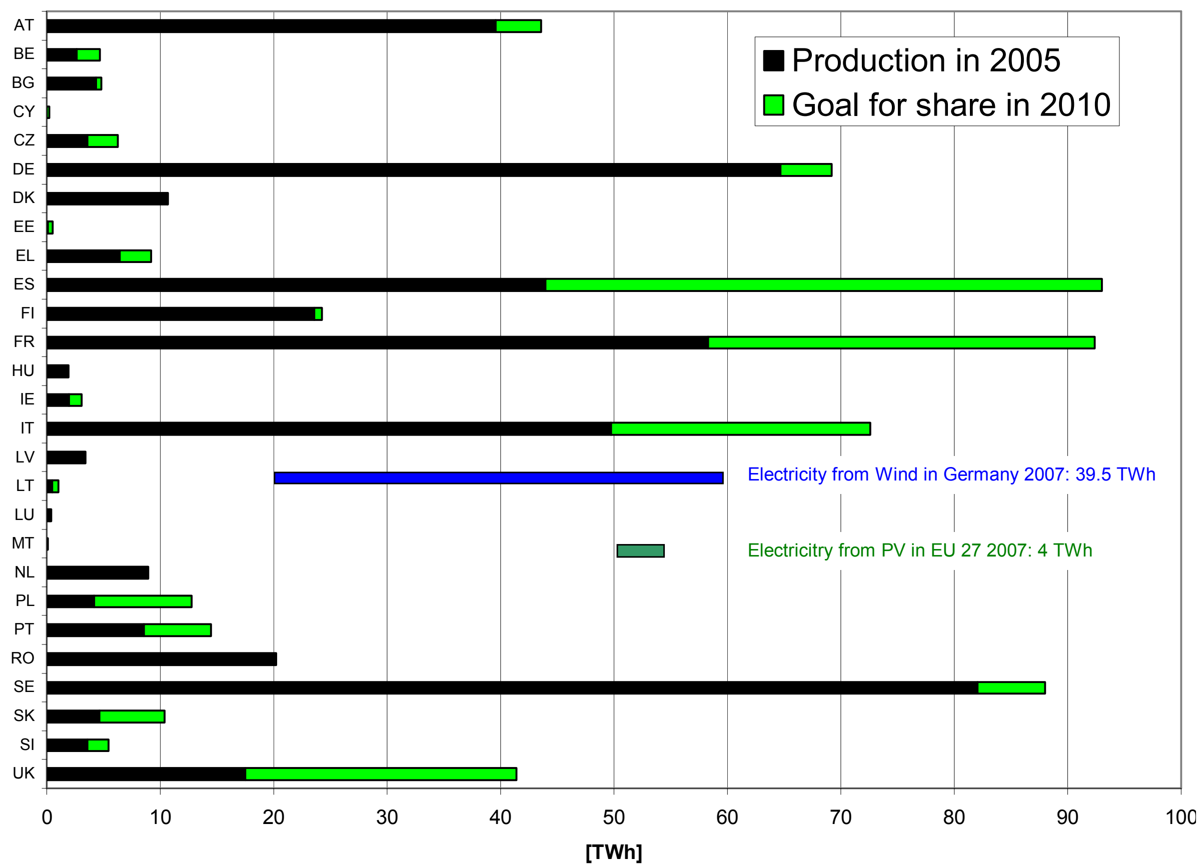

Fig. 20: Electricity generation in TWh from renewable energies in the European Union (Status 2005)

"Due to widely varying potentials and developments in different Member States regarding renewable energies, a harmonisation seems to be very difficult to achieve in the short term. In

addition, short term changes to the system might potentially disrupt certain markets and make it more difficult for Member States to meet their targets. Nevertheless, the advantages and disadvantages of harmonisation towards the different current systems have to be analysed and monitored, also notably for the medium to longer term development."

"The Commission considers a ***co-ordinated*** *approach to support schemes for renewable energy sources to be appropriate, based on two pillars:* ***co-operation*** *between countries and optimisation of the impact of national schemes."*

The Draft Directive presented in January 2008 just indicated the overall percentage of renewable energies for the different Member States (Fig. 21), leaving it to their decision what kind of technologies to utilise in order to reach the national targets [EC 2008]. It is expected that the European Parliament finalises its discussions with a final vote on the Directive in December 2008.

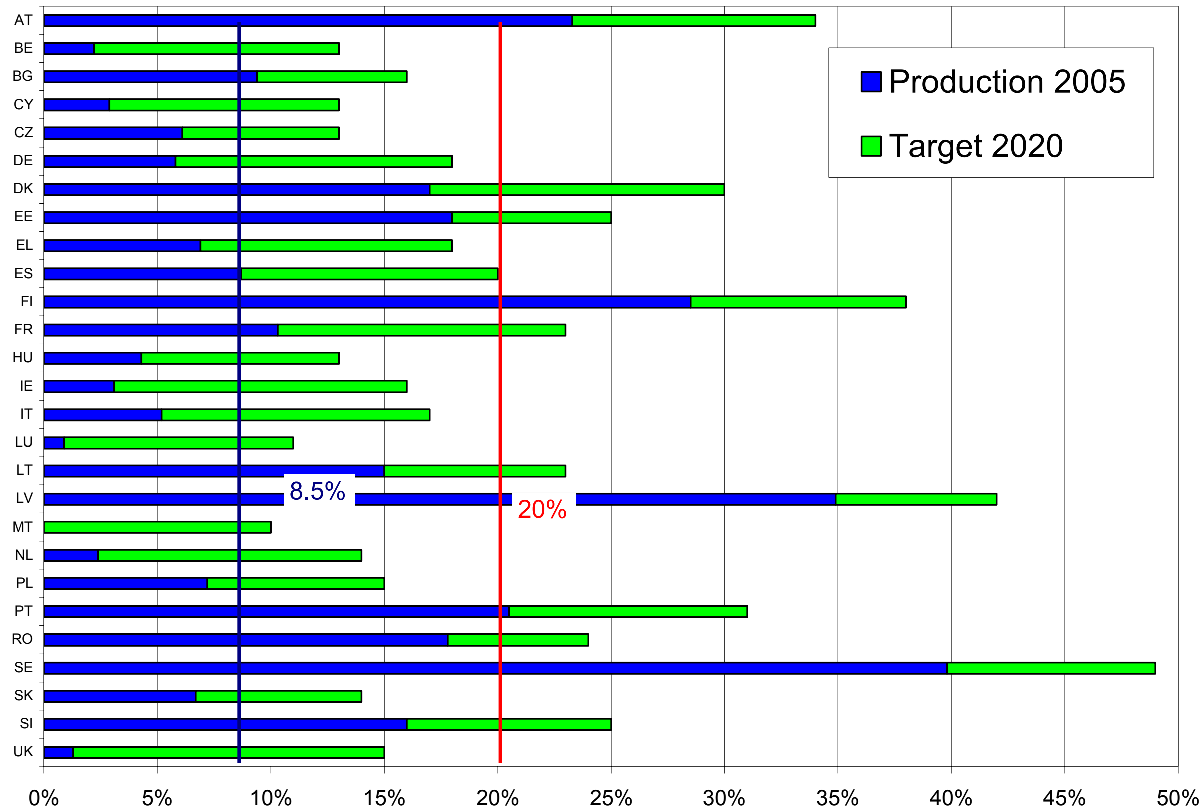

Fig. 21: Share of renewable energies in the European Union in 2020

7.1 Market and Implementation in the European Union

The 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 grade of liberalisation of domestic electricity markets. Between 2001 and 2007, installations of Photovoltaic systems in the European Union increased more than ten times and reached 4.7 GW cumulative installed capacity at the end of 2007 (Fig. 22) [Sys 2008].

In 2007, like the years before, Germany was the largest single market with 1,100 MW, followed by Spain with 340 MW and Italy with 50 MW [Sys 2008]. Since 2005 the estimates of the German Solar Industry Association and the Photon magazine differ significantly. The discrepancies in the reported data arise from the different data collection methods, ranging from installer surveys to grid operator surveys and inverter sales statistics. Unfortunately, the annual statement of the German Federal Energy and Water Association (Bundesverband der Energie- und Wasserwirtschaft – BDEW) on the kWhs actually produced cannot be used, as this is not available before September/October of the following year and in the last years it was even corrected after that. Therefore, it is difficult to verify the different numbers. However, it is clear that more than 80% of the EU 27 PV installations are in Germany (Fig. 22). For 2007 the BDEW reports 3.07 TWh electricity produced from PV solar electricity systems in Germany, for 2008 the estimate made in April 2008 is 5 TWh and in its annual prognosis from September 2008, the estimate for 2009 is 5.6 TWh [Bde 2008, a,b].

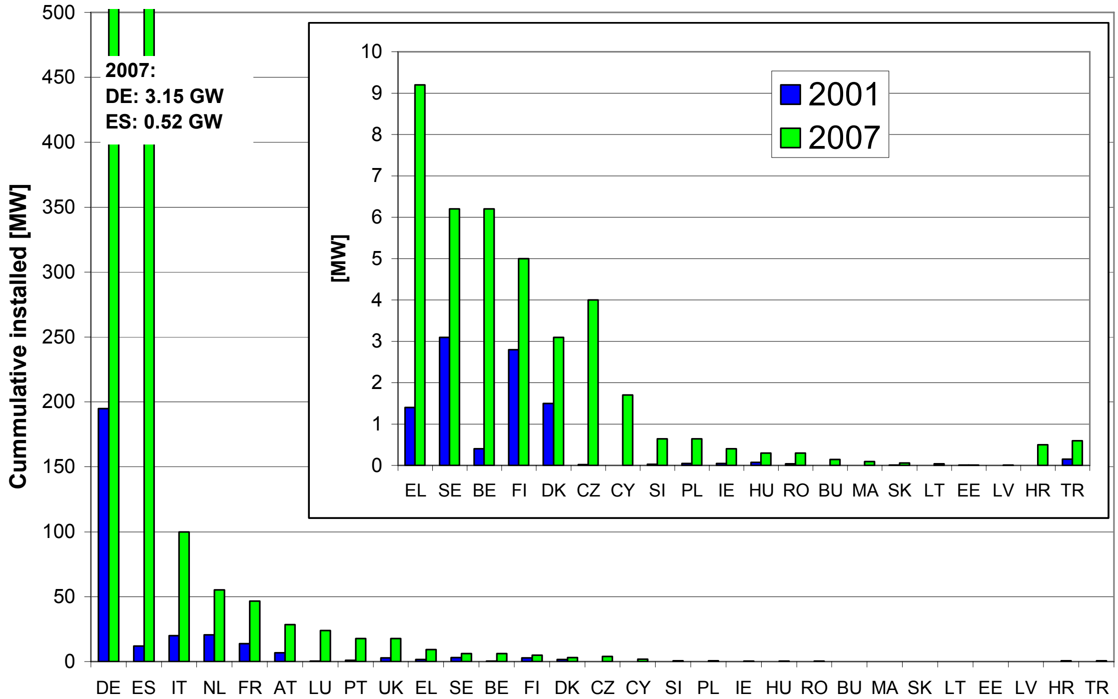

Fig. 22: Cumulative installed grid connected PV capacity in EU + CC. Note that capacities do not seem to correlate with solar resources.

As foreseen in the *"Erneuerbare-Energien-Gesetz"* (EEG) the feed-in tariffs were reviewed and the new law was passed on 6 June 2008 by the Bundestag (Parliament) and on 4 July by the Bundesrat (Federal Council) [EEG 2004, EEG 2009]. In the new law the feed-in tariffs are reduced by more than 12% from 2008 to 2009 and the degression for new systems increases from 5% resp. 6.5% to 8 and 10% in 2010 and 9% in 2011 and after. To limit the monetary effects of the feed-in regime to consumers without introducing a cap, the law has an additional provision to increase or decrease the degression rate if the market growth is above or below a certain volume in 2009, 2010 and 2011 (details see Table 16).

In 2007, the Spanish market grew to 340 MW of annual installations [Sys 2008] and in 2008 almost 1 GW is expected to be installed. The reason for this drastic market expansion was the Spanish Government's approval of the *Plan de Energías Renovables en España* (PER) for 2005 – 2010 in August 2005. The objectives were to cover 12.1% of Spain's overall energy needs and 30.3% of total electricity consumption with renewable energy sources by 2010. The generous feed-in tariffs set by the Royal Decree 436/2004, dated 12 March 2004, started the development of the Spanish PV market. In 2007 the Royal Decree 661/2007 was passed with an increased cap of 1.200 MW for PV installations and triggered a run on permits to install multi-megawatt free-field solar Photovoltaic electricity systems. This development led to the revision of the solar PV legislation in 2008, and the new Royal Decree 1758/2008 which was approved on 26 September 2008. The new decree sets considerably lower feed-in tariffs for new systems and limits the annual market to 500 MW with the provision that two thirds are rooftop mounted and no longer fee field systems.

The Italian feed-in tariffs, agreed in July 2005, led to a steep rise in applications in the second half of 2005 and the first half of 2006, but only a moderate increase in the amount of new systems capacity could be observed in 2006. After the end of the first quarter of 2006, applications with more than 1.3 GW were submitted to the "implementing body" *Gestore del Sistema Elettrico* (GRTN SpA.), 2.6 times more than the 500 MW cap up to 2012. The actual installations in 2006 were only 12.5 MW, far less than the 50 to 80 MW predicted. On 19 February 2007 a Decreto interministeriale was issued, which changed the national target for cumulative installed PV systems from 2,000 MW in 2015 to 3,000 MW in 2016 [Gaz 2007]. This led to a steep growth in PV installations and 50.2 MW were installed in 2007 [Sys 2008].

Revised feed-in tariffs in France went into force on 26 July 2006 and resulted in a moderate growth of the French PV market. In 2006 and 2007 just 7.6 MW and 12.8 MW were installed [Sys 2008], despite the rather attractive and cost competitive feed-in tariff for PV installations integrated in a building. The general tariff is 0.30 €/kWh (0.40 €/kWh in Overseas Departments and Corsica) for 20 years. For building-integrated PV installations, there is a supplement of 0.25 €/kWh (0.15 €/kWh in Overseas Departments and Corsica). In addition, 50% of the investment costs are tax deductible and a lower VAT of 5.5% on system costs (without labour) is applied. Accelerated depreciation of PV systems is possible for enterprises. Regional support is still possible. The 5% tariff degression for new installations was cancelled. All tariffs (old and new) will be adjusted annually in accordance with the inflation during their duration. However, the legislation has a build in cap of 160 MW cumulative system capacity in 2010 and 490 MW in 2015.

The second amendment of the Ökostromgesetz (Eco electricity law) in Austria finally passed the Parliament on 1 August 2008. It is foreseen that Photovoltaic electricity systems with a capacity larger than 5 kW are eligible for an investment subsidy, but the total amount is limited to € 2.1 million. The provisions of the first amendment in 2006 stating that electricity from all renewable energy sources is supported with € 17 million per year and 10% are earmarked for PV, were not changed. As this money is already allocated to the existing systems, new systems can only receive investment subsidies. How large the interest in PV systems is became obvious, when the handout of the € 8 million investment subsidies for PV systems from the Climate Fund ended after about 30 minutes on 18 July 2008.

It came as a surprise, when Switzerland adopted in April 2008 their new feed-in tariffs which range between 0.90 CHF/kWh (0.563 €/kWh[16]) for small building integrated systems < 10kW and 0.49 CHF/kWh (0.306 €/kWh) for ground mounted systems > 100 kW. In 2007 7 MW of PV systems were installed, bringing the cumulative capacity to 29 MW. However, the budget for PV is caped to 5% of the total amount or roughly CHF 16 million (€ 10 million), which can be spent for the support of electricity from Renewable Energy Sources. The application phase opened on 1 May 2008 and included new systems as well as those which became operational after 1 January 2006. The number of applications received in May alone already exceeded by far the fundable capacity.

Despite the fact that the European PV production grew again by almost 60% and reached 1,060 MW, the huge German market demand did not change the role of Europe as a net importer of solar cells and/or modules. Further capacity expansions and technology progress are necessary to change this in the future and to secure a leading role of the European PV industry.

The support measures for Photovoltaics in the European Union Member States and Switzerland are listed in Table 16.

Table 16: Support mechanisms for Photovoltaic in the European Union and Switzerland

Austria	The second amendment of the Austrian Eco Electricity Law (Ökostrom-gesetz) will go into force on 1 January 2009. There are no new feed-in tariffs for new solar electricity systems. **Key elements of the Law are:** Eco electricity generation is supported with investment subsidies and feed-in tariffs. New PV systems with a capacity larger then 5 kW are only eligible for an investment subsidy. Some of the Federal States have additional investment support schemes.

[16] Exchange Rate: 1 € = 1.60 CHF

Belgium [Ode 2006]	Green Certificates (with guaranteed minimum price): 0.15 €/kWh; Flanders from 1 January 2006: 0.45 €/kWh for 20 years. Additional support in Flanders depends on whether the PV installation is done privately, by an enterprise or a farmer. The support schemes used are investment subsidies, eco premiums, tax reductions and interest reduced mortgages.
Bulgaria	In 2007 new feed in tariffs for Renewable Electricity were introduced. The State Energy and Water Regulatory Commission has adopted the commitment to purchase alternative energy at a higher tariff and for the duration of 12 years. Suppliers refusing to accept renewably-produced electricity would be fined up to € 500,000 in response to renewable power producers' reports of difficulty in grid connection. The tariffs for PV are: • 0.782 BGN/kWh (0.3998 €/kWh)[17] for systems up to 5 kW • 0.718 BGN/kWh (0.3598 €/kWh) for systems over 5 kW
Cyprus	Investment grants for households, other entities and organisations, not engaged in economic activities are limited to a maximum 55% of the eligible costs and the maximum grant is 16.5 k€ (CY£ 9.500). For enterprises, the grant is 40% of eligible costs and the maximum amount of the grant is 12 k€ (CY£ 7.000). 2007: New feed-in tariff guaranteed for 15 years for systems up to 20 kW capacity: Without investment subsidy • 0.224CYP£/kWh (0.415 €/kWh)[18] for households • 0.196CYP£/kWh (0.363 €/kWh) for enterprises. With investment subsidy • 0.12CYP£/kWh (0.222 €/kWh).
Czech Republic	New Law on the Promotion of Production of Electricity from Renewable Energy Sources went into effect on 1 August 2005. Feed-in is guaranteed for 15 years. Producers of electricity can choose from two support schemes: • Fixed feed-in tariff for 2007: Systems commissioned after 01/01/06: 13.46 CZK/kWh (0.538 €/kWh)[19] Systems commissioned before 01/01/06: 6.41 CZK/kWh (0.2568 €/kWh) • Market price + Green Bonus; Green Bonus for 2007 Systems commissioned after 01/01/06: 12.75 CZK/kWh (0.51 €/kWh) Systems commissioned before 01/01/06: 5.70 CZK/kWh (0.228 €/kWh) From 2007 onwards the annual price decrease for new installations should be 5% maximum. In 2007 the tariff was slightly increased compared to 2006. No change from 2007 to 2008.
Denmark	No specific PV programme, but settlement price for green electricity 60 Øre/kWh (0.08 €/kWh) for 10 years, then 10 more years 40 Øre/kWh.

17 Exchange rate: 1 € = 1.9958 BGN

18 Exchange rate: 1 € = 0.5401 CYP

19 Exchange rate: 1 € = 25 CZK

Estonia	No specific PV programme, but Renewable Portfolio Standard and tax relief. Feed-in tariff for 12 years for electricity produced out of RES except wind is: • 1.16 EEK/kWh (0.074 €/kWh)[20]. Start of operation 2007 – 2009 • 0.85 EEK/kWh (0.054 €/kWh) start of operation 2010 ff.
Finland	No PV programme, but investment subsidy up to 40% and tax/production subsidy for electricity from renewable energy sources (6.9 €/MWh).
France	New feed-in tariff since 26 July 2006: (only valid for new installations) 0.30 €/kWh (0.40 €/kWh in Overseas Departments and Corsica) for 20 years. For building-integrated PV installations there is a supplement of 0.25 €/kWh (0.15 €/kWh in Overseas Departments and Corsica). 50% of the investment costs are tax deductible. Lower VAT of 5.5% on system costs (without labour). Accelerated depreciation of PV systems for enterprises. Regional support still possible. The 5% tariff digression for new installations was cancelled. All tariffs (old and new) will be adjusted annually in accordance to the inflation during their duration.
Germany	The new feed-in tariff for 20 years and annual degression rates passed the German Parliament on 6 June 2008 and are valid from from 1 January 2009. **Tariffs for new installations in 2009:** • System size < 30 kW: 0.4301 €/kWh • System size 30 to 100 kW: 0.4091 €/kWh • System size 100 kW to 1 MW: 0.3958 €/kWh • System size > 1 MW: 0.33 €/kWh The annual degression rate for new systems increased as follows: • System size < 100 kW: 2010 – 8% • System size > 100 kW: 2010 – 10% • From 2011: 9% for all system sizes In addition there is a build in increase or decrease of the degression rate if the installed capacity is above or below certain values in the year before. In order to monitor this all new systems which become operational after the 1 January 2009 have to be registered in a central PV system register. • Increase of degression rate by 1% the following year if the following installed capacity is exceeded: 2009: 1,500 MW, 2010: 1,700 MW, 2011: 1,900 MW • Decrease of degression rate by 1% the following year if the following installed capacities are not reached: 2009: 1,000 MW, 2010: 1,100 MW, 2011: 1,200 MW The former façade integration bonus was cancelled.

[20] Exchange rate: 1 € = 15.64 EEK

Greece	Feed-in tariff: 0.45 €/kWh (0.50 €/kWh on islands) for systems < 100 KWp and 0.40 €/kWh (0.45 €/kWh on islands) for systems > 100 KWp guaranteed for 20 years. Commercial installations are eligible for grants (30 to 55% of total system costs), while small domestic systems are eligible for a 20% tax deduction capped at € 500 per system (€ 700 in 2007). For 2020 a target to reach at least 700 MWp (500 MWp mainland, 200 MWp islands) has been set.
Hungary	Support for RES is regulated through the Electricity Act, which entered into force on 1 January 2003. From January 2008 onwards the feed-in tariff for PV is: 26.46 HUF/kWh (0,106 €[21])
Ireland	The Alternative Energy Requirement (AER) Tender Scheme was replaced by a new Renewable Energy Feed in Tariff (ReFIT) scheme in 2006. However, PV is not included.
Italy	Feed-in tariff (23 February 2007): guaranteed for 20 years. The tariffs for 2007 and 2008 are listed below, after that there is a 2% decrease for new systems each year. National target of 2,000 MW for 2015 was changed to 3,000 MW in 2016 [Gaz 2007]. Nominal Power — not integrated — partly integrated — building integrated 1 – 3 kWp — 0.40 €/kWh — 044 €/kWh — 0.49 €/kWh 3 – 20 kWp — 0.38 €/kWh — 0.42 €/kWh — 0.46 €/kWh > 20 kWp — 0.36 €/kWh — 0.40 €/kWh — 0.44 €/kWh The following additions exist: • 5% bonus if in the case of a non-integrated system 70% of the electricity is used by the producer. • 5% bonus for all systems on schools and public health buildings, as well as for all public buildings of communities with less than 5,000 inhabitants. • 5% bonus for integrated systems on farms and if cladding of asbestos cement is substituted.
Latvia	Feed-in tariff for RES but not PV specific: Licensed before 01.06.2001: double the average sales price (~ 0.101 €/kWh) for eight years, then reduction to normal sales price. Licensed after 01.06.2001: Regulator sets the price The feed in system has been amended through Regulation N°. 503 on Electricity Production from RES (in force since August 2007) but without PV provisions. A national investment programme for RES has been running since 2002.
Lithuania	No specific PV support. National Control Commission for Prices and Energy approves **long-term purchase prices for renewable electricity**, and grid operators must give priority to its transport.

[21] Exchange rate: 1 € = 250.26 HUF

Luxembourg	A support scheme was set with a "Règlement Grand Ducal" in September 2005. The Règlement had a cap of 3 MW by 2007. The feed-in tariffs have been amended in February 2008. The new tariffs are in force for installations starting which became operational after **1 January 2008**. Tariffs are guaranteed over 15 years with simpler administrative procedures. They are differentiated according to technology and capacity. Some tariffs are degressive. For Photovoltaic, this tariff is set as follows: • System size ≤ 30 kW: 0.42 €/kWh (with an annual degression rate of 3%) • System size 31 to 1,000 kW: 0.37 €/kWh In addition investment subsidies are available to private companies (Framework Law of Economy Ministry- Framework Law of the Ministry of Middle Classes), communes (Environment Protection Fund of the Environment Ministry), farmers (Law from the Agriculture Ministry supporting rural development) and households (Regulation of 21 December 2007 of the Environment Ministry) investing in RES-E technologies. In January 2008, new grants for households entered into force to promote RES-E: Investment aid amounts to 30% of the investment for all PV panels.
Malta	Net metering for electricity from PV systems. At the moment it is difficult to determine the value due to the fact that an energy surcharge which changes every two months is applied. Surplus exported to the grid: 0.07 €/kWh. 20%-grant for roof-top PV installations.
Netherlands	In October 2007, the Dutch government published a new regulation for a feed-in premium for renewable energy. The new support mechanism, called SDE ('Stimuleringsregeling duurzame energieproductie') resembles the old MEP premium system. Producers will get a premium covering extra costs on top of the wholesale energy price for a number of years. The premium will be provided to the generator of green power for maximum ten years. The new Premiums published in January 2008 for electricity generated with small PV systems (0.6 – 3 kWp) are 0.33 €/kWh Premium + 0.234 €/kWh expected electricity price.
Poland	No specific PV programme. In January 2007, changes in the Energy Law Act were made resulting in the requirement of an energy generation licence regardless of the power installed (previously required only > 50 MW). An excise tax exemption on RES-E was introduced in 2002. It amounts to 0.02 PLN/kWh (0.585 €cent/kWh)[22].
Portugal	Revision of feed-in tariff in 2005 with cap of 150 MW (2010). The tariff is guaranteed for the first 15 years or 21 GWh/MW (whatever is reached first). : • 0.45 €/kWh < 5 kWp • 0.28 €/kWh > 5 kWp. Reduction of VAT rate from 21 % to 12 % on renewable equipment, custom duties exemption and income tax reductions (up to € 730 for solar equipment).

[22] Exchange rate: 1 € = 3.4190 PLN

Romania	No specific programme for PV. For the promotion of the production of electricity from Renewable Energy Sources, a system of Tradable Green Certificates is in place. For the period 2005-2012, the annual maximum and minimum value for Green Certificates trading is 24 € per certificate, respective 42 € per certificate, calculated at the exchange rate established by the Romanian National Bank, for the last working day of December of the previous year. The penalty level is 0.84 €/kWh.
Slovakia	Feed-in tariff set by regulator each year. The new feed-in tariff for 2009 is 13.2 SKK/kWh (0.434 €/kWh[23]) guaranteed for 12 years. In addition, PV like all other RES, qualifies for investment subsidies under the framework of the EU Structural funds.
Slovenia	Feed-in tariff: either fixed-price or electricity price (3.36 €cent/kWh) + premium. The plant size limit was removed in June 2006. Uniform annual price / Uniform annual premium 0.377 €/kWh / 0.343 €/kWh
Spain	New feed-in tariff with cap of 400 MW + 100 MW (addition for ground based systems) were decided on September 2008 with a provision that two thirds of the 400 MW installations will be on roof-tops. Current tariffs are: • 0.34 €/kWh < 20 kWp; building integrated and rooftop • 0.32 €/kWh > 20 kWp; building integrated and rooftop, max. 2 MW • 0.32 €/kWh ground mounted systems up to a maximum size of 10 MW
Sweden	No specific PV programme. Energy tax exemption.
Switzerland	New feed-in tariff in 2008 for new PV systems and those which became operational after 1 January 2006 (Current Budget cap: CHF 16 million or € 10 million): Nominal Power / Ground mounted / Rooftop / Building integrated [CHF/kWh (€/kWh)][24] < 10 kWp / 0.65 (0.406) / 0.75 (0.469) / 0.90 (0.563) 10 – 30 kWp / 0.54 (0.338) / 0.65 (0.406) / 0.74 (0.463) 30 – 100 kWp / 0.51 (0.319) / 0.62 (0.389) / 0.67 (0.419) > 100 kWp / 0.49 (0.306) / 0.60 (0.375) / 0.62 (0.389)
United Kingdom	Investment subsidies in the framework of a PV demonstration programme. Reduced VAT. Renewable Obligation, but not PV specific.

As depicted in Table 16, 15 out of 27 Member States and Switzerland have already introduced feed-in tariffs. However, the efficiency of this measure to increasingly exploit these countries' PV-potential varies considerably in function of the details in each national regulation. In those States where the tariff does not cover the expenses, impact is very limited. In some other States there is a motivating tariff, but its effectiveness is limited due to

[23] Exchange rate: 1 € = 30.396 SKK

[24] Exchange rate: 1 € = 1.60 CHF

- too early fulfilling the cap,
- too short a period of validity for the guaranteed increased tariff, or
- administrative requirements being too complicated or even obstructive.

Only in those countries in which the tariff has been high enough to recuperate the investment cost in a reasonable time, and a set cap realistic enough, have PV installations increased and competition in production and trade developed substantially. From the socio-economic data at hand, feed-in tariffs should be designed to potentially enable a pay-back of the initial investment within 10 to 12 years and should be combined with a built-in "sun-set". Such a decrease of the guaranteed tariff by a certain percentage each year compensates early technology users, enforces realistic price reductions, if well designed, and offers a long-term perspective for investors and producers of solar systems.

The New Member States and Candidate Countries still have much lower installation figures, despite good to very good solar resources, in some States with up to 1,600 kWh/kWp (Cyprus, Malta, Romania, Bulgaria, and South-East Hungary). Even in the Baltic States yearly average values of more than 800 kWh per year are possible for a 1 kWp system, which is comparable to Northern Germany [Sur 2004].

An important advantage for feed-in tariffs comes to light when analysing the effectiveness with which individuals are motivated – i.e. hundreds and thousands of private (domestic) investors, who have relatively easy access to grid connection, standardised accountability and last but not least, neighbourhood pride – an ideal situation for intrinsically decentralised PV-energy. Where local common action (at village or town level) or "locally centralised" investment gives better revenue, the market automatically plays its efficiency-enhancing role. Developments threatening electrical grid stability in terms of demand (e.g., large increase of air conditioning units in the Mediterranean EU) could be compensated much more economically, ecologically and socially balanced by decentralised generation and injection – partly avoiding expensive grid reinforcements. In addition, jobs would be created regionally in installation and maintenance businesses.

Stable political and socio-economically viable frame conditions do not only convince private and commercial investors to install Photovoltaic power plants, but also stimulate the investment in new production capacities for solar cells and modules. Especially in Germany and Spain, the most dynamic markets in Europe, the production capacities for solar cells and modules have increased faster than in the other European countries (Fig. 23).

It is interesting to note that since 1999, the majority of investments in solar cell production facilities in Europe were made in Germany and Spain – the two countries that offered so far the most stable and realistic legal framework conditions for citizens investing in a PV system. Only two of the current top-ten European companies hold this position since 1999.

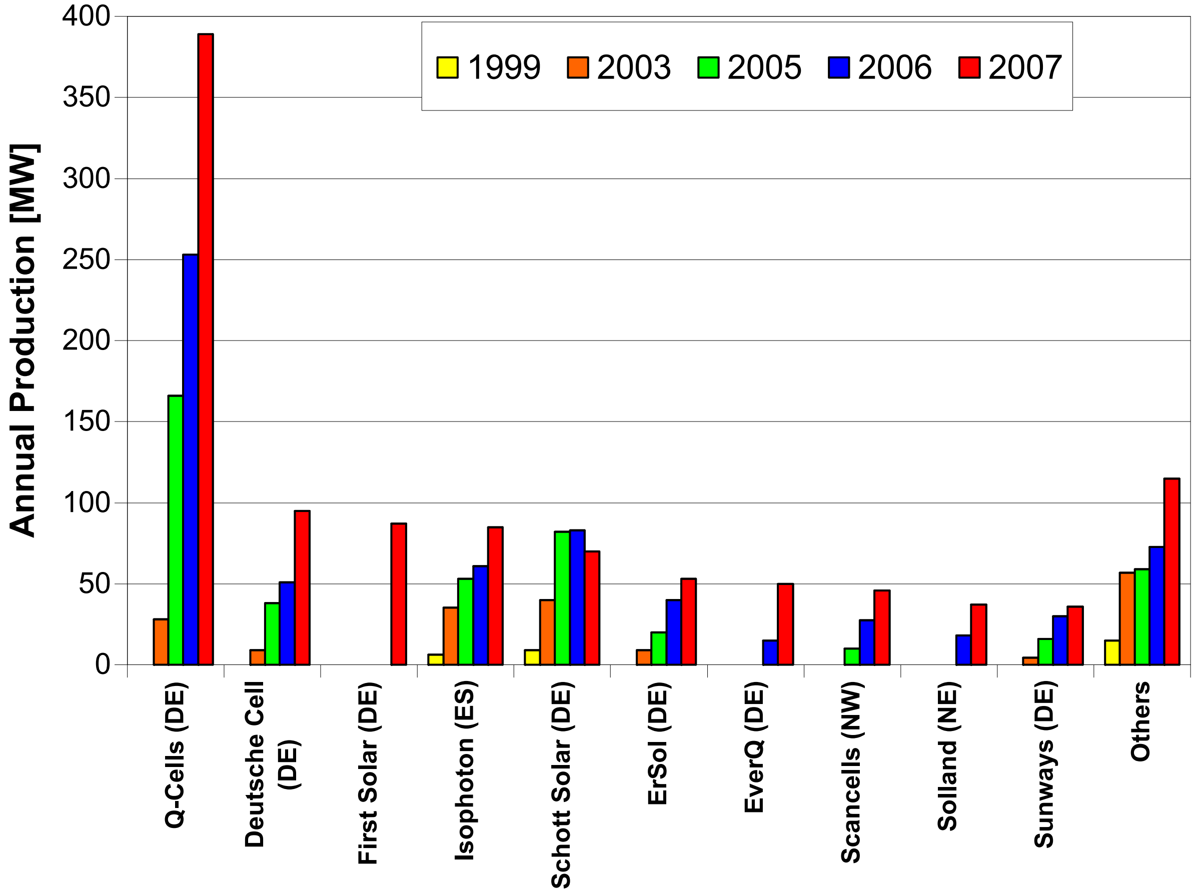

Fig. 23: Annual production of the 10 largest European PV manufacturers in 2007 [Pvn 2008]

Based on information provided by the industry, Greenpeace and EPIA have assumed in their new study "Solar Generation V – 2008" that 10 jobs are created per MW during production and about 33 jobs per MW during the process of installation [Gre 2008]. Wholesaling of the systems and indirect supply (for example in the production process) each create 3-4 jobs per MW. Research adds another 1-2 jobs per MW. Based on this data the employment figures in Photovoltaics for the European Union was estimated to be about 70,000 in 2007. This corresponds quite well with figures reported from 42,600 jobs [Bsw 2008] respectively 38,600 jobs [Kra 2008] reported for Germany and 26,500 for Spain [Aso 2008].

In 2005, the European Commission did an impact assessment to evaluate the effectiveness of support measures for renewable energies in the European Union. The results were published in the Communication from the Commission "The support for electricity from renewable energy sources" already states [EC 2005a]:

*The renewable energy sector is particularly promising in terms of **job and local wealth creation**. The sector invests heavily in research and technological innovation and generates employment, which to a very high degree means skilled, high quality jobs. Moreover, the renewable energy sector has a decentralised structure, which leads to employment in the less industrialised areas as well. Unlike other jobs, these jobs cannot be "globalised" to the same* *extent. Even if a country were to import 100% of its renewable energy technology, a significant number of jobs would be created locally for the sale, installation and maintenance of the systems. A number of studies on the job creation effects have already been published and different estimates have been provided [Epi 2004a, Ere 2004, Ike 2005].*

It is of no surprise that the studies quoted refer to the Photovoltaics industry. The German Solar Industry Association reported that despite the fact that a significant amount of the solar cells installed in PV systems in Germany are imported, more than 65% of the added value stays within the German economy [Bsw 2008].

Electricity generated with Photovoltaic systems has additional positive benefits for the European economy in the long run. First, with increasing installations of Photovoltaic systems, the electricity generated can help to reduce the import dependency of the European Union on energy imports. The impact assessment already quoted states:

Rising oil prices and the concomitant general increase in energy prices reveals the vulnerability and dependency on energy imports of most economies. The European Commission's DG ECFIN predicts that a \$10/bbl oil price increase from \$50 to \$60/bbl would cost the EU about 0.3% growth and the US 0.35% [EC 2005b]. For the European Union, the negative GDP effect would be in the order of €41.9 billion from 2005 to 2007. ***Further price increases would worsen the situation****.* (It would be interesting to have a new assessment with the current oil prices) *The European Renewable Energy Council (EREC) estimates that € 140 billion in investment would be required to reach the 2010 goal of 12% renewable energy consumption [Ere 2004]. This would ensure fuel cost savings of €20 billion (not even taking into account the substantial price increases since 2003 and the spike in July 2008[25] [IEA 2008]) and reduce external costs by €30 to €77 billion. If we add the employment benefits, the overall costs for society can be estimated to be positive compared to a negative result if no RES were introduced. 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 economic benefits of avoided fuel costs and external costs (GHG), money which could be spent within the economy and used for local wealth creation [Awe 2003].*

Second, electricity from Photovoltaic systems is generally produced during times of peak demand, or economically speaking, when electricity is most expensive. In addition, Photovoltaic electricity is produced at its best during those times when in the case of extreme heat and resulting water shortages thermoelectric power plants have to reduce their output due to a lack of cooling water.

During the extreme heatwave in July 2006, peak prices paid at the European Electricity Exchange (EEX) spot market exceeded the feed-in tariff paid in Germany.

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[25] Crude oil prices went up from US\$26/bbl (June 2003) and spiked at almost US\$ 15080 (July 2008), source: Oil report IEA

The continuous expansion of the production capacities for solar cells is of particular importance in the light of the export markets for solar systems to the rural areas in Asia, Africa and South America, where about 2 billion people are still without electricity. The Europeans should not lose this future market, also with respect to the possibility it offers for the labour market. In June 2004 the European Photovoltaic Industry Association (EPIA) published its Photovoltaics Roadmap and stated therein: *"Failure to act on the recommendations of this Roadmap will be a huge missed opportunity. Europe will suffer the loss of its current strong market position and potential major industry for the future. The PV industry can be of great importance to Europe in terms of wealth and employment, with 59,000 PV related jobs in the EU in 2010 if the targets are met, and a figure of 100,000 jobs would be realistic if export opportunities are exploited."*

According to EPIA, new PV production facilities create about 10 jobs per MW of capacity, adding about 36 additional jobs per MW installed capacity in the wholesale, retail, installation and maintenance services sector. The latter jobs are mostly located on a regional level near to the final customer.

A prerequisite for all such developments is that parallel to the public market introduction incentives, electricity generated by solar systems can be *freely traded and attain preferential grid access.* As PV systems contribute to the avoidance of climatically harmful greenhouse gases, it has to be ensured that electricity generated from solar systems be exempt from eco taxes, where applicable. In addition, one has to enable PV system operators to sell green certificates to CO_2-producers.

In 2006 the European Union already surpassed its own target of 3 GWp cumulative installed capacity for **Renewable Electricity from Photovoltaics** for 2010. In Figure 24 the growth scenario is shown if the 2001 to 2007 growth rate can be maintained. More than 15 TWh of electricity could be generated in 2010. This would be 0.5% of the EU 27 total net production of electricity in 2005. The PV installation growth-rate curve in the European Union exactly mirrors that of wind power, with a delay of approximately 12 years.

The European PV Industry has to continue its impressive growth over the coming years, in order to maintain its market position. This will only be achieved if reliable political framework conditions are created and maintained to enable return on investment for PV investors and the industry alike. Besides this political issue, targeted improvements of the solar cell and system technology are still required.

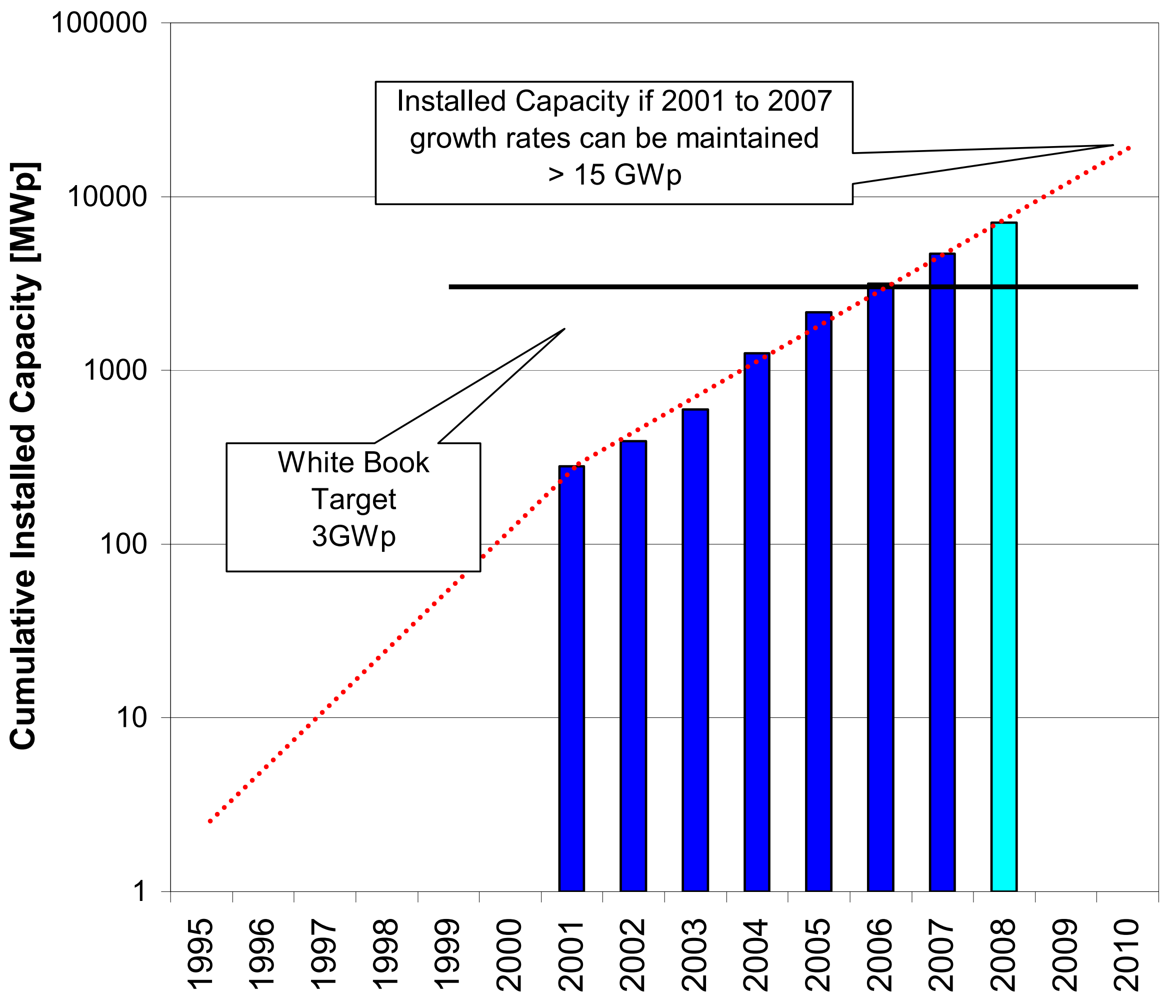

Fig. 24: PV growth in the European Union and 2010 extrapolated from 2001 to 2007 installations (2008 figures are estimates).

7.2 PV Research in Europe

In addition to the 27 national programmes for market implementation, research and development, the European Union has been funding research (DG RTD) and demonstration projects (DG TREN) with the Research Framework Programmes since 1980. Compared to the combined national budgets, the EU budget is rather small, but it plays an important role in creating a European Photovoltaic Research Area. This is of particular interest and importance, as research for Photovoltaics in a number of Member States is closely linked to EU funds. A large number of research institutions from small University groups to large research centres, covering everything from basic material research to industry process optimisation, are involved and contribute to the progress of Photovoltaics. In the following, only activities on the European level are listed, as the national or regional activities are too manifold to be covered in such a report.

The European Commission’s Research and Development activities are organised in multi-annual Framework Programmes (FP), with a duration of 4 years. Support for Photovoltaic Research Projects started in 1980. In FP4 (1994 – 1998) 85 projects were supported with a budget of € 84 million. During the next Framework Programme FP5 (1998 to 2002) the budget was increased to around € 120 million and was divided into research projects and demonstration projects. In the demonstration part, around 40 projects were supported with € 54 million and within the research budget 62 projects were funded with € 66 million.

In the 6th Framework Programme (2002 to 2006) € 810 million were foreseen for the topic “Sustainable Energy Systems”, split into two equal parts for “short to medium” and “medium to long” term research, which includes PV. However, no specific budget was earmarked, especially for PV. About € 107.5 million were allocated to Photovoltaic projects. This represents a share of roughly 13.3 % of the “Sustainable Energy Systems” budget for Photovoltaics.

In addition to these technology-oriented research projects, there were Marie Curie Fellowships and the "Intelligent Energy - Europe" (EIE) Programme. The CONCERTO initiative launched by the European Commission was a Europe wide initiative proactively addressing the challenges of creating a more sustainable future for Europe’s energy needs. CONCERTO is supervised by DG Energy and Transport and made available € 14 million for solar related projects.

During the 6th Framework Programme, the PV Technology Platform was established [Pvt 2007]. The aim of the Platform is to mobilise all the actors sharing a long-term European vision for Photovoltaics. The Platform developed the European Strategic Research Agenda for PV for the next decade(s) and gives recommendations for its implementation to ensure that Europe maintains industrial leadership [Pvt 2007a].

For the first time, the **7th EC Framework Programme** for Research, Technological Development has a duration of 7 years and runs from 2007 to 2013. The first call for projects closed on 3 May 2007 for the DG RTD managed projects (FP7-ENERGY-2007-1-RTD) and on 28 June for those managed by DG TREN (FP7-ENERGY-2007-2-TREN).

The call motivated the research topics for Phtovoltaics as follows: *Photovoltaics is the most capital-intensive renewable source of electricity. Currently, the generation costs of grid-connected PV electricity in Europe range from 0.25 €/kWh to 0.65 €/kWh, depending on both local solar irradiation and market conditions. The work will include the development and demonstration of new processes for Photovoltaic equipment manufacturing, standardised and tested building components and the demonstration of the multiple additional benefits of Photovoltaic electricity. Longer term strategies for next generation Photovoltaics (both high-efficiency and low-cost routes) will also be supported. The content of this Area takes into consideration the Strategic Research Agenda (SRA) developed within the European Photovoltaic Technology Platform.*

The Commission expects the following impacts from the research activities: *Through technological improvements and economies of scale, the cost of grid-connected PV electricity in Europe is expected to be lowered to a figure in the range of 0.10-0.25 €/kWh by 2020. Research and development should lead to reduced material consumption, higher efficiencies and improved manufacturing processes, based on environmentally sound processes and cycles.*

The following Projects were selected:

- FP7-ENERGY-2007-1-RTD
  - **APPOLON**: Multi-approach for high efficiency integrated and intelligent concentrating PV modules (systems)
    The project aims at the optimisation and development of Point focus and Mirror Based Spectra Splitting Photovoltaic concentrating (CPV) systems (multi-approach). MJ solar cells will be manufactured by using new materials and deposition technologies. New concepts will be applied for Mirror based spectra splitting systems which will allow eliminating the cooling needs. Both the optimised and the new technologies will be properly tested in order achieve reliable long life time CPV systems
    The project started on 1 July 2008 and has a duration of 60 months.
    Coordinator: CESI Ricerca Spa., Italy
  - **HETSI**: Heterojunction solar cells based on a-Si c-Si
    The project aims to design, develop and test novel a-Si/c-Si hetero-junction solar cell structure concepts with high efficiency.
    The project covers all aspects of the value chain, from upstream research of layer growth and deposition, to module process and cell interconnection, down to upscaling and cost assessment of hetero-junction concept.
    The project started on 1 February 2008 and has a duration of 36 months.
    Coordinator: Commissariat à l'Energie Atomique (CEA), France
  - **HIGH-EF:** Large grained, low stress multi-crystalline silicon thin film solar cells on glass by a novel combined diode laser and solid phase crystallisation process
    The project will develop a unique process allowing for high solar cell efficiencies (potential for >10%) by large, low defective grains and low stress levels in the material at competitive production costs. This process is based on a combination of melt-mediated crystallisation of an amorphous silicon (a-Si) seed layer (<500 nm thickness) and epitaxial thickening (to >2 μm) of the seed layer by a solid phase crystallisation (SPC) process.
    The project started on 1 January 2008 and has a duration of 36 months.
    Coordinator: Institute of Photonic Technology e.V., Germany
  - **IBPOWER**: Intermediate Band Materials and Solar Cells for Photovoltaics with High Efficiency and Reduced Cost.
    This project pursues the manufacturing of intermediate band materials and solar cells according to the following main strategies:
    - Insertion of transition elements into III-V semiconductor matrices;
    - Use of quantum dot systems to artificially engineer intermediate band solar cells;
    - Development of intermediate band materials and solar cells based on InGaN;

- Insertion of transition elements into thin film polycristalline hosts;
The project started on 1 February 2008 and has a duration of 48 months.
Coordinator: Universidad Politecnica de Madrid, Spain

- **ROBUST DCS**: Dye Sensitised Solar Cells (DSC)
ROBUST DSC aims to develop materials and manufacturing procedures for ***Dye*** Sensitised ***Solar Cells*** (DSC) with long lifetime and increased module efficiencies (7% target). The project intends to accelerate the exploitation of the DSC technology in the energy supply market. The approach focuses on the development of large area, robust, 7% efficient DSC modules using scalable, reproducible and commercially viable fabrication procedures.
The project started on 1 February 2008 and has a duration of 36 months.
Coordinator: Energy Research Centre of the Netherlands (ECN), The Netherlands

♦ FP7-ENERGY-2007-2-TREN
- **SOLASYS**: Next generation Solar Cells and Module Laser Processing Systems. The main objective is to improve and demonstrate new laser based manufacturing processes and the related manufacturing equipment for the PV industry.
Duration of Project: 36 months.
- **ULTIMATE**: Ultra Thin Solar Cells for Module Assembly – Tough and Efficient The main objective of the project is to demonstrate the production feasibility of PV modules with substantially thinner solar cells (100 μm) than today.
Duration of Project: 36 months.

The second call for projects was launched on 3 September 2008 and the Call specified the following topics in the area of Photovoltaics (ENERGY 2.1):

♦ Photovoltaics is the most capital-intensive renewable source of electricity. Research will include the development and demonstration of new processes for Photovoltaic manufacturing, including the manufacturing of equipment for the PV industry, new Photovoltaic-based building elements complying with existing standards and codes and the demonstration of the multiple additional benefits of Photovoltaic electricity. Longer term strategies for next generation Photovoltaics (both high-efficiency and low-cost routes) will also be supported.

- **Topic ENERGY.2009.2.1.1: Efficiency and material issues for thin-film Photovoltaics**
Content/scope: Thin-film Photovoltaics has an inherent low-cost potential because its manufacture requires only small amounts of active materials and it is suited to fully-integrated processing and high throughputs. Research is needed to improve device quality and module efficiency, and to develop a better understanding of the relationship between the deposition processes and parameters, the electrical and optical properties of the deposited materials, and the device properties that result. Key issues to be addressed are improvement of understanding of electronic properties of materials and their interfaces, improvement of the quality and stability of transparent conductive oxides (TCOs), and development of advanced methods for optical confinement. Results should be transferred to production lines by the end of the project.

Funding scheme: Collaborative project. Application Deadline 25 November 2008.
Expected impact: Accelerated market development of cost-effective and more efficient thin-film Photovoltaics.
Other information: In order to maximise industrial relevance and impact of the research effort, the active participation of SMEs represents an added value to this topic. This will be reflected in the evaluation. The active participation of relevant Chinese partners could add to the scientific and/or technological excellence of the project and/or lead to an increased impact of the research to be undertaken; this will also be considered by the evaluators.

- **Topic ENERGY.2009.2.1.2: Solar Photovoltaics: Manufacturing and product issues for thin-film Photovoltaics**
  Content/scope: Demonstration of standard production equipment and better processes to reduce materials and energy use, achieve higher throughputs and yields, increase recycling rates and improve both the environmental profile and the overall economics of thin-film Photovoltaics. Quality assurance procedures, in-line monitoring techniques, integration and automation of production and processing steps are also needed to improve production yield and module efficiency and reduce production costs. Equipment manufacturers will play a leading role in this development. Knowledge gained in relevant industries outside PV should be also exploited.
  Funding scheme: Collaborative project. Application Deadline 29 April 2009.
  Expected impact: Improved productivity parameters (e.g. process yield, throughput) and lower costs leading to accelerated market development and market uptake of cost-effective and more environmentally friendly thin-film Photovoltaics.
  Other information: This topic is coordinated with the parallel research work. The active participation of key industrial partners and technology suppliers is essential to achieve the full impact of the project. This will be considered in the evaluation. The guidelines for demonstration projects figure in the guide for applicants. The industrial partners should include a realistic and convincing market deployment plan with clear roles, tasks and responsibilities of defined partners if the project is successful.
  Up to two projects may be funded.

- **Topic ENERGY.2009.2.1.3 Support to the coordination of stakeholders' activities in the field of Photovoltaics**
  Content/scope: Major stakeholders in the field of Photovoltaics have established the European Photovoltaic Technology Platform in order to foster cooperation in the field and to design and implement a Strategic Research agenda. This process should be supported by appropriate administrative and communication activities. Administrative activities include the organisation and management of workshops, conferences and meetings among stakeholders. Communication activities will focus on facilitating the flow and exchange of information within the Technology Platform, with other relevant Technology Platforms, and externally; on development and maintenance of IT tools, as well as on the preparation of information leaflets, brochures, reports and other relevant documents.
  Funding Scheme: Coordination and support action. Application Deadline 25 November 2008
  Expected Impact: A further deepening of the cooperation of relevant stakeholders would contribute to increase the efficiency and competitiveness of research in the field of Photovoltaics.

Other Information: Up to one project may be funded. For this topic, the EC contribution will be up to 50% of the total eligible costs of the project for all participants, with a maximum contribution of EUR 500 000 for a period of three years.

7.2.1 The Strategic Energy Technology Plan

On 22 November 2007 the European Commission unveiled the European Strategic Energy Technology Plan (SET-PLAN) [EC 2007]. The SET-Plan will focus, strengthen and give coherence to the overall effort in Europe, with the objective of accelerating innovation in cutting edge European low carbon technologies. In doing so, it will facilitate the achievement of the 2020 targets and the 2050 vision of the Energy Policy for Europe. The Communication on the SET-Plan states:

Europe needs to act now, together, to deliver sustainable, secure and competitive energy. The inter-related challenges of climate change, security of energy supply and competitiveness are multifaceted and require a coordinated response. We are piecing together a far-reaching jigsaw of policies and measures: binding targets for 2020 to reduce greenhouse gas emissions by 20% and ensure 20% of renewable energy sources in the EU energy mix; a plan to reduce EU global primary energy use by 20% by 2020; carbon pricing through the Emissions Trading Scheme and energy taxation; a competitive Internal Energy Market; an international energy policy. And now, we need a dedicated policy to accelerate the development and deployment of cost-effective low carbon technologies.

Within the SET-Plan, Photovoltaics was identified as one of the key technologies and the SET-Plan calls for six different European initiatives, one of them being solar. The ***Solar Europe Initiative*** will focus on large-scale demonstration for Photovoltaics and concentrated solar power.

During the 23rd European Phtovoltaic Solar Energy Conference and Exhibition from 1 to 5 September 2008, the new vision of the European Photovoltaic Industry Association for 2020 was presented. With the help of the SET-Plan, the Association aims to develop the sector in such a way that 6 to 12% of European electricity should then be generated with Photovoltaic systems. This would correspond to 210 to 420 TWh of electricity or 175 to 350 GWp installed capacity of Photovoltaic electricity systems. To realise this new vision around 170 GW to 345 GW of new capacity have to be installed between 2008 and 2020. Installations of new Photovoltaic systems would have to increase from around 1.6 GW per annum in 2007 to 3.3 – 4 GW per annum in 2010 and 40 – 90 GW per annum in 2020. This corresponds to a CAGR of 28% to 37% over the next 13 years. At the same time, electricity generation costs with Photovoltaic systems will have reached grid parity in most of Europe by then.

The intention of the SET-Plan initiatives is that they are industry led and for this reason the European Photovoltaic Industry Association (EPIA) is developing an outline of the necessary measures for Photovoltaics. During a workshop held in Brussels on 25 September 2008 it was agreed that all the necessary research has to be influenced by industry needs, but that certain research topics have to be led by either industry or academia [Epi 2008]. The following categorisation was done:

- **Split the responsibilities between industry and academic research**
    - Industry Lead
        - Upscaling
        - Cost Reduction in the realm of currently commercialised technologies:
            - modules,
            - BOS,
            - Storage (including utilities)
        - Material availability
    - Academia Lead
        - Grid Integration + control & Smart Grid ; storage solutions (mainly industry lead & cooperation with utilities) this topic must be in both areas
        - Next Generation technologies: high efficiency si-TF, organics TF, breakthrough of c-Si (tbd)
        - Material fundamentals
        - Radically new manufacturing processes? (other industries)

- **Short Term research issues**
    - Grid Integration & stability (BOS), Smart Grid and Storage
    - Solutions for scarce materials hindering the growth targets (e.g. Silver, Indium, Telluride)
    - BIPV (as a construction element)
    - Definition of Life-time, how to measure it (accurately), how to certify
    - Macro economic model “Power Generation”
- **Medium/ Long Term research issues**
    - Fundamental Material Research
    - Next Generation PV Technology (e.g. MC-cells, 22% 50 µm)
    - Focus on “expandable technologies“,
      e.g. Si Thin Films → going to high efficiency solutions
    - Radically new mass production processes
      (e.g. print vs. vacuum deposition ; wafers without kerf loss)
    - Module Lifetimes > 35 years

This list is not yet complete, but the basis for further stakeholder consultations. In addition to the research needs, other issues concerning the necessary policy framework, securing human resources and a general awareness campaign were presented. A list of pre-requisites included:

- Co-operation with other RES technologies
- Interaction with utilities and grid operators

- Internalisation of external costs
- Liberalised utility market
- Fair and transparent electricity rate structure

One of the boundary conditions to reach the 12% target is a favourable political framework (EU and national) in the Pre-competitive phase, as well as in the phase when Grid parity is reached and beyond. The following necessary supportive national policies for the pre-competitive phase were listed:

- Reasonable-feed in tariffs (7-8% ROI)
- No caps
- Investment security
- Waive of administrative barriers /simplification (one-stop-shop)
- Priority access to the grid
- Support of building codes

Supportive national policies for the grid parity phase and beyond:

- Investment security
- Waive of administrative barriers/simplification
- Priority access to the grid and grid regulation
- Support of Buildings codes

7.3 Solar Companies

In the following, some European solar cell manufacturers are described briefly. This listing does not claim to be complete, especially concerning the great number of start-up companies. In addition it has to be noted that information or data for some companies are very fragmented and limited. A lot of the data were collected from the companies' web-sites. Despite the fact that BP Solar is a European company, it was already listed in Chapter 6.3, because its headquarters is in the USA.

7.3.1 CSG Solar

CSG Solar AG was founded in June 2004 by former employees of Pacific Solar, together with Q-Cells and other investors. Based in Thalheim, Germany, the company aims to produce "Crystalline Silicon on Glass" (CSG) solar modules. The ownership of the CSG technology has been acquired from Pacific Solar Pty Ltd. A pilot-line team has been developing the CSG technology since 1995, first as part of Pacific Solar Pty Ltd, Australia, and now as CSG Solar Pty Ltd., a wholly-owned subsidiary of CSG Solar AG.

The first factory for CSG Solar AG opened on 15 March 2006 [Csg 2006]. Initial CSG-1 production capacity was 10 MW, but the plant was designed for 25 MW. In April 2007 the company expanded its work-force and moved to 24/7 operation. Current production capacity is given by the company with 13 MW/annum.

7.3.2 ErSol Solar Energy AG

ErSol Solar Energy AG Erfurt, Germany was founded in 1997 and is a producer of polycrystalline solar cells and modules. The company went public on 30 September 2005. In 2008 the Robert Bosch GmbH acquired the majority of shares and held 85.48% in August 2008 [Ers 2008]. The ErSol Group manufactures and distributes Photovoltaic products. Its core business is the production and distribution of moncrystalline and multicrystalline solar cells. In 2007 the company had a production of 53 MW [Pvn 2008]. According to the company, production capacity at the end of 2008 will be: 180 MW wafers, 220 MW crystalline solar cells and 40 MW thin film.

In late 2004, the ErSol Group expanded its marketing activities in the field of solar modules, inverters and other components and transferred them to Aimex-Solar GmbH, a 100% owned subsidiary. Some of the modules sold are based on solar cells that are manufactured by ErSol AG, others are based on third-party products purchased by ErSol AG.

A further expansion of the business is planned with the joint venture company Shanghai Electric Solar Energy AG Co. Ltd., Shanghai, People's Republic of China (SESE Co. Ltd.), which was established in 2005 and in which ErSol AG holds a 35% interest. The module production was officially opened on 28 February 2006 and ErSol is supplying SESE Co. Ltd. with solar cells for the manufacturing of solar modules.

In July 2005, ErSol purchased ASi Industries GmbH and ASi Silizium Technology GmbH which became wholly-owned subsidiaries. ASi Industries GmbH is a specialist manufacturer of monocrystalline ingots and wafers and currently produces monocrystalline silicon ingots (p- and n-type) and monocrystalline silicon wafers (p- and n-type).

Like other wafer-silicon-based producers, ErSol AG is diversifying its product portfolio. For this purpose, the company founded ErSol New Technologies GmbH in December 2005, now ErSol Thin Films GmbH. This name change followed ErSol's entry into thin-film module production. ErSol Thin Film GmbH's new production plant for amorphous silicon thin-film modules was officially inaugurated on 15 June 2007 [Ers 2007]. On 31 August 2007 ErSol announced to postpone the ramp-up of the amorphous silicon plant and instead prepare for the introduction of the micromorph silicon thin-film production already in 2008 [Ers 2007a]. The medium-term annual capacity target remains 100 MWp.

7.3.3 EverQ GmbH

EverQ GmbH is a joint venture between Q-Cells AG (Thalheim, Saxony-Anhalt), REC (Oslo, Norway) and Evergreen Solar Inc. (Marlboro, MA USA). In June 2006 the first factory to produce 30 MW String-Ribbon™ wafers, solar cells and solar modules in Thalheim, Germany was opened. The second factory with 60 MW capacity was then opened on 19 June 2007 and in January 2008 the company laid the cornerstone for a third production plant with

80 MW bringing the total capacity to 180 MW in 2009 [Eve 2008a]. From 2012 the company plans to produce 600 MW. In 2007 EverQ had a production of 50 MW.

7.3.4 Isofotón

Isofotón, a private-owned company, was set up in Malaga to produce silicon solar cells by Professor D. Antonio Luque from the Universidad Politécnica de Madrid. In 1985, Isofotón expanded their activities in the solar sector and also started to fabricate solar collectors. In 2007 Isofotón was the fourth largest manufacturer of solar cells in Europe with 85 MW and has a production capacity of 180 MW in 2008 [Pvn 2008].

Isofotón teamed up with the utility Endesa and GEA 21. Together with the Andalusian Department of Innovation, Science and Business, they plan to build the first polysilcon plant in Spain [Iso 2007]. The plant will be built in Los Barrios, Cadiz Province of Andalucía, Southern Spain. An initial production capacity of 2,500 tons of solar grade polysilicon is planned for 2009 and a further expansion to 5000 tons in 2010.

To be present in a developing market in South Africa, Isofotón Southern Africa, an 80% subsidiary, started its operation in December 2002.

Besides silicon solar cells and modules, Isofotón is very active in developing flat-panel concentrator systems based on GaAs solar cells. This kind of system is favourable for areas with a high proportion of direct sunlight and for large-scale solar plants.

7.3.5 Photowatt

Photowatt was set up in 1979 and relocated to Bourgoin-Jallieu in 1991, where the company converts silicon waste into the raw material used for the manufacturing of solar energy cells. At the beginning of 1997, Matrix Solar Technologies, a subsidiary of the Canadian company, ATS (Automation Tooling Systems), acquired Photowatt International and started to expand the production capacities. According to the mother company ATS Automation, Photowatt has currently a production capacity of 60 MW and plans to expand it by 25 MW in 2009 [Ats 2008]. Furter expansions in the 100 MW range are planned. In 2007 Photowatt had a production of 20 MW [Pvn 2008].

7.3.6 Photovoltech

Photovoltech was set up in 2002 by Total, Electrabel, Soltech and IMEC for the manufacturing and worldwide marketing of Photovoltaic cells and modules. It is located in Tienen (Belgium) and uses the most advanced IMEC technology.

According to the company current production capacity is 80 – 85 MW and an expansion of almost 400 MW to 500 MW is planned. The first phase of the current expansion will add at least 60 MW to be operational at the beginning of 2010.

In 2007 the company had a production of 29 MW of polycrystalline solar cells [Pvn 2008].

7.3.7 Q-Cells AG

Q-Cells AG was founded at the end of 1999 and is based in Thalheim, Sachsen-Anhalt, Germany. Solar cell production started mid 2001 with a 12 MWp production line. In the 2008 2^{nd} quarterly report, the company stated that the nominal capacity had increased to 630 MW by 30 June 2008 and should reach 800 MW in Thalheim/Germany and 520 MW in Malaysia by the end of 2009 [Qce 2008]. 2007 production was 389 MW, moving to the first place worldwide.

Q-Cells broadened and diversified its product portfolio by investing in various other companies or forming joint ventures. It has one fully and two partially owned subsidiaries, Suntor (amorphous/micromorph silicon thin-films), Calylyxo GmbH (CdTe) (93%), VHF-Technologies SA, Switzerland (57.10%), two joint ventures Solibro (67.5%) and EverQ (33.33%), as well as holdings in three companies, CSG (21.71%), REC, Norway (17,18%) and Solaria Corp., USA (31.40%).

7.3.8 Renewable Energy Corporation AS

REC's vision is to become the most cost-efficient solar energy company in the world, with a presence throughout the whole value chain. REC is presently pursuing an aggressive strategy to this end. Through its various group companies REC is already involved in all major aspects of the PV value chain. The company located in Høvik, Norway has five business activities ranging from silicon feedstock to solar system installations.

2005, Renewable Energy Corporation AS ("REC") took over Komatsu's US subsidiary, Advanced Silicon Materials LLC ("ASiMI") and announced the formation of its silicon division business area "REC Silicon Division", comprising the operations of REC Advanced Silicon Materials LLC (ASiMI) and REC Solar Grade Silicon LLC (SGS) [Rec 2005]. The company is expanding the Moses Plant capacity by adding a new fluidised bed reactor and 6,500 tons of capacity. The production is expected to be around 10,000 tons production capacity in 2009 and close to 13,500 tons by 2010 [Pvn 2008a, Rec 2006]. REC produced 5,600 tons of polysilicon in 2007 [Pvn 2008a].

Since 2004, ScanWafer has become a fully owned subsidiary. ScanWafer started wafer production at the end of 1997 and has grown to become one of the world's largest producers of multicrystalline wafers. In 2006, REC Wafer's plants produced wafers of approximately 290 MWp. Significant expansion projects at both Herøya and in Glomfjord are underway and if the current expansion projects are completed in 2010, total production cpacity should be 1.3 GW [Rec 2007].

REC ScanCell is located in Narvik, producing solar cells. From the start-up in 2003, the factory has been continuously expanding and during 2006 ScanCell produced 46 MW [Pvn 2008]. According to the company, 2008 capacity will be 180 MWp of solar cells per year.

Further expansion is under way in Singapore with the ramp up phase for the 550 MW facility planned for 2010 [Rec 2008].

7.3.9 Schott Solar AG

Schott Solar AG is a fully owned subsidiary of Schott AG, Mainz and plans to go public in October 2008. In 2005 Schott took over the former joint venture RWE-Schott Solar, except the Space Solar Cells Division in Heilbronn. Schott Solar's portfolio comprises crystalline wafers, cells, modules and systems for grid-connected power and stand alone applications, as well as a wide range of ASI® thin-film solar cells and modules. In 2007, the company had a production of 80 MW (70 MW from Germany, 10 MW from US) [Pvn 2008]. For 2008 the production capacity is 195 MW.

Schott Solar uses silicon wafers grown by Edge-Defined, Film-Fed Growth (EFG) developed by Tyco Laboratories and the Mobil Corporation.

Development of amorphous silicon solar cells started at MBB in 1980. Phototronics (PST) was founded in 1988. In 1991 one of the world's first large-area pilot production facilities for amorphous silicon was built. In January 2008 the company announced the first shipments of modules from its new 33 MW manufacturing facility for amorphous silicon thin film solar modules in Jena, Germany [Sch 2008a].

On 2 August 2007 Schott Solar and Wacker Chemie AG signed an agreement to set up two joint ventures to produce and market silicon wafers for solar applications. Over the next years, the two partners plan to invest a total of € 370 million in facilities in Jena (Thuringia) and Alzenau (Bavaria), creating at least 700 new jobs at these German sites. The joint venture –Wacker Schott Solar GmbH – started its operations in 2007. It will produce multicrystalline silicon ingots and wafers, the starting material for solar cells. Solar-wafer production capacity is set to expand in stages, reaching about one 1 GW per annum by 2012. This will make the joint venture one of the world's five largest solar-wafer manufacturers.

7.3.10 Solar World AG

Since its founding in 1998, Solar World, Germany has changed from a solar system and components dealer to a company covering the whole PV value chain from wafer production to system installations. Solar World's corporate group consists of: Solar World AG, Bonn (marketing, development and plant engineering and construction), Joint Solar Silicon GmbH & Co. KG, Freiberg in co-operation with Degussa AG (development of raw silicon), Deutsche Solar AG, Freiberg (silicon wafer production and recycling of used PV products), Deutsche Cell GmbH, Freiberg (solar cell production), Gällivare Photovoltaic, Sweden (solar module production) and Solar Factory GmbH, Freiberg (solar module production).

In February 2007 SolarWorld acquired an old computer factory from Komatsu-Group in Hillsboro (OR), USA [Sol 2007]. It is planned to develop the site into an integrated solar silicon wafer and solar cell production facility with a capacity of 500 MW by 2009. As a consequence, the SolarWorld Group is shifting its solar crystallisation activities from Vancouver (WA), to Hillsboro. In the first stage of the production increase, capacities will be expanded to 100 MW. At the same time, production capacities of the solar module factory at Camarillo (CA) will double to 100 MW. Together with the ongoing expansion of the silicon wafer production at Freiberg/Saxony to 500 MW the group will then have a total global production in excess of one 1 GW. Solar cell production in 2007 was 130 MW (95 MW Germany, 35 MW U.S.) [Pvn 2008].

In 2003 the Solar World Group was the first company worldwide to implement silicon solar cell recycling. The Solar World subsidiary, Deutsche Solar AG, commissioned a pilot plant for the reprocessing of crystalline cells and modules.

7.3.11 Solland Solar Energy BV

Solland Solar is a Dutch-German company and was registered in 2003. At the end of 2004 the construction of the factory went underway and start-up of production was in September 2005. At the end of 2007 production capacity was 60 MW and increased to 170 MW in the first half year of 2008. In addition, the company is planning to expand it to 500 MW in 2010. Solland had a production of 37 MW in 2007 [Pvn 2008].

7.3.12 Solterra Fotovoltaico SA

Solterra located in Chiasso, Switzerland, is a private company established in August 1994 as a Research and Development company focused on the development of new technologies in renewable energy. The company produces monocrystalline solar cells and had a production of 12 MW in 2006 [Pvn 2007].

7.3.13 Sunways AG

Sunways AG was incorporated in 1993 in Konstanz, Germany, and went public in 2001. Sunways produces polycrystalline solar cells, transparent solar cells and inverters for PV systems. In 2007 the company produced 36 MW.

Sunways opened its second production facility with a production capacity of 30 MW in Arnstadt, Germany on 9 September 2005. With this expansion, total production capacity rose to 46 MW. The new production facility can be expanded to 80 MW in the future.

7.3.14 Würth Solar GmbH

Würth Solar GmbH & Co. KG was founded in 1999 with the aim of building up Europe's first commercial production of CIS solar modules. The company is a joint venture between Würth Electronic GmbH & Co KG and the Centre for Solar and Hydrogen Research (ZSW). Pilot production started in the second half of the year 2000, a second pilot factory followed in

2003 increasing the production capacity to 1.3 MW. The Copper Indium Selenide (CIS) thin layer technology was perfected in a former power station to facilitate industrial-scale manufacture.

In August 2008 the company announced the successful ramp up of their production facilities to 30 MW [Wür 2008]. A further expansion to at least 40 MW in 2009 is planned. For 2007 a production volume of 14 MW is estimated.

7.3.15 Additional Solar Cell Companies

- **AVANCIS GmbH & Co KG** is a joint venture between Shell and Saint-Gobain. The company plans to produce CIS thin film solar modules in a new factory to be built in Torgau, Germany. The initial annual capacity is 20 MW and the first commercial modules should become available in 2008.

- **Calyxo GmbH** is a subsidiary of Q-Cells AG located in Wolfen, Saxony-Anhalt. The company plans to manufacture CdTe thin film solar cells. The pilot plant has a production capacity of 25 MW and is currently in the ramp up phase. The company has already started a 60 MW expansion project. Which is planned to become operational in 2009.

- **G24 Innovations Limited** (G24i), headquartered in Cardiff, Wales, manufactures and designs solar modules based on Dye Sensitised Thin Film (DSTF) technology. In 2007 production of dye sensitised solar cells with a roll to roll process started.

- **Helios Technologies** located in Carmignano di Brenta (PD), Italy, was established 1981 and manufactures solar cells, modules and Photovoltaic systems. The company produced around 5 MW solar cells in 2006 [Pvn 2007]. According to the company it is expanding its production facility by 30 MW to become operational in 2009.

- **Inventux Technologies AG** was founded in spring 2007 to manufacture amorphous/microcrystalline thin film silicon solar modules and broke ground for its 33 MWp factory in Berlin, Germany in September 2007. Ramp up of the plant is planned for the autumn of 2008.

- **Johanna Solar Technology GmbH**: In June 2006 the company started to build a factory for copper indium gallium sulphur selenide (CIGSSE) thin film technology in Brandenburg/Havel, Germany. The technology was developed by Prof. Vivian Alberts at the University of Johannesburg. It is planned to start the solar cell production with an initial capacity of 30 MW in 2008. In March 2008 the company granted a license to the Chinese company Shandong Sunvim Solar Technology Co. Ltd. for the construction of a thin-film solar module production plant.

- **Odersun AG** was founded in 2002 and developed a unique thin-film technology for the production of copper indium sulphide based solar cells. The main investor is Doughty Hanson Technology Ventures, London and the company has signed an agreement with Advanced Technology & Materials Co. Ltd., which is listed on the Shenzhen Stock Exchange to co-operate in August 2004. The first production line was inaugurated on 19 April 2007. On 26 March 2008 the company laid the cornerstone for its 30 MW expansion project.

- **Scheuten Solar,** took over the assets of Flabeg Solar, Gelsenkirchen, in 2003 and is producing standard glass-tedlar PV modules (Multisol®) and custom made glass-glass PV modules (Optisol®). The company is developing a spheral copper indium selenide based solar cell. The pilot plant was opened on 21 June 2007 and it is planned to build an industrial production plant with a capacity of 250 MW in 2009 [Sch 2007].

- **SOLARTEC** was established in 1993 and is located in the industrial area of Roznov pod Radhostem, in the eastern part of the Czech Republic. The company is a producer of solar cells and modules, as well as a PV system integrator. In 2006 the company had a production capacity of about 30 MW.

- **Solibro GmbH** was established early 2007 as a joint venture between Q-Cells AG (67.5%) and the Swedish Solibro AB (32.5%). The company develops thin-film modules based on a Copper Indium Gallium Diselenide (CIGS) technology. A first production line in Thalheim, Germany with a capacity between 25 and 30 MWp is being ramped up and should be expanded to 45 MW in 2009 [Qce 2008]. A second line with 90 MW is already planned and should become operational at the end of 2009.

- **Sontor** is a fully owned subsidiary of Q-Cells AG located in Wolfen, Saxony-Anhalt. The company plans to manufacture amorphous/micromorph thin film solar cells. The pilot plant is expanded into a production line with 25 MW and it is planned to be fully operational in 2008. According to Q-Cells, a second line with 120 MW will be constructed and should be operational at the end of 2009 [Qce 2008].

- **Sulfurcell Solartechnik GmbH** was incorporated in June 2001 and is jointly owned by its founders and investing partners. In 2004, the company set up a pilot plant to scale up the copper indium sulphide (CIS) technology developed at the Hahn-Meitner-Institut, Berlin. First prototypes were presented at the 20th PVSEC in Barcelona in 2005. Production of CIS modules started in December 2005 and in 2006 the company had sales of 0.2 MW. For 2007 a production increase to 1 MW and 2008 to 5 MW is planned.

- **Sunfilm** was founded at the end of 2006 located in Groβröhrsdorf, Germany. According to the company they are ramping up their first production line delivered by Applied Materials (AMAT) with an annualised capacity of over 60MWp.

- **T-Solar Global, S.A.** (T-Solar) was founded in October 2006. In July 2007 the construction of the factory with an initial production capacity of 40 MW started in Ourense, Spain. The production plant is based on technology from Applied Materials. The construction work and the installation of the process equipment finished in July 2007 and the production is in the ramp-up phase.

- **VHF Technologies SA**, is located in Yverdon-les-Bains in Switzerland and produces amorphous silicon flexible modules on plastic film under the brand name „Flexcell". Q-Cells AG has a 57.1% share in the company. The first production line on an industrial scale of 25 MW is planned to become operational in 2008.

7.3.16 Leybold Optics Solar

Leybold Optics is one of the leading providers of vacuum technology, headquartered in Alzenau, Germany. Since the year 2001 the company is owned by the Private Equity Fund EQT. Leybold Optics Solar designs, manufactures and installs complete production systems for the manufacturing of thin film single junction a-Si and a-Si/µc-Si tandem solar modules, along with the total project support. In addition, they offer various kinds of production equipment for the solar industry.

7.3.17 PV Crystalox Solar plc

PV Crystalox Solar plc arose from the merger of Crystalox Ltd. in Wantage near Oxford, UK, and PV Silicon AG in Erfurt, Germany. The product range includes: solar grade silicon; single crystal ingots, single crystal wafers and multicrystalline wafers. The company went public in June 2007 and is listed on the London Stock Exchange. In September 2007, PV Crystalox Solar broke ground for their new production facility for solar-grade silicon and it is planned to complete the construction by the end of 2008. The facility is expected to produce 900 tons in 2009, rising to 1,800 tons thereafter [Cry 2008]. In 2007, wafer production was 190 MW [Cry 2008a].

7.3.18 Elkem AS

Elkem AS is a subsidiary of Orkla ASA, and one of Norway's largest industrial companies and the world's largest producer of silicon metal. In 2004 Elkem acquired a 23% share in the Renewable Energy Corporation, which was increased to 27.5% in 2005 and to 39.73% in 2007. Elkem Solar is developing a cost-effective metallurgical process to produce silicon metal for the solar cell industry. According to PV News, the company will have a production capacity of 1,667 tons of solar grade silicon in 2008, ramping up to 5,000 tons in 2010 [Pvn 2007a].

7.3.19 NorSun AS

NorSun AS is a subsidiary of the technology group SCATEC AS. The Norwegian start-up company was established in 2005 by Dr. Alf Bjorseth, the founder and former president of the Renewable Energy Corporation ASA (REC). The company is specialising in the production of mono-crystalline wafers for the PV industry. According to a press release by the Finnish silicon wafer processing company Okmetic Oyi, the company signed an agreement to sell its crystal growth technology to NorSun [Okm 2006].

Production has started at the facility in Årdal – Norway, where the annual capacity will be approx. 155 MW. In addition, NorSun has production in Finland and has started the building process for a 350 MW plant in Singapore where production will commence in the 3rd quarter 2009.

In January 2008 NorSun signed a joint venture agreement with the Saudi Arabian companies Swicorp-Joussour (Swicorp) and Chemical Development Company (CDC) [Nor 2008]. The purpose of the agreement is to establish a joint venture company with the aim to build and operate a polysilicon complex in the industrial city of Jubail in Saudi Arabia. The production capacity of polysilicon at the initial plant will be the equivalent of 500 MW per year. Commercial production is planned to commence in 2010. The site will allow for subsequent expansions up to an annual production capacity equivalent to 2000 MW.

7.3.20 Wacker Schott Solar GmbH

Wacker Schott Solar GmbH, a joint venture of Wacker Chemie AG (Munich) and SCHOTT Solar AG (Mainz), was established in 2007. In April 2008 a second factory for the production of silicon wafers for the solar industry was opened in Jena. After just six months' construction, WACKER SCHOTT Solar has commenced wafer production, and plans to ramp up the factory's annual capacity to 50 MW by autumn 2008. This will increase their total annual capacity to 120 MW by the year's end. Total solar-wafer production capacity is set to expand in stages, reaching about 1 GW per year by 2012.

7.3.21 Wacker Polysilicon

Wacker Polysilicon, Burghausen, Germany is one of the world's leading manufacturers of hyper-pure polysilicon for the semiconductor and Photovoltaic industry, chlorosilanes and fumed silica. In 2007 Wacker produced 6,500 tons of polysilicon [Pvn 2008a]. The company plans to increase its production capacity to 10,000 tons at the beginning of 2008 and 14,500 tons by the end of 2009 [Wac 2006].

7.3.22 OERLIKON Solar

The co-operation of the Institute of Microtechnology (IMT), the University of Neuchâtel (Switzerland) and UNIAXIS led to the establishment of UNAXIS Solar. In August 2006 the company changed its name to OERLIKON Solar. UNAXIS Solar started operation on 1 July 2003 and the aim was to develop the production technology for large-scale production of PV modules, based on the micromorph solar cell concept developed at IMT and Unaxis's KAI production systems.

In the meantime, Oerlikon Solar has developed into a supplier of turn-key production equipment for thin-film silicon solar modules. The technology available is for amorphous silicon, but the amorphous/micromorph tandem cell is under development at the first customers.

8. OUTLOOK

In 2007 China and Europe overtook Japan as the major producers of solar cells. Japan still had the highest number of top ten manufacturers, with three companies (Sharp N°2, Kyocera N°4, Sanyo N°7). The other top-ten companies consisted of two Chinese companies (Suntech N°3, Yingli Solar N°9), one European company (Q-Cells N°1), one Taiwanese company (Motech N°6) and three companies with production capacities in more than one continent (First Solar N°5, SunPower N°8, Solarworld N°10). Since 1999 the European PV production grew on average by 50% per annum and reached about 1060 MW in 2007. The market shares of European and Chinese manufacturers increased from 20% to 25% and from 1% to 25% respectively, whereas the US and Japanese shares decreased to 7 and 23% respectively.

The continuous and consistent support for Photovoltaics in Japan made it possible for the ambitious goal of 1994 to install 200 MWp of PV systems in 2000, to be reached with only a one year delay in 2001. The long-term strategy up until 2010 is another reason why the Japanese Photovoltaic industry has advanced within only 10 years, to take the market lead. However, the stagnation of the Japanese home market, the silicon shortage and the aggressive growth of production in China and Taiwan have led to a reduction in world market shares from around 50% to 23%.

Before the start of the Japanese market implementation programme in 1997, annual growth rates of the PV markets were in the range of 10%, mainly driven by communication, industrial and stand-alone systems. Due to this programme and the introduction of the German Feed-in Law in 1999, the PV market has increased its growth to over 40% annually during the last years and reached a production volume of 4 GWp 2007.

The ongoing shortage in silicon feedstock, triggered by the extremely high growth rates of the Photovoltaics industry over the last years, is showing its effects. New production plants for polisilicon, advanced silicon wafer production technologies, thin film solar modules and technologies, like concentrator concepts, are introduced into the market much faster than expected a few years ago.

The rising number of market implementation programmes worldwide, as well as the rising energy prices and the pressure to stabilise the climate will continue to keep the demand for solar systems high. In the long-term, growth rates for Photovoltaics will continue to be high, even if the economic frame conditions can lead to a short-term slow-down. This view is shared by an increasing number of financial institutions, which are turning towards renewables as a sustainable and lucrative long-term investment. Increasing demand for energy is pushing the prices for fossil energy resources higher and higher. An increasing number of analysts predicted last year that oil prices could well hit 100 $/bbl by the end of 2007 or early 2008 [IHT 2007]. After the spike of oil prices in July 2008 with close to 150$/bbl, prices have decreased due to the worldwide financial crisis and the anticipated slow down of the economies. However, once the world economy has recovered from this effect, the fundamental trend of increasing demand for oil will put pressure on the oil price again.

If Oil-futures for December 2010 and 10 year US treasury bonds (3.85%) are taken as a benchmark, the oil price will rise to at least $ 105 $/bbl (€ 72) in December 2010. At the same time, electricity costs are on the rise and peak prices in July 2006 were higher than what was paid as feed-in tariffs. These developments work in favour of Photovoltaics as the cost gap is closing on both sides at the same time. PV system costs are still decreasing according to the learning curve and energy prices are rising at the same time. Therefore, the future for PV looks bright.

According to investment analysts and industry prognoses, solar energy will continue to grow at high rates in the coming years. The different Photovoltaic Industry Associations, as well as the European Renewable Energy Council (EREC), have developed scenarios for the future growth of PV. Table 17 shows the projections of the 2004 Japanese Roadmap, the *"Fukuda Vision"* and the EREC 2040 "Advanced International Policy Scenario" (AIP) and the "Dynamic Current Policy Scenario" (DCP) [Ere 2004] combined with own calculations based on the new U.S. and EPIA visions. The installed capacities for 2020 are given in the visions. However, the values for 2030 are calculated with growth rates of 15% for Europe and 20% respectively 25% for the U.S.

Table 17: **Evolution of the cumulative solar electrical capacities until 2030 (Sources: New U.S. and EPIA Visions, Japanese Roadmap, Fukuda Vision and EREC 2040 scenarios)**

Year	2000	2010	2020	2030
USA [GW]	0.14	3 – 5	84	520 – 780
Europe [GW]	0.15	12.7 – 14	175 – 350	1,100 – 2,600
Japan [GW]	0.25	4.8	30	205
Japan *"Fukuda Vision"* [GW]	0.25	4.8	14	50
Worldwide DCP [GW]	1.00	8.6	125	920
Worldwide AIP [GW]	1.00	14.0	200	1830

These projections show that there will be huge opportunities for Photovoltaics in the future. The growth rate seems large, however for Europe this corresponds to a CAGR (Compound Annual Growth Rate) of 28% to 37% over the next 13 years (2007 to 2020), and the sector has seen growth rates far above that. At the same time we have to bear in mind that such a development will not happen by itself, but that it will require constant support of all stakeholders to implement the envisaged change to a sustainable energy supply with Photovoltaics delivering a major part. The main barriers to such developments are perception, regulatory frameworks and the limitations of the existing electricity transmission and distribution structures.

The International Energy Agency's World Energy Investment Outlook 2003 states that the OECD countries will have to spend approx. US$ 4,000 billion or US$ 133.3 billion per year by 2030, in order to maintain and expand their electricity grid and power production capacities [IEA 2003]. In a speech on 13 May 2008 the IEA Executive Director Nobuo Tanaka presented new, much higher, figures which state for the current Reference Scenario that the "Cumulative Investment in Energy-Supply Infrastructure, 2006-2030" would amount to $ 21.9 trillion[26] (€ 15.1 trillion [IEA 2008a]. According to this data $ 11.6 trillion (€ 8 trillion) would be needed for the electricity sector split in 49% for power generation and 51% for transmission and distribution.

The new figures imply that the EU, with roughly 18.5% of the total worldwide electricity consumption, will have an investment need of almost US$ 85.8 billion (€ 59.2 billion) per year. Distributed generation of renewables can help to reduce investment in transmission costs. Therefore, there is a unique opportunity at the moment to use the need for an infrastructure overhaul to change to a transmission and distribution systems which will be capable of absorbing the large new quantities of different renewable energy sources, centralised and decentralised all over Europe and the neighbouring countries.

Due to the long life-time of power plants (30 to 50 years), the decisions taken now will influence the socio-economic and ecological key factors of our energy system in 2020 and beyond. In addition, the 2003 IEA study pointed out that fuel costs will be in the same order of magnitude as investment in infrastructure. The price development over the last five years has exacerbated this trend and increased the scale of the challenge, especially for developing countries.

The above-mentioned scenarios will only be possible if new solar cell and module design concepts can be realised, as with current technology the demand for materials like silver would exceed the available resources within the next 30 years. Research to avoid such kind of problems is underway and it can be expected that such bottle-necks will be avoided.

The Photovoltaic industry is developing into a fully-fledged mass-producing industry. This development is connected to an increasing industry consolidation, which presents a risk and an opportunity at the same time. If the new large solar cell companies use their cost advantages to offer lower-priced products, customers will buy more solar systems and it is expected that the PV market will show an accelerated growth rate. However, this development will influence the competitiveness of small and medium companies as well. To survive the price pressure of the big companies, made possible by economies of scale that come with large production volumes, they have to specialise in niche markets with high value added in their products. The other possibility is to offer technologically more advanced and cheaper solar cell concepts.

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26 In 2006 U.S.$

Europe already reached its 2010 target in 2006 and the production volume in Europe increased again significantly. Additional production capacities will become available over the next years to secure the market position. Japanese manufacturers are increasing their capacities also considerably, but the stagnating home market pushes them for a stronger export orientation where they have to compete with the new rapidly growing PV manufacturers from China and Taiwan and the new market entrants from companies located in India, Malaysia, Philippines, Singapore, South Korea, UAE, etc. Should the current trend in the field of worldwide production capacity increase continue, Europe will only be able to stabilise its market share around 25%, even with a continuation of the impressive growth rates of the last years. At the moment it is hard to predict how the market entrance of the new players all over the world will influence future developments of the markets. In 2010 it is very likely that China will dominate the market followed by Europe, Japan and Taiwan (Fig. 25).

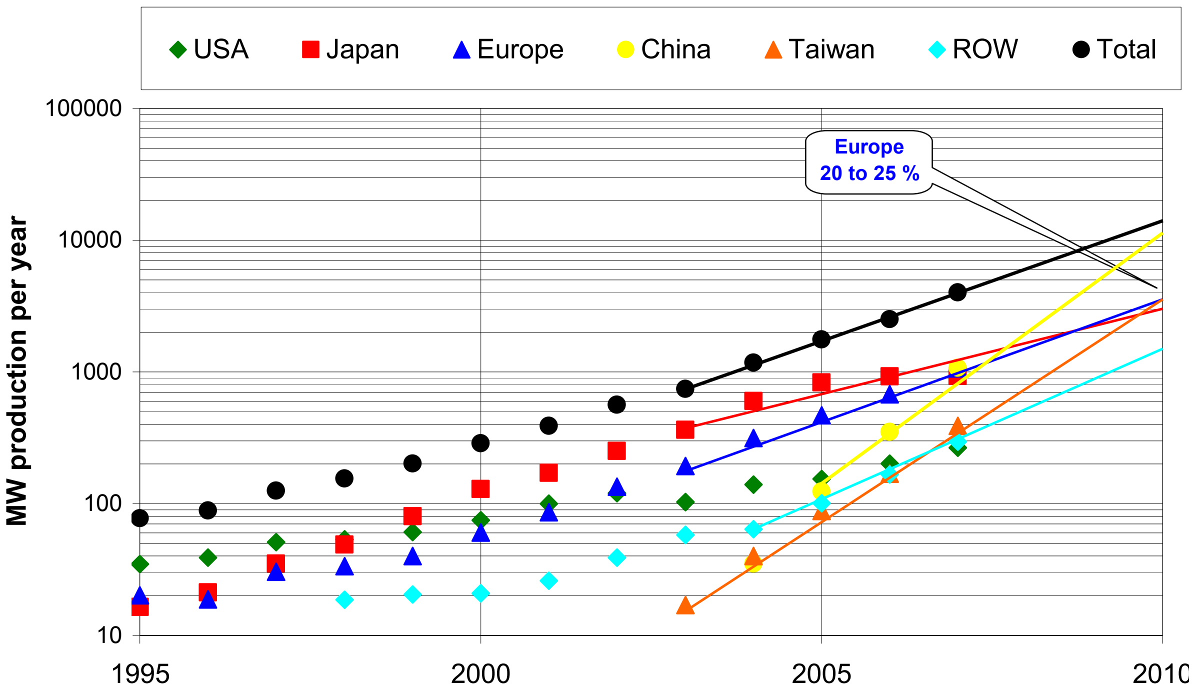

Fig. 25: Extrapolated increase of production capacities up until 2010 using the growth rates from 2003 to 2007 (Data source: PV News and own analysis [Pvn 2008])

A lot of the future market developments, as well as production increases, will depend on the realisation of the currently announced worldwide PV programmes and production capacity increases. During 2008, the flood of announcements from new companies which want to start a PV production, as well as established companies to increase their production capacities, again increased compared to 2007. The total capacity announcement during that period was larger than the total available production capacity at the end of 2007. If all these plans are realised, thin-film production companies will increase their total production capacities even faster than the silicon wafer-based companies and increase their market share from the 2007 market share of 10% to around 20 to 25% in 2010. This will have significant impact on the price reduction of PV modules as well as systems.

Since already a few years, we have now observed a continuous and quite steep rise of oil and energy prices, which highlights the vulnerability of our current dependence on fossil energy sources and increases the burden developing countries are facing in their struggle for future development. On the other hand, we see a continuous decrease in production costs for renewable energy technologies as a result of steep learning curves. Due to the fact that external energy costs are not yet taken into consideration, renewable energies and Photovoltaics are still perceived as more expensive in the market than conventional energy sources. Nevertheless, electricity production from Photovoltaic solar systems have already shown now that it can be cheaper than peak prices in the electricity exchange in a wide range of countries and if the new EPIA vision can be realised electricity generation cost with Photovoltaic systems will have reached grid parity in most of Europe by 2020. In addition, renewable energies are, contrary to conventional energy sources, the only ones to offer a reduction of prices rather than an increase in the future.

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Abstract

Photovoltaics is a solar power technology to generate Electricity using semiconductor devices, known as solar cells. A number of solar cells form a solar "Module" or "Panel", which can then be combined to solar systems, ranging from a few Watts of electricity output to multi Megawatt power stations.

The unique format of the Photovoltaic Status Report is to combine international up-to-date information about Research Activities with Manufacturing and Market Implementation data of Photovoltaics. These data are collected on a regular basis from public and commercial studies and cross-checked with personal communications. Regular fact-finding missions with company visits, as well as meetings with officials from funding organisations and policy makers, complete the picture.

Growth in the solar Photovoltaic sector has been robust. Yearly growth rates over the last five years were on average more than 40%, thus making Photovoltaics one of the fastest growing industries at present. Business analysts predict that the market volume will increase to € 40 billion in 2010 and expect rising profit margins and lower prices for consumers at the same time. The PV Status Report provides comprehensive and relevant information on this dynamic sector for the public interested, as well as decision- makers in policy and industry.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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