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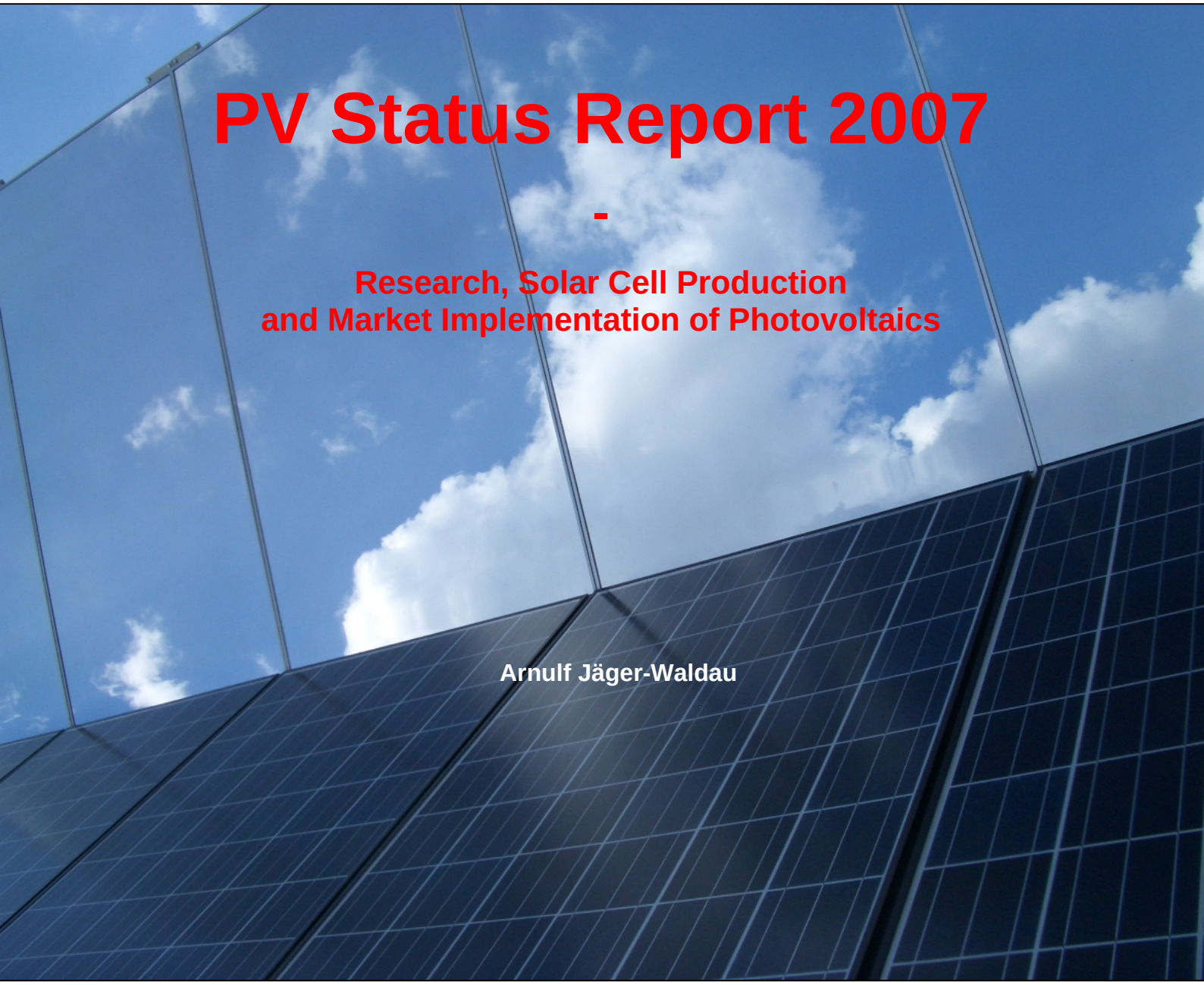

PV Status Report 2007

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Research, Solar Cell Production and Market Implementation of Photovoltaics

Arnulf Jäger-Waldau

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PV Status Report 2007

Research, Solar Cell Production and Market Implementation of Photovoltaics

September 2007

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PREFACE

Record oil prices and speculations when the oil price will exceed $ 100 per barrel have already become a reality. This development has shifted the focus to more abundant fossil energy resources like gas and coal. However, the *Gas Crisis* at the beginning of 2006 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 2006, the photovoltaic industry production again grew by over 40% reaching a world-wide production volume of 2,520 MWp of photovoltaic modules and has become a € 12 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. 2006 was also the year when thin film photovoltaics started to grow faster than the overall PV market and this trend continued in 2007.

The Sixth 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 world-wide. 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 2007

Arnulf Jäger-Waldau
European Commission
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1. INTRODUCTION

In 2006, the photovoltaic industry continued its impressive growth and delivered world-wide some 2,520 MWp [Pvn 2007] of photovoltaic generators (Fig. 1). Since 2003 total PV production grew in average by almost 50%, whereas the thin film segment – starting from a very low level – grew by almost 80% and reached 196 MW or 8% of total PV production in 2006. 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 and that the current market leader Sharp announced a 1 GW thin film factory to be operational in 2010 [Sha 2007].

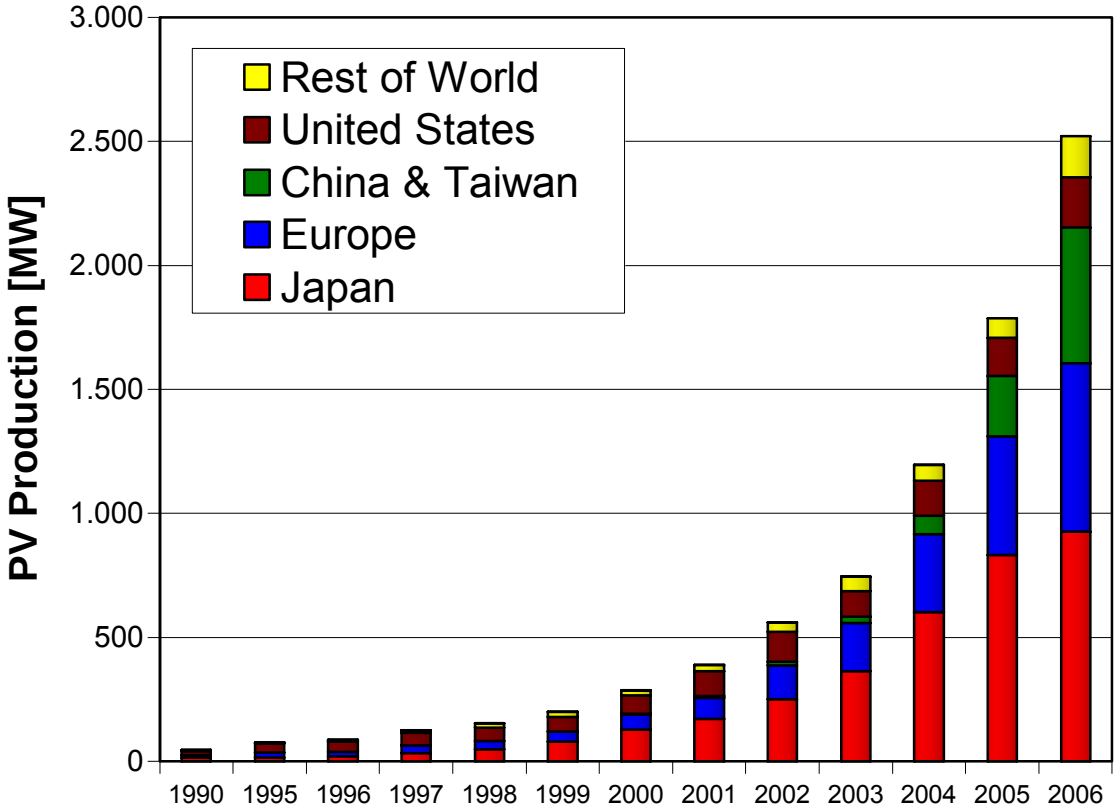

Fig. 1: World PV Cell/Module Production from 1990 to 2005
(data source: PV News [Pvn 2007])

Public traded companies manufacturing solar products or offering related services are attracting a growing number of private and institutional investors. In June 2007 alone 5 companies went public and collected more than $ 1 billion (€ 0.75 billion[1]) on the stock exchanges. The number of consulting companies and financial institutions offering market

[1] Exchange rate: 1 € = 1.33 $

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. The total market capitalisation of the 30 PPVX[2] (Photon Pholtovoltaic stock index) companies[3] increased from € 20 billion to around € 55 billion from August 2006 to August 2007. Market predictions for the 2010 PV market vary between 5 GW [Sar 2006], 7 GW [Pvn 2007b] and 10 GW [Rog 2006]. Massive capacity increases are underway or announced and if all of them are realised, the world wide production capacity for solar cells could exceed 20 GW in 2010/11.

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 increasing potential of electricity interruption due to 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 and the relative slow response of the established silicon producers led to the market entry of new potential silicon producers. In addition, the incumbent manufacturers accelerated their build up of additional capacities. The following developments can be observed at the moment:

- Silicon producers have now reacted and 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.

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[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.

- New silicon producers enter the market and are in the process to finalise 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 2005, thin film shipments increased by around 80% to 196 MW in 2006. If all currently announced thin film production capacities are realised, close to 6 GW production capacity could be reached by 2010.

Projected silicon production capacities available for solar in 2010 vary between 79,000 metric tons [Pvn 2007b] and 115,000 metric tons according to various press releases of the different companies. 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 again by more than 40% in 2006 to 2,520 MW. Like in the last years, Germany was the largest single market with 1,153 MW followed by Japan with 286.6 MW and the US with 140 MW [Sys 2007, Ikk 2007, Sol 2007a]. The Photovoltaic Energy Barometer reported that with a cumulative installed PV system capacity of 3.4 GW Europe has exceeded the 2010 White Paper Target of 3,000 MW in 2006.

Despite the fact that the European PV production grew again by 39% and reached 657 MW, the size of the German market 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 second biggest market was Japan with 286.6 MW of new installations, almost the same as the 291.1 MW of 2005. The slight decrease of new installed capacity is mainly due to the completion of the Residential PV System Dissemination Programme in FY 2005. 99% of the new installations were grid-connected residential systems, bringing the accumulated power of grid-connected distributed solar systems to 1,617 MW out of 1,708 MW total installed PV capacity at the end of 2006 [Ikk 2007]. In 2006 the Japanese solar cell production increased only by 11.3% and consequently the world market share of photovoltaic devices manufactured in Japan decreased from 47.4% to 36.9%. Nevertheless, four of the *Top Ten* companies are Japanese (Fig. 2). For FY 2007 the PV industry is confident that, the residential market will grow again due to the trend to fully electrified houses and the new Renewable Portfolio Standard with an increased amount of electricity generated from renewable energy sources.

Sharp Corporation continues to dominate the PV scene with 17.2%, but lost considerable market shares due to a very unusual low production growth of just 1%, despite the fact that the production capacity increased to 600 MW in FY 2006 [Ikk 2007a]. An explanation could be that Sharp did not have enough silicon feedstock. This would explain why Sharp announced in January 2007 the start of the production of solar silicon at a new factory site in Toyama [Sha 2007a] and the development of a new Thin Film Plant with 1 GW capacity in Sakai City [Sha 2007]. In addition, the importance of the Solar Systems Group for the company was made clear during the 113th Stakeholders meeting with the appointment of Mr. Toshishige Hamano, Corporate Senior Executive Director and member of the board, as Director of the Solar Systems Group [Sha 2007b].

The third largest market was the USA with 140 MW of PV installations, 101.5 MW grid connected [Pvn 2007c]. California and New Jersey account for 85% of the US grid connected PV market. 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.

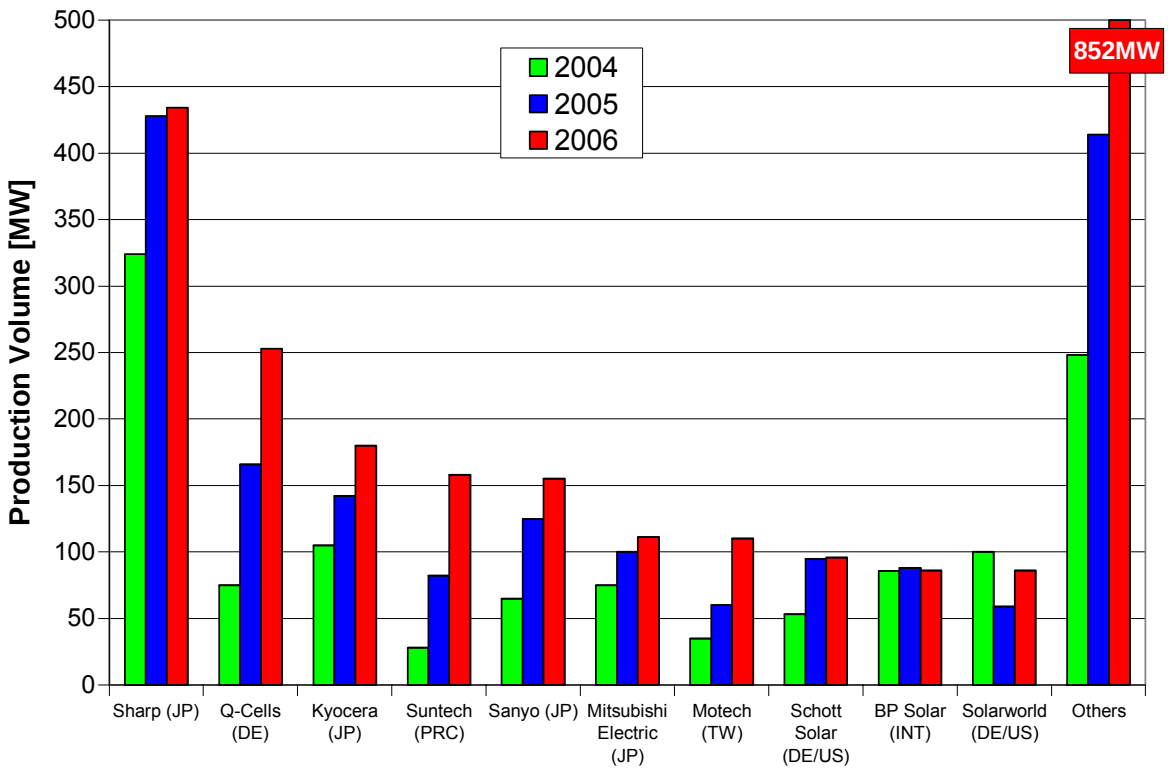

Fig. 2: Top 10 Photovoltaic companies in 2006 (total shipments in 2006: 2520 MW)
[Pvn 2007]

The rapid expansion of solar cell manufacturing capacities and production volume in China and Taiwan is not yet reflected in a significant size of the respective home markets. For 2006 the estimates of the Chinese PV market are in the order of 5 to 10 MW. As a result more than 98% of the 547 MW Chinese and Taiwanese PV production is exported.

Another noteworthy development is the fact that the market share of the ten largest PV manufacturers together decreased from 80% in 2004 to 66% in 2006. This development is owned to 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.

Besides the exponential increase of the world market, the even more rapid increase of the Chinese and Taiwanese production capacities is of particular interest. If the announced production increases can be realised, China and Taiwan will represent about 32% of the worldwide 23 GW [Edf 2006, Sun 2007, various press releases and stock market notes]. Europe will then be second with almost 31% and Japan third with 16% (Fig. 3). It has to be

noted that the assessment of all the capacity increases is rather difficult as it is affected by the uncertainties given below.

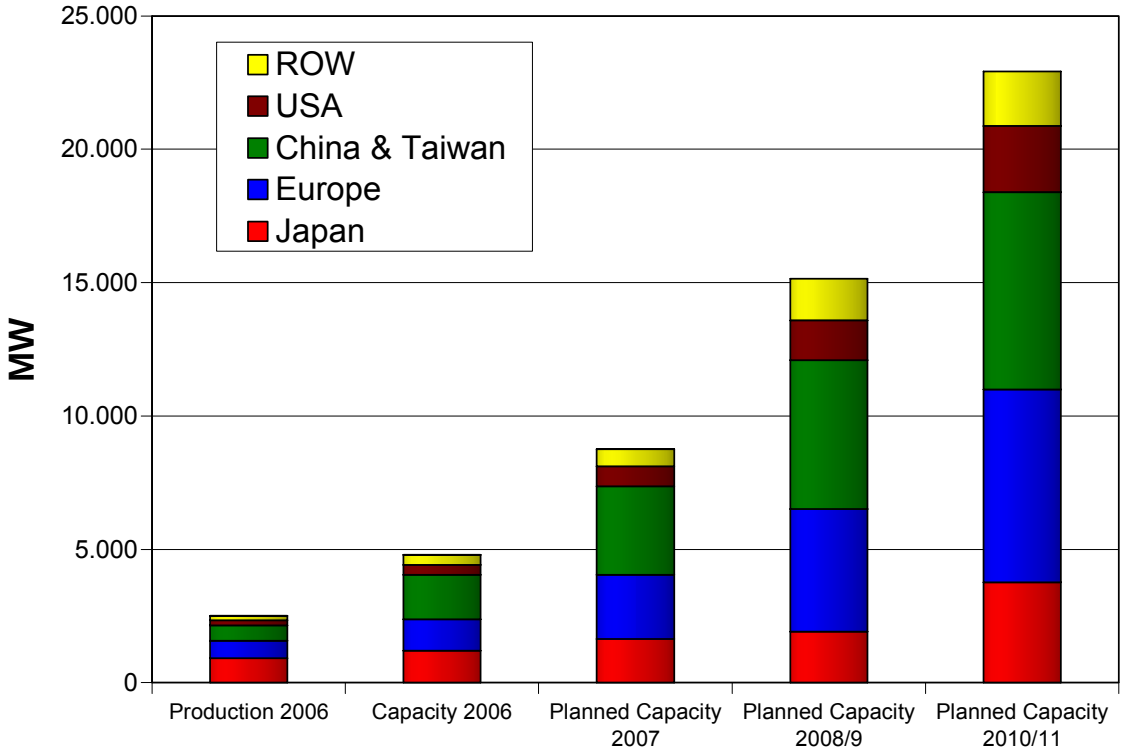

Fig. 3: World-wide PV Production 2006 and planned production capacity increases

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 might miss out on a major increase if it is well above normal predictions.

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 such as number of shifts, operating hours per year, etc. Production capacities are not equal to sales and therefore there is always a noticeable difference between the two figures, which cannot be avoided.

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 of all, should the announced increases be realised, total production capacities will then stand at 23 GW of which 6 GW could be thin films (Fig: 4). However, one should bear in

mind, that out of the ca. 80 companies, which have announced their intention to increase their production capacity or start up production, only 21 companies have actually produced thin film modules. Sharp and First Solar together would contribute with about 1.5 GW, whereas the other existing producers would add about the same capacity. For that reason, I consider 3 GW as quite certain, another 1 GW as possible. For the remaining 2 GW there is a high uncertainty whether or not it can be realised in the time-frame given.

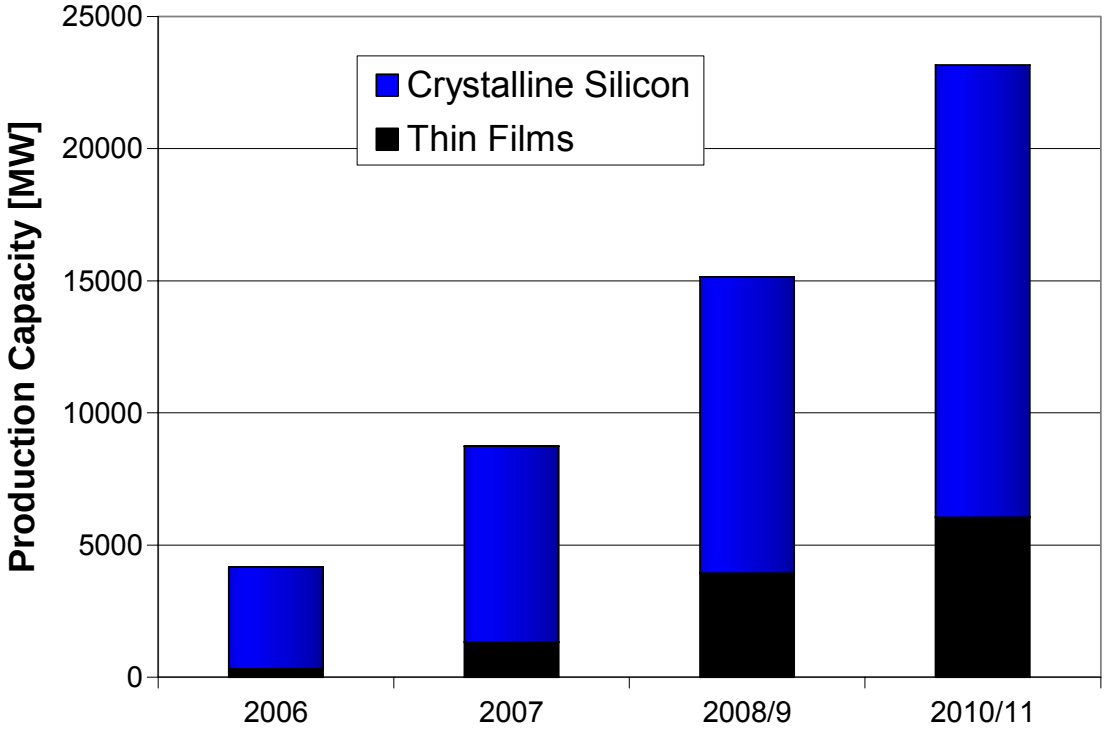

Fig. 4: PV Production Capacities 2006 and planned production capacity increases.

The technology as well as the company distribution varies significantly from region to region (Fig. 5). 34 companies are located in Europe, 19 in the US, 12 in China and Taiwan, 9 in Japan and 8 elsewhere. The majority of 47 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. 20 companies will use $Cu(In,Ga)(Se,S)_2$ as absorber material for their thin-film solar modules, whereas 10 companies will use CdTe and 5 companies go for Dye & other materials.

In the case of the more optimistic silicon feedstock expansions to 115,000 metric tons 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 predictions forecast. Another important factor is the actual utilisation rate of the production capacities. In 2006, Japan had a Capacity to announced production ratio of 77%, Europe of 61% and China of 35%.

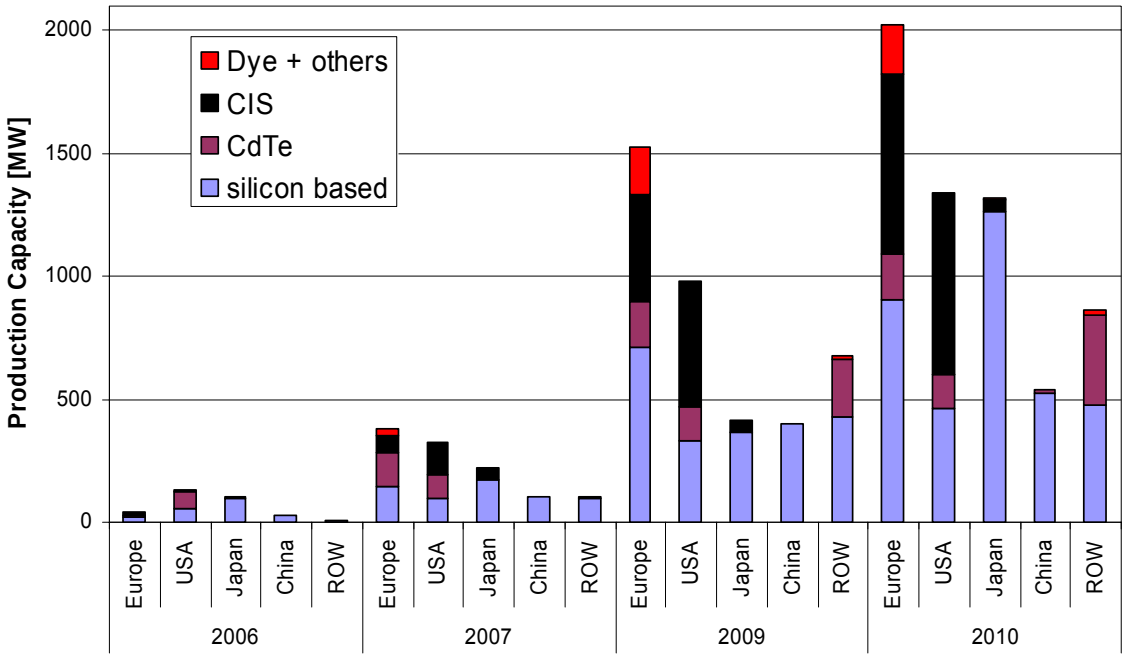

Fig. 5: Regional and technology distribution of the thin film production capacity increases.

Second, 6 companies are aiming at total production capacity in the order of 1GW or more, whereas another 12 aim at 500 MW or more. The majority of these super factories are planned in Europe (5), followed by China (4), Taiwan (3) and Japan (3).

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 32 % in 2010/11. 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 (95% in 2006) of their production to the growing markets in Europe, the US and developing countries.

Europe reached its White Paper target of 3 GW cumulative installed PV system capacity in 2006. During the last few years since the introduction of the German Feed-in Law in 1999, more than 90% of European PV systems were installed in Germany. The Spanish PV market grew from 14.5 MW in 2005, to 60.5 MW in 2006, and it is expected that in 2007 it will be above 100 MW. Since 1999, European PV production has grown on average by 50% per annum and reached about 680 MW in 2006. The European market share rose during the same time from 20% to 26.9%, followed by the Chinese and Taiwanese with 21.7%. 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 36.7% in 2006.

The European PV industry has to continue its high growth over the next years in order to maintain that level. This will, however, only be possible if reliable political frame conditions are in place in Europe to enable a return on investment for the PV industry.

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 and the House of Representatives approved two bills on 4 August 2007 as amendments to the Energy Bill, which would extend the 30% solar investment tax credit for businesses through 2016 and improve the tax credits for homeowners as well. However, it is not clear yet if these bills will finally become law as the White House has raised concerns and is even considering to veto the new Energy Bill.

It is already visible that 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. The grid connected PV market in the USA was 101.5 MW in 2006.

The Japanese PV market has stabilised at around 285 MW, but this is by far not enough to reach the 4.8 GW target set for 2010. In 2006 Japan Photovoltaic Energy Association (JPEA) revised its "Vision of the Future of the Photovoltaic Industry in Japan" published in 2002 and announced their new "Vision for the independence of the PV industry". In this vision paper, JPEA predicts that the Japanese domestic market will increase to 1.2 GW and Japanese exports will increase to 1 GW in 2010. It has to be seen if the efforts by the Japanese PV industry, as well as by the Japanese Government will lead to a realisation of this vision.

A new and emerging market is South Korea. Despite the fact that at the end of 2006 the cumulative installed capacity of photovoltaic electricity systems was only in the range of 25 MW, the market will accelerate in the coming years if the government's goal of 1.3 GW by 2012 is reached. South Korea has introduced an attractive feed in tariff for 15 years along with investment grants up to 60%. The tariffs are 711.25 Korean Won/kWh (€ 0.55/kWh) for systems smaller than 30 kWp and 677.38 Korean Won/kWh (€ 0.52/kWh) for systems larger than 30 kWp. 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 Clean Development Mechanism (CDM) credits, allowing for trading of Certified Emission Reductions (CER) under the Kyoto Protocol.

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 world-wide. On the supply Japan is still No. 1, but with massive capacity increases in China and Europe the overall market share is decreasing. On the demand-side Germany has surpassed Japan but the country is still the second largest PV market.. 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 the 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'. This 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

The legislation is aimed at tripling the FY 1999 ratio of new energy in the total power supply to 3.2% by FY 2010 (currently: 0.2% is RE excluding hydro and geothermal; target here 1.1%) as part of Japan's efforts to attain the greenhouse gas reduction target of the Kyoto Protocol. The bill requires each power retailer to set an annual sales target for six types of renewable energies: sunlight, wind, terrestrial heat, water and "sources other than oil that the government specifies", which may include biomass and waste. The Agency for Natural Resources and Energy (ANRE) of METI sets the aggregate targets (with special treatment of PV) for the use of the different new energies in the coming eight years – a scheme which will serve as the basis of the annual target calculations by each energy retailer. Each retailer will be required to report its specific targets for the coming year and results from the preceding year to the Ministry. The companies could achieve their targets either by generation of new energy with own facilities, buying electricity from authorised new energy generators or buying surplus from other retailers. The exchange of surplus will be handled by certificates issued by METI. These certificates will be valid for two years and issued for every 1000 kWh of renewable energies generated. A company that fails to meet its target in the first year will be allowed to pay METI an amount of certificates equivalent to its annual target in the following year, plus the first year's shortage. RPS will replace the pay-back system, but MITI will set frame conditions to ensure future growth of PV installations.

For FY 2006, ANRE decided to increase the amount of electricity to be purchased under the RPS from the original 4.1 TWh to 4.55 TWh. For FY 2007 it increased to 6.1 TWh. This measure is intended to strengthen the independence of the "New Energy" businesses.

6. Science and Technology Policy 2006

At its 56th session on June 14, 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]. Over the next five years the Government wants to spend ¥ 25 trillion (ca. € 180 billion[4]) for Science & Technology to strengthen international competitiveness and developing the Human Resources. The strategy encompassed the creation of the world's top class research centres, enhancement of industry/academia collabo-

[4] Exchange rate used: 140 ¥ = 1 €

ration, continuous financial support to get through the "valley of death" procurement of new technology product and services, and international standardisation. 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".

Prime Minister Koizumi concluded the meeting by saying, "We have been increasing the S&T budget because it is investment for tomorrow. We will formulate the S&T budget, with selection and focus, to make Japan an advanced S&T-oriented nation, taking into account the creation of innovation, collaboration among industry, academia, government and cooperation among relevant ministries."

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).

3.2 Implementation of Photovoltaics

The Japanese 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 Infra-structure 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 the past 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]. At the same time, Japanese exports increased by 21% to 640 MW. For FY 2007 the PV industry expects a stable residential market in line with the trend to fully electrified houses and the Renewable Portfolio Standard with an increased amount of electricity generated from renewable energy sources.

During the lifetime of the "Residential PV System Dissemination Programme", it could be observed that notwithstanding the decrease of METI subsidies, the number of residential photovoltaic systems in Japan increased considerably year by year. According to Osamu Ikki and his colleagues, the following reasons contributed significantly to the dissemination of PV systems [Ikk 2004]:

1) The number of municipalities offering additional subsidies and soft loans for residential PV systems increased substantially;
2) More and more municipalities adopting PV systems for public buildings;
3) PV companies developing and commercialising systems, especially adopted for roofs with small areas and complicated shapes;
4) The market for houses which use electricity as the only energy source is increasing and PV systems were adopted as a key item for these “all-electrification” houses;
5) Several housing manufacturers developing “zero-energy houses”. Such houses combine PV installation, energy efficient water supply and an airtight housing structure that maintains a constant temperature inside the home. In addition, they trained their sales staff to understand the functionality of photovoltaic systems;
6) More and more solar cell and house manufacturers promoting PV systems through TV commercials, thus increasing the consumers' understanding of PV systems and their purchase intention;
7) An increasing number of customers focusing their attention on economic efficiency, as well as environmental impact.

In conclusion, one can summarise that the driving forces for residents to install PV systems are growing public and environmental awareness, as well as the net-metering of generated electricity. Electricity production averages 950 kWh/kWp per year in Japan and even the snow-rich west coast along the Japanese Sea, the so-called Snow-Land, averages 850 kWh/kWp per year. This means that average annual electricity savings are approximately 23,400 ¥/kWp and 21,000 ¥/kWp respectively.

The METI's “Vision for New Energy Business”, announced in June 2004 and the "New National Energy Strategy", published in 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 world-wide. The strategy was implemented in the revised "PV Roadmap towards 2030" (Fig. 6), which was drafted by NEDO, METI, PVTEC[5] and JPEA[6].

The Government Budget for FY 2007 was passed in December 2006 with a 4% increase compared to 2006. The METI Budget for photovoltaics increased by 31% 2006 ¥ 18.758 billion (€ 115.79 million[7]) to ¥ 24.60 billion (€ 151.852 million), and the Ministry of the Environment (MOE) will add a budget of ¥ 4.8 billion (€ 29.629 million) for the "Solar Promotion Programme" and ¥ 3.302 billion (€ 20.383 million) for the "Project for developing technology to prevent global warming" [Ikk 2007b].

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).

The main changes in the METI Budget are due to the substitution of the "Field Test Project on Advanced PV Power Generation Technology" by the new "Field Test Project on New Energy Technology", the introduction of the "New Energy Technology Development" Programme and a substantial increase in the Budgets for the "Verification of Grid Stabilisation with Large-scale PV Power Generation Systems" Programme as well as the "Strategic Technology Development for Practical Use of Next-Generation Storage System" Programme.

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5 Phtovoltaic Power Generation Technology Research Association

6 Japan Photovoltaic Energy Association

7 Exchange rate: € 1 = ¥ 162

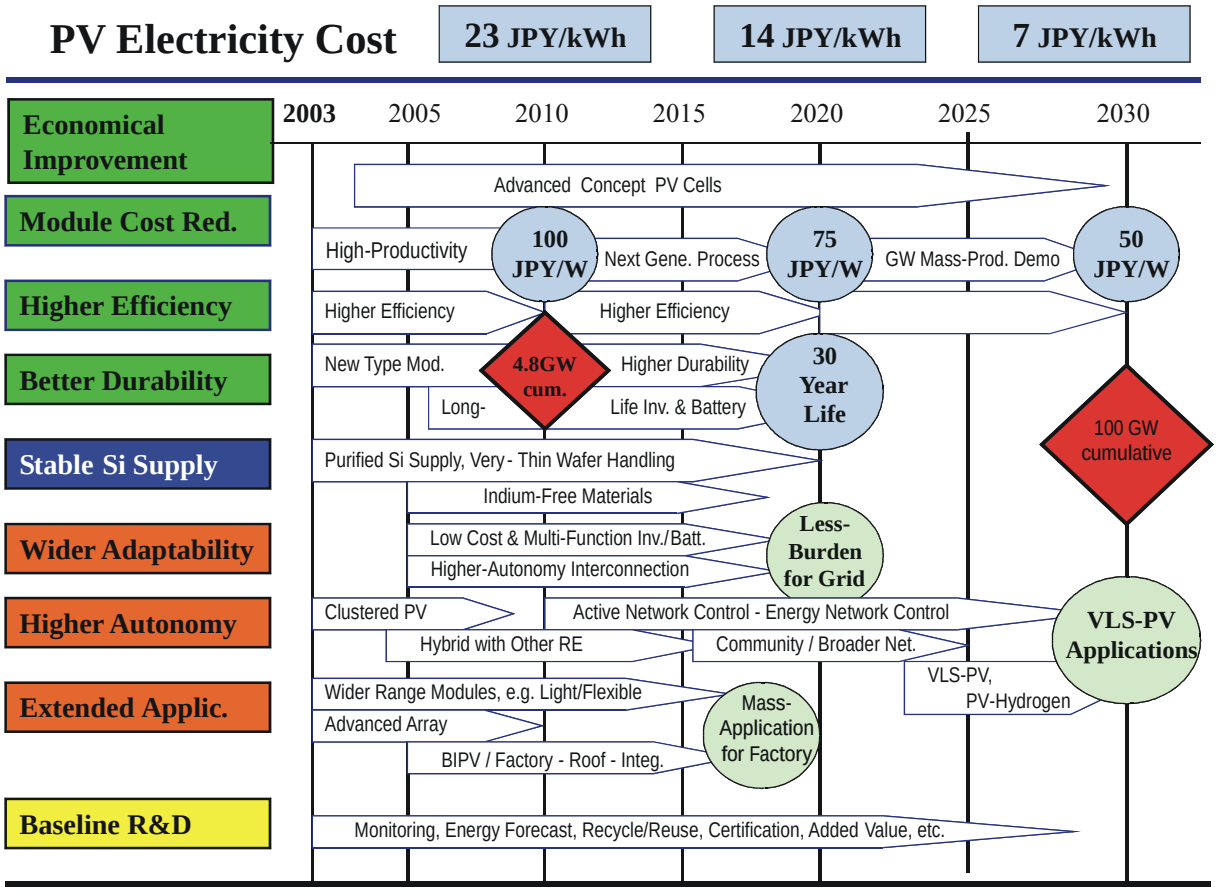

Fig. 6: Japanese Roadmap for PV R&D and market implementation [Kur 2004]

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 Research Programme has two main pillars:

- R&D for Next Generation PV Systems
- PV System Technology for Mass Deployment, Phase II

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.

The R&D Programme is divided into short-term targets and mid to long-term targets. The short term issues are related to a cost reduction in 2010 to 23 ¥/kWp (see Roadmap Fig. 6) and research issues are covered by a 2005 to 2007 programme called "PV Systems for Advanced Practical Technology". Mid to long-term issues are covered by the Research Programmes "R&D for Next Generation PV Systems" and "PV System Technology for Mass

Deployment, Phase II". These two programmes run from 2006 to 2009. The topics are listed below.

♦ **PV Systems for Advanced Practical Technology**

To achieve the target of 4.82GW cumulative PV installation capacity by FY2010, R&D for reducing the manufacturing costs and improving solar cell efficiency is being carried out under this programme. NEDO and joint researchers each bear 50% of the costs.

♦ **R&D for next generation PV systems**

This project is focused on a mid- to long-term perspective and R&D will include the development of new pioneering-types of solar cells and technological innovations beyond the augmentation of existing technologies. The programme will pay attention to global environmental considerations as well as a stable energy supply. The aim of this project is to accelerate the utilisation of PV systems as a result of dramatic improvements in economic efficiency, performance, function, applicability and convenience. In addition, long-term, high-risk research themes that private firms are unable to carry out are selected.

In terms of a mid-term perspective, this project selects promising results of past *Seed Research* to develop new technologies. A long-term vision is addressed through continuing the search for further technological innovations, including the development of revolutionary solar cells and other technologies. The PV Roadmap 2030 has been used to select R&D subjects and determining the targets of this project. R&D themes and contents of this project are as follows:

- **Thin-Film CIS Solar Cells**
  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
- **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)
- **Dye-Sensitized Solar Cells**
  High efficiency of 15% for small area ($1cm^2$) cells
  Durability of modules wit targhet efficiency of 8% (900 cm^2)
- **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

- **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

Although these R&D themes are targeted toward a mid- to long-term horizon of 2020 to 2030, solid and practical technological R&D results will be applied and their commercialisation promoted during the current 4-year project term, as well as after the completion of the programme.

♦ PV System Technology for Mass Deployment, Phase II

To achieve mass deployment of PV power generation systems, it is essential to improve the infrastructure in conjunction with the R&D of solar modules and systems. This project includes the following:

1) Performance monitoring and forecasting technology for both new solar cell and PV system development,
2) Recycling and re-use process technology, and
3) International cooperation and the collection of information on international trends, which will be carried out through the International Energy Agency's (IEA) "Photovoltaic Power Systems Program (PVPS)."

R&D themes and contents of this programme are as follows:

1) R&D for characterising new solar cells and modules:
   - Performance monitoring technology for new types of solar cells:
     - ➢ Develop basic evaluation methods for new types of solar cells such as DSC, organic, multijunction, CIS, etc.
     - ➢ Promote standardisation
   - Precise measurement technologies for reference cells and reference modules
     - ➢ Improve the precision for the reference solar cell measurement technology from the current ± 2% to ± 1%.
     - ➢ Establish precise reference solar module measurement technology
   - Performance monitoring for large-area solar modules
     - ➢ Address and resolve the technological issues to establish a performance monitoring technology for large-area solar modules (e.g. 2 m × 1.5 m)
   - Energy Rating: Construction of database necessary for PV output rating
     - ➢ Collect the "actual" PV operating data, including the spectra data corresponding to Japan's climate zones and clarify the correlation
     - ➢ Develop radiation forecasting technology
     - ➢ Provide data to IEA-PVPS and encourage standardisation of PV energy rating technology
     - ➢ Develop in-house energy rating technology aiming to calculate the annual PV output under various conditions using the database
   - Reliability evaluation:
     - ➢ Identification of the degradation factors for solar modules exposed to extreme conditions

- Identification of technological issues for the development of evaluation methods; Development of in-house durability evaluation method corresponding to 20 to 30 years of outdoor exposure.

2) Development of PV environmental technology
   - Establishing necessary environmental conditions and technology guidelines for PV installation in various environments
   - Development of technologies related to “reduce”, “re-use” and “recycle”, and life cycle assessment (LCA) evaluation, including disposal and evaluation tools.

3) Investigation of PV R&D trends and promotion of international cooperation
   - Insight into global R&D trends and national projects through investigation, analyses, etc., and compilation of R&D trends.

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. Despite the fact that the Residential Market Implementation Programme has come to an end, the Japanese Photovoltaic Energy Association (JPEA) is confident that the market will continue to grow. PV systems have developed into additional added value for existing or new houses as an increasing number of Japanese consumers are now considering the lower environmental impact by using a PV system to be more important than the higher price.

After 30 years of PV development under the different NEDO programmes, 7 Japanese PV manufacturing companies are listed in the international sales statistics [Pvn 2007] and produced approx. 37% (927 MWp) of the solar cells sold world-wide in 2006. Despite the production growth of 11.3% from 2005 to 2006, the Japanese manufacturers lost overall market shares due to the overall production growth of 41%. Additional companies are doing research or pilot plant activities. Furthermore, there are some silicon producers, a few module manufacturers, as well as inverter and glass producers.

In addition to the substantial production increases in the past, all major solar cell manufacturers announced massive increases of production capacities for 2008 onwards, signalling the expectations for a continuation of the high growth rates. The number of residential PV systems to be installed this year in Japan is expected to stabilise at around 70,000 systems, with an average of 3.8 to 4 kWp per system. Together with the installations under the "Field Test Project on New Photovoltaic Power Generation Technology", the "Solar Promotion Programme" and the "Project for developing technology to prevent global warming" as well as the DFAA, MLIT and MAFF installations, total solar photovoltaic installations in 2007 could be in the order of 300 to 350 MWp.

So far, the majority of PV systems were installed on residential houses. At the end of FY 2006, 1,617 MWp out of the total 1,709 MWp installed, were on residential buildings. About 80% of the residential installations are on existing houses and 20% are on newly built houses.

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 response to METI's “New National Energy Strategy”, the Japanese Photovoltaic Energy Association announced its new vision on the "Future of the Photovoltaics Industry in Japan" in June 2006 [Ikk 2006]. This vision paper is 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. In comparison to the 2002 version, the outlook for the domestic market has not changed, but the perspective of the overseas markets changed considerably. In 2010, JPEA expects a domestic market of 1.18 GW (¥ 377.1 billion/€ 2.34 billion) and exports of 1 GW (¥ 200 billion/€ 1.23 billion). For 2030, the figures have been revised to 7.55 GW (¥ 1 trillion/ € 6.17 billion) domestic installations and 5 GW (¥ 600 billion/€ 3.70 billion) exports.

In 2010, prices for residential PV systems are estimated to be reduced to 300,000 ¥/kWp (1,852 €/kWp), whereas for public and industrial use they are estimated to be 380,000 ¥/kWp (2,346 €/kWp). In 2030 the price for all these systems should be 200,000 ¥/kWp (1,235 €/kWp). JPEA expects the market for large PV systems for power generation to start in 2015 and to expand to an annual 1.25 GW market in 2030. The prices for such systems are expected to be lower with 160,000 ¥/kWp (988 €/kWp) in 2030. The price expectations for exports are even lower. JPEA expects them to be in the range of 200,000 ¥/kWp (1,235 €/kWp) in 2010 and 120,000 ¥/kWp (741 €/kWp) in 2030.

For the near future it is expected that the domestic PV market will be dominated by the residential sector. About 100,000 to 200,000 systems per year or 400 to 800 MWp are estimated. The market for larger installations on public and industrial facilities is expected to grow, with market volumes of over 100 MW for each sector by 2010. Additional market segments could be developed in the area of transport applications (roads, railways) and in the agricultural sector, but with quite small quantities in the order of 10s of MWp by 2010.

To reach the target for PV installations set for 2010 at 4.8 GWp, the installation of PV systems has to be increased significantly over the next few years. In 2006, there was no growth compared to 2005 and a continuation of this trend would result in 3.2 GW installed in 2010 instead of 4.8 GW (Fig. 7). In September 2007 the Osaka Chamber of Commerce and Industry (OCCI) called for the reinstatement of a subsidy scheme for the installation of residential-use solar photovoltaic electricity generation systems. The OCCI made the call in a position paper in an interim report issued by the government in August, with regard to plans for achieving the greenhouse gases reduction targets. The OCCI said the promotion of solar power generation with the use of subsidies will help to reduce emissions in the residential sector.

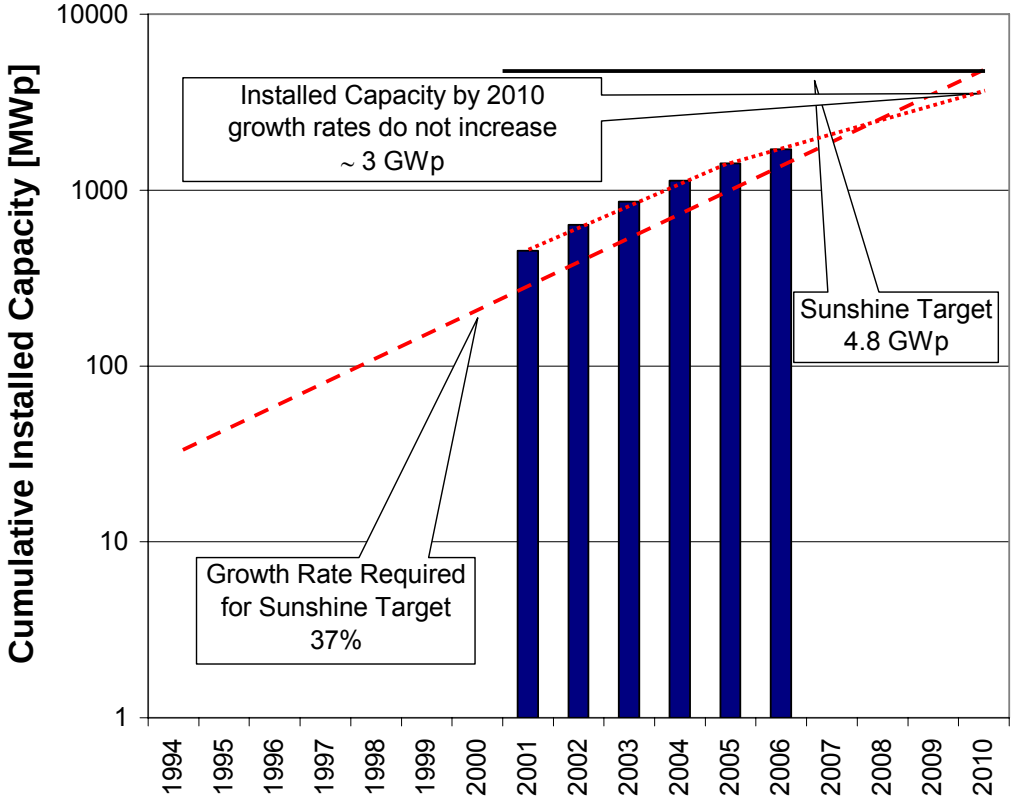

Fig. 7: Sunshine Target and current trends

A special condition of the Japanese PV industry is the fact that a few large companies 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 Market Players

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 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. The total production capacity is currently 30 MWp/year with FY 2006 sales of 30 MW. An increase of the production capacity of the Toyooka plant to 55 MWp (2007) and 70 MW (2008) is planned [Mat 2007]. In 2006 the company opened a module factory with 10 MW capacity in Olomouc, Czech Republic. An important market with future potential is at present Germany (because of the high demand following the introduction of the feed-in tariff) and greater Europe in the future.

3.5.2 Kyocera Corporation

In 2006, Kyocera Corp. had sales of 180 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 2004a]. 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].

Kyocera is primarily active in R&D and the production of solar cells used to generate electric power. It is working to create more efficient, lower-priced solar cells with a larger surface area and reduced thickness by further developing the multicrystalline silicon solar cell technology.

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. The current production capacity is 230 MW [Ikk 2006a]. With 110 MW sales in 2006, Mitsubishi Electric held the 6th position.

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 2006 MHI shipped 12 MW of amorphous silicon solar cells and in 2007 a total production capacity of 90 MW should become operational [Tak 2007].

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 2006 Sanyo had sales of 155 MW solar cells. Current production capacities are 165 MWp. The latest expansion plans foresee focus on the solar business and a rapid expansion to 260 MW in FY 2007 and 600 MW in 2010 [Reu 2006].

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 opened its module manufacturing plant in Dorog, Hungary. Production capacity was planned to grow to 100MW in 2006 [San 2005, Ikk 2006a].

Sanyo has set a world record for the efficiency of the HIT solar cell with 22% under laboratory conditions [San 2007]. 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. This application is interesting for sound barriers, rooftop fences or horizontal installation as car-ports, etc. Since FY 2003, Sanyo has been marketing its latest version of the HIT module with 19 % cell efficiency and 17 % module efficiency.

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 (31.6 metres at its centre point) making it the largest single-structure solar installation in the world. In the meantime, it has become one of the symbols of photovoltaics. Power generation began in April 2002. Placed underneath the Ark is the "Solar Lab", a Solar Energy Museum opened in 2002. The main activities are:

- Cultivate children's awareness in Science and Ecology.
- Release 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.

Sharp is the world largest PV cell and module manufacturer with production capacity of 710 MWp/year in FY 2007 [Sha 2007a]. An enhanced production line (15 MW) for new large format thin-film polycrystalline solar cells went into operation in September 2005. 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 2007c], the company announced the construction of a 1 GW thin-film plant by 2010 [Sha 2007].

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 3.8×4.8 m^2 and the system output is 2,922 W. According to a press release from September 2007 the system is now available [Sha 2007d].

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.

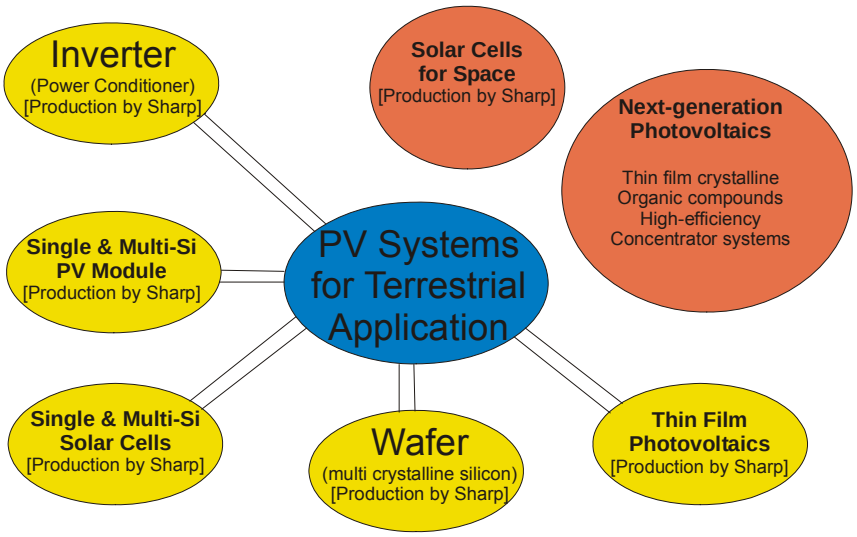

Fig. 9: Development concept of Sharp

In addition to the solar cell factory at the Katsuragi plant[8], 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. For the last seven years Sharp has managed to be the leading company world-wide and in 2006 has shipped 434 MW of solar cells. To increase output, Sharp is working to minimise the silicon use by reducing the cell film thickness from 200 µm to 180 µm and at the same time will continue to strive to have lower costs.

3.5.7 Additional Solar Cell Companies

- **Fuji Electric Suystems 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

[8] Former name: Shinjo plant

initial capacity of 15 MW to be expanded to 30 MW in 2009 [Fuj 2005]. The start of operation was scheduled for October 2006.

- **FujiPream/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 significant reduced silicon use. CV21 entered into an exclusive sale agreement with FujiPream Corporation in December 2005. In January 2007 the Canadian ATS Automation Tooling Systems Inc. announced that its subsidiary, Photowatt Technologies Inc., has signed a non-binding letter of intent to enter into a business relationship with Clean Venture 21 and FujiPream Corporation, in order to advance the development of its Spheral Solar(TM) Technology. [Ats 2007].

- **Hitachi:** Tokyo-based Hitachi Ltd. has a production capacity for its bi-facial crystalline solar cell of 10 MW/a and further expansion is under planning [Ikk 2006a]. In addition, Hitachi developed a dye-sensitized solar cell with 9.3% efficiency according to the company. It was planned to commercialise this cell type in 2005 [Nea 2004].

- **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 will start in the autumn of 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.

- **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].

3.5.8 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 (PV) module systems for its houses. Owing to rising demand, they began manufacturing the modules in November 2001 at the Takasago Works in Hyogo, Japan.

3.5.9 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 thirds equity interest in MSK for $ 107 million (€ 85.6 million) in cash [Msk 2006]. The second step to acquire the remaining shares is expected to take place by the end of 2007.

3.5.10 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. In February 1999, Daiwa House began testing a pilot “all-electric house” in the Niigata Prefecture. This model of house utilises surplus night-time electricity to supply hot water for central heating, and was a new approach to “ecological coexistence” in housing [Dai 1999].

3.5.11 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. This Eco House uses polycrystalline PV modules from BP Solar (1992 Solarex), which have been especially developed by BP Solar's exclusive Japanese distributor MSK Corporation. In 1999 the "Hybrid Z" energy-efficient home was introduced with either a six or 12.5 kW PV system [May 1999]. However, Misawa Homes also co-operates with Kobe Steel and others as a module supplier [Rio 2001]. 2003/4 Misawa Homes built “Hills Garden Kiyota”, a 503-home residential community in Kiyota, Hokkaido. The homes are all equipped with solar photo-voltaic 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].

3.5.12 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 16,000 houses/apartments 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 FY 2006 51% of the detached houses Sekisui sold were equipped with a PV system [Sek 2007]. According to the Annual Report 2007, the "zero-utility-cost-houses" carved new markets and the company will continue to promote the sale of these homes.

3.5.13 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.

3.5.14 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 2006 Tokuyama had an annual production capacity of 5,300 tons and is planning to expand this to 7,000 tons by 2009 and 8,400 tons by 2010 [Pvn 2007b].

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.

3.5.15 Additional Silicon Producers

- **JFE Steel Corporation:** JFE Steel began to produce silicon ingots in 2001 and has since become one of the world's leading ingot manufacturers in terms of production volume. To stabilise increasingly tight 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 has started construction of a commercial plant with a capacity of 100 tons/year, to be completed in October 2006 and has also begun designing a plant to mass produce the material [Jfe 2006]. According to PV News the capacity should reach 1,000 tons in 2010 [Pvn 2007b].

- **M.Setek:** M.Setek is a 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 initial capacity is 200 tons to be increased to 6,000 tons in 2010 [Pvn 2007b].

- **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 capacity is about 3,100 tons [Pvn 2007b]. The polysilicon is produced by their affiliates *Mitsubishi Polycrystalline Silicon Corp.* and *Mitsubishi Polycrystalline Silicon America Corp.* Mitsubishi produces approximately 1,250 tons polysilicon annually in the US. When the expansion is complete in March 2007, US output will increase to 1,600 tons.

- **OSAKA Titanium technologies Co. Ltd** (Name until 30 September 2007: Sumitomo Titanium Corporation, STC) 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.

4. THE PEOPLE'S REPUBLIC OF CHINA AND TAIWAN

Since 2004, the MW announcements of planned production capacity increases in the People's Republic of China, as well as Taiwan, have sky-rocketed. Production rose from 70 MW in 2004 to 216 MW in 2005 and 547 MW in 2006. For 2007 capacity increases to 3,300 MW are announced, with 2,485 MW planned in the PRC. In parallel, China is aiming to build up its own polysilicon production capacity. The numbers given are 2,800 tons in 2007 and 5,000 tons in 2010 [Pvn 2007b]. 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. 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.

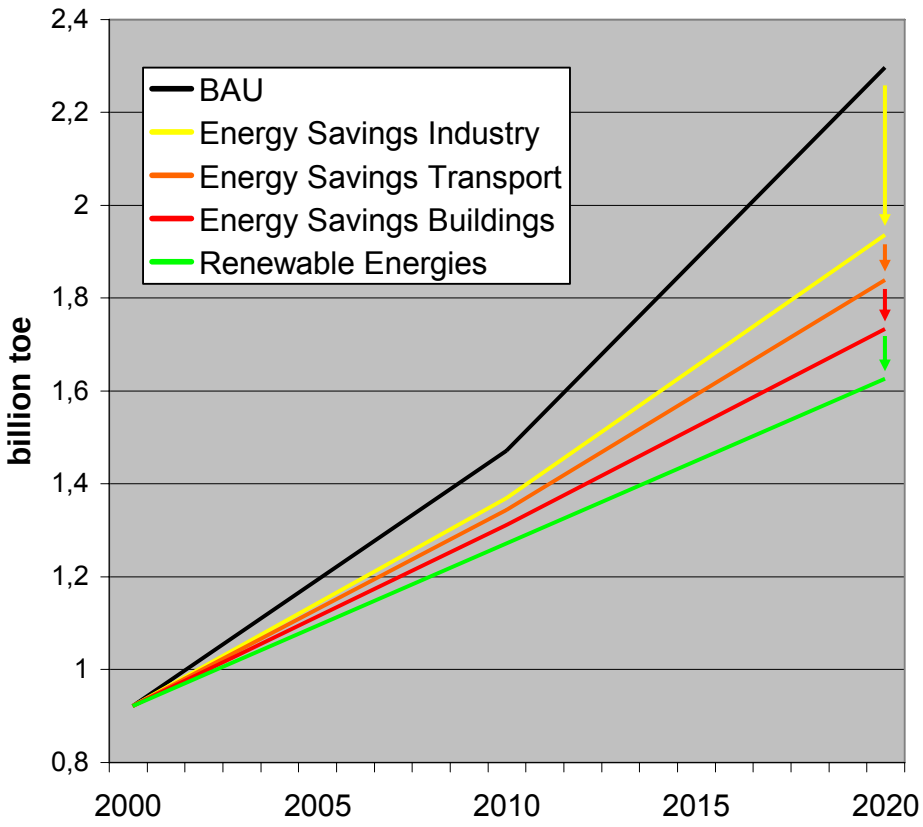

Fig. 10: Scenarios of PRC's fossil energy demand up until 2020 for different scenarios [Fuq 2003]

4.1 PV Resources and Utilisation

4.1.1 People's Republic of China

The PRC's continental solar power potential is estimated at 1,680 billion toe (equivalent to 19,536,000TWh) per year [CDF 2003]. One percent of China's continental area, with 15% transformation efficiency, could supply 29,304 TWh of solar energy. This are 189% of the world-wide 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 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 with 30 GW and include 12 GW in the frame of the Chinese Large-Scale PV Development Plan, a project which should start in 2010 [Fig. 11]. 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.

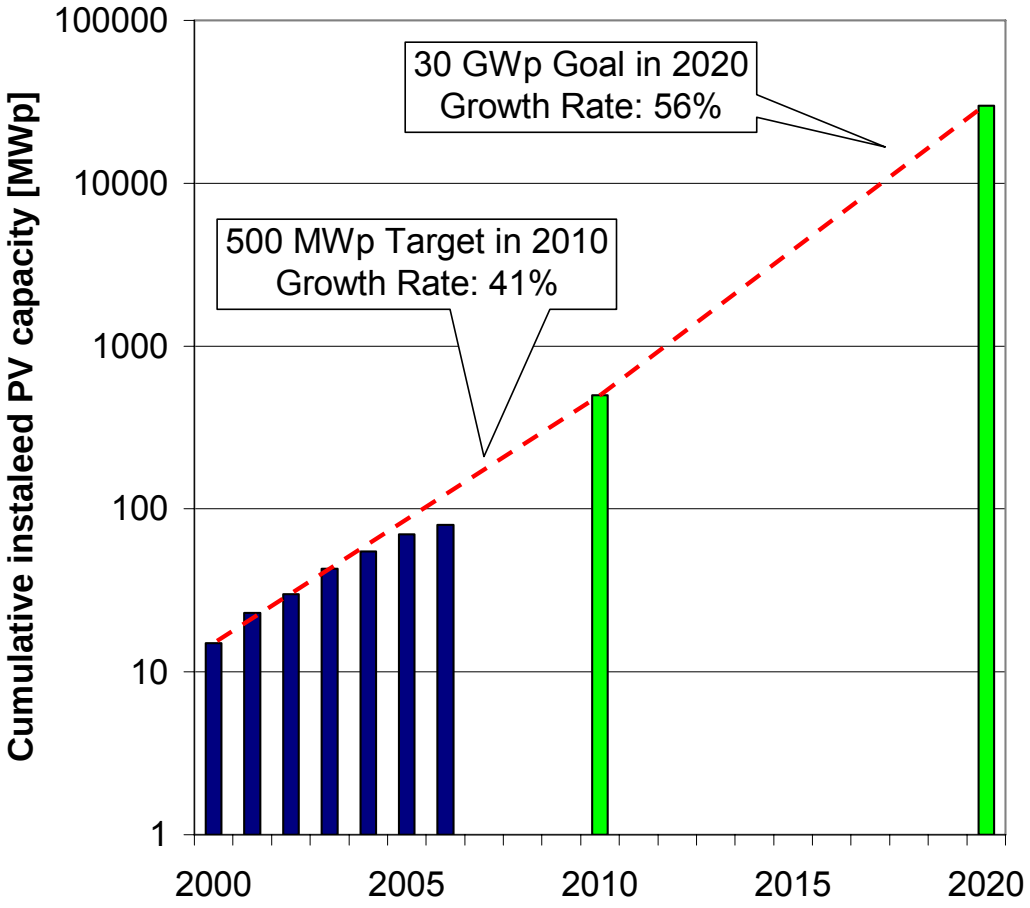

Fig. 11: Cumulative installed photovoltaic capacities and targets for 2010 and 2020 in PRC

For 2006, installation costs for free-fields system in China were quoted with 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 with 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 has been developed, in line with the idea of sustainable development. The first step concerning photovoltaics is the construction of a 30 kWp grid-connected pilot plant by the Chinese Ministry of Science and Technology and the Beijing Municipal Government. The plan proposes the outer walls of the Olympic Stadium and gyms to be covered with solar cells and 80 to 90% of the street lights in the Olympic Village to be solar powered. Despite the fact that no plans for installed capacities are mentioned, it is expected that this event will further accelerate the dissemination and implementation of solar photovoltaics in China.

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 part of the programme supports participating PV system companies in the provision of 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 should support 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 Dessert. 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.

4.1.2 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.

These political developments and buoyant world market growth have triggered start up and expansion activities of various larger photovoltaic business operations in the PRC as well as in Taiwan.

4.2 Solar Companies

In the following chapter, some of the market players in the PRC and 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.

4.2.1 DelSolar Co. Ltd., Taiwan

DelSolar is a subsidiary of Delta Electronics established in 2004. DelSolar has a strategic co-operation with the Industrial Technology Research Institute (ITRI). DelSolar had a production capacity of 25 MW at the end of 2005 and produced 20 MW in 2006 [Pvn 2007]. For 2007 a capacity increase to 100 MW is planned.

4.2.2 E-TON Solartech Co. Ltd., Taiwan

E-Ton Solartech was founded in 2001 and produced 32.5 MW in 2006 [Pvn 2007]. At the end of 2006 the production capacity was 100 MW per annum and a capacity increase to 200 MW was planned for 2007. The company produces monocrystalline solar cells and announced a new record efficiency average approaching 17% in August 2004.

4.2.3 Gintech Energy Corporation, Taiwan

Gintech was established in August 2005 and went public in December 2006. In 2006 the company increased its production capacity to 60 MW and had a production of 15 MW [Pvn 2007]. The expansion target is 300 MW by 2009.

4.2.4 Motech Solar, Taiwan

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 110 MW in 2006 [Pvn 2007]. With this output, Motec Solar was No. 7 of the top 10 list for 2006, increasing its production capacity to 200 MW by the end of 2006. 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].

4.2.5 Additional Taiwanese Companies

- **Big Sun Energy Technology Incorporation** was founded in 2006 and started its solar cell production in the 3rd Quarter of 2007 [Dig 2007]. For 2007 the production capacity is given with 30 MW and it is planned to increase this to 90 MW in 2008 [Big 2007].

- **Formosun Technology Corporation** was established 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. The start of production is scheduled for the end of 2007 with an initial capacity of 5.5 MW and 15 MW in the near future.

- **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. At the end of 2006, a total of 26 furnaces represented 80 – 90MW capacity of 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.

- **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 is moving into the solar cell business and has decided to use its existing 6-inch wafer factory for solar cell production. Solar cell production is expected to be Mosel's main business by the fourth quarter of 2007 [Dai 2006]. According to the company, the first production line with 30 MW was completed and started volume production in 2007. Mosel also plans to develop thin-film solar cell production from its own technology.

- **Nanowin Technology** was established in 2003 and according to press info they are constructing an amorphous silicon thin-film solar cell plant at the Tainan Science Part in Southern Taiwan. The equipment should be delivered by NanoPV (NJ), USA, with whom a strategic development agreement was signed in October 2006. By the end of 2007 the company plans to have 5.5 MW capacity to be ramped up to 35 MW in 2008 and 150 MW in 2011.

- **Neo Solar Power Corporation** was founded in 2005 and is owned by PowerChip Semiconductor, Taiwan's largest DRAM company. The current multi-crystalline solar cell production line with 30 MW capacity will be expanded to 90 MW in 2008. Within the next five to six years the company plans to expand to 500 to 600 MW capacity.

- **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].

- **Sinonar Corporation** located in the Science-Based Industrial Park in Hsinchu, Taiwan, produces amorphous solar cells and was founded in July 1988. In 2005 Sinonar was reported to have a production of 1 MW, compared to 4 MW in 2004 [Pvn 2006b, May 2005]. According to Wisely Chen, Sales Manager of the solar cell department, the company aimed have a production of 5 MW in 2004. In addition, they set up a

joint-venture production facility in the PRC. The planned capacity at the first stage was 10 MWp.

- **Solartech Energy Corporation** based in Gueishanis is listed on Taiwan's emerging stock market. The company produces mono- and multi-crystalline silicon solar cells and announced in June 2007 that it plans to expand its activities into thin-films. Current production capacity is quoted with 30 MW, to be doubled by the end of 2007. Solartech plans to partner with other Taiwanese solar cell manufacturers and establish a new company, which will construct a polysilicon fab in the US.

- **Sunwell Solar Corporation,** a subsidiary of CMC Magnetics Corporation, Taiwan's top compact disc maker, contracted a 40 MW thin-film PV production plant with Oerlikon Solar. The plant is scheduled to go online in the middle of 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.

- **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.

4.2.6 China Sunergy (formerly CEEG Nanjing PV-Tech Co. Ltd.), PRC

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 2006 was 192 MW and plan to increase it to 390 MW by the second quarter of 2008.

In June, 2005, China Sunergy started solar cell production with its first 30MW production line. In 2006, production was 60 MW [Pvn 2007].

4.2.7 JA Solar Holding Co. Ltdt., PRC

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 to 175 MW in 2007. In 2006, sales of 25 MW were reported [Pvn 2007].

4.2.8 Shenzhen Topray Solar Co.Ltd.

The company was founded in 2002 and manufactures solar cells, solar chargers, solar lights, solar gardening products and solar power systems, as well as solar charge controllers, solar fountain pumps and solar fan caps. The company has production capacities of 6 MW for

dual junction amorphous silicon solar cells, as well as 20 MW for mono and poly crystalline solar cells. In August 2007 the company reported that they have completed their development of a "dual-junction" + "laser edge isolation" technology for amorphous solar cells [She 2007]. In 2007 a production of 15 MW was reported [Pvn 2007.

4.2.9 Solarfun Power Holdings, PRC

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 plans to increase its production capacity to 240 MW by the end of 2007 and 260 MW by the end of 2008. In 2006 a production of 25 MW was reported [Pvn 2007].

4.2.10 Suntech Power Co. Ltd, PRC

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 2006 Suntech had a production of 158 MW and held 4th place in the Top-10 list. The annual production capacity of Suntech is on track to increase to 480 MW by the end of 2007 [Sun 2007a]. On 2 August 2006, Suntech Power signed an agreement to buy the Japanese PV module manufacturer MSK [Msk 2006]. Suntech bought a two thirds stake in the 3rd quarter of 2006 with the option to buy it completely in 2007. The company has a commitment to become the "lowest cost per watt" provider of PV solutions to customers worldwide.

4.2.11 Yingli Green Energy Holding Company Ltd., PRC

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 [Yin 2006]. When the RMB 3 billion (€ 295 million) investment is finished in 2008, Yingli Solar will have production capacities of 500 MW for wafers, solar cells and modules. The investment includes a Photovoltaic System Research Centre and a Professional Training Centre as well. The first stage of this expansion was finished in July 2007 and the current production capacity for wafers, cells and modules strands now at 200 MW [Yin 2007]. In 2006, solar cell production was reported with 35 MW [Pvn 2007].

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

- **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.

- **NingBo Solar Electric Power Co. Ltd**. has been a 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. Total output each year is given with 6 MW.

- **Shanghai Solar Energy Science & Technology Co.** produces mono-crystalline and multi-crystalline solar cells. According to the company they have a production capacity of 10 MWp since August 2003.

- **Semiconductor Manufacturing International Corporation (SMIC),** with its head-quarters in Shanghai, is one of the major semiconductor companies world-wide. The company announced that its solar cell products have received validation from clients in Europe, and is also awaiting product validation from other clients in Japan [Dig 2006]. SMIC's production of solar cells was expected to reach 10 MW in 2006. According to the company, the raw materials needed should come from reclaimed silicon generated by its core businesses. SMIC is planning to enter the polysilicon production in the future.

- **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 2007.

- **TaiZhou Sopray Solar Co. Ltd.** is a joint venture. Sopray manufactures solar cells and modules but provides 20 kinds of solar related consumer goods as well. The annual output capacity of mono- and poly-crystalline solar cells is 100MW (50 MW capacity according to ENF) and that of solar modules is 60MW (2007 estimate).

- **Trina Solar Ltd** ("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 commercial production of solar cells with a production capacity of 50 MW started in April 2007. It is planned to increase the production capacity to 150 MW by the end of the year.

- **Wuxi Shangpin Solar Energy Science & Technology Co. Ltd.** is located in Wuxi, Jiangsu Province, China. 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.

- **Yunnan Tianda Photovoltaic Co. Ltd.** is a part of the Sicong Group and started with research and mono-crystalline silicon solar cells and modules production in 1978. With the support of the People's Government of Yunnan Province, Yunan Tianda Photovoltaic Co., Ltd. built a new production base in the national level economic and technological development area in Kunming. According to the company the production capacity at the end of 2006 was 35 MW and in 2007 the capacity will be increased to 100 MW.

- **Additional Companies** listed in a joint presentation by JIKE and CRED during the 5th Korea-China Joint Seminar on New and Renewable Energy in Jeju, Korea, 20 June 2005:
  Shanghai Topsun: mono crystalline silicon cells, 2 MW production capacity
  Shenzhen Sun-Moon-Circle (Sumoncle) Solar Energy Industrial Co. Ltd.: a-Si, 1 MW production capacity
  Tianjin Jinneng Solar Cell Co., Ltd., a-Si, 3 MW production capacity
  Shihua, Beijing, a-Si, 10 MW

4.2.13 LDK Solar Co. Ltd., PRC

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 2007 was 215 MW. Further expansion plans are to ramp the production up to 400 MW by the end of 2007, 800 MW in 2008 and 1,600 MW in 2009. 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.

4.2.14 ReneSola, PRC

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 2006 was 80 MW and in 2007 an expansion to 373 MW is underway [Ren 2007].

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

- **CSG Holding Co. Ltd.,** a Chinese glass producer is planning to invest in polycrystalline silicon materials production [Enf 2006b]. They announced a first phase investment of €117 million to build a 1,500 tonne polycrystalline silicon factory in Hubei, China. The construction is planned to take 18 months, and will use technology from a Russian research institute. Further phases are expected to bring the capacity to 4,500-5,000 tonnes. In addition, they founded a subcompany "*CSG PVTECH CO., LTD*" in January of 2006. The main products are silicon solar cells and modules with a planned capacity of 450MW.

- **EMEI Semiconductor Material Factory** is located in Chengdu and produces and markets semiconductor material silicon. Production capacity is 100 tons/year multi-crystalline silicon and 50 tons/year of mono-crystalline silicon. For 2010 the production capacity is estimated to reach 1,700 tons [Ron 2006].

- **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 1000 tons and 25 million wafers.

- **Jinzhou Xinri Silicon Material Co. Ltd.,** is located in Hua (Jin). The silicon production capacity of this company was quoted with 760 tons in 2006 [Ron 2006].

- **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 with 450 tonnes of annual capacity. It is planned to increase the capacity to 3,000 tons by 2010 [Ron 2006].

- **Luoyang Zhonggui Material Co. Ltd.** has a production capability of over 300 tons of multi-crystal silicon. 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.

- **Sichuan Xinguang Silicon Technology Co. Ltd.** constructed a production plant for silicon material and began commercial operation in February 2007. Once in full operation, it should produce 900 tons of electronic polycrystalline silicon, 200 tons of zone melting polycrystalline silicon and 150 tons of polycrystalline silicon for solar cell use.

- **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].

- **Wangxiang Guifeng Electronics Co., Ltd.** is located in Quzhou. The company produces semiconductor silicon materials and has a capacity of 100 tons mono-crystalline silicon.

- **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. In 2006, the company plans to complete its production line to produce 35 tons of 6 to 8 inch (MCZ) mono-crystalline silicon sticks and process 2.8 million mono-crystalline silicon pieces annually.

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 the PRC and Taiwan photovoltaics is discussed at the level of a strategic industry policy for the future.

5. THE UNITED STATES

In 2006, the USA was the third largest market for PV, with around 140 MW of PV installations, 101.5 MW grid connected [Pvn 2007c]. Again, California and New Jersey accounted for more than 85% of the US grid-connected PV market. In 2006 the cumulative installed capacity was around 610 MW (343 MW grid connected). Production grew by 31% to 201 MW, mainly driven by the production increase of *First Solar* with their CdTe thin film product. The US market share in the thin film market is around 54% and much higher than the overall market share of 8%.

First Solar is continuing to expand its CdTe thin film production capacity and plans to have 570 MW fully operational by the end of 2009 [Fst 2007]. United Solar has decided to expand its production capacity to 300 MW by 2010 [Uni 2006a]. At the beginning of 2006 Shell Solar announced the sale of its silicon production facilities to SolarWorld (Germany) [She 2006, Sol 2006]. With the acquisition of the 80 MW production capacity in the US, Solarworld became the largest producer of solar cells in the US and started to expand the production facilities [Sol 2006a].

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 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 now expands 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 (€ 2.68 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. However, as administrative hurdles are still not sorted out everywhere, the overall effect still has to be seen.

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. Due to increasing support measures on regional and state level, the grid-connected market has surpassed the PV market for off-grid applications in 2003 and is now growing at a much faster pace

Despite the increase of grid-connected photovoltaic system installations during the last years, with growth rates of around 28%, much still needs to be done to reach the targets of the "One Million Roofs" Initiative (Fig. 12).

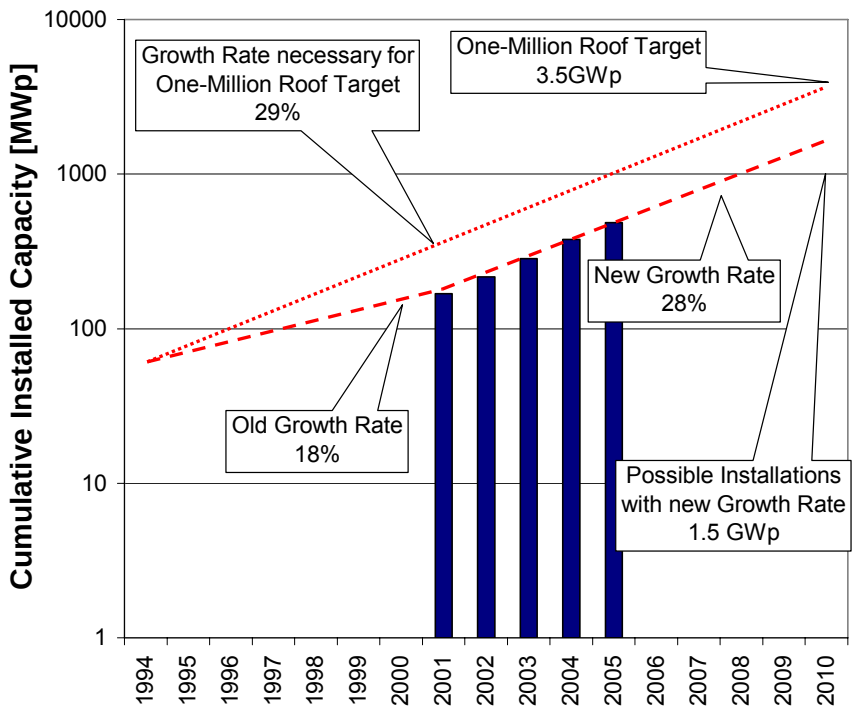

Fig. 12: One Million Roofs Target growth rate and new estimates based on 2001 to 2004 installations

Figure 13 shows the nation-wide figures for electricity prices in April 2007. 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; 9 States: California, Connecticut, Colorado, Delaware, Hawaii, Nevada, New Jersey, New York, 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; 10 States + DC Arizona, Florida, Maine, Massachusetts, Illinois, Ohio, Oregon, Rhode Island, Utah, Vermont, Washington DC	Significant incentives needed: (blue) below 2.5 $/Wp; 23 States

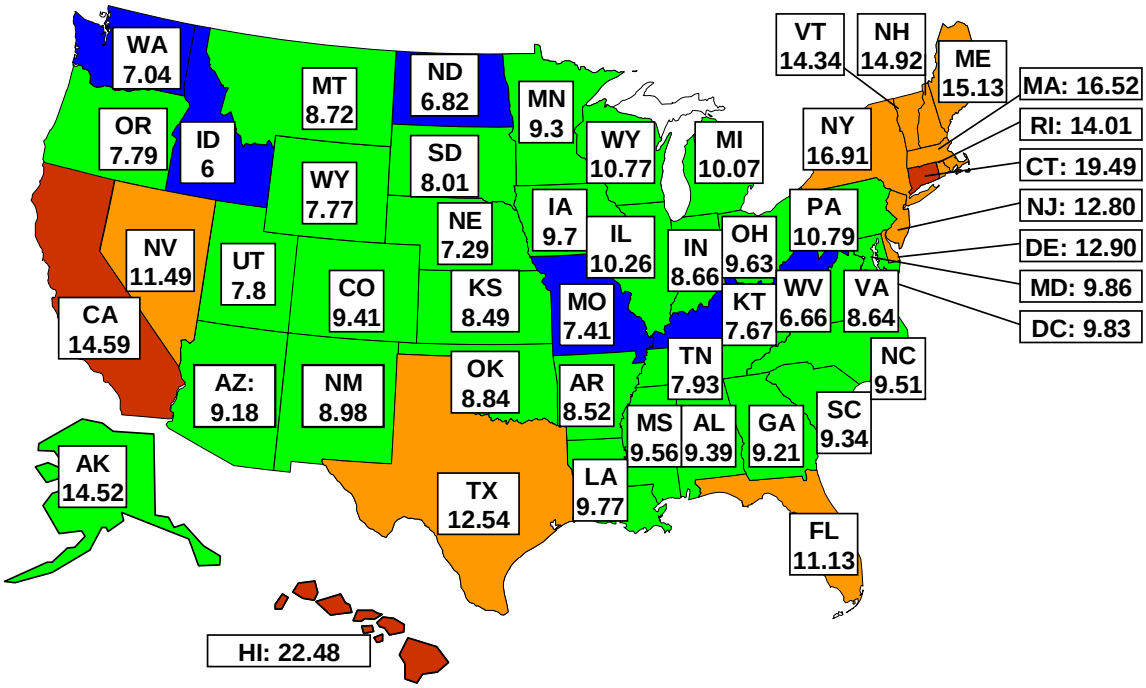

Fig. 13: Average residential electricity prices for April 2007 [Eia 2007]

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 2005 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 order to reach the target, installation rates of 60% year by year until 2010 are necessary. This is very ambitious, but not impossible.

In September 2004, the US photovoltaic industry published their updated 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.

5.1 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 last year. 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. It has to be seen how the market develops after this jump-start.

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 will 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[9] (such as tax credits). Financial incentives typically involve appropriations or other public 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., 21 States)
- sales tax exemptions for renewable investments (20 States + Puerto Rico)
- property tax exemptions (29 States)
- buy-down programmes (18 States + Virgin Islands, 152 utilities, 5 local)
- loan programmes and grants (Federal Gov., 28 States + DC + Virgin Islands; 45 utilities, 14 local, 10 private)
- industrial recruitment incentives (10 States)

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[9] 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 good or service; and/or (3) creates or expands a market for producers [Gie 2000].

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 2007]. 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 3: 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				4-U	1-S	1-S, 1-U			1-U
Alaska							2-S			1-U
Arizona	3-S	1-S	1-S	1-S	6-U					
Arkansas										
California	1-S			1-S	4-S, 20-U, 1-L	1-L	1-U, 1-S			1-S, 1-U
Colorado			1-S, 1-L	2-S	6-U, 1-L	1-L	3-U, 1-L			
Connecticut			1-S	1-S	1-S	5-S	3-S			1-P
Delaware					1-S	2-S				
Florida		2-S	1-S		1-S, 4-U	1-S	1-U			
Georgia			1-S		3-U		4-U			1-U
Hawaii	1-S	1-S			3-U		2-U, 1-L	1-S	1-L	
Idaho	1-S		1-S		1-U	2-P	1-S		1-S	1-P
Illinois				1-S	1-S	3-S, 1-P				
Indiana				1-S	4-U	2-S				
Iowa	1-S	1-S	1-S	3-S	4-U	1-S	2-S			
Kansas				1-S						
Kentucky					5-U		1-P, 3-U			1-U
Louisiana	1-S	1-S		1-S			1-S			
Maine					1-S	1-S				
Maryland	2-S	2-S	1-S	3-S	1-S, 1-L		2-S			
Massachusetts	2-S	4-S	1-S	1-S	1-S, 1-U	4-S	3-S, 1-U	2-S		1-P
Michigan				1-S	1-U	4-S		2-S		
Minnesota			2-S	1-S	1-S, 35-U	3-U	3-S, 1U			1-S, 3-U
Mississippi					3-U		1-S			1-U
Missouri		1-S			3-U, 1-L		1-S, 1-U			
Montana	2-S	1-S		3-S	2-U	2-P, 1-U	1-S			1-P
Nebraska	1-S	1-S	1-S		2-U		1-S			
Nevada				3-S	1-S					1-S
New Hampshire				1-S	2-U		1-S			
New Jersey			1-S		2-S		1-S	1-S		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	6-S, 2-U	1-S	2-S	1-S		
North Carolina	1-S	1-S		1-S			1-S			1-U, 1-P
North Dakota	1-S	1-S		2-S						
Ohio		1-S	1-S	1-S	2-U	2-S				1-S

State/Territory	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Bonds	Production Incentive*
Oklahoma		1-S					1-S	1-S		
Oregon	1-S	1-S		1-S	2-S, 11-U, 1-L	2-P, 1-S	1-S, 7-U			1-P, 1-L
Pennsylvania				1-S		3-S, 4-L	2-S, 5-L, 1-U			
Rhode Island	1-S		1-S	1-S	1-S, 1-U					1-P
South Carolina	1-S	2-S			1-S, 2-U		5-U			
South Dakota				2-S	1-U					
Tennessee				1-S		1-S	1-S			1-U
Texas		1-S		1-S	7-U			1-S		
Utah	1-S	1-S	1-S		1-U					
Vermont			1-S		1-S	1-U				1-U
Virginia				1-S				1-S		1-U
Washington			1-S		12-U	2-P, 1-L	8-U	1-S		1-S, 3-U, 1-P
West Virginia		1-S		1-S						
Wisconsin				1-S	1-S, 3-U	1-S, 1-U	1-U			2-U
Wyoming			1-S		1-S, 1-U					
D.C.						1-S				
Palau										
Guam										
Puerto Rico	1-S		1-S							
Virgin Islands					1-S	1-S				
N. Mariana Isl.										
American Samoa										
Totals	**31**	**33**	**24**	**41**	**186**	**59**	**84**	**12**	**3**	**35**

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

Table 4: Incentives for Renewable Energy - Rules, Regulations & Policies [DSIRE]

State / Territory	PBF	Disclo sure	RPS	Net Meter-ing	Inter-connec tion	Exten-sion Analysis	Contrac tor License	Equipment Certifi-cation	Access Laws	Construc-tion & Design Standards	Green Power Purchase	Required Green Power
Alabama												
Alaska									1-S			
Arizona			1-S	2-U	1-U	1-S	1-S	1-S	1-S	2-S, 3-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, 6-U	1-S. 1-U	1-S			1-S, 2-L	1-S, 3-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	1-S, 1-U	1-S	1-S	1-S	1-S							2-U
Florida		1-S	1-U	5-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	1-S		
Idaho				3-U	2-U				1-S			
Illinois	1-S	1-S	1-S	1-U	1-U					1-L	1-S, 1-L	
Indiana				1-S	1-S				1-S		1-S	
Iowa		1-S	1-S	1-S	1-S				1-S		1-S	1-S
Kansas									1-S			
Kentucky				1-S					1-S			
Louisiana				1-S, 1-L	1-S			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	1-S	1-S, 2-L	
Massachusetts	1-S	1-S	1-S	1-S	1-S				1-S	1-S	2-L	
Michigan	1-S	1-S		1-S	1-S		1-S			1-S	2-L	
Minnesota	1-S	1-S	2-S	1-S	1-S			1-S	1-S	2-S		1-S
Mississippi												
Missouri			1-S 1-L	1-S	1-S				1-S			
Montana	1-S	1-S	1-S	1-S, 1-U	1-S				1-S			1-S
Nebraska									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		
New Jersey	1-S	1-S	1-S	1-S	1-S				1-S	1-S	1-S	
New Mexico			1-S	1-S	1-S	1-S			1-S	1-S		1-S
New York	1-S	1-S	1-S	1-S	1-S				1-S		1-S, 1-L	
N. Carolina				1-S	1-S				1-S, 1-L	1-L		
North Dakota				1-S					1-S			
Ohio	1-S	1-S		1-S, 1-U	1-S				1-S			
Oklahoma				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	
Pennsylvania	1-S	1-S	1-S	1-S	1-S						1-S	
Rhode Island	1-S	1-S	1-S	1-U	1-S				1-S	1-S	1-S	
S. Carolina										1-S	3-L	

State / Territory	PBF	Disclo sure	RPS	Net Meter-ing	Inter-connec tion	Exten-sion Analysis	Contrac tor License	Equipment Certifi-cation	Access Laws	Construc-tion & Design Standards	Green Power Purchase	Required Green Power
South Dakota												
Tennessee									1-S			
Texas		1-S	1-S, 1-L 1-U	1-S, 1-U	1-S	1-S				2-S, 1-L		
Utah				1-S, 2-U	1-S		1-S		1-S		1-L	
Vermont	1-S	1-S	1-S	1-S	1-S							
Virginia		1-S	1-S	1-S	1-S				1-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-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							
Palau												
Guam										1-S		
Puerto Rico								1-S				
Virgin Islands				1-S					1-S			
N. Mariana Isl.												
Amer. Samoa												
Totals	**21**	**25**	**34**	**65**	**40**	**4**	**10**	**7**	**51**	**48**	**36**	**8**

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

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.*

In July 2007, 27 States and the District of Columbia had Renewable Portfolio Standards and, with the exception of Minnesota, all include photovoltaics (Fig. 14). In addition, 7 States have set minimum solar or customer site requirements and one State has an increased credit for solar electricity.

Another very important measure for photovoltaic is the grid access. In August 2007, 42 US States + Washington DC had already implemented measures for the net-metering of electricity produced by PV (Fig. 15).

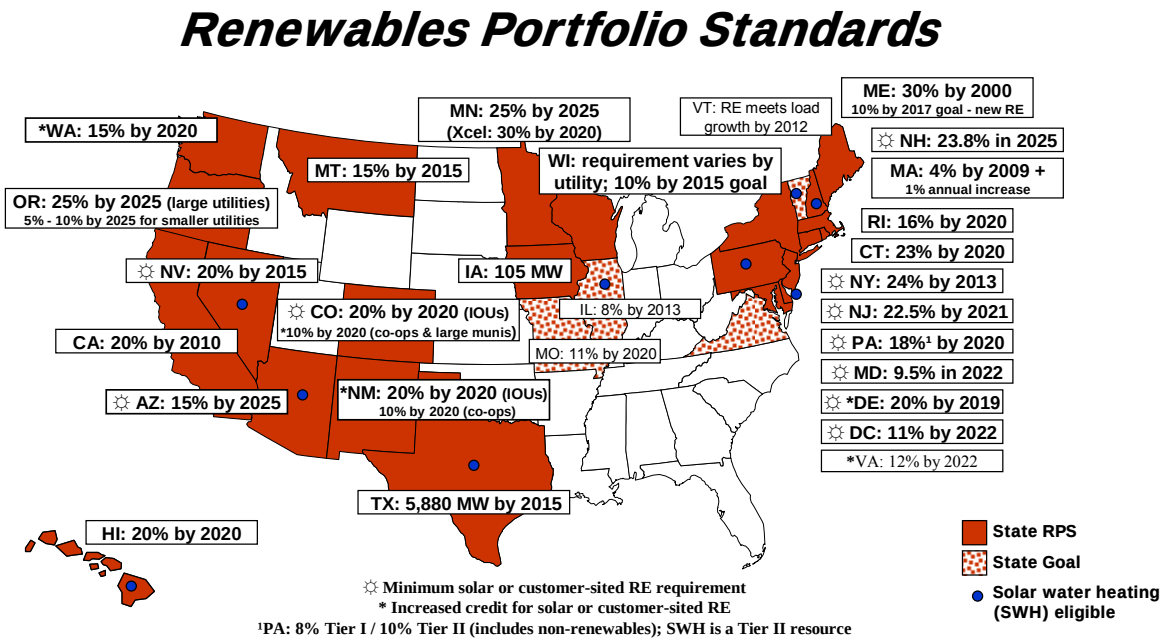

Fig. 14: States with Renewable Portfolio Standards in the US (July 2007); Figure © DSIRE [Dsi 2007]

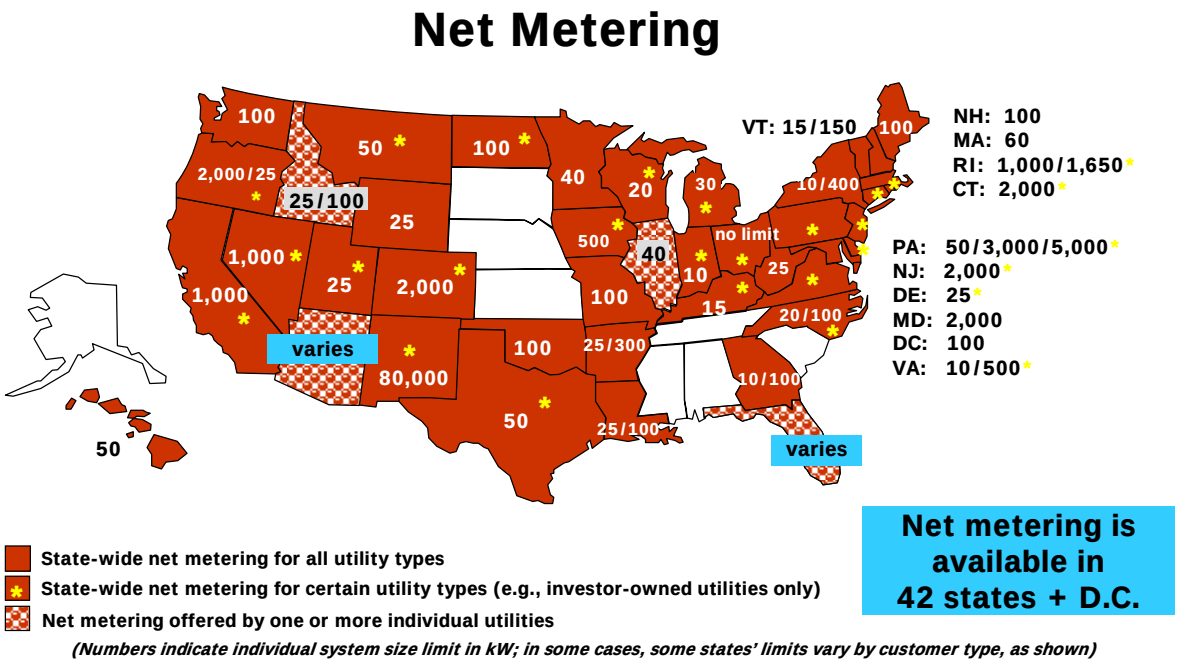

Fig. 15: States with Net-metering in the US (August 2007) and upper limits; Figure © DSIRE [Dsi 2007]

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) – a two-fold increase over total 1997 US levels (excluding hydro). Most of these capacities will be wind, but photovoltaics 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.

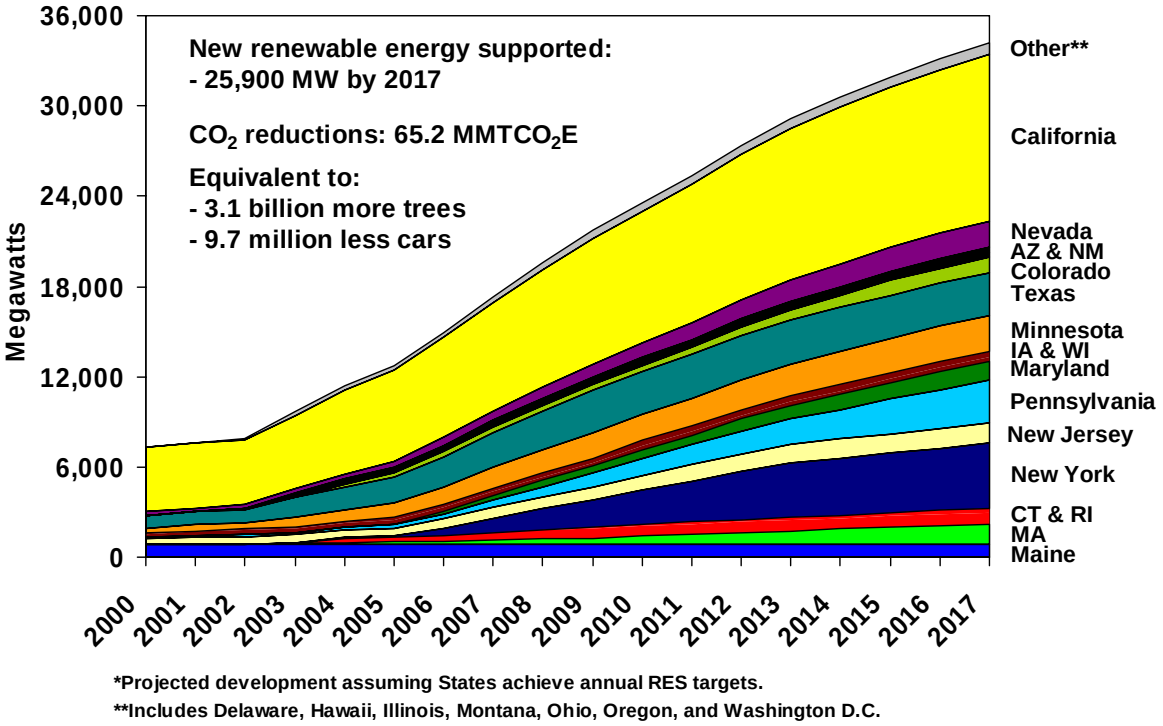

Fig. 16: Prediction of new Renewables from State Standards and Renewable Energy Funds Figure © Union of Concerned Scientists [Uni 2005]

5.2 Photovoltaics Technology Plan

Most of the federal research is co-ordinated by the National Renewable Energy Laboratory (NREL) and its National Centre for Photovoltaics (NCPV). The current Department of Energy (DOE) "Photovoltaics Technology Plan" runs from 2003 to 2007 [DOE 2003]. The technology plan is divided into three main areas with 10 sub chapters.

- Fundamental Research: Basic University Research
  Measurements and Characterisation
  High Performance and Concentrator Research
  Crystalline Silicon
- Advanced Materials & Devices: Crystalline Silicon
  Thin Films
  Manufacturing Research and Development
  Module Performance and Reliability
- Technology Development: Module Performance and Reliability
  System Engineering and Reliability
  Partnerships for Technology Introduction
  Programme Integration and Facilities.

The Programme's objectives are to:

- Improve the cost, integration, and performance of solar heating, cooling, electricity, and lighting technologies in combination with building systems to levels where they are a competitive, reliable option for building owners and occupants;
- Add significant security, reliability, and diversity to the US energy system and improve the quality of life in this country by providing clean, distributed electricity to all;
- Make solar technologies and systems an accepted and easily integrated option for distributed-energy production, both on and off the electric utility grid;
- Develop next-generation technologies and systems with the potential to create new high-value applications of solar energy in producing hydrogen fuel, generating competitive bulk power at central stations, desalinating water, or creating other products that are beyond present capability;
- Reduce the environmental signature (air emissions) by replacing fossil fuel energy systems with cost-effective solar energy systems.

2007 Goals:

1) Basic University Research
   - Demonstrate rapid validation of a next-generation material or cell structure through application of combinatorial research techniques.
   - Identify commercialisation pathways for promising new technologies via university/industrial partnerships.
   - Assess potential of nanotechnologies for achieving third-generation goals of very high efficiency and very low cost.
2) Measurements and Characterisation
   - Obtain ISO 17025 accreditation for secondary module calibration under ASTM and IEC standards.
   - Explore and develop novel characterisation techniques to obtain microstructural and chemical information with high spatial resolution and chemical sensitivity.
3) High Performance and Concentrator Research
   - Demonstrate, with participation from industry, 20%-efficient thin-film prototype submodules operating under moderate concentration.
   - Demonstrate 39% efficiency under concentration.
4) Crystalline Silicon
   - Demonstrate competitive efficiency and cost potential of thin crystalline silicon technologies.
   - Assess new opportunities and directions for crystalline silicon technologies.
5) Thin Films
   - Complete solutions for device-level issues supporting industry 20-year warranties for CIS and CdTe modules.
   - Assist thin-film industry in achieving significant (>100 MW) annual module production in the United States.
6) Manufacturing Research and Development
   - Solicit new partnerships, as appropriate.

7) Module Performance and Reliability
   - Assess and document correlation of accelerated environmental stress testing with results from long-term field data and observations.
8) System Engineering and Reliability
   - Update system design and simulation tools to include documented failure and degradation rates at the component level.
   - Revise Systems Multi-Year Programme Plan to reflect review of requirements by the systems-driven approach.
   - Demonstrate systems-driven approach advances in inverters and power electronics for PV systems.
9) Partnerships for Technology Introduction
   - Assess NCPV's contributions toward building capacity and expanding markets, leading to 20-Year Industry Roadmap goal of domestic markets gaining parity with continual growth of international markets.
10) Programme Integration and Facilities
   - Issue revised DOE PV Subprogramme Five-Year Technology Plan.

Long-Term Goals: The 2020 goal for the Solar Programme is for the cost of solar energy to be competitive with fossil fuels. Although it is difficult to predict the cost of energy that far into the future, it is projected that by 2020, intermediate load electricity will be $ 0.04 to $ 0.06/kWh, while homeowners will pay $ 0.08 to $ 0.10/kWh. Solar must be at or below the cost of fossil fuels if it is going to play a major role in the market. If photovoltaic (PV) goals are met, PV capacity could reach 30,000 MW in the United States by 2020. Projections for applications of concentrating solar power and solar thermal are under development. These levels of market penetration will be attained by sustaining a Federal R&D programme that results in technology improvements and breakthroughs that steadily decrease the cost of solar energy, in combination with Federal and State policy actions that encourage the increased use of solar energy (e.g., renewable portfolio standards, system benefit charges, tax incentives, net-metering standards).

To reach these goals, emphasis is given to high-risk research and development (R&D) that industry is unable or unlikely to do on its own. The Solar Programme supports the R&D in industry, universities, and the national laboratories. This R&D is the heart of the programme's strategy for positioning solar technologies to help meet the new demands of a restructured energy industry.

Field testing of solar systems is supported to learn where improvements in the technology are required to attain cost and reliability goals. This information is fed back to researchers and engineers to help guide their work. Commercialisation and deployment of the technology is outside of DOE's mission. As such, those important steps are left to industry.

The 2007 to 2011 multi-year programme has set the following Five-Year Performance Objectives [DOE 2006].

- 16% efficient crystalline-silicon module that can be produced at a direct manufacturing cost of $ 260/m^2 ($ 1.60/Wp)

- 10% efficient CdTe module that can be produced at a direct manufacturing cost of $ 90/m^2 ($ 0.90/Wp)
- 12% efficient CIGS module that can be produced at a direct manufacturing cost of $ 170/m^2 ($ 1.40/Wp)
- 8% efficient a-Si module that can be produced at a direct manufacturing cost of $ 90/m^2 ($ 1.15/Wp)
- 25% efficient concentrator module that can be integrated into a completely installed system at a systems level price of $ 50/m^2 ($ 3.00/Wp)
- 95% efficient inverter that has a 10 year life-time
- Systems manufacturing as well as integration techniques and tools to achieve levelised energy cost targets in the utility ($ 0.10 – $ 0.15/kWh), commercial ($ 0.09 – $ 0.12/kWh), and residential ($ 0.13 – $ 0.18/kWh) sectors.

5.3 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 project is co-ordinated by the University of Delaware and the initial phase started in November 2005. Partners in the initial 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 enables 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

Now DARPA is initiating the next 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. This phase is scheduled for three years.

5.4 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 solar power costs by nearly 50% in a decade and is essential to make solar power 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 that are a model for research that should be expanded and strengthened. Our 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 us out of research leadership. To reverse this trend, we call for the United States 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.

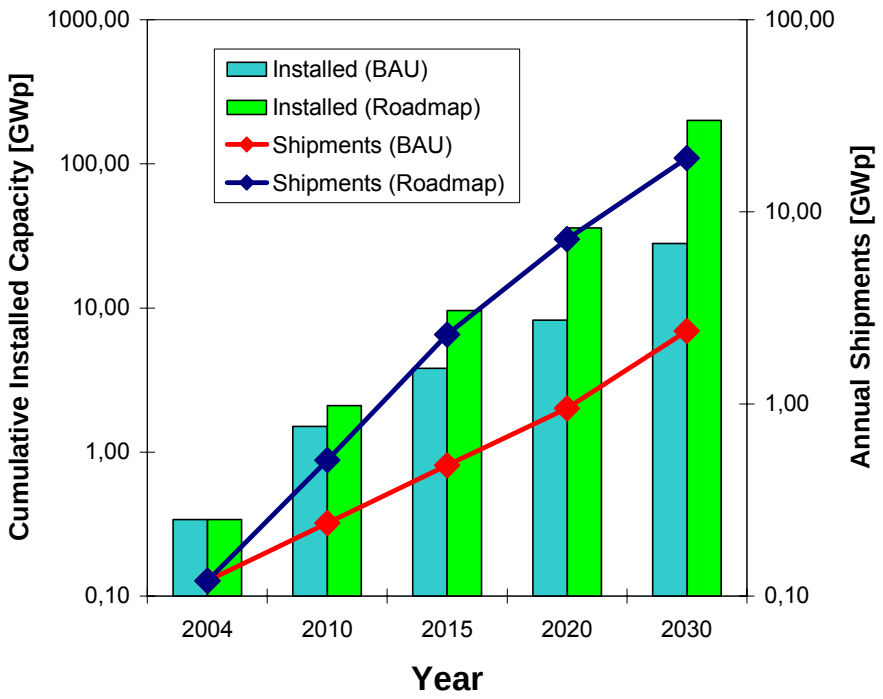

Fig. 17: US PV-Industry Roadmap [Sei 2004]

Compared to the 2001 scenario, the new update emphasizes 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 the US lost its market leader position, held for many years, and is now at fourth place behind Japan Europe and China. In addition it should be noted that the two largest US PV manufacturers are owned by European companies.

5.5 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.

5.5.1 BP Solar

BP Solar has its headquarters in Linthicum, MD, and has various factories world-wide. In number of sales, BP Solar moved from third place in 2004, with 85 MW to number 10 in 2006 with 96 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.

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].

5.5.2 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. Sales in 2006 were 13 MW [Pvn 2007]. In September 2007 the company just broke ground for a 75 MW production capacity expansion [Eve 2007].

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 2007a].

The market situation in the US is described by Evergreen Solar as "focused on costs not on aesthetics". This is reflected by the fact that building integration of photovoltaics in the US does not have the same importance yet as in Japan or Europe. Nevertheless, Evergreen Solar sees this as one of the most important markets in the future and has formed strategic alliances with American companies such as Solar Works, Inc. (VT) to offer solar systems in the frame of the Long Island Power Authority (LIPA) pay-down programme or Japanese companies like Kawasaki Steel for building integration of systems in Japan.

5.5.3 First Solar LLC.

First Solar LLC, is one of the companies world-wide 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 massively expanding its CdTe thin film production capacity [Fst 2007]. In March 2005 it announced the tripling of production capacity to approximately 75 MW at their manufacturing facility in Perrysburg (OH), which was scheduled for August 2006. In the meantime the capacity there was increased to 90 MW. In addition, the company built a plant in Frankfurt/Oder, Germany, with a capacity of 120 MW, which was opened in July 2007. The company has announced to build four additional 120 MW nameplate capacity production lines, all in Malaysia. The completion dates for these three lines are 2008 and 2009.

5.5.4 GE Energy

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.

In September 2007, GE Energy announced that it had acquired a minority equity interest in the thin-film solar company PrimeStar Solar.

5.5.5 United Solar Systems

United Solar Systems Corp. is a subsidiary of Energy Conversion Devices, Inc. (ECD). The first 25MW 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 [Uni 2006]. The current nameplate capacity in Auburn Hills is quoted with 58 MW and a further expansion in Greenville, Michigan to 120 MW is on schedule [Uni 2007]. The first Greenville phase with 60 MW is scheduled to be completed late 2007 and the second phase in 2008. 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. Sales in 2006 increased to 28 MW [Pvn 2007.

5.5.6 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 [Sun 2007]. Fab. No 2 was dedicated in July 2007 and once finished should have a capacity of 300 MW. Fab. No 3 is planned with 500 MW and the first lines in the plant should be operational by late 2009.

According to the 2nd Quarter 2007 results, the company has secured silicon feedstock to increase its production to 110 MW in 2007, 250+ in 2008 and 400+ in 2009. Production in 2006 was given with 62.7 MW [Pvn 2007].

5.5.7 Additional Solar Cell Companies

- **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.

- **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. In 2006, 2.5 MW production was reported [Pvn 2007].

- **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].

5.5.8 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.

Dow Corning announced on 31 July 2006 that Hemlock Semiconductor Corporation is searching for a potential second manufacturing site to produce polycrystalline silicon in order to support the growing demand from the solar industry and electronic markets [Dow 2006]. The new factory should become operational within the next five years. Currently, the company has 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.

5.5.9 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.

Hoku Materials is planning to start the manufacturing of polysilicon materials with an initial production capacity of 1,500 tons, 300 tons to be delivered to Hoku Solar and 1,200 tons being sold. In a Press Release, dated 9 August 2007, the company announced that it had awarded a contract to JH Kelly LLC, a Washington-based general contractor, to provide construction services for Hoku Materials' polysilicon production plant located in Pocatello, Idaho [Hok 2007].

5.5.10 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 capacity for 2007 is given as 4,900 tons and the company plans to increase it to 8,000 tons, doubling production by 2009 [Pvn 2007b].

In 2006, the company signed a 10-year supply agreement with Suntech, PRC [Mem 2006]. Under the terms of the definitive agreement and in order for MEMC to meet Suntech's supply requirements, Suntech will advance funds to MEMC in the form of an interest-free loan or security deposit, which will be used by MEMC for expansion of MEMC's manufacturing capacity. In addition, MEMC has received a warrant to purchase an approximately 4.9% equity stake in Suntech.

It is also rumoured that MEMC and Hong Kong Speciality Gases could become partners to make silane gas and polysilicon in China [Eet 2006].

6. 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 2007 for a new comprehensive Directive on the use of all renewable energy resources. 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.

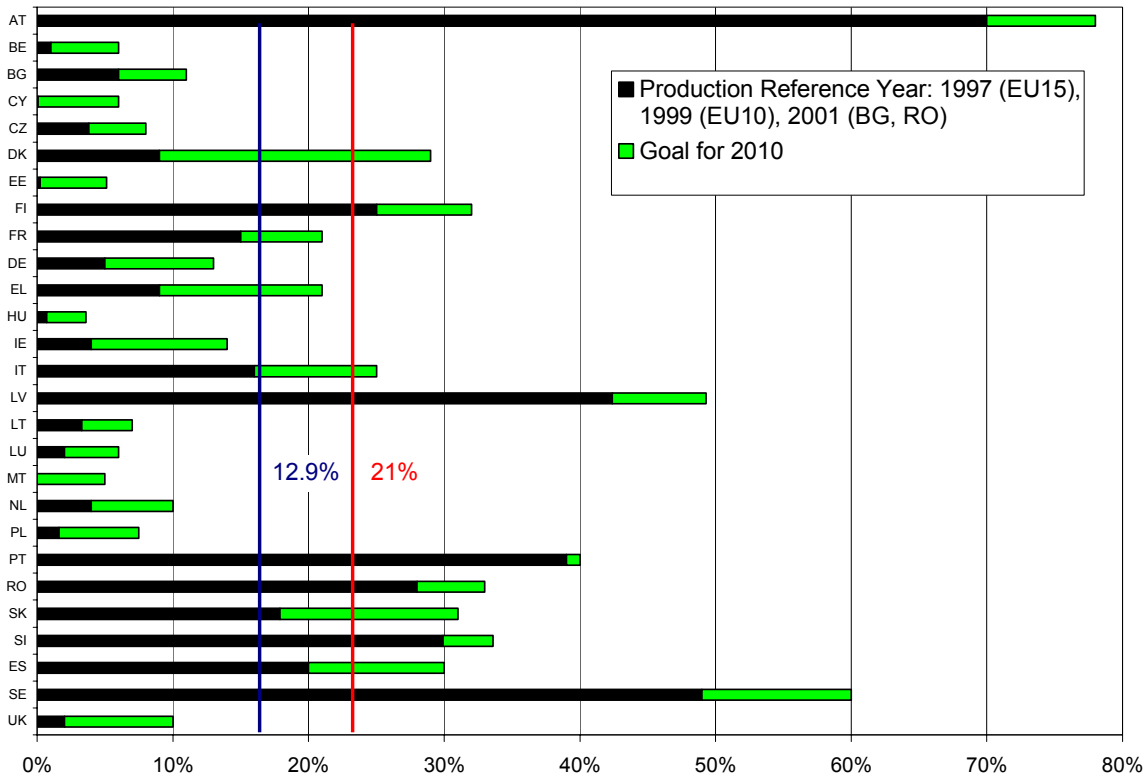

Fig. 18: Share of renewable energies of total European Union electricity production

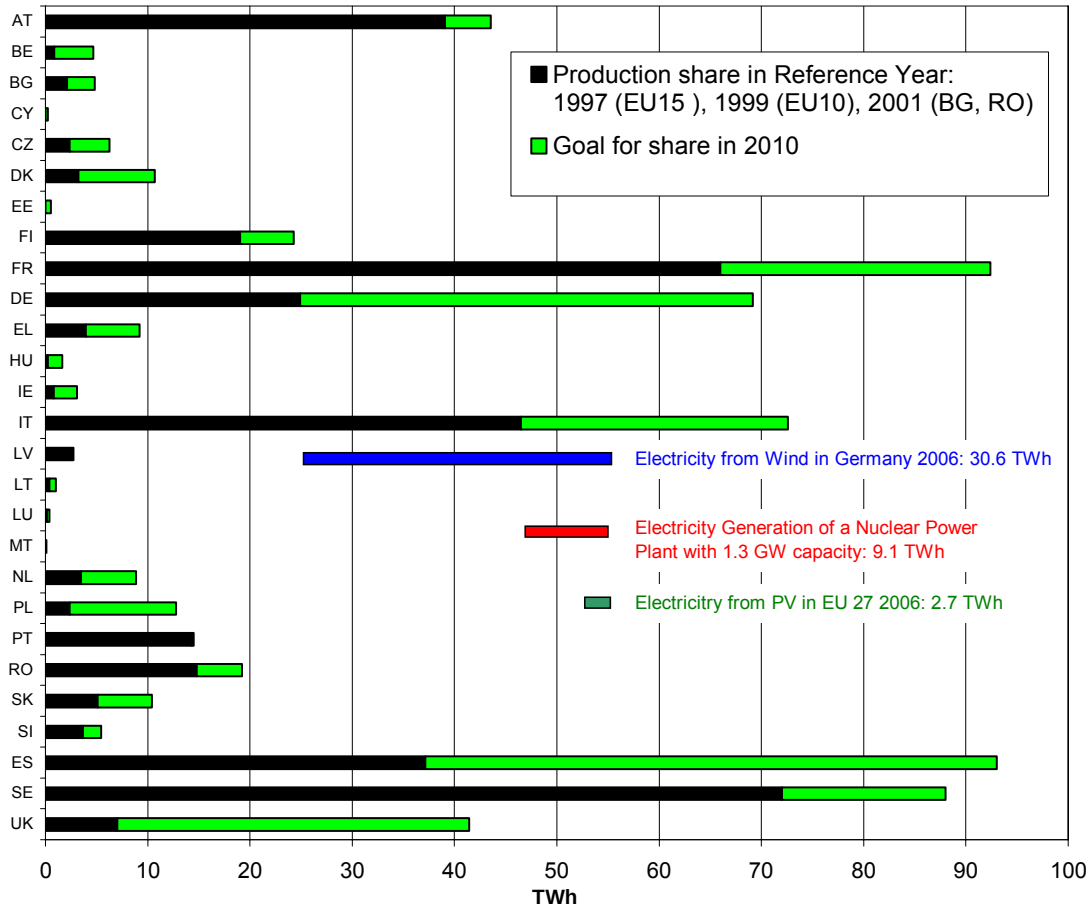

Fig. 19: Electricity generation in TWh from renewable energies in the European Union

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.

"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."*

6.1 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 2006, installations of Photovoltaic systems in the European Union increased ten-fold to reach 3.4 GW cumulative installed capacity at the end of 2006 (Fig. 18) [Sys 2007].

In 2006, like the years before, Germany was the largest single market with 1,150 MW, followed by Spain with 60.5 MW and Italy with 11.6 MW [Sys 2007]. 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 grid operators (VDN) 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 85% of the EU 27 PV installations are in Germany (Fig. 20). For 2006 the VDN reports 2.22 TWh electricity produced from PV solar electricity systems in Germany in its mid-term prognosis from June 2007 the estimate for 2007 is 3.4 TWh and for 2008 the estimate made in September 2007 is 4.13 TWh [Vdn 2007, a, b].

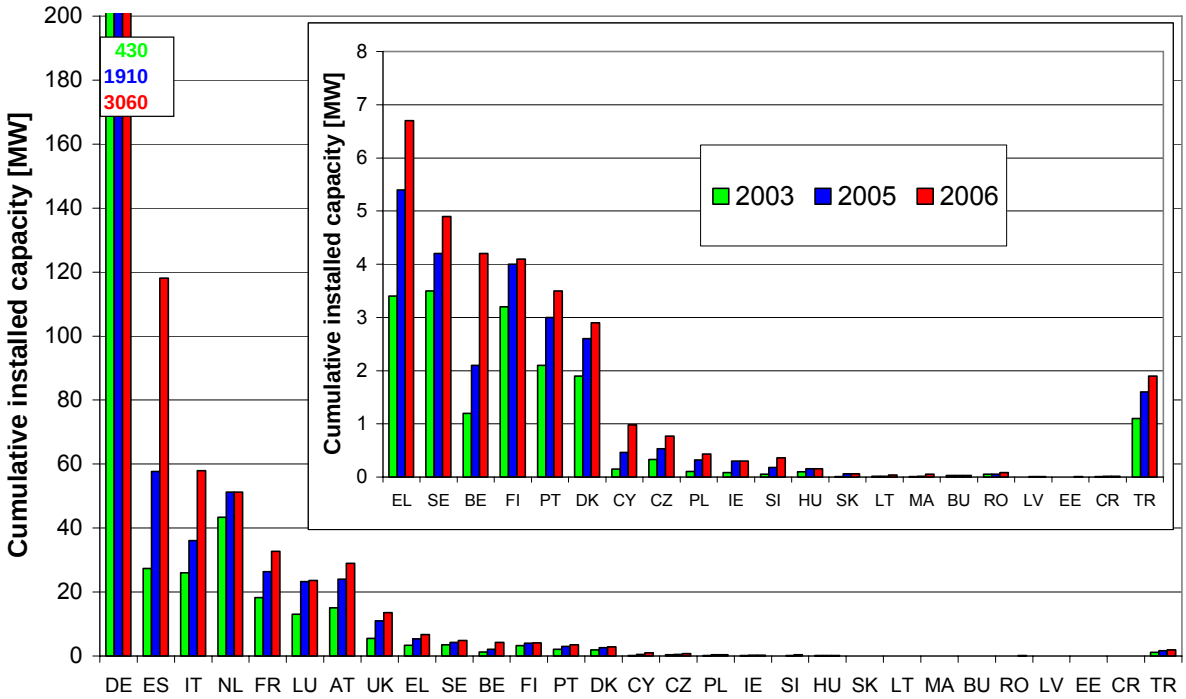

Fig. 20: Cumulative installed grid connected PV capacity in EU + CC
Note that capacities do not seem to correlate with solar resources

As foreseen in the *"Erneuerbare-Energiesn-Gesetz"* (EEG) the feed-in tariffs are under review [EEG 2004]. The German Environment Ministry has proposed an increase of the annual degression for new installations by two percentage points starting 2009 and a further increase by one percentage point from 2011 onward. The new amendment of the EEG is expected to be finalised this autumn and discussed in the parliament early next year.

In 2006, the 60.5 MW of new installations in Spain more than doubled the previous cumulative amount of 57.6 MW. For 2007 the market size is expected to be about 200 to 280 MW, mainly larger-size projects in the 10 to 20 MW range are broken down into 100 kW shares. The reason for this market expansion is the Spanish Government's approval of the *Plan de Energías Renovables en España* (PER) for 2005 – 2010 in August 2005. The objectives are to cover 12.1% of Spain's overall energy needs and 30.3% of total electricity consumption with renewable energy sources by 2010. The cap on PV of 150 MW set by the Royal Decree 436/2004, dated 12 March 2004, was increased to 400 MW by 2010.

The new 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 11.6 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].

The new feed-in tariffs in France which went into force on 26 July 2006 resulted in a slight increase so far. Only 6.4 MW were installed in 2006, 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.

Despite the fact that the European PV production grew again by almost 50% and reached 680 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 are necessary to change this in the future.

The support measures for Photovoltaics in the European Union Member States are listed in Table 5.

Table 5: Support mechanisms for Photovoltaic in the European Union and Switzerland

Austria	The amendment of the Austrian Eco Electricity Law (Ökostromgesetz) went into force on 1 July 2006. The feed-in tariffs were fixed in October and went into force retroactively from 1 October 2006 onward. **Key elements of the Law are:** Electricity from all renewable energy sources are supported with € 17 million per year. 10% are earmarked for PV, with the same amount added by the Federal States, because of their co-financing duty. The support will be constant for 10 years, with a degressive support for 3 more years and thereafter an obligation for the utilities to accept the electricity from a PV system for another 13 years. Start of operation: 2006: up to 5kW: 0.49 €/kWh, 5 – 10 kW: 0.42 €/kWh, > 10 kW: 0.32€/kWh 2007: up to 5kW: 0.46 €/kWh, 5 – 10 kW: 0.40 €/kWh, > 10 kW: 0.30€/kWh Some of the Federal States have investment support schemes.

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	No specific PV programme, but RES are preferentially treated both towards the purchase electricity prices and towards the obligatory purchase of RES electricity by transmission and/or distribution companies. The Energy and Energy Efficiency Act sets following advantages towards RES: • No license is required for the generation of electricity from RES with a capacity of up to 5 MW and for thermal energy production. • The energy distribution company is obliged to purchase electric energy generated from RES with a capacity up to 10 MW. • Preferential prices are set for electricity generated utilising RES (no set price for PV).
Cyprus	Feed-in tariff: 0.224CYP£/kWh (0.391 €/kWh) for households and 0.196CYP£/kWh (0.342 €/kWh) for enterprises. If an investment grant is taken, the tariff is reduced to 0.012CYP£/kWh (0.21 €/kWh). 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).
Czech Republic	New Law on the Promotion of Production of Electricity from Renewable Energy Sources went into effect on 1 August 2005. 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 (0.479 €/kWh)[10] Systems commissioned before 01/01/06: 6.41 CZK/kWh (0.228 €/kWh) • Market price + Green Bonus; Green Bonus for 2007 Systems commissioned after 01/01/06: 12.75 CZK/kWh (0.454 €/kWh) Systems commissioned before 01/01/06: 5.70 CZK/kWh (0.203 €/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.
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.
Estonia	No specific PV programme, but Renewable Portfolio Standard and tax relief. Feed-in tariff for electricity produced out of RES is 5.1 ct/kWh.
Finland	No PV programme, but investment subsidy up to 40% and tax/production subsidy for electricity from renewable energy sources (6.9 €/MWh).

[10] Exchange rate: 1 € = 28.107 CZK

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	Feed-in tariff for 20 years with built-in annual decrease of 5% from 2005 onward. For plants, neither on buildings nor sound barriers, the annual decrease is 6.5% from 2006 onward. **Tariffs for new installations in 2007:** Free standing systems: 0.3796 €/kWh Systems on buildings and sound barriers: 0.4921 €/kWh < 30 kWp, 0.4682 €/kWh > 30 kWp and 0.4630 €/kWh > 100 kWp. For façade integration there is an additional bonus of 0.05 €/kWh.
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 to 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	Feed-in tariffs for RES were set through the Electricity Act, which entered into force on 1 January 2003. According to Regulation No. 105/2003. (XII.29.) GKM, the Electricity Suppliers are obliged to purchase electricity from producers utilising RES, if their capacity is over 100 kW. However, in the case of smaller plants, individual arrangements are possible. The feed-in tariff for RES which depends on the weather (solar and wind) from 01/02/2007 onward is: 24.71 HUF/kWh (0,098 €[11])
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.

[11] Exchange rate: 1 € = 250.95 HUF

Italy	New 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 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 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.
Luxembourg	A support scheme was set with a "Règlement Grand Ducal" in September 2005. The Règlement has a cap of 3 MW by 2007. The new feed-in tariff is 0.56 €/kWh for 20 years, for 20 years (but due to the fact that this is a "Règlement" and not a Law it is not binding.). In addition, grants up to 15% are available, but limited to € 900 per each member of a household (only the head of the household can receive double that amount).
Malta	Net metering for electricity from PV systems: 0.126 €/kWh Surplus exported to the grid: 0.063 €/kWh – but there is a one-off charge of € 46 for the extra metre. 20%-grant for roof-top PV installations.
Netherlands	Feed-in tariff: 0.097 €/kWh for 10 years and Net metering up to 3000 kWh/year for existing systems. On 25 August the Minister of Economy announced the immediate suspension of support for new electricity generation plants using renewable energy sources.
Poland	Tax incentives: no customs duty on PV and reduced VAT (7%) for complete PV systems, but 22% for modules and components. Some soft loans and subsidies. A new law was passed in April 2004 that tariffs for all renewable energies have to be approved by the regulator (until now only for projects larger than 5 MW).

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). Grants up to 40 % of the total eligible cost (max. € 150,000 per application) are available under the PRIME programme (2000-2006).
Romania	No specific programme for PV. For the promotion of the production of electricity from Renewable Energy Sources, a system of 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.
Slovakia	Feed-in tariff set by regulator each year. 8.2 SKK/kWh (0.245 €/kWh[12]) for 2007. Tax deduction on income earned. RES feed-in tariff in 2005: ~ 3 ct/kWh
Slovenia	Feed-in tariff: either fixed-price or electricity price (8 SIT/kWh) + premium The plant size limit was removed in June 2006. Uniform annual price — Uniform annual premium 89.67 SIT/kWh — 81.67 SIT/kWh 0.377 €/kWh[13] — 0.343 €/kWh
Spain	Feed-in tariff with cap of 400 MW: Tariffs for 2007 • 0.44 €/kWh < 100 kWp for 25 years (575% of average electricity price). Then 0.3523€/kWh. • > 100 kWp < 10 MWp: 0.4145 €/kWh for 25 years then 0.332 €/kWh • 0.23 €/kWh > 10 MWp for 25 years (300% of average electricity price), after 25 years 240% of average electricity price.
Sweden	70% tax deduction on investment and installation cost for systems on public buildings from May 2005 until end 2007, with a maximum limit per building of € 550,000 and covers both material and labour costs. Electricity certificates for wind, solar, biomass, geothermal and small hydro. Energy tax exemption.
Switzerland	Net metering with feed-in tariff of min. 0.15 CHF/kWh (0.10 €/kWh); investment subsidies in some cantons; promotion of voluntary measures (solar stock exchanges, green power marketing).
United Kingdom	Investment subsidies in the framework of a PV demonstration programme. Reduced VAT.

As depicted in Table 5, 15 out of 27 Member States 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

[12] Exchange rate: 1 € = 33.437 SKK

[13] Exchange rate 1 € = 237.77 SIT; since 01.01.2007 Slovenia is a member of the Eurozone

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

- too early a fulfilled 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, 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. 21).

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 three of the current top-ten European companies held this position since 1999. In 2006 the employment figures in Photovoltaics for the European Union is estimated to be 50,000 to

55,000. These figures are estimated from over 35,000 jobs reported for Germany [Bsw 2007] and 6,300 for Spain [IEA 2006]. The PV systems installed in Germany produced 2.22 TWh in 2006 and it is estimated that they will produce 3.4 TWh in 2007 [Vdn 2007, a].

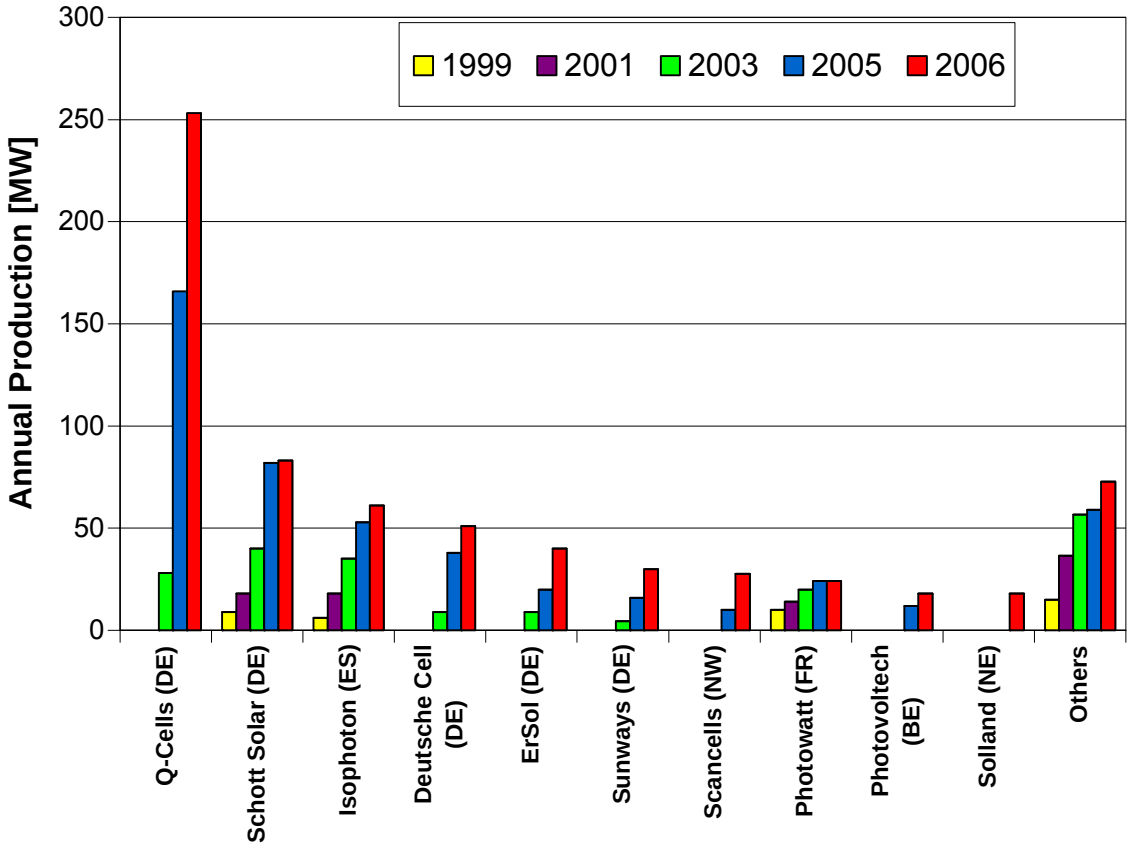

Fig. 21: Annual production of the 10 largest European PV manufacturers in 2006 [Pvn 2007]

According to a 2006 industry survey, amongst renewable energy companies in Germany, every second company plans to increase the number of employees by 30 to 100% within the next 5 years. Photovoltaic companies are amongst the most optimistic ones and in total expect a doubling of employment by 2010. In 2006, photovoltaics accounted for a turnover in Germany of € 4.8 billion and 70% of the added value remained inside Germany.

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 more than 50% 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 2007].

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 generated electricity 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. 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[14] [IEA 2007] 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 heat wave 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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[14] Crude oil prices went up from US$26/bbl (June 2003) to over US$80 (September 2007), source: 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 20 jobs per MW of capacity, adding about 30 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 22 the growth scenarios for two growth rates are shown: 35% per annum and 45% per annum. If the 45% growth could be maintained, 15.1 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 comming 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.

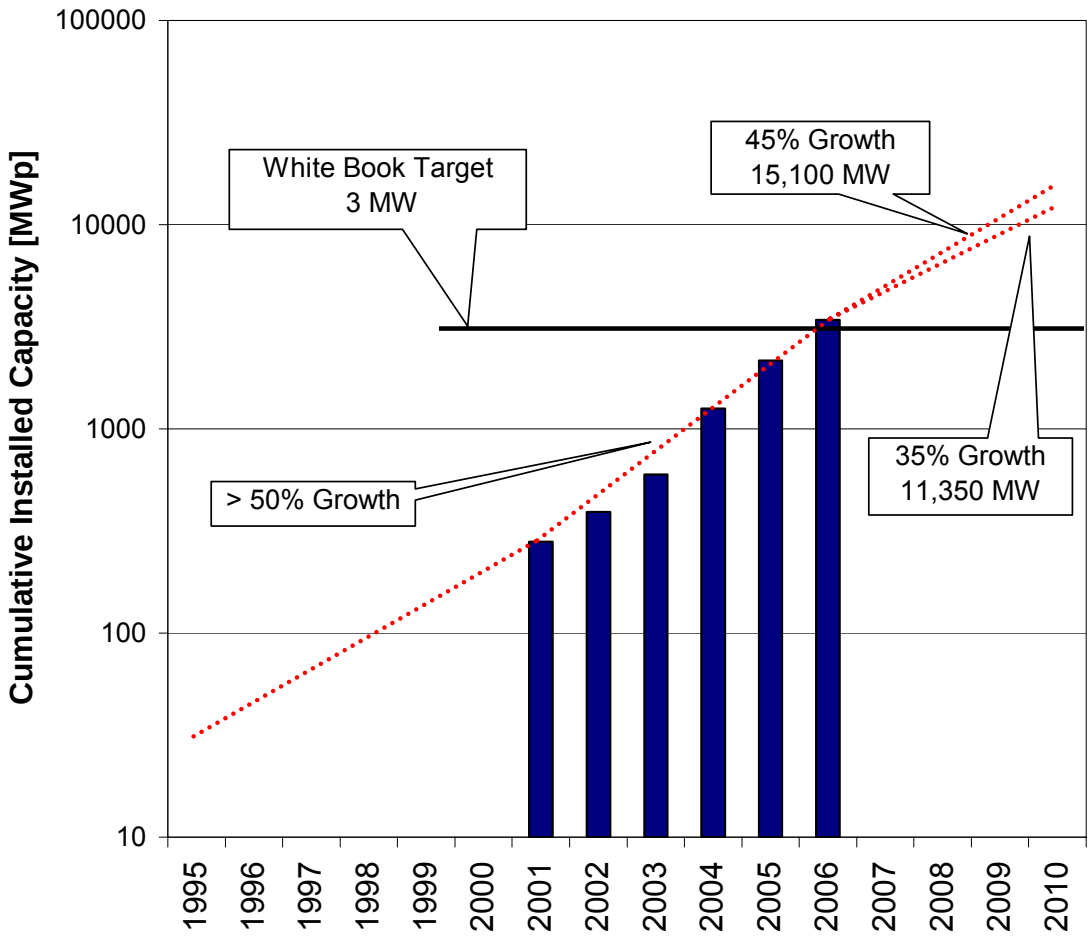

Fig. 22: White Paper target growth rate and estimates based on 2001 to 2005 installations

6.2 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 will be 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.

Wafer-Based Silicon Solar Cells Projects

- CRYSTAL CLEAR (**Integrated Project)**: Development of Crystalline Silicon PV technologies for low-cost high-efficiency and reliable modules
  EU funding: € 16 million – Co-ordinator: ECN, Petten, The Netherlands
- BITHINK (**STREP)**: Bi-facial thin industrial multi-crystalline Silicon Solar cells
  EU funding: € 2 million – Co-ordinator: CENER-CIEMAT, Madrid, Spain
- FOXY (**STREP)**: Development of solar-grade silicon feedstock for crystalline wafers and cells by purification and crystallisation
  EU funding: € 2.7 million – Co-ordinator: SINTEF, Trondheim, Norway
- SISI (**SMEs-Co-operative Research)**: Silicon for solar cells at low costs on an intermediate scale
  EU funding: € 0.99 million – Co-ordinator: ECN, Petten, The Netherlands
- UPSSIM (**SMEs-Co-operative Research)**: Upgrading Semiconductor Silicon Wafers to Manufacture cheap *solar* cells
  EU funding: € 0.92 million – Co-ordinator: IMEC, Leuven, Belgium
- SOLSIC Demonstrator **(STREP)**: Validation of a direct route for production of solar-grade silicon feedstock for crystalline wafers and cells
  EU funding: € 1.5 million – Co-ordinator:
- LAB2LINE **(STREP):** From the Laboratory to the production Line
  EU funding: € 1.27 million – Co-ordinator: NaRec, Blyth, United Kingdom
- SELFLEX **(STREP)**: Demonstration of SELF-formation based FLEXible solar cells manufacturing technology
  EU funding: € 0.7 million – Co-ordinator: Applied Research Centre for Prospective Technologies (ProTech), Vilnius, Lithuania

Thin-Film Projects

- ATHLET (**Integrated Project):** Advanced Thin-Film Technologies for Cost Effective Photovoltaics
  EU Funding: € 11 million – Co-ordinator: Hahn-Meitner-Institut Berlin, Germany
- BIPV-CIS (**STREP)**: Improved integrated PV using thin-film CIS modules for building retrofit
  EU funding: € 2.3 million – Co-ordinator: ZSW, Stuttgart, Germany
- FLEXCELLENCE **(STREP)**: Roll-to-roll technology for the production of high-efficiency low-cost thin film silicon photovoltaic modules

EU funding: € 3.1 million – Co-ordinator: Université de Neuchâtel, Neuchâtel, Switzerland

- LARCIS **(STREP)**: Large-Area CIS Based Thin-Film Solar Modules for Highly Productive Manufacturing
  EU funding: € 4.19 million – Co-ordinator: ZSW, Stuttgart, Germany
- LPAMS **(STREP)**: Production process for industrial fabrication of low price amorphous-microcrystalline silicon *solar* cells
  EU funding: € 0.61 million – Co-ordinator: ECN, Petten, The Netherlands
- SEPOWERFOIL **(STREP)**: Roll-to-roll manufacturing technology for high efficient multi-junction thin film silicon flexible photovoltaic modules
  EU funding: € 2.2 million – Co-ordinator: Helianthos b.v, The Netherlands
- HIGSPEEDCIGS **(STREP)**: High speed pilot production line for CIGS manufacturing
  EU funding: € 1.12 million – Co-ordinator: Midsummer AB, Bandhagen, Sweden
- SOLARPLAS (**SMEs-Co-operative Research)**: Development of Plasma-Chemical Equipment for Cost-Effective Manufacturing in Photovoltaics
  EU funding: € 1.1 million – Co-ordinator: Fraunhofer Insitut für Solarforschung, Freiburg, Germany

New Concepts

- FULL SPECTRUM (**Integrated Project)**: Development of new concepts for third-generation PV materials and techniques aiming at very high efficiency solar cells
  EU funding: € 8.4 million – Co-ordinator: IES-Madrid
- HICONPV (**STREP)**: High-concentration PV system
  EU funding € 2.7 million – Co-ordinator: SOLUCAR Energia, Sevilla, Spain
- MOLYCELL **(STREP)**: Molecular materials and hybrid nano-crystalline/organic solar cells
  EU funding: € 2.5 million – Co-ordinator: CEA-GENEC, Cadarache, France
- ORGAPVNET **(Co-ordination Action)**: Co-ordination Action towards stable and low-cost organic solar cell technologies and their application
  EU funding € 1.2 million – Co-ordinator: IMEC, Leuven, Belgium,
- NANOPHOTO **(STREP):** Nanocrystalline silicon films for photovoltaic and opto-electronic applications
  EU funding: € 1.7 million – Co-ordinator: University of Milano-Bicocca, Milano, Italy
- WELLBUS **(Mobility):** Study of Efficiency Enhancement Mechanisms in Quantum Well Solar Cells for Better Utilisation of the Solar Spectrum
  EU funding: € 0.108 million
- FV-TR-SMS **(Mobility):** Time Resolved Single Molecule Spectroscopy Studies of Photo-induced Charge Separation and Charge Transfer in Model Photovoltaic Solar Energy Devices
  EU funding: € 0.271 million

Pre-normative Projects

- PERFORMANCE (**Integrated Project)**: A science base on photovoltaics performance for increased market transparency and customer confidence
  EU funding: € 7 million – Co-ordinator: Fraunhofer Insitut für Solarforschung, Freiburg, Germany

Innovative Large Scale Plants

- PV-MIPS (**Integrated Project)**: Photovoltaic module with integrated power conversion and interconnection system
  EU funding: € 4.4 million – Co-ordinator: ISET-Kassel, Germany
- SOLAR PLOTS **(STREP)**: Multiple-ownership grid-connected PV with optimised tracking and low concentration reflectors
  EU funding: € 1.8 million – Co-ordinator: Alternativas Energéticas Solares, Tafalla, Spain

PV Integration

- PV EMPLOYMENT **(Specific Support Action):** The role of the European PV industry for Europe's jobs and education today and tomorrow
  EU funding: € 0.38 million – Co-ordinator: European Photovoltaic Industry Association (EPIA), Brussels, Belgium
- SOS-PVI **(STREP):** Security of Supply PhotoVoltaic Inverter: combined UPS, power quality and grid support function in a photovoltaic inverter for weak low voltage grids
  EU funding: € 1.5 million – Co-ordinator: Commissariat à l'Energie Atomique (CEA), Paris, France
- UPP-Sol (**STREP):** Urban Photovoltaics: Polygeneration with Solar Energy
  EU funding: € 1.748 million – Co-ordinator: Consorzio Roma Ricerche, Italy
- MULTISOLAR (**SMEs-Co-operative Research)**: Development of an Integrated Solar System for Buildings
  EU funding: € 0.6 million – Co-ordinator: Millenium, Israel

Education, Dissemination & Co-ordination

- PV-CATAPULT **(Co-ordination Action)**: Long-term research, technology, market and socio-economic aspects for the PV sector; PV-Thermal Forum; European Photovoltaic Performance Initiative Collaboration (completed)
  EU funding: € 1.7 million – Co-ordinator: ECN, Petten, The Netherlands
- PV SEC **(Co-ordination Action)**: Strengthen the European Photovoltaic Sector and support to establish a PV Technology Platform
  EU funding: € 0.65 million – Co-ordinator: European Photovoltaic Industry Association (EPIA), Brussels, Belgium
- PV-ERA-NET: **Objective:** Networking and Integration of National and Regional Programmes in the Field of Photovoltaic (PV) Solar Energy Research and Technological Development (RTD) in the European Research Area (*ERA*).
  EU funding**:** € 2.62 million, Co-ordinator: Forschungszentrum Jülich GmbH; Project Management Group "Energy - Technology- Sustainability" (PT-ETN).
- SUNRISE: (**Co-ordination Action): Objective:** Strengthening the European PV sector by co0operation with important stakeholders.
  EU funding: € 0.65 million – Co-ordinator: European Photovoltaic Industry Association (EPIA), Brussels, Belgium

In addition to these technology-oriented research projects, there are some Marie Curie Fellowships and the "Intelligent Energy - Europe" (EIE) Programme. The CONCERTO initiative launched by the European Commission is 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.

Intelligent Energy – Europe Programme

The Intelligent Energy - Europe (IEE) Programme is the Community's support programme for non-technological actions in the field of energy efficiency and renewable energy sources. The programme was adopted in June 2003 with a duration from 2003 – 2006.

In the first call, PV was included mainly in the vertical action dealing with renewable electricity, and this led to proposals aiming to tackle market barriers in line with the RES-E Directive. It also resulted in projects aiming to bring together PV market actors with a view to raising awareness, as well as sharing knowledge and experience. An example of projects launched under the first call is the *PV Policy Group,* a network of national energy agencies and the PV Industry Association aiming at analysing key policy issues for PV promotion which has already prepared the *European Best Practice Report.* For down-loading the report and for up-to-date information, please visit the project web-site [Pvp 2006].

- *PV Policy Group:* This project aims at overcoming political-legal barriers that are currently preventing investments in the majority of European PV markets. Eight national energy agencies of the key "solar nations" (DE, FR, NL, AT, SI, PT, GR, ES) formed a "PV Policy Core Group" to define common actions for the improvement and alignment of national support systems for PV. Co-ordinator: German Energy Agency (DENA), Berlin; EU-Funding € 0.541 million

The Second Call included photovoltaics in the context of the vertical action on small scale renewable energy systems. The aim here was to focus on promoting the market for systems which are sold directly to end users and building owners. An example of the projects launched under the second call is *PV-UP-SCALE,* with the main objective to enhance large-scale implementation of dispersed grid-connected PV in the urban environment. The project focuses on four interest areas: Planning our cities; Connection to the grid; Economical drivers; Targeted information and dissemination. Co-ordinator: ECN, Petten, The Nether-lands; EU-Funding € 0.548 million.

The Third and Fourth Calls have included PV in both of the above-mentioned key actions, and therefore address all forms of market barriers to the use of PV electricity. In particular, the Commission was keen to encourage the submission to the final Call of the IEE programme of high quality PV proposals which involve and engage the key market actors in the PV systems supply chain, and which contain convincing arguments to justify EU support for ambitious actions aiming to accelerate the growth of clearly defined markets for PV systems.

- PURE – Promoting the use of photovoltaic systems in the urban environment through demo relay nodes
  Co-ordinator: Robotiker-Tecnalia, Spain; EU-Funding € 0.574 million.
- deSOLaSOL –European co-operation project that aims at bringing photovoltaic energy closer to the people. More precisely, deSOLaSOL aims at raising the awareness about PV energy, and in particular on its decentralised deployment, through the promotion of grid-connected jointly-owned PV plants. The main objective of deSOLaSOL is to minimise these barriers – delivering high-quality information – and to make it easier for people to invest jointly in grid-connected PV plants – disseminating the best investment schemes. Co-ordinator: Fundación Ecología y Desarrollo, Spain; EU-Funding € 0.238 million.

In addition, several IEE supported actions under the COOPENER field are addressing issues related to the promotion of electricity services for poverty alleviation and sustainable development, which include work on the future use of PV systems for electricity supply in the poorest areas of developing countries

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 has been published on 22 December 2006. These calls 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 evaluation procedures as well as the contract negotiations are still ongoing and it is expected that the first project will start towards the end of 2007.

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 Call specified the following topics in the area of Photovoltaics:

- FP7-ENERGY-2007-1-RTD
  - **Intermediate band (IB) materials and cells for PV** (Collaborative Project):
    Content/scope: The research should cover basic studies of the IB cell, development of bulk IB materials and possible low-cost growth methods in order to reach enhanced performance (especially under concentrated sunlight).
    Expected impact: The results should lay the foundation for a breakthrough in high efficiency intermediate band-gap cells.
  - **Dye-sensitised PV solar cells** (Collaborative Project):
    Content/scope: The aim is to increase the efficiency and stability of dye-sensitised solar cells and to improve their potential for upscaling and fabrication. The activities should cover basic research, e.g. long-term stability, reduction of interfacial recombination and device simulation, as well as applied technology aspects, e.g. interface engineering, optimisation of sensitiser and module design. The work should include testing and analysis of the devices under real operating conditions.
    Expected impact: The project should increase technical expertise and accelerate the exploitation of this technology.
  - **Concentrating Photovoltaics: cells, optics, modules** (Collaborative Project):
    Content/scope: The project should address the following aspects:
    (i) improvement of existing cell materials and develop new materials, in order to increase the cell efficiency, stability and life-time of multi-junction, high-concentration solar cells;
    (ii) development of high-efficiency optics with long-term stability and wide acceptance angles, for high concentration and suitable for cost-effective mass production;
    (iii) development of dedicated, cost-effective, high through-put module assembly techniques, with due consideration of durability and temperature issues.
    Environmental and economical aspects should be fully addressed.
    Expected impact: The results should lead to economically-attractive concentrating photovoltaics, based on higher efficiencies, stable optics and optimised assembly techniques.
  - **Research for binary thin-film photovoltaics** (Collaborative Project):
    Content/scope: The aim is to develop cadmium telluride photovoltaic technology by

    i) advancing the understanding of physical parameters and processes (e.g. material interfaces, influence of impurities and grain boundaries) and
    ii) improving production technology (e.g. improved ohmic back contact, advanced TCOs, improved nucleation, film morphology and doping). Environmental and health aspects should be given due consideration.
    Expected impact: The results should lead to more cost-effective and more efficient thin film modules based on environmentally sound processes and cycles.
  - **Environmental aspects of photovoltaics** (Co-ordination and Support Action)
    Content/scope: The objective is to deliver up-to-date environmental data and information, in order to benchmark and optimise the environmental profile of

photovoltaic technologies. The project should provide indicators (e.g. LCA/LCE, energy pay-back) for all main technologies. The project should also publish analyses and recommendations on, for example, reduction or avoidance of the use of critical materials (i.e. scarce or hazardous), more environmentally friendly processing steps, and recycling issues, with reference to environmental legislation where appropriate. The project consortium must take full account of past and ongoing work, and the conclusions of the project should be widely disseminated.
Expected impact: The project will increase awareness and enable benchmarking of the environmental aspects of photovoltaic technologies.

- **Alternative approaches for crystalline silicon PV** (Collaborative Project)
  Content/scope: The aim is to develop innovative approaches for the production of crystalline silicon cells and modules based on, for example, hetero-junctions or ribbons, having a high potential for cost reduction and efficient use of silicon, with due consideration of environmental aspects. This topic is not intended for the mainline production technology of crystalline silicon PV.
  Expected impact: The project is expected to deliver marked improvements in silicon usage which are suitable for industry implementation, thus improving the competitiveness of crystalline silicon photovoltaics.
- **Solar irradiation resource assessment and forecasting** (Co-ordination and Support Action)
  Content/scope: Assessment of solar irradiation in Southern Europe and Northern Africa, including historic data and short-term forecasting.
  Expected impact: The results should facilitate the matching of different concepts to various solar environments, reduce the cost of integration through improved predictability, and accelerate the rate of solar energy deployment in the EU and neighbouring countries.

♦ FP7-ENERGY-2007-2-TREN

- **Secure, reliable and affordable supply of feedstock for the PV industry** (Co-ordination and Support Action)
  Content/scope: The objective of this topic is to ensure a secure, reliable and affordable supply of feedstock for the PV industry. Here the problem is more related to the need to facilitate the demand from the PV industry to meet the supply side by setting-up actions to properly kick-start new and efficient routes for the silicon-feedstock production of at lower cost.
  Expected impact: Actions aimed at kick-start routes for silicon-feedstock production.
- **Improved production equipment and cost reduction** (Collaborative project)
  Content/scope: The objective of this topic is to reflect on the crucial role of cost reduction played by the production equipment used by the PV manufacturing industry in silicon cells and modules and identifies the need for development and demonstration of new equipment (for instance: systems for high handling yield/high throughput of thin wafers; equipment for novel manufacturing technologies of solar cells) to be put on the market. Cost, efficiency and environmental aspects should be taken in consideration.
  Expected impact: Higher performances and innovative equipment for the PV industry.
- **Innovative/improved PV manufacturing processes** (Collaborative project)
  Content/scope: This topic has the objective to develop and demonstrate innovative processes in the PV manufacturing industry to increase yield and reduce costs.
  Expected impact: Innovative and/or improved processes in the PV industry.

- **Development and demonstration of standardised building components** (Collaborative project)
  Content/scope: The objective of this topic is the development and demonstration of standardised and tested building components, based on photovoltaics which comply with existing standards and building codes. The building industry should have the lead of the initiative, with the involvement of architects and testing laboratories. Test results should be communicated together with the products (educational material and tools for professionals and students).
  Expected impact: Enhanced use of PV building components by architects and builders.
- **Multiple benefits of PV systems** (Collaborative project)
  Content/scope: The objective of this topic is the demonstration of the multiple benefits of PV systems for:
  i) Power quality improvement in industrial and residential environment;
  ii) Security of supply in residential and urban environments, as well as for autonomous power supply systems in new Member States and in developing countries. The demonstration of these additional benefits aims at increasing the value of PV electricity. Production of educational material should be included.
  Expected impact: Enhanced deployment of PV technologies.

6.3 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 4.3, because its headquarters is in the USA.

6.3.1 ANTEC Solar Energy AG

Antec Solar Energy AG was formed in the Autumn of 2003 by a merger of ÖKOLOGIK ECO-VEST AG, Frankfurt, a venture capital fund which acquired the assets of the bankrupt Antec Solar GmbH in the Spring of the same year. The company distributes its modules almost exclusively in Germany via wholesale dealers.

The company manufactures Cadmium Telluride thin film solar modules with a format of 120×60 cm^2 and a rated power of 43Wp and 50Wp. The nominal capacity of the 180 m long production line located in Arnstadt, Thüringen is 10 MW. According to the company, the plant has been running at full capacity since the beginning of 2004 in three shifts. Expansion plans are in preparation, but no further information was available so far. Production for 2006 was reported with 8 MW [Pvn 2007].

6.3.2 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. In April 2007 the company expanded its work-force and moved to 24/7 operation. The ramp-up phase should be completed and full production capacity of 25 MWp reached by the end of the year. CSG Solar now has more than 120 employees and produced 1.2 MW in 2006 [Pvn 2007].

6.3.3 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. The ErSol Group manufactures and distributes photovoltaic products. Its core business is the

production and distribution of moncrystalline and multicrystalline solar cells. In 2006 the company had sales of 40 MW and is planning to expand production capacity from 100 MW to 400 MW in 2010 [Ers 2007].

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 2007a]. 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 2007b]. The medium-term annual capacity target remains 100 MWp.

6.3.4 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 [Eve 2007a]. In 2006 EverQ had sales of 15 MW and it is planned to increase the capacity to 300 MW by 2010.

6.3.5 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

2006 Isofotón was the third largest manufacturer of solar cells in Europe with 61 MW and has a production capacity of 130 MW in 2007.

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.

6.3.6 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. Matrix Solar Technologies used its marketing and management expertise, with the twin objectives of assisting the growth and reinforcing the position of Photowatt International in the world market, by facilitating its presence in new countries. This is particularly true in the Cape, in South Africa, where Photowatt is involved in a joint-venture technology transfer, installing and starting up an assembly unit. Other countries are presently being studied for such operations. In 2006 Photowatt had sales of 24 MW [Pvn 2007].

6.3.7 Photovoltech

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

On 16 December 2004, Photovoltech's Board of Directors approved a decision to increase the photovoltaic cell production capacity, from 13 MWp to close to 80 MWp a year. The expansion project will create close to 80 jobs and will be commissioned in three steps:

- Upgrade current cell production line by end of 2005: from 13 MWp to 22 MWp
- Extension up to 50-55 MWp: by mid 2007
- Extension up to 80-85 MWp: by end of 2008

In 2006 the company had sales of 18 MW of polycrystalline solar cells [Pvn 2007].

6.3.8 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 2007 2nd quarterly report, the company stated that the nominal capacity had increased to 450 MW by 30 June 2007 and should reach 645 MW by the end of the year [Qce 2007]. Sales in 2006 were 253 MW, securing the second place world-wide.

Q-Cells broadened and diversified its product portfolio by investing in various other companies or forming joint ventures. It has two fully owned subsidiaries, Calylyxo GmbH (CdTe) and Brilliant 234 (amorphous/micromorph silicon thin-films), two joint ventures Solibro (67.5%) and EverQ (33.33%), as well as holdings in four companies, CSG (21.71%), VHF-Technologies SA, Switzerland (51%), REC, Norway (17,18%) and Solaria Corp., USA (33%).

6.3.9 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 2007b, Rec 2006]. REC produced 5,250 tons of polysilicon in 2006 [Pvn 2007b].

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 produeced 27.5 MW [Pvn 2007]. 2007 capacity will be 100 MWp of solar cells per year.

6.3.10 Schott Solar GmbH

Schott Solar GmbH is a fully owned subsidiary of Schott AG, Mainz. 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 2006, the company had sales of 96 MW (83 MW from Germany, 13 MW from US). For 2007 the production capacity is 162 MW.

Schott Solar uses silicon wafers grown by Edge-Defined, Film-Fed Growth (EFG) developed by Tyco Laboratories and the Mobil Corporation. Although the Mobil Solar Energy Corporation began selling around the world in 1981, by 1986 a strategic decision was made to focus exclusively on the US utility market. In 1994, Mobil Oil Corporation decided to leave the photovoltaic industry and in July of that same year, ASE GmbH of Germany acquired 100% of Mobil's technology and assets.

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. On 27 March 2006, Schott AG announced that it will invest € 60 million to enable Schott Solar GmbH to build a manufacturing facility for amorphous silicon thin film solar modules in Jena, Germany. The manufacturing capacity will exceed 30 MW per year and the facility is scheduled to open in the fall of 2007 [Sch 2007a].

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 – Schott Wacker Solar GmbH – is scheduled to start operations this year. 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.

6.3.11 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).

At the beginning of 2006 SolarWorld bought the silicon production facilities of Shell Solar [Sol 2006]. With the acquisition of the 80 MW production capacity in the US, SolarWorld became the largest producer of solar cells in the US and started to expand the production facilities [Sol 2006a]. In the framework of the agreement Solar World has secured the option to participate in the development of the copper indium selenide (CIS) technology in the future.

In February 2007 SolarWorld acquired an old computer factory from Komatsu-Group in Hillsboro (OR), USA [Sol 2007c]. It is planned to develop the site into 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 crystallization 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 2006 was 86 MW [Sol 2007c].

In 2003 the Solar World Group was the first company world-wide 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.

6.3.12 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 started and start-up of production was in September 2005. The present production capacity is 60 MW and Solland had sales of 18 MW in 2006 [Pvn 2007]. The company is currently expanding its production capacity to 170 MW [Sol 2007d].

6.3.13 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].

6.3.14 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 2006 the company produced 30 MW.

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

6.3.15 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.

The construction of a new production facility for CIS photovoltaic modules with an investment volume of around € 55 million and a production capacity of 14.8 MW was completed in the Autum of 2006. The ramp-up to full capacity was completed in March 2007 and the production volume is about 500 CIS modules a day [Wür 2007]. The production capacity will be expanded to 30 MW in 2008.

6.3.16 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.

- **Brilliant 234 GmbH** 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 the first quarter of 2008.

- **Calyxo GmbH** is a fully owned subsidiary of Q-Cells AG located in Wolfen, Saxony-Anhalt. The company plans to manufacture CdTe thin film solar cells. The pilot plant has expanded into a production line with 25 MW and is planned to be fully operational in the first quarter of 2008

- **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].

- **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 mid 2007. By 2009 the factory output should be increased to 60 MW.

- **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.

- **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 a 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 and produced 7 MW of solar cells.

- **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. Solibro will construct its first production line with a capacity of between 25 and 30 MWp in Thalheim, Germany. The production start is planned by mid 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.

- **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 51% share in the company which currently has a pilot production line with 2 MW capacity. The first production line on an industrial scale of 25 MW will be built by mid-2008.

6.3.17 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. In 2006, it increased its capacity to 288 MW and production was about 215 MW [Cry 2007]. The company went public in June 2007 and is listed on the London Stock Exchange.

6.3.18 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. 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 2007b].

6.3.19 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 Finish silicon wafer processing company Okmetic Oyi, the company signed an agreement to sell its crystal growth technology to NorSun [Okm 2006].

NorSun will establish a solar wafer factory in Norway and the crystal growth at the new factory will be based on technology developed by Okmetic. In the first stage of the project Okmetic's crystal growth capacity will be extended in Vantaa.

On 30 August 2006, Econcern, Photon Power Technologies (PPT) and NorSun announced a plan to build a polysilicon (poly-Si) plant with an initial annual output of between 2,000 and 3,000 tonnes of solar grade silicon [Eco 2006]. Saint-Auban in the Provence region (south-east France) is the preferred site for the plant but the consortium is also considering other possible locations in Europe.

6.3.20 Wacker Polysilicon

Wacker Polysilicon, Burghausen, Germany is one of the world's leading manufacturers of hyperpure polysilicon for the semiconductor and photovoltaic industry, chlorosilanes and fumed silica. In 2006 Wacker produced 5,800 tons of polysilicon [Pvn 2007b]. 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].

6.3.21 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 customer.

7. OUTLOOK

In 2006 Japan again had the major market share in photovoltaic device production, with four companies in the top ten manufacturers (Sharp N°1, Kyocera N°3, Sanyo N°5, Mitsubishi Electric N°6). The other top-ten companies were one European company (Q-Cells N°2), one Chinese company (Suntech N°4), one Taiwanese company (Motech N°7) and three companies with production capacities in more than one continent (Schott Solar N°8, Solarworld N°9, BP Solar N°10). Since 1999 the European PV production grew on average by 50% per annum and reached about 680 MW in 2006. The market shares of European and Chinese manufacturers increased from 20% to 27% and from 1% to 22% respectively, whereas the US and Japanese shares decreased to 8 and 37% 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 37%.

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 volume of 2.5 GWp or € 12 billion in 2006.

The current 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 world-wide, 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 predict that oil prices could well hit 100 $/bbl by the end of 2007 or early 2008 [IHT 2007].

If Oil-futures for 2010 and 10 year US treasury bonds (4.75%) are taken as a benchmark, the oil price will rise to at least $ 83/bbl (€ 59) in 2010. Otherwise Oil-futures will be a loss,

which is highly unlikely. 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 6 shows the projections of the Japanese, US and EPIA Roadmaps combined with the EREC 2040 "Advanced International Policy Scenario" (AIP) and the "Dynamic Current Policy Scenario" (DCP) [Ere 2004].

Table 6: **Evolution of the cumulative solar electrical capacities until 2030 (Sources: Japanese, US EPIA Roadmaps and EREC 2040 scenarios)**

Year	2000	2010	2020	2030
USA [GW]	0.14	2.1	36	200
Europe [GW]	0.15	3.0	41	200
Japan [GW]	0.25	4.8	30	205
World-wide DCP [GW]	1.00	8.6	125	920
World-wide AIP [GW]	1.00	14.0	200	1830

These projections show that there will be huge opportunities for photovoltaics in the future. 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 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.

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. Should the current trend in the field of world-wide 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 in the United States, India and China will influence future developments of the markets. In 2010 it is very likely that China and Taiwan will compete with Japan for the major market share (Fig. 23).

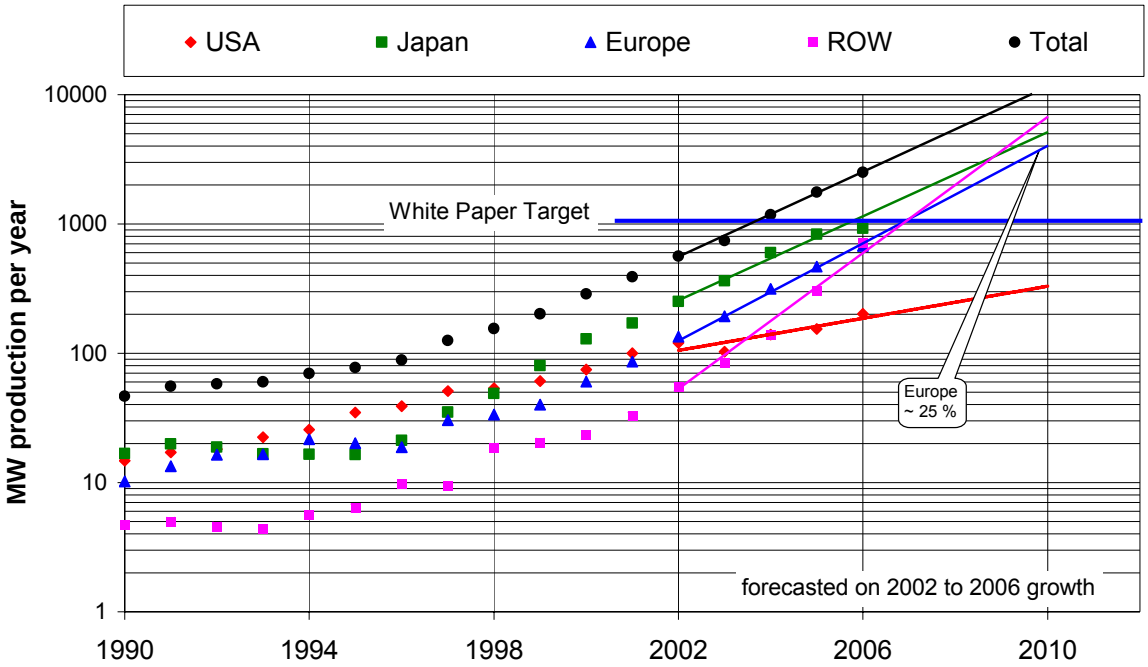

Fig. 23: Extrapolated increase of production capacities up until 2010 using the growth rates from 2002 to 2006 (Data source: PV News [Pvn 2007])

A lot of the future market developments, as well as production increases, will depend on the realisation of the currently announced world-wide PV programmes and production capacity increases. During the last half year, the flood of announcements from new companies which want to start a PV production, as well as established companies to increase their production capacities, was enormous. The total capacity announcement during that period was larger than the total available production capacity at the end of 2006. 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 2006 market share of 7.8% to around 20% in 2010. This will have significant impact on the price reduction of PV modules as well as systems.

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]. The EU25, with 18.2% of the total world-wide electricity consumption (and a 29.9% share within OECD), will have an investment need of almost US$ 39.8 b per year. About half of the costs are for new and refurbished power generation capacities and the other half is for transmission and distribution costs. Distributed generation of renewables can help to reduce investment in transmission costs. 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 IEA study points out that fuel costs will be in the same order of magnitude as investment in infrastructure, increasing the scale of the challenge, especially for developing countries.

Since already a few years, we have 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 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. The future price decrease of the systems will very soon make electricity from PV systems price-competitive for consumers. 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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9. REFERENCES

[App 2007] Applied Materials, Press Release, 26 June 2007
http://www.appliedmaterials.com/news/pr2007.html?menuID=6

[Ats 2007] ATS Automation Tooling Systems Inc., Press Release, 11 January 2007
http://www.atsautomation.com/profile/news/2007/11012007a.htm

[Awe 2003] Shimon Awerbuch, The True Cost of Fossil-Fired Electricity in the EU: A CAPM-based Approach, January 2003.

[Big 2007] Big Sun Energy, http://www.bigsun-energy.com/Eng/About/

[Bon 2004] International Conference for Renewable Energies, Bonn, 1 -4 June 2004, International Action Plan and List of Actions and Commitments
http://www.renewables2004.de/en/2004/outcome_actionprogramme.asp

[Bps 2007] BP Solar, Press Release, 16 July 2007
http://www.bp.com/genericarticle.do?categoryId=3050551&contentId=7034815

[Bps 2007a] BP Solar, Press Release, 21 March 2007
http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7031238

[Bps 2007b] BP Solar, Press Release, 22 March 2007
http://www.bp.com/genericarticle.do?categoryId=2012968&contentId=7031277

[BSW 2007] Bundesverband Solarwirtschaft, Statistische Zahlen der deutschen Solarwirtschaft, June 20077

[CDF 2003] China Development Forum 2003, 15 to 17 November 2003
Background Reports for China's National Energy Strategy 2000 to 2020
http://www.efchina.org/documents/Draft_Natl_E_Plan0311.pdf

[CEU 2007] Council of the European Union 8/9 March 2007, Presidency Conclusions 7224/07, 9 March 2007

[Chi 2007] 2007 China Solar PV Report, China Renewable Energy Industry Association, Greenpeace China, European PV Industry Association, and WWF, China Environmental Science Press, September 2007

[Cry 2007] PV Crystalox Solar plc, Sales Prospectus
http://www.crystalox.com/ViewProspectus.aspx

[Csg 2004] CSG Solar, Press Release, 7 June 2004
http://www.csgsolar.com/CSGAnnounce7Jun04.pdf

[Csg 2006] CSG Solar, Press Release, 15 March 2006
http://www.csgsolar.com/pages/medias.php?lang=en

[Dai 1999] Daiwa House Annual Report 1999

[Dai 2006] Daily News - The Taiwan Economic News, 26 June 2006
http://news.cens.com/php/getnews.php?file=/news/2006/06/26/20060626015.htm&daily=1

[Dig 2006] DigiTimes, 27 March 2006
http://www.digitimes.com/bits_chips/a20060327A4012.html

[Dig 2007] DigiTime2, 15 August 2007
http://www.digitimes.com/news/a20070815PD212.html

[DOE 2003] Department of Energy Photovoltaic Technology Plan 2003 to 2007, US Department of Energy, Energy Efficiency and Renewable Energy; DOE/GO-102003-1491, September 2003

[DOE 2006] Department of Energy Photovoltaic Technology Plan 2007 to 2011, US Department of Energy, Energy Efficiency and Renewable Energy; http://www1.eere.energy.gov/solar/pdfs/set_myp_2007-2011_proof_1.pdf

[Dow 2006] Dow Corning, Press Release, 31 July 2006 http://www.dowcorning.com/content/news/HSC_new_site_search.asp?DCWS=&DCWSS=

[EC 1997] Energy for the Future: Renewable sources of energy; White Paper for a Community Strategy and Action Plan, COM(1997)599 final (26/11/97)

[EC 2000] Towards a European Strategy for the Security of Energy Supply; Green Paper, COM (2000) 769 final

[EC 2001] Directive 2001/77/EC (27.09.2001); Official Journal of the European Communities L 283/33 (27.10.2001)

[EC 2004] Communication from the Commission to the Council and the European Parliament on the share of renewable energy in the EU; COM (2004) 366 (30.03.2004)

[EC 2004a] Commission staff working document: The share of renewable energy in the EU, country profiles; Overview of renewable energy sources in the enlarged European Union {COM (2004) 366 final}; SEC (2004) 547 (26.5.2004).

[EC 2005] Communication from the Commission; The support of electricity from renewable energy sources; COM (2005) 627 (07.12.2005)

[EC 2005a] Commission Staff Working Document; Annex to the Communication from the Commission, *The support for electricity from renewable energy sources*, Impact Assesment {COM(2005) 627 final}; SEC(2005) 1571

[Eco 2006] Econcern Press Release 30 August 2006 http://www.econcern.com/cms/download/PressRelease_Econcern_SildeProv_300806_EN.pdf

[EEG 2004] Gesetz zur Neuregelung des Rechts der Erneuerbaren Energien im Strombereich (Erneuerbare-Energien-Gesetz – EEG); Bundesgestzblatt Jahrgang 2004 Teil I, Nr. 40, p.1918 (31.07.2004) http://217.160.60.235/BGBL/bgbl1f/bgbl104s1918.pdf

[Eet 2006] EE Times, 7 June 2006 http://www.eetimes.com/news/semi/showArticle.jhtml;jsessionid=L1FVTPNGVCHJKQSNDLPSKH0CJUNN2JVN?articleID=188702614

[Eia 2007] Energy Information Administration, http://www.eia.doe.gov/fuelelectric.html

[Enf 2006] ENF Ltd, 21 March 2006 http://www.enf.cn/news/060321/1839.html

[Enf 2007] ENF European and Chinese Solar Cell & Panel Manufacturer Market Survey 2006

[Epi 2004] European Photovoltaic Industry Association Roadmap, 2004; www.epia.org

[Epi 2004a] European Photovoltaic Industry Association; Solar Generation, October 2004

[Ere 2004] *Renewable Energy Scenario to 2040 – Half of the Global Supply from Renewables in 2040*, EREC – European Renewable Energy Council 2004 www.erec-renewables.org

[Ers 2007] ErSol AG, Press Release, 17 April 2007 http://www.ersol.de/uploads/media/Pressemitteilung_170407.pdf

[Ers 2007a] ErSol AG, Press Release, 15 June 2007 http://www.ersol.de/uploads/media/PI_ersol_15.6.2007.pdf

[Ers 2007b] ErSol AG, Press Release, 31 August 2007
http://www.ersol.de/uploads/media/PI_ersol_20070831.pdf

[Eve 2007] Evergreen Solar, Press Release, 12 September 2007
http://www.evergreensolar.com/app/en/investors/

[Eve 2007a] EverQ GmbH, Press Relaese 19 June 2007
http://www.everq-gmbh.com/typo3/fileadmin/everq/download/
EverQ_Opens_Second_Major_Manufacturing_Plant.pdf

[Fst 2007] First Solar Inc., Press Release 27 September 2007
http://investor.firstsolar.com/releasedetail.cfm?ReleaseID=266440

[Fuj 2005] Fuji Electric, Press Release, 25 August 2005
http://www.fujielectric.co.jp/eng/news/index.html

[Fuq 2003] *Launching a Least-Cost Energy Development Path*, Y. Fuquiang, Proceedings of the China Development Forum 2003, 15 to 17 November 2003
http://www.efchina.org/documents/Briefing_book_031115_EN.pdf

[Gee 2004] GE Energy, Press Release, 31 March 2004
http://www.gepower.com/about/press/en/2004_press/033104.htm

[Gaz 2007] Gazzetta Ufficiale, n. 45, 23 February 2007

[GoJ 2006] Government of Japan, 3rd Science and Technology Basic Plan (FY2006-FY2010) (provisional translation)
http://www8.cao.go.jp/cstp/english/basic/3rd-BasicPlan_06-10.pdf

[Hok 2007] Hoku Scientific, Press Release, 9 August 2007
http://www.shareholder.hokuscientific.com/ReleaseDetail.cfm?ReleaseID=259096

[Hon 2007] Honda Soltec, Press Release, 12 June 2007
http://world.honda.com/news/2007/c070612HondaSoltec/printerfriendly/index.html

[IEA 2003] IEA World Energy Investment Outlook 2003, ISBN 92-64-01906-5 (2003)

[IEA 2006] IEA Annual Report 2005, Spain; http://www.iea-pvps.org/ar05/index.htm

[IEA 2007] IEA Oil Market Report

[IHT 2007] International Herald Tribune, 24 July 2007
http://www.iht.com/articles/2007/07/24/bloomberg/bxoil.php

[Ike 2005] Informationskampagne für Erneuerbare Energien, Press Release, 4 July 2005,
http://www.unendlich-viel-energie.de/fileadmin/dokumente/Pressemitteilungen/Pressemitteilung-050704.pdf
http://www.unendlich-viel-energie.de/fileadmin/dokumente/Pressemitteilungen/Hintergrund-Arbeitsplaetze-PK-050704.pdf

[Ikk 2004] Osamu Ikki, PV Activities in Japan, Volume 10. No 5, May 2004

[Ikk 2006] Osamu Ikki, PV Activities in Japan, Volume 12. No 7, July 2006

[Ikk 2006a] Osamu Ikki, PV Activities in Japan, Volume 12. No 2, February 2006

[Ikk 2007] Osamu Ikki and Koji Matsubara, IEA PVPS – National Survey Report of PV Power Applications in Japan 2006, May 2007

[Ikk 2007a] Osamu Ikki, PV Activities in Japan, Volume 13 No 2, February 2007

[Ikk 2007b] Osamu Ikki, PV Activities in Japan, Volume 13 No 1, January 2007

[Iso 2007] Isofoton, Press Release, March 2007
http://www.isofoton.com/corporate/material/pdf/dossier/notas/200702.pdf

[Jäg 2004} Arnulf Jäger-Waldau, PV Status Report 2004, Office for Official Publication of the European Communities, EUR 21390 EN, ISBN 92-894-8447-0

[Jap 2003] The Japan Times, 16 April 2003
http://www.japantimes.co.jp/cgi-bin/getarticle.pl5?nb20030416a7.htm

[Jfe 2006] JFE Steel Corporation, Press Release, 26 July 2006
http://www.jfe-steel.co.jp/en/release/2006/060726.html

[Kyo 2003] Kyocera Corporation, Press Release, 04 November 2003

[Kyo 2004] Kyocera Corporation, Press Release, 10 December 2004

[Kyo 2007] Kyocera Corporation, Press Release, 18 April 2007

[Mat 2007] Hiroshi Matsukawa, RTS Corporation, PV Seminar at JRC Ispra, August 2007

[May 1999] Paul Maycock, PV News, 7 January 1999

[MET 2006] METI Brochure, Energy in Japan 2006
http://www.enecho.meti.go.jp/energy2006E.pdf

[Mis 2005] Misawa Homes, Environmental Report
http://www.misawa.co.jp/misawa/kankyou_e/gizyutu/ayumi/2000.html

[Mot 2007] Motech, http://www.motech.com.tw/Motech_Solar.asp

[Msk 2006] MSK Corporation, Press Release, 02 August 2006
http://www.msk.ne.jp/news-file/k0000023_02.pdf

[Nan 2006] Nanosolar, Press Release, 21 June 2006
http://www.nanosolar.com/pr5-6.htm

[Nea 2004] NE Asia Online, 24 March 2004
http://neasia.nikkeibp.com

[NDR 2006] Report on the Development of the Photovoltaic Industry in China, China Renewable Energy Development Project Office, August 2006

[Ode 2006] ODE Vlaandern; http://www.ode.be

[Pho 2007] Photon International, http://www.photon-magazine.com/ppvx/index.htm

[Pvn 2007] PV News, published by The Prometheus Institute, April 2007, ISSN 0739-4829

[Pvn 2007a] PV News, published by The Prometheus Institute, June 2007, ISSN 0739-4829

[Pvn 2007b] PV News, published by The Prometheus Institute, May 2007, ISSN 0739-4829

[Pvn 2007c] PV News, published by The Prometheus Institute, Mach 2007, ISSN 0739-4829

[Pvt 2007] PV Technology Platform; http://www.eupvplatform.org/

[Pvt 2007a] PV Technology Platform: Strategic Research Agenda for Photovoltaic Solar Energy Conversion Technology, March 2007
www.eupvplatform.org/fileadmin/Documents/PVPT_SRA_Complete_070604.pdf

[Qce 2007] Q-Cells AG, 2nd Quarter Report
http://www.q-cells.com/medien/ir/berichte/qcells_q2_2007_english.pdf

[Okm 2006] Okmetic Oyi, Press Release, 6 July 2006
http://www.okmetic.com

[Rec 2005] REC, Press Release, 11 October 2005
http://www.scanwafer.com/default.asp?V_ITEM_ID=611&xml=/R/136555/PR/200510/1045798.xml

[Rec 2006] REC, Press Release, 6 August 2006
http://www.scanwafer.com/default.asp?V_ITEM_ID=611&xml=/R/136555/PR/200608/1069553.xml

[Rec 2007] REC, Annual Report 2006

[Reu 2006] REUTERS, 21 June 2006

[Rio 2001] Carol Riordan, NCPV Hotline, 24 - 31 December 2001

[Rog 2006] M. Rogol, Interest in Solar, Photon International, June 2006, p. 102 - 105

[Ron 2006] Cui Rongqiang, *Current Status and Future Development of Photovoltaics,* Presentation, November 2006

[San 2005] Sanyo, Press Release, 21 July 2005 http://www.sanyo.co.jp/koho/hypertext4-eng/0507/0721-e.html

[San 2007] Sanyo, Press Release, 19 June 2007 http://www.sanyo.co.jp/koho/hypertext4-eng/0706/0619-1e.html

[Sar 2006] Bank Sarasin, Solarenergie 2006, December 2006

[Sch 2007] Schott Solar, Press Release, 21 June 2007 http://www.schott.com/german/news/press.html?NID=2046

[Sch 2007a] Schott Solar, Press Release, 2 August 2007 http://www.schott.com/german/news/press.html?NID=2074

[Sch 2007b] Scheuten Solar, Press Release, 21 June 2007 http://www.scheutensolar.com/media/raw/OpeningSunrise210607_EN_proofread.pdf

[Sei 2004] US Photovoltaics Industry Roadmap; http://www.seia.org/

[Sek 2007] Sekisui Chemicals, Annual Report 2007 http://www.sekisuichemical.com/ir/pdf/ar2007e.pdf

[Sha 2004] Sharp Corp., Press Release, 29 July 2004

[Sha 2007] Sharp Corp., Press Release, 31 July 2007

[Sha 2007a] Sharp Corp., Press Release, 12 January 2007

[Sha 2007b] Sharp Corp., Notice of Convocation of the 113th Ordinary General Meeting of Shareholders, 31 May 2007

[Sha 2007c] Sharp Corp., Press Release, 24 January 2007

[Sha 2007d] Sharp Europe, Press Release, 3 September 2007

[Shen 2007] Shenzen Topray Solar, Press Release, 18 August 2007

[Sho 2007] Showa Shell, Press Release, 15 August 2007 http://www.showa-shell.co.jp/english/press_release/pr2007/0815.html

[Sic 2005] Wang Sicheng, Proceedings of the China Renewable Energy Development Strategy Workshop, 28 October 2005, Tsinghua, PRC

[Sol 2001] *Solar Electric Power*, The US Photovoltaic Industry Roadmap, prepared by Energetics, Incorporated, Columbia, Maryland, under contract to Sandia National Laboratories, (2001)

[Sol 2006] Solar World AG; Ad hoc Announcement 02.02.2006 http://www.solarworld.de/sw-eng/presse-adhoc/index.php

[Sol 2006a] Solar World, Press Release, 23 August 2006 http://www.solarworld.de/sw-eng/presse-corporatenews/

[Sol 2007] Solar Maps, National Renewable Energy Laboratory, http://www.nrel.gov/gis/solar.html#maps

[Sol 2007a] Solarbuzz, 2007 World PV Industry Report Highlights

[Sol 2007c] SolarWorld AG, Ad Hoc Message, 1 March 2007 http://www.solarworld.de/Ad-hoc-Messages.135.0.html?&L=1

[Sol 2007d] SolarWorld AG, Annual Report 2006

[Sol 2007b] Solland Solar, Press Release, 15 August 2007 http://www.sollandsolar.com/about/news.htm

[Sum 2007] Sumitomo Titanium Corporation, Press Release, 18 May 2007 http://www.sumitomo-ti.co.jp/whatsnew_e/pdf/completion_of_the_polycrystalline.pdf

[Sun 2007] Sun & Wind Energy 1/2007, ISSN 1861-2741

[Sun 2007a] Suntech Power, 2nd Quarter 2007 Results http://www.suntech-power.com/News/tabid/99/Default.aspx?id=296&Module=597

[Sun 2007b] SunPower Corporation; Press Release; http://investors.sunpowercorp.com/releasedetail.cfm?ReleaseID=255204

[Sur 2004] PV Electricity Potential in EU25 Member States, M. Šúri, T. Huld, E. Dunlop, in "Status Report 2004 - Energy End-use Efficiency and Electricity from Biomass, Wind and Photovoltaics and in The European Union", ed. A. Jäger-Waldau, European Commission, DG JRC Euro Report No. EUR 21297 EN; Luxembourg: Office for Official Publications of the European Communities, 2004; ISBN 92-894-8193-5

[Sys 2007] Photovoltaic Energy Barometer, Systèmes Solaires n° 178, April 2007, ISSN 0295-5873

[Tak 2007] H. Takatsuka and Y. Yamauchi, Proceedings of the 21st European Photovoltaic Solar Energy Conference and Exhibition, 3 to 7 September 2007, Milan, Italy

[Tok 2006] Tokuyama Corporation, Fiscal 2005 Presentation, 15 May 2006 http://www.tokuyama.co.jp/eng/ir/report/briefing/pdf/2006mar_setsumeikai(E).pdf

[Ulv 2007] ULVAC Technologies, Press Release, 23 March 2007 http://www.ulvac.com/news.asp

[Uni 2005] Union of Concerned Scientists http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=895

[Uni 2006] United Solar Ovonic LLC., Press Release, 16 February 2006 http://www.uni-solar.com/uploadedFiles/ UnitedSolarOvonicCapacityExpansion _2%2016%2006.pdf

[Uni 2007] United Solar, Press Release, 29 August 2007 http://www.ovonic.com/ne_ecd_ovonics_press_releases_more.cfm?pressrelease_id=486

[Vdn 2007] Verband der Netzbetreiber - VDN - e.V, Jahresabrechnung 2006, 21.09.2007 http://www.vdn-berlin.de/eeg_jahresabrechnung_2006.asp

[Vdn 2007a] Verband der Netzbetreiber - VDN - e.V, Mittelfristprognose, 08.06.2007 http://www.vdn-berlin.de/global/downloads/Netz-Themen/eeg/EEG-Mifri-2013.pdf

[Vdn 2007b] Verband der Netzbetreiber - VDN - e.V, Jahresprognose 2008, 17.09.2007 http://www.vdn-berlin.de/eeg_prognose_2008.asp

[Wac 2006] Wacker Chemie AG, 28 June 2006 http://www.wacker.com/cms/de/press_media/press-releases/pressinformation-detail_7070.jsp

[Wür 2007] Würth Solar GmbH, Press Release, 22 March 2007

[Yin 2006] Yingli Solar, Press Release, 29 April 2006 http://www.yinglisolar.com/en/news/news_view.asp?newsid=3

[Yin 2007] Yingli Solar, Press Release, 23 July 2007

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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 base 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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