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PV Status Report 2006

Research, Solar Cell Production and Market Implementation of Photovoltaics

Arnulf Jäger-Waldau

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PREFACE

Record oil prices and speculations whether the oil price would peak at $ 105 in 2010 or whether it would be well above has become a reality in 2005. 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.

At the same time, the need to stabilise atmospheric greenhouse gases in the 450 to 550 ppmv range 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 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 instead of an increase in the future.

In 2005, the photovoltaic industry production again grew by almost 50% reaching a world-wide production volume of 1,759 MWp of photovoltaic modules and has become a € 9 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 rising profit margins and lower prices for consumers at the same time. All market players expect that in the long-term the growth rates for photovoltaics will continue to be high, even if political or economic frame conditions could lead to a short-term slow down of the growth rates.

To maintain this growth continuous introduction of new technologies, made possible by sound fundamental research, has to take place. The ongoing shortage in silicon feedstock, triggered by the extremely high growth rates of the photovoltaics industry over the last years is providing a window of opportunities for the accelerated introduction of advanced production technologies, thin film solar modules and technologies like concentrator concepts.

The Fifth 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 be 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, August 2006

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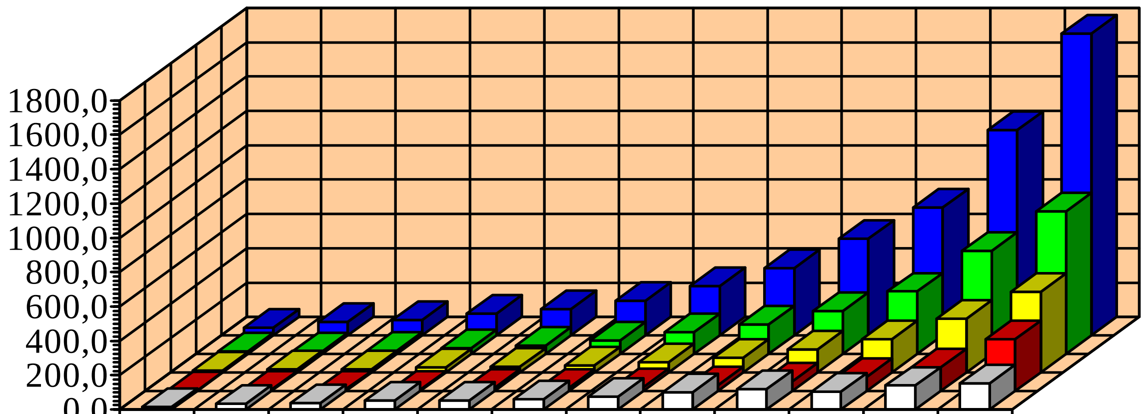
1. INTRODUCTION

In 2005, the photovoltaic industry continued its impressive growth and delivered world-wide some 1,700 MWp [Pvn 2006] of photovoltaic generators (Fig. 1). In the past 5 years, the average annual world growth rate was above 40%, making the further increase of production facilities an attractive investment for industry. An investment report published in 2004 by Credit Lyonnais Security Asia forecasts that the photovoltaics sector has a realistic potential to expand from € 5.6 billion[1] in 2004 to € 24 billion in 2010, corresponding to 5.3 GWp in annual sales [Rog 2004]. In the meantime the bank analyst Mr. Rogol estimates that even 10 GW of annual sales with a € 40 billion turnover of the sector could be reached in 2010 [Rog 2006].

The IEA Photovoltaic Power Systems Programme reported in October 2005, that by the end of 2004 "*Total direct employment in the sector in the reporting countries may now exceed 50,000 persons, with rapid growth indicated in Germany and the USA*" [IEA 2005]. If the growth of Photovoltaics in the IEA PVPS reporting countries, as well as others like China and India are taken into account it is very likely that in 2005 the world-wide solar electricity industry already provided employment for over 70,000 people, about double the number estimated by the European Photovoltaic Industry Association (EPIA) in 2003 [Epi 2004].



	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
United States	14,8	34,8	38,9	51,0	53,7	60,8	75,0	100,0	120,6	103,0	140	154
Rest of World	4,7	6,4	9,8	9,4	18,7	20,5	23,4	32,6	55,5	83,8	139	302
Europe	10,2	20,1	18,8	30,4	33,5	40,0	60,7	86,4	135,1	193,4	314	470
Japan	16,8	16,4	21,2	35,0	49,0	80,0	128,6	171,2	251,1	363,9	602	833
Total	46,5	77,6	88,6	125,8	154,9	201,3	287,7	390,2	561,8	744,1	1195	1759

Fig. 1: World PV Cell/Module Production from 1990 to 2005
(data source: PV News [Pvn 2006])

[1] Exchange rate used: $ 1.25 = € 1

Photovoltaic companies are attracting a growing number of private and institutional investors. The number of market studies and investment opportunities has considerably increased in the last few years and business analysts are very confident that despite raising interest rates the photovoltaics sector is in a healthy condition. 2005 and early 2006 saw an increasing number of very successful Initial Public Offerings (IPO) of solar companies. The 30 companies listed in the PPVX[2] (Photon Pholtovoltaic stock index) together have a market capitalisation of more than € 20 billion at the end of August 2006.

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. The top advantage of this technology is that complete production lines can 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.

The current temporary shortage in silicon feedstock was triggered by the extremely high growth rates of the photovoltaics industry over the last years, which was not followed by the silicon producers. Three 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 two to three 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.
- 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 production capacities of existing manufacturers are under way and a large number of new thin film manufacturers try to enter the market to supply the growing demand for PV modules. Compared to 2004 thin film shipments increased by over 50% to 108 MW in 2005. In 2010 EPIA forecasts that 20% of the then 5.3 GW module shipments will be thin films [Unz 2005].

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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 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 2006].

Similar to learning curves in other technology areas, new products will enter the market, enabling further cost reduction. After years of research and technology development, thin film production plants with a few hundred MW cumulative production capacities are now under construction. Equally, competitive technologies are amorphous Silicon, CdTe and CI(G)Se thin films. The growth of these technologies is accelerated by the positive development of the PV market as a whole and the current silicon wafer shortage. The expansions for the required scale-up to manufacturing units of 50 MWp annual capacity and more are under way and will now join the wafer silicon devices technology in satisfying demand [Fir 2005/6, Uni 2005/6]. 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.

If thin film should supply 20% of the photovoltaic devices by 2010, the growth of production capacities must be about double as high as the rest of the industry, assuming that total PV growth continues at a constant of 32% per year, as predicted by the Credit Lyonnais Security Asia study. By then, Silicon wafer technology would deliver about 4,000 MWp per year, requiring 40,000 metric tons of Si-feedstock, about 40% more than today's entire world production capacities of semiconductor silicon (28,000 metric tons). Even the more conservative EPIA scenario of 27% growth would result in a silicon demand of 30,000 metric tons of Si-feedstock [Epi 2004].

These scenarios show that in order to maintain such a high growth rate, 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

In 2005 the photovoltaic market grew again by more than 45%. Most of the installations were sited in Germany, but additional markets like California, Spain and Italy added to it. The question of what quantity of photovoltaic systems are installed where, is becoming more and more difficult to answer. Already last year the reported figures for the German installations in 2004 varied from an initial 360 MW, reported by the German Solar Industry Association and then revised to 500 MW up to 770 MW and later revised to 720 MW, reported by Photon International [Pho 2005/6a].

The problem started with the end of the German interest-reduced loan programme in June 2003. No system was in place to register the number of systems installed and the dramatic increase of systems installed after the revision of the German feed-in law took everybody by surprise. 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 actually produced kWhs cannot be used either, as it is not available until October of the following year and in the last years was even corrected after that. It is therefore difficult to verify the different numbers.

Besides this controversial issue, the new industry policy for Photovoltaics in the People's Republic of China, and the ongoing consolidation of the PV industry by merger and acquisition, are additional hot topics for the market. The current silicon shortage and the related price rise of the wafers forced the solar cell manufacturers to sign long term supply contracts with considerable down payments to finance the capacity expansion. At the same time that new thin film production capacities are under construction, new thin film manufacturers are entering the scene and established silicon-based PV cell manufacturers diversify into thin film PV to reduce their exposure to future consequences of this development.

The Photovoltaic world market grew again by more than 45% in 2005 to 1,759 MW. Like in the case of 2004, Germany was the largest single market with 603 MW followed by Japan with 291 MW and the US with 108 MW [Sys 2006, Jpe 2006, Pvn 2006]. The revised German Feed-in Law [EEG 2004] went into force on 1 August 2004. The transitional arrangement before, and the revision itself resulted in a dramatic increase in PV installations. The German Solar Industry Association estimates that new grid connected systems with a capacity of about 600 MW were installed in 2005. Photon reported systems installations with a total of about 710 MW [Pho 2006a]. Even with the more conservative 603 MW installed photovoltaic systems (including off grid installations) Germany accounted for more than 93% of the EU 25.

Spain followed second with a little over 20 MW, almost the double of 2004 and for 2006 and 2007 projects with about 200 MW are already under construction or planned [Pho

2006b]. On 26 August 2005, the Spanish Government approved the *Plan de Energías Renovables en España* (PER) for 2005 – 2010. The objectives are to cover 12.1% of Spain's overall energy needs and 30.3% of total electricity consumption by 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 no considerable increase in the amount of new systems capacity could be observed in 2005. 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. However, it is estimated that between 50 and 80 MW at the most might be installed this current year.

Despite the fact that the European PV production grew again by 50% and reached 470 MW, the extreme growth 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. In February 2006 SolarWorld announced to take over the silicon wafer based solar business of Shell Solar [Sol 2006].

Between 2001 and 2005 PV installations in the European Union increased six-fold to reach almost 1.8 GW cumulative installed capacity at the end of 2005. More than 85% of the total PV installations in the EU were placed in Germany. With a three-year programme from 2002 to 2004, Luxembourg propelled itself to World Champion and leads the statistics in terms of installed PV with 52.4 Wp per capita. Due to a new legal situation, there was no significant addition of PV capacity in 2005. Nevertheless, if the enlarged European Union, as a whole, would have the same PV quota per capita as Luxembourg, 26.4 GWp installed PV or about 26.4 TWh (0.93% of total EU energy consumption in 2002) per year could be achieved.

The second biggest market with 291.1 MW of new installations was Japan with a 8.3% growth rate compared to 2004. The lower than usual growth rate was mainly due to the completion of the Residential PV System Dissemination Programme in October 2005. This programme had supported the expansion of Japan's PV market for the past 12 years. 89% or 260.4 MW of the new installations were grid connected residential systems bringing the accumulated power of solar systems under the Japanese PV residential programme to 1095 MW out of 1,420 MW total installed PV capacity at the end of FY 2005 [Ikk 2005. Jpe 2006]. At the same time Japanese exports increased by 65% to 528 MW with 386.8 MW being exported to Europe [Jpe 2006]. The world market share of Photovoltaic devices manufactured in Japan decreased slightly by 2.6% to 47.4%, but four of the Top Ten companies are Japanese (Fig. 2). For FY 2006 the PV industry is confident that, even without subsidies, the residential market will show an increase due to the trend to fully electrified houses and new Renewable Portfolio Standard with an increased amount of electricity generated from renewable energy sources.

Sharp Corporation continues to dominate the PV scene with more than 24% market share and a production capacity of 500 MW/year in FY 2005, and it can be expected that this will not change in 2006 [Ikk 2006]. In addition, it is interesting to note that Sharp finally announced the start of their large scale thin film production in September 2005 [Sha 2005]. The ten largest PV manufacturers together held 76.5% of the market, whereas the rest was shared by over 30 different companies.

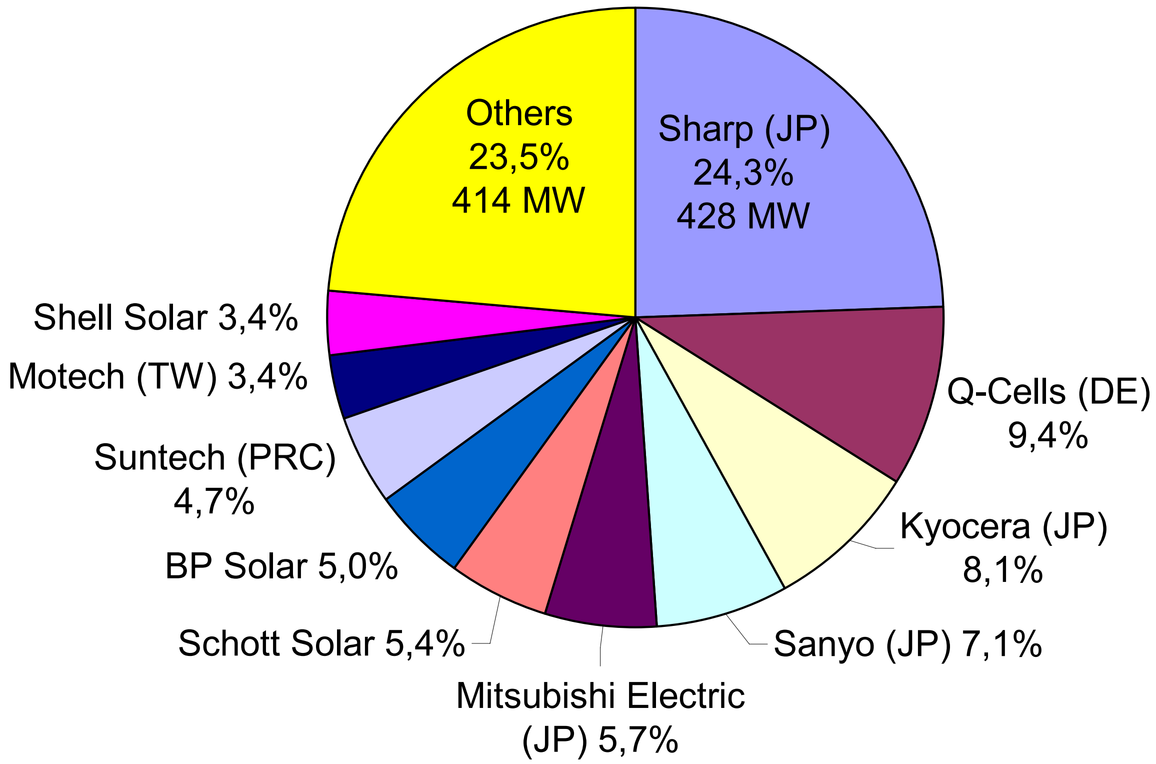

Fig. 2: Top 10 Photovoltaic companies in 2005 (total shipments in 2005: 1759 MW) [Pvn 2005]
Please note that BP Solar, Schott Solar and Shell Solar have cell production capacities in more than one country.

The third largest market was the USA with 108 MW of PV installations, 65 MW grid connected [Pvn 2006a]. California and New Jersey account for 90% 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. Until 2002, the US PV market was dominated by off-grid applications, such as remote residential power, industrial applications, telecommunications and infrastructure, such as highway and pipeline lighting or buoys. In 2005 the cumulative installed capacity of grid-connected PV systems surpassed that of off-grid systems. Since 2002 the grid connected market is growing much faster thanks to a wide range of “buy-down” programmes, sponsored either by States or utilities.

After the first Chinese (Taiwan) company MOTECH reached the top 10 list in 2004, Suntech Power (PRC) followed in 2005. On 2 August 2006, Suntech Power signed an agreement to buy the Japanese PV module manufacturer MSK [Msk 2006]. Suntech bought a two third stake in the 3rd quarter of 2006, with the option to buy it completely in 2007. The People's Republic of China and Taiwan together produced 210 MW in 2005, almost tripling the 75 MW production of 2004 and surpassing the US production of 154 MW. The market in the PRC is still quite small, but is expected to grow drastically within the next few years. The goal is to supply 10% of the total primary energy in 2020 by renewable energy. To reach this goal the build up of a renewable energy and photovoltaics industry is supported by a renewable energy industry policy, as well as a feed-in law for electricity from renewable energy.

Figure 3 shows the announced and estimated increase of production capacities by 2007. The figures are taken from press releases [Bps 2004, Kyo 2005, Mit 2004, Qce 2004, Sun 2005], company web-sites, public reports [Ikk 2005, Pvn 2006b] or extrapolated from the production increases of the companies during the last years. 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.

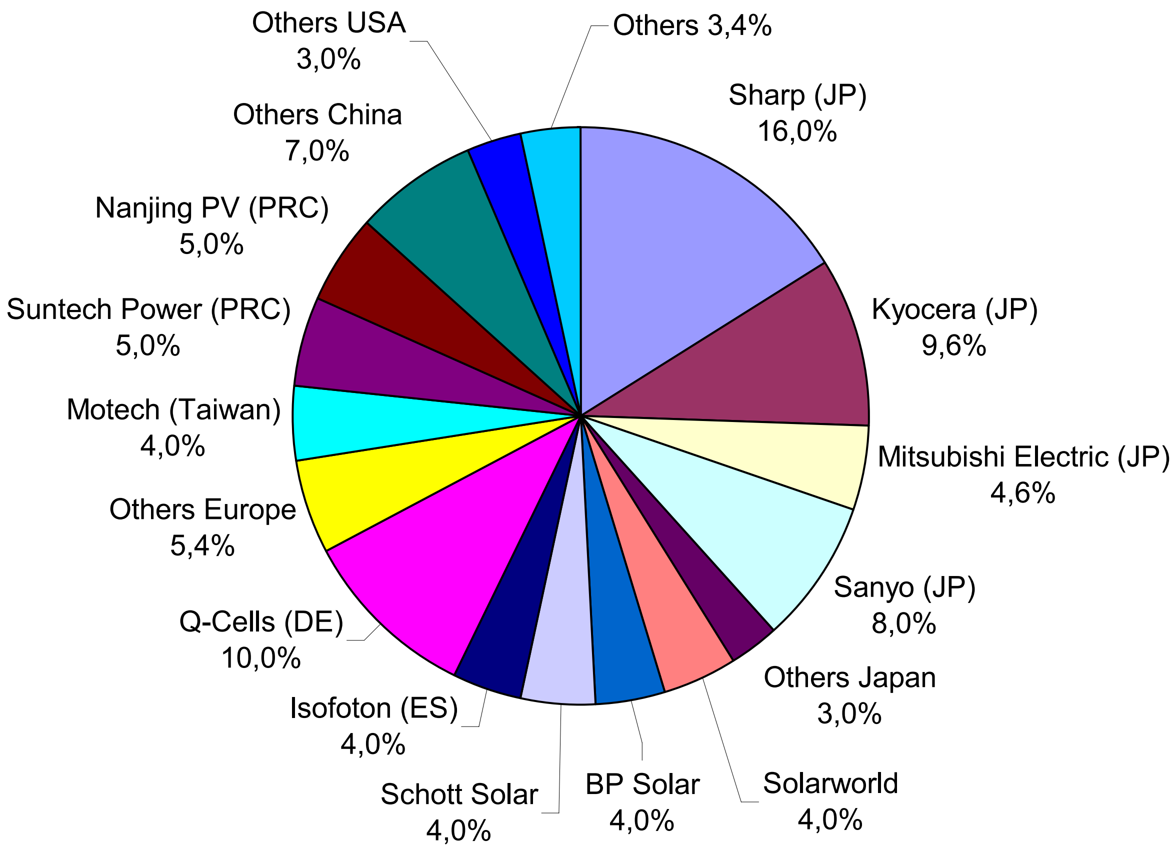

Fig. 3: Announced and estimated increase of production capacities world-wide by 2007 (5 GW)

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. In the case of Sharp, the prediction is probably too low, taking into account their dominating role in the PV industry. Some of the figures have been revised slightly compared to last year's report because of recent industry developments [Jäg 2005]. 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. The given figure for Sharp is the one most likely to approximate actual production, whereas others might just give the capacity installed in the factory at the end of the year even though it is not yet operational. Despite the fact that only limited comparisons between the different world regions are possible, the planned cell production capacities for 2007 portray some very interesting developments.

First of all, should the announced increases be realised, total production capacities will then stand at 5 GW of which roughly 600 MW could be thin films. The more than doubling of the 2005 silicon production figures has serious implications on the silicon feedstock demand and it is expected that not enough feedstock will be available to guarantee full operation of the 4.4 GW production capacity in 2008.

Secondly, 11 companies have plans to increase their production capacities to 200 MW, or more by the end of 2007. Four companies even plan to have 400 MW and more (Sharp, Kyocera, Sanyo and Q-Cells) compared to only one company (Sharp) at present. It is very interesting to note that three out of the eleven companies aiming for 200 MW and more are from the People’s Republic of China and Taiwan.

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 20 % or 1 GW in 2007. This production capacity would be much more than the 450 MW of cumulative installed solar systems in the People’s Republic of China by 2010, as announced at the International Conference for Renewable Energies in Bonn [Bon 2004]. It is obvious that the solar cell manufacturers in China intend to continue the high export rate (90% in 2005) of their production to the growing markets in Europe, the US and developing countries.

Europe is on track to fulfil its targets for 2010, which were however not as ambitious as the Japanese 4.8 GW one. In view of enlargement and the remarkable market growth these targets should be revised upwards. The introduction of the German Feed-in Law in 1999 and its renewal in 2004 [EEG 2004], led to a significant change in the frame conditions for investors and has been one of the major driving forces behind European growth. Since 1999 European PV production has grown on average by 50% per annum and reached about 470 MW in 2005. The European market share rose during the same time from 20% to 26.7%, whereas the US share decreased due to a weak home market and the Japanese share increased and stabilised around 50 ± 3%. 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 put in place in the rest of Europe as well 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 follow up of the Bonn Conference was held on 8-9 November 2005 in Beijing. The "2005 Beijing International Renewables Conference" discussed the status of the global implementation of Renewable Energies. The outcome of the Conference was the Beijing Declaration which states [Bei 2005]:

"We emphasize the multiple benefits of increased energy efficiency and the use of renewable sources of energy for improving access to energy services, thereby contributing to the eradication of poverty as called for in the UN Millenium Development Goals (MDGs), increasing job opportunities, improving air quality and public health, reducing greenhouse gas emissions and combating climate change, enhancing energy security, and offering a new paradigm for international co-operation."

In the Action Plan of the Bonn Conference, China had announced a 10% renewables target by 2010 and 17% by 2020. The 2010 plan includes the installation of 450 MW photovoltaic systems. However, as already mentioned earlier, the Chinese PV production is expected to grow much faster and Chinese manufacturers will export their products. This trend can again be observed looking at the large number of already registered exhibitors of the 21th European Photovoltaic Solar Energy Conference and Exhibition in Dresden, 4 to 8 September 2006. 38 exhibitors out of 334 are from China and Taiwan, the second largest group after Germany.

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.

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, which was passed by the Senate on 29 July 2005, and signed by President Bush on 8 August 2005, already shows first results. The Bill's main support mechanisms are:

- To 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.
- To establish a 30 percent residential energy credit for solar for two years. For residential systems, the tax credit is capped at $2,000.

It is already visible that this 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. However, as administrative hurdles have still not been overcome everywhere, the overall effect still has to be seen.

In June 2006 the Japan Photovoltaic Energy Association (JPEA) held its "23rd Symposium on Photovoltaic Generation Systems". During this Symposium Mr. Nobuyori Kodaira, General Director of the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry (METI) announced the "New National Energy Strategy" which aims to reduce Japan's dependence on oil by 40% by 2030. New Energy (this includes renewable energy sources) is considered as one of the four major pillars of the strategy. Besides the well known target "*to reduce PV power generation costs to the level of thermal power generation*" the intended measures to realise this strategy call for "*Creation of a thick 'industrial structure' through integration with peripheral related industries and local communities*" [Ikk 2006].

As a consequence, JPEA has 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.

These developments have stimulated a plethora of investment decisions all over the world to invest in new solar cell, module and Balance-of-System (BOS) component plants.

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 the leading PV nation world-wide, both on the supply as well as the demand side. The principles of Japan's Energy Policy are the 3Es:

- Security of Japanese Energy Supply (Alternatives to oil)
- Economic Efficiency (Market mechanisms)
- Harmony with Environment (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 of 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 to have 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 represent 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 this will then increase 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 Prime Minister Junichiro 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[3]) for Science & Technology to strengthen international

[3] Exchange rate used: 140 ¥ = 1 €

competitiveness and developing the Human Resources. The strategy encompassed the creation of the world's top class research centres, enhancement of industry/academia collaboration, 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 Infrastructure for the Introduction of Residential PV Systems”, which has been running since 1997. During this period, the average price for 1 KWp in the residential sector fell from 2 million ¥/kWp in 1994 to 670,000 ¥/kWp in 2004. With the end of the "Residential PV System Dissemination Programme" in October 2005, it looks like the price data base of the New Energy Foundation (NEF) will be no longer be continued.

The Residential PV System Dissemination Programme has been leading the expansion of Japan's PV market for the past 12 years. In 2005, 89% or 260.4 MW of the new installations were grid connected residential systems bringing the accumulated power of solar systems under the Japanese PV residential programme to 1095 MW out of 1,420 MW total installed PV capacity at the end of FY 2005 [Ikk 2005. Jpe 2006]. At the same time, Japanese exports increased by 65% to 528 MW with 386.8 MW being exported to Europe [Jpe 2006]. For FY

2006 the PV industry is confident that even without subsidies, just 20,000 ¥/kWp, the residential market will show an increase following 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, the subsidies offered, as well as 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. 4), which was drafted by NEDO, METI, PVTEC[4] and JPEA[5].

The government budget for FY 2006 was passed in December 2005 with a 3% reduction compared to 2004. The METI budget for photovoltaics decreased slightly from the 2004 ¥ 18.128 billion (€ 129.456 million) to ¥ 17.558 billion (€ 125.414 million), but the Ministry of the Environment (MOE) will add a budget of ¥ 4.145 billion (€ 29.607 million) with "Operation Solar" measures intended to reduce CO_2 with the help of PV electricity generation systems [Ikk 2006b]. The Defence Facilities Administration Agency (DFAA) will continue its ¥ 1.4 billion (€ 10.0 million) project on soundproofing measures for houses around airbases by using PV systems. Last but not least, the Ministry of Land, Infrastructure and Transport (MLIT) will continue to use PV systems to construct eco-friendly government office buildings as well as start to use PV systems in road facilities.

The main changes in the METI budget are due to the end of the Residential PV System Dissemination Programme and the 5 year plan of technological research and development for PV systems (2001 – 2005). The new budget shows an increase for the "Field Test Project on New Photovoltaic Power Generation Technology" from ¥ 9.23 billion (€ 65.929 million) to ¥ 11.80 billion (€ 84.286 million). Under this programme, PV systems for public and indus-

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[4] Phtovoltaic Power Generation Technology Research Association

[5] Japan Photovoltaic Energy Association

trial facilities as well as other non-residential applications will be supported. As a follow-up to the "Development of Photovoltaic Power Generation" Programme (2001 – 2005), the new 4-year programme "R&D for Next Generation PV systems" was established with a budget of ¥ 1.965 billion (€ 14.057 million) in FY 2006.

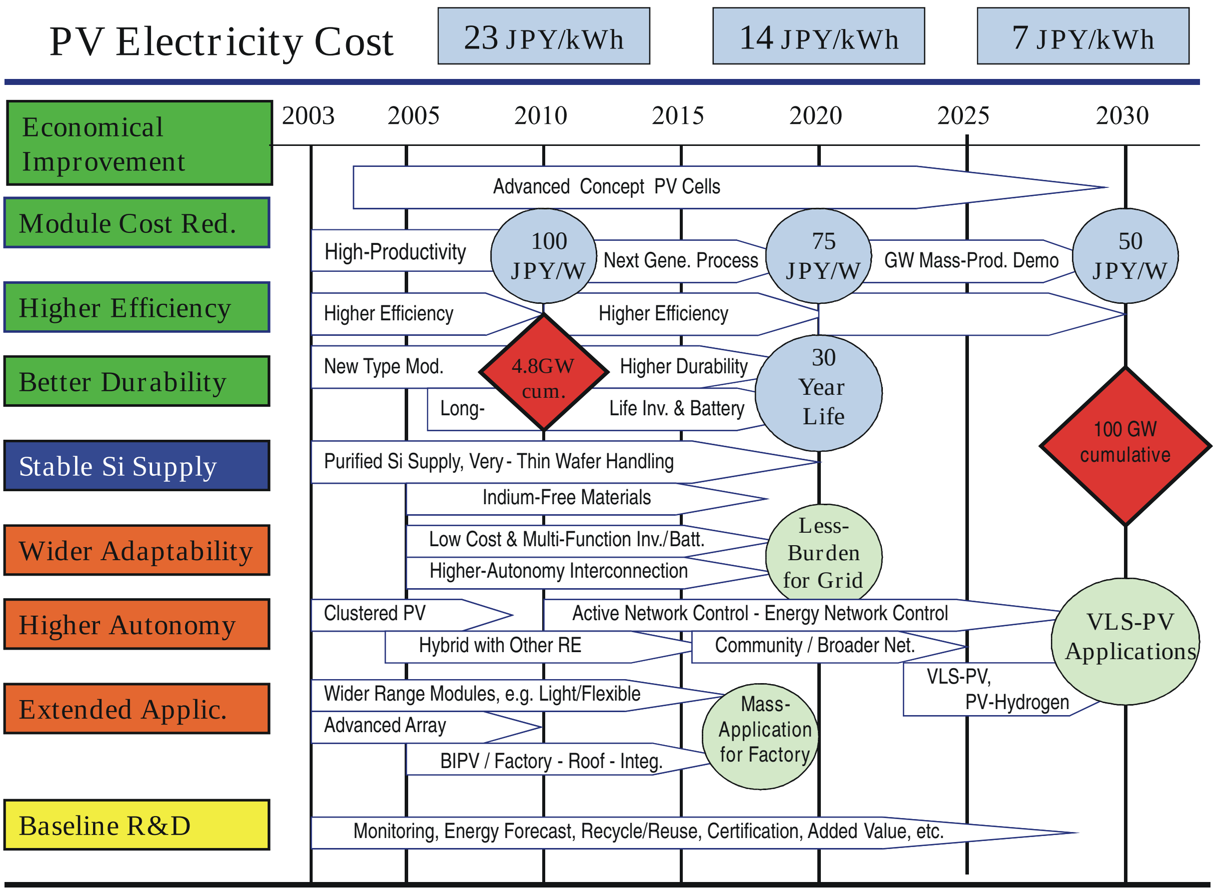

Fig. 4: Japanese roadmap for PV R&D and market implementation [Kur 2004]

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 programme “Projects for New Energies” is a follow up of the very successful “New Sunshine Project”. Taking effect in FY 2001, NEDO replaced the New Sunshine Project by a programme called “Advanced PV Generation” (APVG). As a result of the New Sunshine Project (NSP or NSS) evaluation in 2001, several important priorities were selected [Ned 2002].

- Technology Development for Future Mass Deployment
- Advanced Solar Cell Technology
- Advanced Manufacturing Technology
- Innovative PV Technology

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. 4) 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 PC Systems" and "PV System Technology for Mass Deployment" Phase II. These two programmes have a duration from 2006 to 2009. It was planned to select the entrusted entities through a public solicitation process between March and July 2006 [Sak 2006]. At the time of printing no results of the selection were available yet.

- 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. The 2006 R&D budget will be approximately ¥ 780 million.

- 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 on their own will be selected. The budget for this programme in 2006 will be approximately ¥ 2 billion.

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 module area of 100 cm^2
  16% for module area of 900 cm^2
  Development of cell production technology on light-weight substrates
- Thin film silicon solar cells
  Target efficiency:
  15% for module area of 1000cm^2 with (film deposition rate: 2.5 nm/s)
  Completion of elemental research of ultra large-scale area (4m^2) module production
- Dye-sensitized solar cells
  Development of low cost, long-life, and large-area (900 cm^2) with efficiency of 8%
  Target efficiency of 15% for small area (1cm^2) cells
- Ultra-thin crystalline silicon solar cells
  Development of production technology for crystalline silicon solar cells with a 100-μm substrate thickness
- Organic thin-film solar cells
  Target efficiency of 7% for small area (1 cm^2) cells
  Improved reliability under actual operating conditions
- Search for dramatic pioneering technology
  e.g. Ultra-low-cost material production technology, Ultra-high-efficiency solar cells, New concept solar cells

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)."

The 2006 R&D budget will be approximately ¥400 million. R&D themes and contents of this programme are as follows:

1) R&D to evaluate performance monitoring technology for new solar cells and modules:
   - Solar Cells and modules:
     - High-efficiency/New types of solar cell performance monitoring technology
     - Precise module measurement technology
     - Large-area modules (e.g. 2 m × 1.5 m)

- PV output performance technology:
  - Compile climate data for assessing output consistency and indoor evaluation technology.
- Reliability:
  - Development of testing methods for gathering and analysing exposure data and evaluating durability.

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 2006] and produced approx. 47% (833 MWp) of the solar cells sold world-wide in 2005. 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 in 2006/7, 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 be about 70,000 systems, roughly the same as last year, 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", "Operation Solar" as well as the DFAA and MLIT installations total solar photovoltaic installations in 2006 could be in the order of 350 MWp.

So far, the majority of PV systems were installed on residential houses. At the end of FY 2005, 1,095 MWp out of the total 1,420 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 2006a]. 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/€ 2.69 billion) and exports of 1 GW (¥ 200 billion/€ 1.43 billion). For 2030, the figures have been revised to 7.55 GW (¥ 1 trillion/ € 7.14 billion) domestic installations and 5 GW (¥ 600 billion/€ 4.29 billion) exports.

In 2010, prices for residential PV systems are estimated to be reduced to 300,000 ¥/kWp (2,143 €/kWp), whereas for public and industrial use they are estimated to be 380,000 ¥/kWp (2,714 €/kWp). In 2030 the price for all these systems should be 200,000 ¥/kWp (1,429 €/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 (1,143 €/kWp) in 2030.

The price expectations for exports are even lower. JPEA expects them to be in the range of 200,000 ¥/kWp (1,429 €/kWp) in 2010 and 120,000 ¥/kWp (857 €/kWp) in 2030.

Expectations for the domestic near future PV market are that the majority of installations will still be in the residential sector. About 100,000 to 200,000 systems per year or 400 to 800 MWp are estimated. In addition, 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. Another market segment could be developed in the area of transport applications (roads, railways) and in the agricultural sector. However, the market size there is estimated to be only in the order of 10s of MWp by 2010.

To reach the target for PV installations set for 2010 at 4.8 GWp, the increase of the production capacity as well as PV system installation has to be maintained. In 2005, the growth has slowed down, but if the average 2001 to 2005 growth rates can be maintained, the total installations by 2010 could reach more than 5 GWp cumulative installed PV system capacity and more than 1.1 GWp installations per year (Fig. 5).

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.

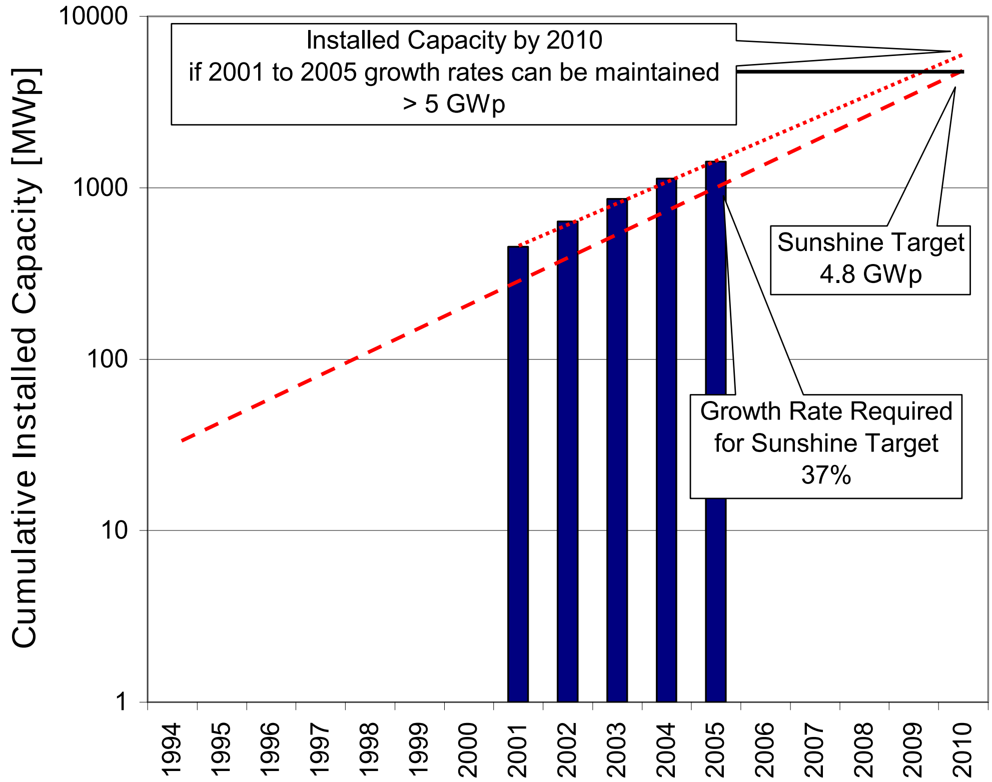

Fig. 5: Sunshine Target growth rate and estimates based on 2001 to 2004 installations

Sekisui Chemicals Co., Ltd reported cumulative sales of over 40,000 homes equipped with PV systems by the end of FY 2004 [Ikk 2005a]. The company reported that 52% of the contracted sales of ready-equipped houses in 2004 had a PV system. In his 2005 Sun Screen II study, M. Rogol reported that for FY 2005 Sekisui expected an increase to 60% in 2005 [Rog 2005]. PV systems with a new house were on average 30% cheaper than add-on systems. In the 2005 annual report, Sekisui stated that the sales of their housing division grew particularly due to the increase of orders for their “zero-utility-cost” houses [Sek 2005]. A mid-term target of Sekisui for the period up to fiscal year 2008 is to increase the ratio of “zero-utility-cost house” contracts from 17% (FY 2005) to 30% and to expand newly built house sales to 13,500 houses (FY 2005: 12,500 houses) [Sek 2006].

Other housing companies like Misawa Homes or PanaHome Corporation are following this development.

For a housing company in Japan, the promotion of PV can be successful for the following reasons:

- The availability of PV modules is secured by the fact that the world's largest PV manufacturers are located in Japan.
- Due to the limitation of available space and the high prices of land in Japan, rooftop or building integration is the most economical solution.
- The growing environmental awareness of the Japanese customer led to the concept of the Life Cycle Cost (LCC) for a total building. This LCC includes the CO_2 emission of a house from building, operation and maintenance until demolition and recycling. Smart concepts for building materials, implementation of building isolation and integration of PV leads to better LCC, compared with conventional houses – a strong selling argument for housing companies towards environmentally concerned customers.

In addition, the integration of the PV system at an early stage in the planning of prefabricated and mass manufactured houses offers the chance for a significant price reduction of the PV systems compared to individually built houses or add-on PV systems. For example, to offer stainless steel roofs and aluminium shadings, there is the advantage of low maintenance costs while being able to be used as PV substrates at the same time. This combination of different functions adds to the cost reduction of the PV system. In addition, an average 3.6 kWp system leads to a saving in electricity costs of approx. 82.000¥ (3,420 kWh). The pre-installation and mass fabrication of the unit homes enable the manufacturer to limit the actual installation work of the PV system on the building site to the optimisation of PV power performance and therefore lead to considerable savings for the installation. In order to attract a large variety of customers, housing companies offer a range of PV systems with different sizes and technologies. The choice of technology depends on the customer's preference for system size and design.

Therefore, the number of house manufacturers, as well as construction companies, offering homes with PV systems is increasing. This development is complemented by interest reduced mortgages for homes with PV systems, e.g. Sumitomo Trust, Shinsei Property Finance or Ogaki Kyouritsu [Kyo 2004, Ikk 2004, Rog 2004]. The reduction in interest rate is 1 to 2 percentage points and is often not only available for the financing of the PV system but for the whole mortgage. In the case of Sumitomo Trust, long term loans for buyers of Sekisui homes are available for 20 or 30 years at fixed rates. Normal rates were 4.65% for 20 years and 4.8% for 30 year loans in March 2004. The respective loans for PV house buyers were 2.95% and 3.1%. In addition, Sumitomo offers an additional 0.05% interest reduction for a system with at least 3 kWp and an additional 0.05% for both 4 and 5 kWp for a 30 year loan. This lowers the interest rate for a Sekisui home with at least 5 kWp system by 1.85% to 2.95%.

The benefits for the customer are manifold. First, the PV system price included in a new house offer is lower than an add-on system. Second, the saving in interest can be substantial, e.g. in the case of a € 250,000 loan for a house with a 3kWp system it can be in the order of € 150 to 200 per month or € 36 – 40,000 over 20 years. In addition, the electricity generated is worth between € 39 and € 44[6] per month.

This calculation highlights the importance of low interest rates for the promotion and introduction of photovoltaic systems in a consumer market. However, there is also a risk. An increase of interest rates by 3% or more would raise costs of solar power by at least 6 €ct and thereby nullify the electricity bill savings of a normal residential installation.

What are the benefits for the financing institution? First, it is a promotion measure for institutions which seek to expand their residential mortgage business. Second, the PV system generates a monthly income for the customer and secures the payments of the interest. Due to this, the customer is also able to afford a higher overall mortgage generating more business for the financing institution.

This example shows that the implementation of photovoltaic systems in Japan is already moving away from a purely government driven subsidy programme. Therefore, the 2004 study of Credit Lyonnais Securities Asia concluded that despite the planned future decreases of subsidies for PV, all 25+ interviewed companies anticipate a continuous growth of at least 30% per year for the Japanese photovoltaic market [Rog 2004]. The rational for this opinion is that Japan has a strong network of solar manufacturers and sales-people who will continue to push solar products. In addition, it is expected that METI would intervene if growth rates were to slow down considerably.

The shrinking markets for classical heavy machinery equipment on the one hand and the dynamically growing PV market, as well as the promising outlook for future growth, have drawn the attention of manufacturers like Mitsubishi Heavy Industries, Ltd. to invest in solar cell production technology. New Energies and PV were identified as a high potential new market by the "Prime Minister's Advisory Committee on Competitiveness". PV manufacturing is now rated by the Japanese Industry as a "key industry" which should not be shifted to China or other Asian countries, but done in Japan. These comments and findings reflect the emotional change in Japanese Industry and Politics towards PV since 1997.

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6 Exchange rate used: € 1 = ¥ 130

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 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 500 MWp/year in FY 2005 [Sha 2006]. 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.

In addition to the continuous increase in solar cell production capacity at the Katsuragi plant[7], Nara Prefecture, Sharp opened its first module factory outside Japan in Memphis, Tennessee (US) in 2003 [Sha 2003]. It is planned to increase its current capacity of 40 MW to 120 MW [Ikk 2006]. A second module plant was opened in Wrexham, UK in July 2004 and it is planned to increase its 50 MW capacity to 110 MW in 2006 [Ikk 2006].

In 2005, the Sharp Solar Systems Group shipped 428 MW. According to the Financial Results released 26 April 2006, the company increased their sales of solar cells by 34.5% compared with 2004 to ¥ 158 billion (€ 1,129 billion) [Sha 2006a]. For FY 2006 the company aims for a further increase of 26.6% to ¥ 200 billion (€ 1,429 billion). In order to reach the announced turnover increases, Sharp has to increase its production capacity to about 800 MW by the end of 2007.

For the last six years Sharp has managed to be the leading company world-wide and with about over 50% market share in the Japanese residential market. The company has close collaboration with major Japanese housing companies and offers complete PV systems with all components made within the company (Fig. 6). At the moment the residential PV market

[7] Former name: Shinjo plant

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.

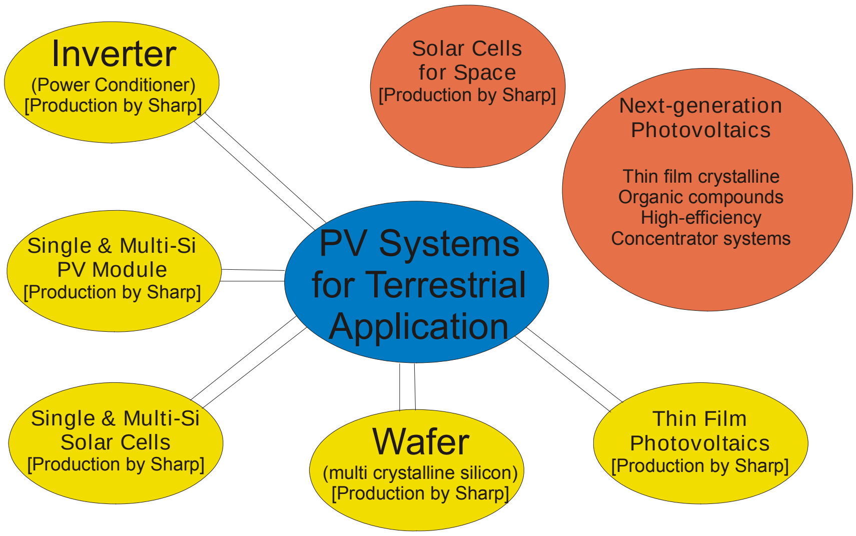

Fig. 6: Development concept of Sharp

To guard against potential shortages of silicon, Sharp is working to use the material more effectively by reducing the cell film thickness from 200 µm to 180 µm, and at the same time will continue to strive to lower costs.

Concentrator Systems: Sharp is involved in developing super high-efficiency Compound Solar Cells and low cost solar concentrator modules and tracking systems, together with Daido Steel and Daido Metal within a NEDO research project. The InGaP/InGaAs/Ge solar cell has an efficiency which is 1.5 to 2 times higher than that of a crystalline solar cell, and the price is expected to be about half of crystalline solar cells in mass production. It is planned to adopt the system for the power generation market and test marketing started in the USA in 2005 [Ikk 2004].

3.5.2 Kyocera Corporation

In 2005, Kyocera Corp. had sales of 142 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 new products take advantage of a government subsidy made available in April 2001 for systems using solar heat. The Sakura Factory in the Chiba Prefecture is involved in everything from R&D and system planning to construction and servicing and the Shiga factory, in the Shiga Prefecture, is active in R&D, as well as the manufacturing of solar cells, modules, equipment parts, and devices, which exploit heat. Like the other Japanese manufacturers, Kyocera is planning to increase its capacity and announced a target of 240 MW production capacity by August 2005 and 480 MW by 2007 [Kyo 2005,a].

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 2006].

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. In 2005 they were the third largest PV manufacturer in the world.

3.5.3 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 by SANYO in 1993 and in 1997 the mass production of HIT solar cells started. In 2005 Sanyo had sales of 125 MW solar cells. Current production capacities are 153 MWp HIT and 7 MWp a-Si. 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. On 20 July 2005 Sanyo held the opening ceremony of its module manufacturing plant in Dorog, Hungary. Production capacity for 2005 was 50MW with plans to grow to 100MW in 2006 [San 2005, Ikk 2006].

Sanyo has set a world record for the efficiency of the HIT solar cell with 21.6% under laboratory conditions and 19.5% in mass production [San 2005a]. This technology offers

Sanyo the possibility to produce PV systems, which need less space per kWp. This is a sales argument especially for small area installations on small Japanese houses. In addition, the HIT technology has a lower thermal budget for producing the cell, and the wafer can be thinner than with conventional cells. This leads to savings in the material used as well as production energy. 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 is working together 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. As part of its solar product strategy, Sanyo Electric acquired home builder Kubota House Co. (since renamed Sanyo Homes Corp.) in 2001 to market houses with roofs incorporating solar cells, according to Shigeru Nomoto, then General Manager of Sanyo's Clean Energy Division [Asa 2002].

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. The Solar Ark was built in the image of an Ark embarking into the 21st century, powered by solar energy (Fig. 7).

Fig. 7: Sanyo’s Solar Ark (Picture: courtesy of Sanyo)

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 on 3 April 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.

3.5.4 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 (2003). The current production capacity is 230 MW [Ikk 2006]. With 100 MW sales in 2005, Mitsubishi Electric held the 5th position.

3.5.5 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. At this time Kaneka decided to move into the power module market for residential and industrial applications. The goal set was to mass-produce a-Si Modules for rooftop applications by 1999. Besides economical consideration, one of the main reasons for this decision was the fact that Dr. Kenji Yamamoto found a possibility to deposit microcristalline silicon at a low enough temperature (200°C) to combine it with an a-Si solar cell and was able to patent this method. The patents on the previous important findings (Hydrogenated a-Si solar cell, Carlson, RCA 1976; pin a-Si solar cell, Hamakawa, Osaka Univ. 1978; integrated a-Si solar cell, Kuwano, Sanyo 1979 and a-SiC/a-Si hetero-junction solar cell, Tawada, Kaneka 1981) expired in 2002, so this decision looked fairly economically backed. The planned cost target was to reach half of the c-Si with an annual capacity of 40 MWp.

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 annual sales in FY 2005 of 21 MW. The locations are Shiga (5 MWp) and Toyooka (25 MWp). An increase of the production capacity of the Toyooka plant to 55 MWp (2007) and 70 MW (2008) is planned [Ikk 2006]. 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.

The 60 W a-Si modules are rated with 8% stabilised efficiency and Kaneka guarantees that the power output will not drop below 80% of the nominal value for 20 years. In FY 2001 they started to produce the "10% hybrid module" for the Japanese market only. The company rates them with an average stable efficiency of 10.5% for which they guarantee at least 9.8% with the 10% deviation over 10 years.

3.5.6 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 2005 MHI shipped 12 MW of amorphous silicon solar cells and is planning to increase their production capacity to 50 MW [Ikk 2006].

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.

One of the main reasons given for the solar cell activities at Mitsubishi Heavy is the increasing market for photovoltaic systems, as well as the promising outlook of the future growth of this field. Why did Mitsubishi Heavy invest in the amorphous silicon technology? The answer to this question lies in the portfolio of the company. The core technologies for the a-Si manufacturing were already well established business sectors: deposition technologies for large scale thin film deposition and the manufacturing of the respective machinery. Especially the fact that Mitsubishi has the equipment development in-house enables a fast feedback and improvement of the production technology.

The marketing strategy of MHI aims to build on a commodity image. Together with a large Japanese housing company, they developed specially designed roofing tiles for the Japanese market. According to the company, these roofing tiles could easily be adapted to other markets if necessary. The design of these tiles was made together with the housing company as well as architects, in order to ensure a wide acceptance of the product. Other module types are being developed for industrial buildings and industrial clients (large-scale application). The same approach is taken for the development of facade modules.

3.5.7 Additional Solar Cell Companies

- Canon: Canon has a pilot plant with a production capacity of 10 MW and a roll-to-roll process in Nagahama, Shiga Prefecure. Originally the triple junction a-Si/a-SiGe/a-SiGe solar cell was developed there. At the 3rd World Conference on Photovoltaic Energy Conversion in Osaka, May 2003, Canon reported about a new development: triple junction a-Si/µ-Si/ µ-Si solar cell with 13.4% stable efficiency on a 0.8 m^2 area. However, no information was available as to if and when this product would be available on the market.

- Fuji Electric Suystems Co. Ltd.: In 1993 Fuji Electric started its activities in amorphous thin film technology. Currently they are developing 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. According to "PV Activities in Japan" Fuji Electric wants to increase their production capacity to 30 MW in 2006 [Ikk 2006].

- 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 2006]. 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: Honda R&D Co. Ltd. has developed a CIGS thin film module with a power output of 112W. The technology was transferred to Engineering Co. Ltd., which operates a 2.8 MW production line in Tochigi Prefecture. Honda is installing their prototype modules on the roofs of several Honda facilities for testing purposes. One of their ideas is to use them to produce Hydrogen for a refuelling station. During the 2005 End of the Year speech, the CEO of Honda Motor Co. Ltd. Mr. Takeo Fkui announced that Honda will start to market its CIGS solar cells in the second half of 2006 and that company will establish a production line in the Kumamoto Plant with annual capacity of 27.5 MW in 2007 [Hon 2005].

- 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 Shell Solar). In 2002 Showa Shell produced about 1.2 MW of modules [IEA 2002]. In addition they are involved in the NEDO sponsored research project "Development of High-Speed Production Process for Thin-Film CIS Solar Cell Modules". According to "PV Activities in Japan" the company is planning to build a CIGS solar cell plant with a production capacity of 20 MW in FY 2007 [Ikk 2006].

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 RWE-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 is a 100% solar energy company and 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 Nagano Prefecture. 1992 they concluded a distribution agreement with Solarex (now BP Solar) and with 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.

MSK develops and produces photovoltaic modules and accessories. In addition, the company designs and installs solar panel systems and related electrical equipment. In 1998 MSK released Photovol Roof, a roof material integrated photovoltaic system and Photovol Dry, an under-floor solar ventilation system. Just Roof obtained the Japan Building Code, Article 38 certification and others in 1999. In August 2003 MSK opened the world's largest PV module production plant with 100 MW annual production capacity in Saku, Nagano Prefecture. An additional new factory in Ohmuta, with 80 MW annual production was opened in September 2004.

On 14 August 2006, Suntech Power (PRC) announced, that it has closed the first step of its acquisition of MSK. Suntech has acquired a two thirds equity interest in MSK for $ 107 million (€ 85.6 million) in cash [Mar 2006]. The second step to acquire the remaining shares is expected to occur 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 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” [TJT 2003]. At that time it cost about ¥ 2.64 million extra, but as a house owner paid nearly ¥ 250,000 per year in electricity charges, it will take about just 10 years to break even. They sold 1,580 Zero-Utility-Cost homes in fiscal year 2003 with a tendency to increase (FY 2005: 1970 houses).

The basic specification of the “utility charges zero dwelling house” are:

1) Use of “creative energy” = the solar energy generation system of 5.5 kWp;
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.

The introduction of this concept became possible thanks to the price-reduction of the PV systems (approx. ¥490,000 per kWp) and the development of the sloping roof responsive to the large volume.

In FY 2005 Sekisui sold 6020 houses equipped with PV systems or 52% of its new house sales [Sek 2006a]. PV systems with a new house were on average 30% cheaper than add-on systems. In the 2005 Annual Report (FY 2004), Sekisui stated that sales of the housing division grew particularly because of the increase of orders for their “zero-utility-cost” houses [Sek 2005]. A mid-term target of Sekisui for the period up to fiscal year 2008, is to increase the ratio of “zero-utility-cost house” contracts from 17% (FY 2005) to 30% and to expand newly built house sales to 13,500 houses (FY 2005: 12,500 houses) [Sek 2006]. The Crédit Lyonnais Securities Asia study called the company the “World leader in solar profits” and forecasts expanding profit margins for the next few years [Rog 2004]. The earlier mentioned team up of the company with Sumitomo Trust, offering interest reduced mortgages for houses with PV systems, should contribute to this trend.

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 a leader in steel-frame prefabricated houses and expected to sell more than 15,000 units in 2005. In 2003 about 1% of its homes included solar and the company is trying to push this more than 15% in 2006. 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. Compared to FY 2004 where 28% of the sold homes were Eco-Life Homes, this percentage has risen in FY 2005 to 34% [Pan 2006].

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 20% of the global supply of electronics and solar grade silicon. In spring 2006 Tokuyama had an annual production capacity of 5,600 tons and is planning to expand this to 6,800 tons by 2008 and 7,400 tons by 2010 [Pho 2006c].

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*

- 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. According to the Annual Report 2006 sales in FY 2005 were higher because of the increased demand from the photovoltaic industry [Mit 2006]. Current production capacity is 3,000 tons [Pho 2006c]. 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.

- Sumitomo Titanium Corporation (STC) is a manufacturer of Titanium and Silicon. On 27 April 2006 the company announced that it would increase production capacity for polycrystalline silicon to meet the strong demand for solar cells [Sum 2006]. The planned increase of 400 tons/year capacity will bring the total production capacity to 1,300 tons/year and should be completed in July 2007.

- 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 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].

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. For 2006 capacity increases to 993 MW are announced, with 550 MW planned in the PRC [Pvn 2006b]. In parallel, China is aiming to build up its own polysilicon production capacity. The numbers given are 1,830 tons in 2007 and 2,830 tons in 2008 [Pvn 2006b]. 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.

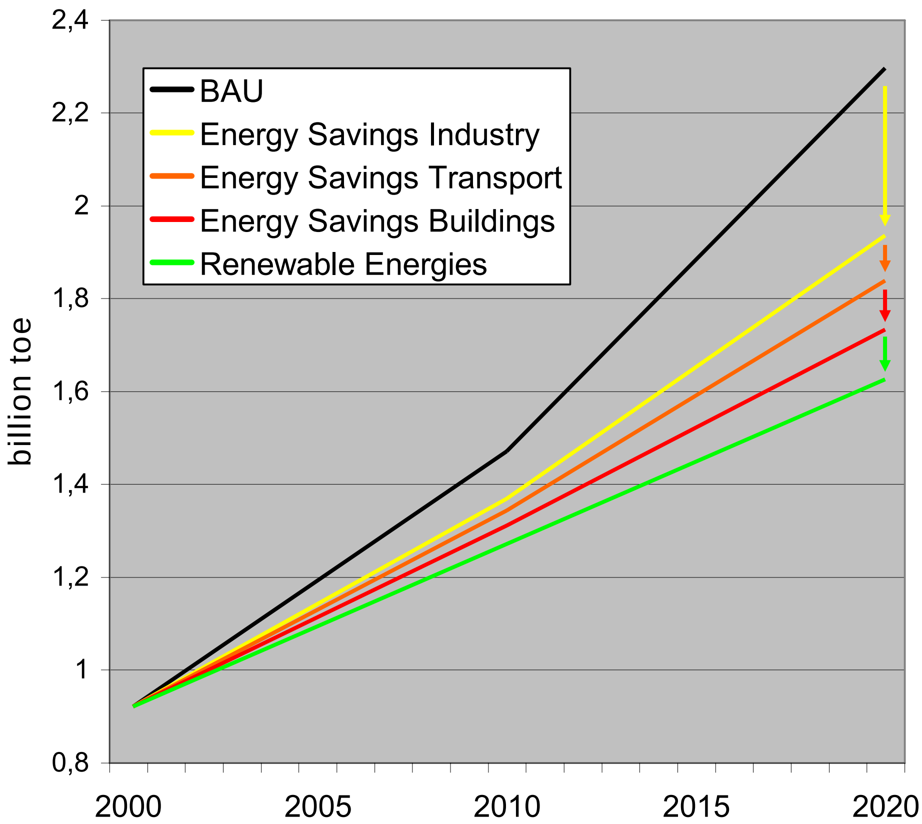

Fig. 8: Scenarios of PRC's fossil energy demand up until 2020 for different scenarios [Fuq 2003]

4.1 PV Resources and Utilisation

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 or 189% of the world-wide electricity consumption in 2001. In the Background Reports of the China Development Forum 2003 a report on "The Market-Oriented Reform in China's Energy Sector" called for the strengthening of legislation to promote renewable energies. The key issues were:

- Renewable Energy Promotion Laws should be launched quickly:
  Presently, there are neither special laws for RE, nor the incentives necessary. Therefore, a set of laws have to be formulated. To begin the legislative process as soon as possible, laws to promote RE should be drafted immediately.
- Strengthen policy:
  In tandem with legislative work, it is imperative to reinforce RE policies. An urgent task is to demonstrate wind concessions to get enough experience to expand throughout the country. Next, the financing environment should be improved. Finally, a mandatory market share (MMS) policy study and demonstration should be speeded up.
- Increase input, strengthen research on key technologies:
  The government should increase its input in projects: large-scale biomass liquid fuel research, wind turbine research, introduction of PV production lines that can output more than 15 MW, electric power distribution into counties without access to electricity, wind power, biomass generation, and PV generation.
- Outdated ideas of RE hindering China's economic goals need to be re-evaluated:
  Compared with foreign countries, China still lags behind in terms of how RE is perceived. RE development should be made a high priority within the national development strategy and incorporated into the government's development plan and budget. Aside from long-term use and annual plans for developing RE, a detailed roadmap of how RE fits into overall development should also be formulated.

Results of this and other strategy meetings became visible in 2004. During the International Conference for Renewable Energies, Bonn, in June 2004, the People's Republic of China (PRC) announced the plan that by 2010, the installed capacity of renewable energies will amount to about 60 GW and account for about 10% of China's total installed power generation capacity [Bon 2004]. This announcement also mentioned the installation of 450 MW solar energy generation capacity by 2010. By 2020, the PRC even plans to double these renewable energy capacities, though no shares for the different technologies have been set. However, according to an earlier report of the China Sustainable Energy Programme, cumulative capacity of installed photovoltaic systems could be in the range of 4 to 8 GWp [Zhe 2002].

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.

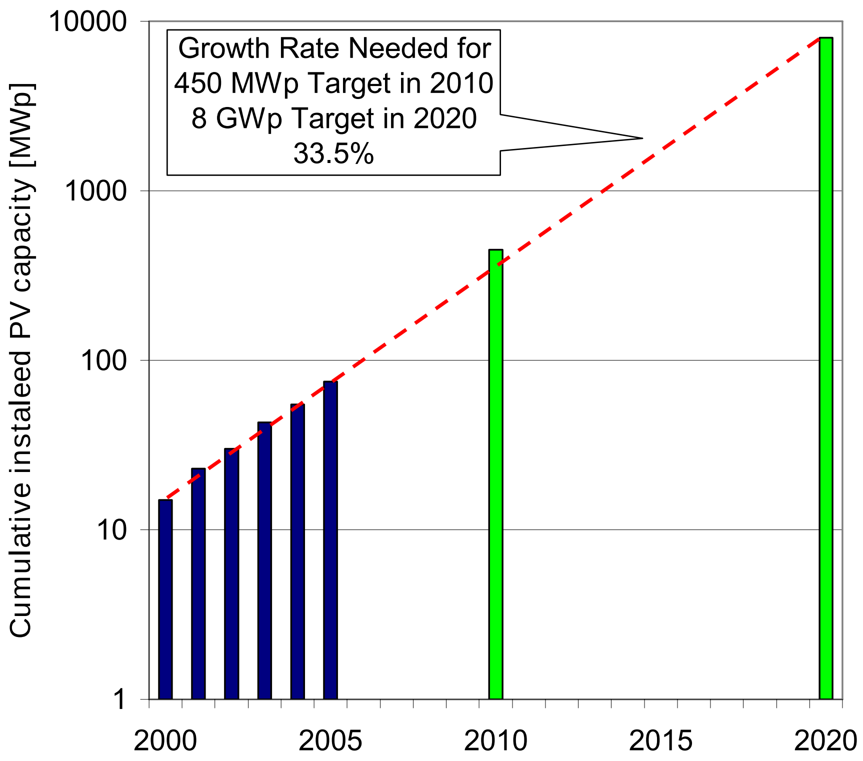

Fig. 9: Cumulative installed photovoltaic capacities and targets for 2010 and 2020 in PRC

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 household 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 the 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 for 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 are 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, will take effect in the city of Shenzhen [Chi 2006]. Projects which are unable to use solar power will require special permission from the government or can't 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.

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 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 60 MW in 2005. With this output, Motec Solar was No. 9 of the top 10 list for 2005 and plans to increase its production capacity to 200 MW by the end of 2006. In order to secure their wafer supply, Motech signed wafer delivery contracts with Renesolar (PRC) in July 2006 (80 MW three-year contract, delivery starting in 2007) and

REC (Norway) in August 2006 (five year take-or-pay contract, value over $ 320 million) [Mot 2006].

4.2.2 E-TON Solartech Co. Ltd., Taiwan

E-Ton Solartech was founded in 2001 and produced 28 MW in 2005. Production capacity in the 3rd Quarter 2006 is 75 MW per annum and capacity is expected to reach 100 MW at the end of the year [Dig 2006]. The company produces monocrystalline solar cells and announced a new record efficiency average approaching 17% in August 2004.

4.2.3 Additional Taiwanese Companies

- Big Sun Energy plans to list on Taiwan's over-the-counter exchange in September 2007 [Dig 2006a]. Test production of solar cells is scheduled to start in February 2007 with a planned production capacity of 30 MW in 2007 and a planned increase to 90 MW in 2008 [Dig 2006b].

- DelSolar Co, Ltd. is a subsidiary of Delta Electronics established in 2004. DelSolar has a strategic co-operation with the Industrial Technology Research Institute (ITRI). DelSolar's production capacity is planned to increase from 6 MW in 2005 to 50 MW in 2006 and 100 MW in 2007.

- Gintech is a new solar cell manufacturer established in August 2005. The company is planning its listing on the Taiwan stock exchange [Dig 2006c]. According to the information given, the company has a production capacity of 30 MW, which will double by the end of the year. The expansion targets vary between 300 MW in 2009 (information given on company Web-site) and a targeted annual capacity of 480 MW by the end of 2008 (DigiTimes).

- Green Energy Technology (GET) is a subsidiary of the Tatung Group of companies in Taiwan. The company designed a new factory to manufacture solar wafers and produce 25 MW of solar panels per year, starting in 2005, with the possibility to expand to several hundred MW. The production equipment will be provided by GT Solar, USA [Tat 2004]. The factory will be located in Kuanyin near the CKS International Airport about 40 miles from Taipei where Tatung has other manufacturing operations. It is unclear whether GET and Top Green Energy are the same company or at least related. Top Green Energy is supposed to have 30 MW production capacity at the end of 2006 [Dig 2006].

- 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 fab for solar cell production. Solar cell production is expected to be Mosel's main business by the fourth quarter of 2007 [Dai 2006]. Mosel also plans to develop thin-film solar cell production from its own technology [Dig 2006d].

- 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 to increase its production to 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.

- Additional Companies mentioned in a DigiTimes Article dated 20 July 2006 [Dig 2006]:
  Neo Solar: 30 MW production capacity
  Solartech Energy: 30 MW production capacity

4.2.4 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 2005 Suntech had a production of 82 MW and held 8th place in the Top-10 list. The annual production capacity of Suntech is scheduled to increase to 150 MW by the end of 2006 [Pvn 2006b]. 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 2006 of 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.

4.2.5 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. Total production capacity is planned to increase to 50 MW by the end of 2006 [Pvn 2006b]. In 2005 a production of 20 MW was reported.

4.2.6 Baoding Tianwei Yingli New Energy Resources Co., Ltd, PRC

Yingli Solar 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 Tianwei 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.

In 2004, production figures were given with 6 MW wafers, 10 MW cells and 50 MW modules [Pho 2005a]. In 2005, the solar cell production rose to 16 MW [Pvn 2006b].

4.2.7 CEEG Nanjing PV-tech Co. Ltd., PRC

CEEG Nanjing PV-Tech Co. (NJPV) is a joint venture established by the Chinese Electrical Equipment Group in Jiangsu and the Australian Photovoltaic Research Centre. Nanjing Photovoltaic Science & Technology Co., Ltd. is a new high-tech enterprise under the support of the state, which applies the internationally advanced solar energy technology and integrates the development, manufacturing, sales and technical service of solar cells. The registered capital at the first stage is RMB ¥10.8 million and the total investment is RMB 30 million. Total design production capacity is 600 MW with a total output value of RMB 15 billion.

In June, 2005, NJPV started solar cell production in its first production line with a designed capacity of 30MW/year. It was planned to increase production capacity to 100 MW by the end of 2005. According to a company press release, the planned capacity was 300 MW without a date given [Njp 2005]. In 2005 NJPV had sales of 9 MW and aims for a capacity increase to 250 MW at the end of 2006 [Pvn 2006b].

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

- Bengbu Polar Beam Co. Ltd. is a new 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 will start in May 2007 with approximately 2 MWp capacity and plans to boost capacity to 10 MWp in 2008.

- Changzhou Trina Solar Energy Co. Ltd ("Trina Solar") was founded in 1998. 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. For 2006 a solar cell production capacity of 50 MW was reported [Pvn 2006].

- Jiangsu Linyang Solarfun Co. Ltd. (Parent company Linyang Electronic Co. Ltd.) is located in the Qidong economic development zone, Jiangzu Province. The company does research, production and marketing of crystalline solar cells, modules and PV systems. The company has set up the Linyang Photovoltaic Research Center and System Application Company in Shanghai together with Shanghai Jiaotong University. Production capacity is given with 25 MW solar cells and 20 MW solar modules.

- 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 2006e]. SMIC's production of solar cells is expected to reach 10 MW in 2006. According to the company, the raw materials needed will come from reclaimed silicon generated by its core businesses. Until now it has accumulated a stock of more than 300,000 recyclable wafers, which provide a sufficient and low-cost supply of materials for the solar cell production. SMIC is planning to enter 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. The Company's strategic plan is to have the initial line with 20 MW in production before the end of fiscal 2006.

- Wuxi Shangpin Solar Energy Science & Technology Co. Ltd. is located in Wuxi, Jiangsu Province, China. It is a U.K. invested company which specialises in R&D, manufacturing and sales of crystalline silicon solar cells, modules and PV powered products. The planned capacity was 20 MW solar modules at the end of 2005. Further plans are to go to 30 MW capacity of mono-crystalline silicon wafers before June 2006, and 30 MW capacity of solar cells and solar modules at the end of 2006.

- 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. The planned productive capacity of the new factory was quoted with 35 MW in late 2005 and 100 MW in late 2007.

- Additional Companies listed in a joint presentation by JIKE and CRED during the 5th Korea-China Joint Seminar on New&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

4.2.9 Jianxi LDK Solar Hi-Tech Co. Ltd., PRC

Jianxi LDK Solar Hi-Tech Co. Ltd. is part of Liouxin Group, which has 12,000 employees and was set up 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. On 11 August 2005, GT Equipment announced the signing of a deal to supply a nearly 75 MW wafer fabrication turn-key line for solar energy applications [Gts 2005]. The line is being produced by GT Equipment Technologies' Solar Division – GT Solar Technologies. The expansion plans are as follows: 2006 – 100 MW, 2007 – 200 MW, 2008 – 400 MW, 2009 – 700 MW and 2010 – 1,000 MW.

4.2.10 ReneSola, PRC

ReneSola, previously known as Zhejiang Yuhui Solar Energy Source Co., Ltd, was listed on London's AIM stock market on 8th 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. Current wafer output is 400 tons/year (50MWp/year) and output is set to reach 800 tons (100 MWp) in 2007. Over half the 100 MWp of wafers that will be produced in 2007 are already sold. Two big deals that have been made: 80 MWp over 3 years (2007 – 2009) to Motech, and 43 MWp over 2 years to Linyang Solarfun (18 MWp in 2007 and 25 MWp in 2008) [Enf 2006a].

4.2.11 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.

- 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.

- Luoyang Monocrystalline Silicon Co. Ltd. is a state owned company. The products of the company are: polycrystalline silicon (annual output 300,000 kg), monocrystalline silicon (annual output 15,000 kg), 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.

- 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. is constructing a plant for the production of silicon material, scheduled to start operation at the end of 2006. 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.

- 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. Photon International has visited major solar companies and published a report in its September 2005 volume. In the meantime a number of consultancies like Energy Focus (ENF), SolarPlaza etc. 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. This trend can also be observed at the European Photovoltaic Solar Energy Conferences and Exhibitions. In Barcelona, 2005, 22 exhibitors out of 237 came from China, the fourth largest group after Germany, Spain and USA. The number increased again this year at the 21st European Photovoltaic Solar Energy Conference and Exhibition in Dresden, 4 to 8 September 2006, with 38 exhibitors out of 334 from China and Taiwan, the second largest group after Germany.

Besides Japan, the PRC is the only country worldwide in which photovoltaics is discussed at the level of a strategic industry policy for the future. This is in line with a remark given at the Conference "A Vision for Photovoltaic Technology for 2030 and Beyond" in Brussels on 28 September 2004:

"Renewable Energy technologies are not necessarily linked to an Environmental Agenda. Environmental targets can be met by importing Renewable Energy Technologies (probably from China, Japan or Korea), or likewise, a European Renewable Energy industry could as well develop without an Environmental Agenda as a future key industry for exports."

5. THE UNITED STATES

In 2005, the USA was the third largest market for PV, with 108 MW of PV installations, 65 MW grid connected [Pvn 2006a]. California and New Jersey account for 90% of the US grid connected PV market. In 2005 the cumulative installed capacity of grid connected PV systems surpassed that of off-grid systems. Production grew to 154 MW compared to 139 MW in 2004, 103 MW in 2003 and 121 MW in 2002. The US market share in the thin film market is around 40% and much higher than the overall market share of 8.75%.

Production at Shell Solar and GE Energy declined, whereas others like Evergreen, First Solar and United Solar increased significantly. *First Solar* is massively expanding its CdTe thin film production capacity to 175 MW in 2007 [Eet 2006]. *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

The latest nationwide figures for electricity prices were available for the year 2000. 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 (Fig. 10).

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 \$ 7/Wp (assuming long-term financing as in a mortgage). These five States also belong to those with the highest economic potentials. In addition, half of the population lives in States in the top two tiers, where PV is cost-effective at a cost of \$ 4.50/W[8].

Best markets: (red) above 7 \$/Wp; 5 States: California, Hawaii, Illinois, New York, North Carolina	Emerging markets: (green) between 3 \$/Wp and 4,5 \$/Wp; 6 States Nevada, New Mexico, North Dakota, Delaware, Connecticut, Maine
Cost effective markets: (yellow) between 4,5 \$/Wp and 7 \$/Wp; 10 States + DC Arizona, Utah, Colorado, Massachusetts, Rhode Island, Pennsylvania, New Jersey, Maryland, Virginia, Florida, Washington DC,	Significant incentives needed: (blue) below 3 \$/Wp; 29 States

8 Based on data from US Census 2000

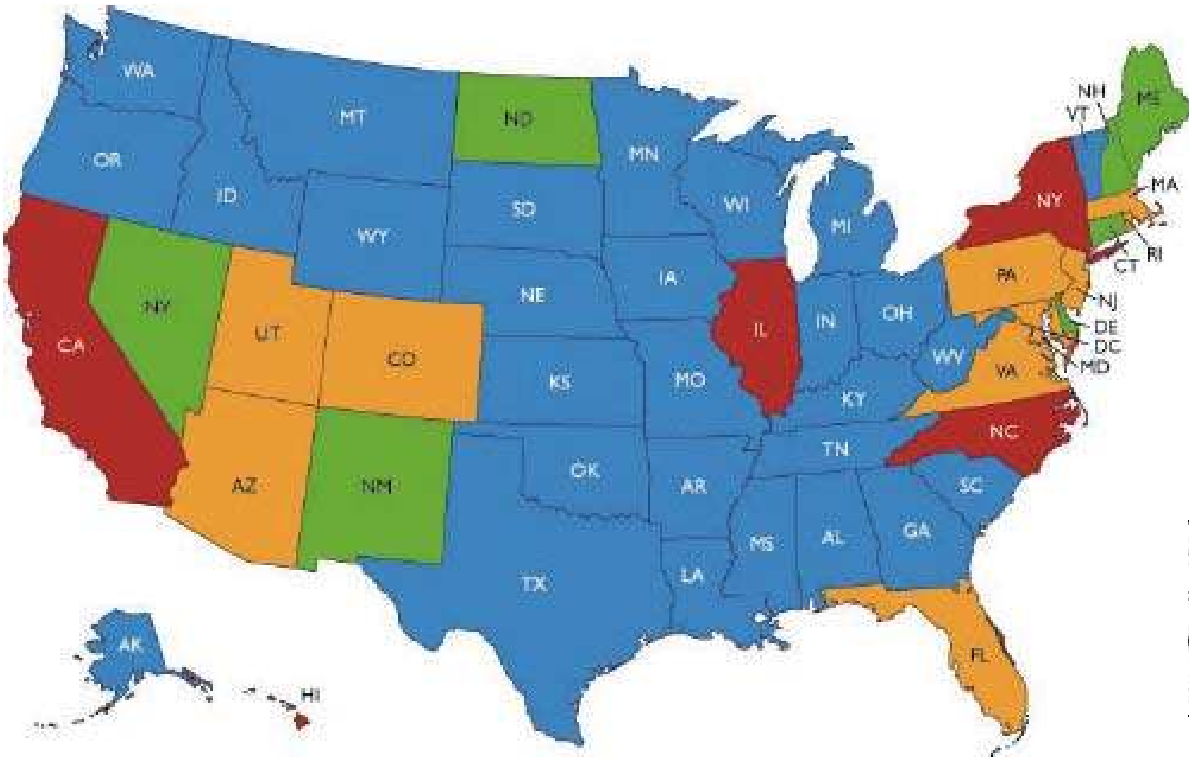

Fig. 10: US-PV-markets [Figure: SEPA]

Despite the increase of grid-connected photovoltaic system installations during the last years with growth rates of around 28%, much needs to be done to reach the targets of the "One Million Roofs" initiative (Fig. 11).

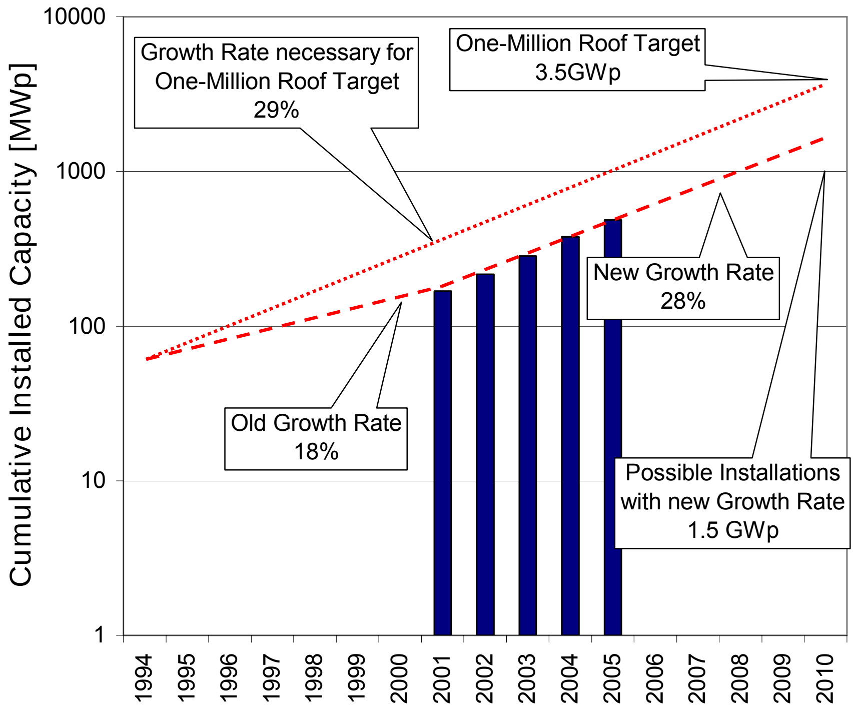

Fig. 11: One Million Roofs Target growth rate and new estimates based on 2001 to 2004 installations

The 2005 Energy Bill, the California SB 1 and other State programmes will help 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 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 in concert 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 California Solar Initiative on 24 August 2006. Beginning 1 January 2007, the PUC will offer 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 organizations 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 organizations.

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

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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 a good or 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].

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. The most common mechanisms are:

- personal tax exemptions (Federal Gov., 16 States + Puerto Rico)
- corporate tax exemptions (Federal Gov., 16 States)
- sales tax exemptions for renewable investments (17 States + Puerto Rico)
- property tax exemptions (26 States)
- buy-down programmes (17 States, 47 utilities, 5 local, 1 private)
- loan programmes and grants (Federal Gov., 28 States + DC; 16 utilities, 13 local, 10 private)
- industrial recruitment incentives (8 States)

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 2006]. 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.	2	2				2	2			1
Alabama	1-S					1-S	1-S			
Alaska							1-S			1-U
Arizona	2-S		1-S		4-U					
Arkansas										
California	1-S			1-S	2-S, 15-U, 2-L	1-L	1-U, 1-S			1-S
Colorado					3-U, 1-L		1-U, 1-L			1-L
Connecticut				1-S	1-S	3-S	3-S			
Delaware					1-S	2-S				
Florida			1-S		2-U					
Georgia										1-U
Hawaii	1-S	1-S			2-U		1-U, 2-L	1-S	1-L	
Idaho	2-S		1-S			2-P	1-S		1-S	
Illinois				1-S	1-S	1-P				
Indiana				1-S						
Iowa	1-S	1-S	1-S	3-S		1-S	2-S			
Kansas				1-S		1-S				

State/Territory	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit.	Bonds	Production Incentive*
Kentucky					1-P		1-P			
Louisiana				1-S			1-S			
Maine					1-S	1-S				
Maryland	1-S	1-S	1-S	2-S	1-S, 1-L		2-S			
Massachusetts	3-S	4-S	1-S	1-S	1-S, 1-U	2-S	1-S			1-S, 1-P
Michigan				1-S		4-S		2-S		
Minnesota			2-S	1-S	1-S, 2-U	1-U	3-S			1-S, 3-U
Mississippi							1-S			1-U
Missouri		1-S				1-S	1-S			
Montana	2-S	1-S		3-S		2-P, 1-U	1-S			
Nebraska							1-S			
Nevada				3-S	1-S					1-S
New Hampshire				1-S	1-U					
New Jersey			1-S		1-S	2-S	1-S			1-S
New Mexico	1-S	1-S	1-S			2-S			1-S	1-U
New York	2-S	1-S	1-S	1-S	3-S, 1-U	1-S	2-S	2-S		
North Carolina	1-S	1-S		1-S			1-S			1-U, 1-P
North Dakota	1-S	1-S	1-S	2-S						
Ohio		1-S	1-S	1-S		1-S	2-S	2-S		
Oklahoma		1-S						1-S		
Oregon	1-S	1-S		1-S	2-S , 6-U	2-P, 1-S	1-S, 4-U			1-P
Pennsylvania					1-L	2-S, 5-L	1-S, 5-L			1-U
Rhode Island	1-S		1-S	1-S	1-S					1-P
South Carolina					1-S					
South Dakota				2-S						
Tennessee				1-S			1-S			1-U
Texas		1-S		1-S	2-U			1-S		
Utah	1-S	1-S	1-S							
Vermont			1-S		1-S	1-U				1-U
Virginia				1-S		1-S		1-S		
Washington			1-S		7-U	2-P	5-U	1-S		1-S, 3-U, 1-P
West Virginia		1-S		1-S						
Wisconsin				1-S	1-S, 1-U	2-S	1-S, 1-U			2-U
Wyoming			1-S		1-S					
D.C.						1-S				
Palau										
Guam										
Puerto Rico	1-S		1-S							
Virgin Islands										
N. Mariana Isl.										
American Samoa										
Totals	25	21	19	35	74	49	54	11	3	29

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) (2006). 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	Disclosure	RPS	Net Metering	Interconnection	Extension Analysis	Contractor License	Equipment Certification	Access Laws	Construction & Design Standards	Green Power Purchase	Required Green Power
Alabama												
Alaska									1-S			
Arizona			1-S	2-U	1-U	1-S	1-S	1-S	1-S	2-S, 2-L	1-L	
Arkansas				1-S	1-S			1-S				
California	1-S	1-S	1-S	1-S	1-S		1-S		2-S, 8-L	1-S, 9-L	4-L	
Colorado		1-S	1-S, 1-L	1-S, 4-U, 1-L	1-S. 1-U	1-S			1-S, 2-L	3-L	2-L	
Connecticut	1-S	1-S	1-S	1-S	1-S		1-S				1-S	
Delaware	1-S	1-S	1-S	1-S	1-S							
Florida		1-S	1-U	2-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	
Indiana				1-S	1-S				1-S			
Iowa		1-S	1-S	1-S	1-S				1-S		1-S	1-S
Kansas					1-S				1-S			
Kentucky				1-S					1-S			
Louisiana				1-S	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-L	
Michigan		1-S		1-S	1-S		1-S					
Minnesota	1-S	1-S	2-S	1-S	1-S			1-S	1-S	1-S		1-S
Mississippi												
Missouri			1-L		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			
New Jersey	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
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-L	1-L		
North Dakota				1-S					1-S			
Ohio	1-S	1-S		1-S, 1-L	1-S				1-S			
Oklahoma				1-S								
Oregon	1-S	1-S		1-S, 1-L	1-S				1-S, 2-L	2-L	1-L	
Pennsylvania	1-S	1-S	1-S	1-S							1-S	
Rhode Island	1-S	1-S	1-S	1-U	1-S				1-S			
S. Carolina											3-L	
South Dakota												

State / Territory	PBF	Disclosure	RPS	Net Metering	Inter-connection	Extension Analysis	Contractor License	Equipment Certification	Access Laws	Construction & Design Standards	Green Power Purchase	Required Green Power
Tennessee									1-S			
Texas		1-S	1-S, 1-L	1-S, 2-U	1-S	1-S				1-S		
Utah				1-S, 1-U	1-S		1-S		1-S		1-L	
Vermont		1-S	1-S	1-S	1-S							
Virginia		1-S		1-S	1-S				1-L			
Washington		1-S		1-S, 1-U	1-S				1-S	1-L	2-L	1-S
West Virginia												
Wisconsin	1-S		1-S	1-S	1-S		1-L	1-L	1-S, 1-L	1-L	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												
N. Mariana Isl.												
Amer. Samoa												
Totals	16	25	28	57	40	4	9	8	49	31	28	5

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) (2006). http://www.dsireusa.org

A recent 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 May 2006 22 States and the District of Columbia had Renewable Portfolio Standards and, with the exception of Minnesota, all include photovoltaics (Fig. 12). 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 June 2006, 40 US States + Washington DC had already implemented measures for the net-metering of electricity produced by PV (Fig. 13).

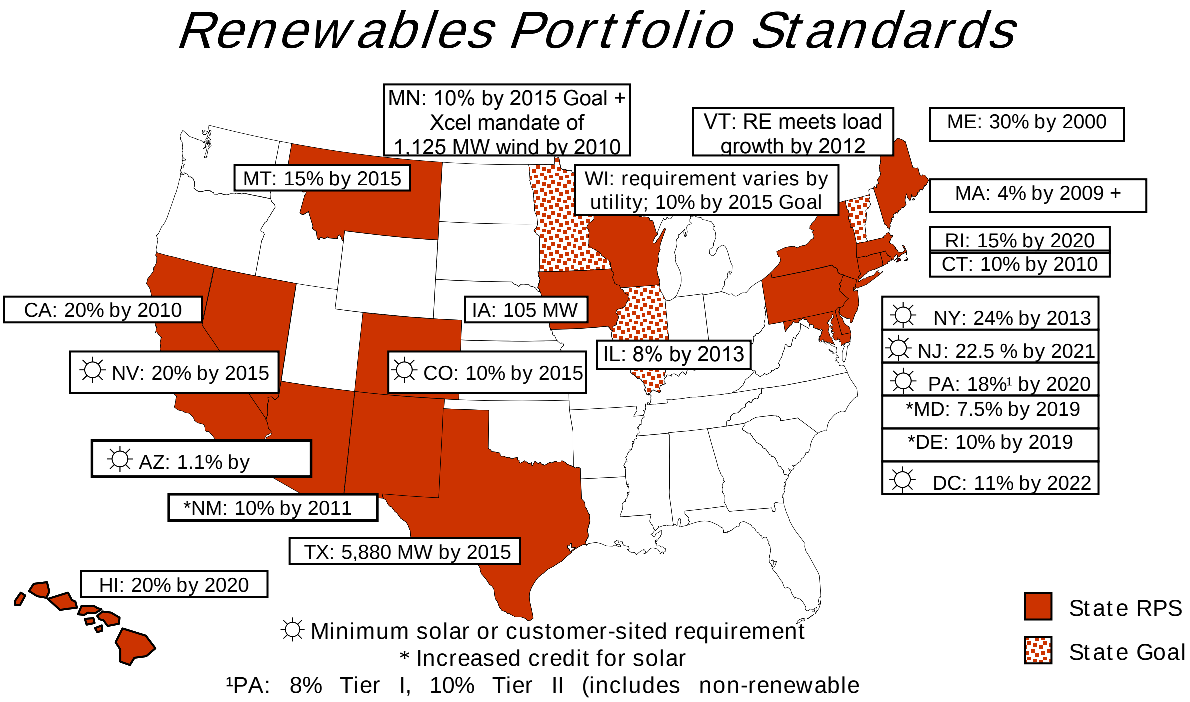

Fig. 12: States with Renewable Portfolio Standards in the US (May 2006); Figure © DSIRE [Dsi 2006]

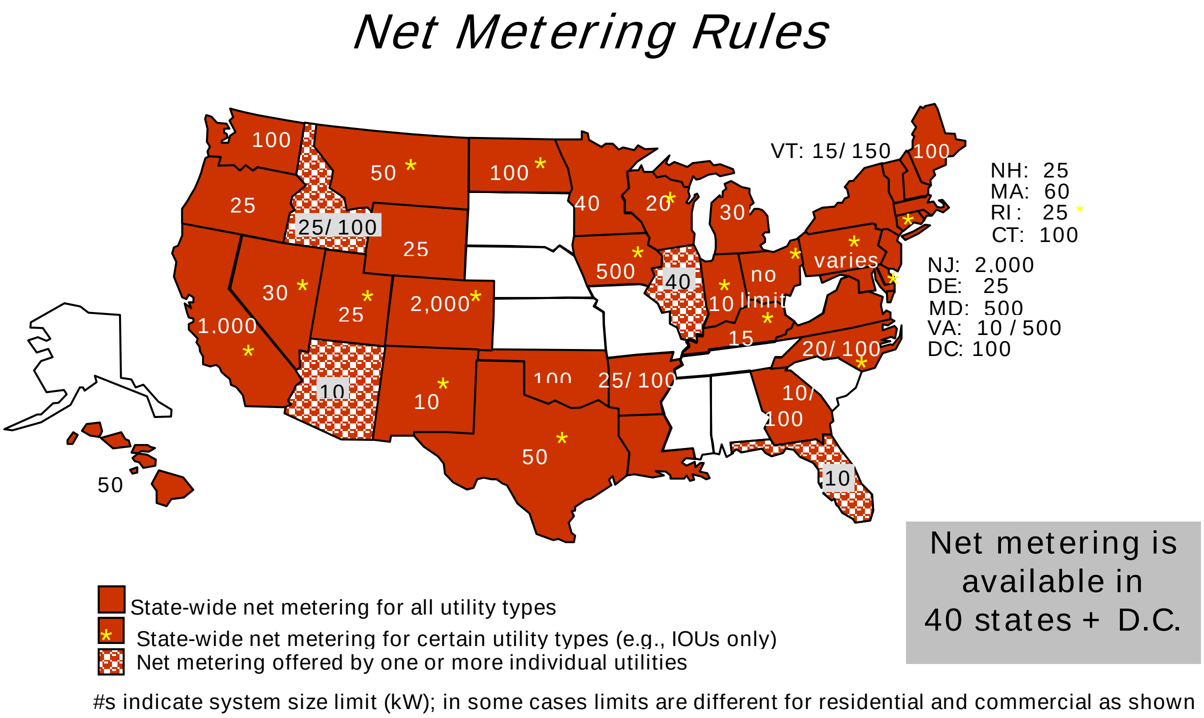

Fig. 13: States with Net-metering in the US (June 2006) and upper limits; Figure © DSIRE [Dsi 2006]

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. 14) – a two-fold increase over total 1997 US levels (excluding hydro). Most of these capacities will be wind, but Photovoltaics is more and more seen 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.

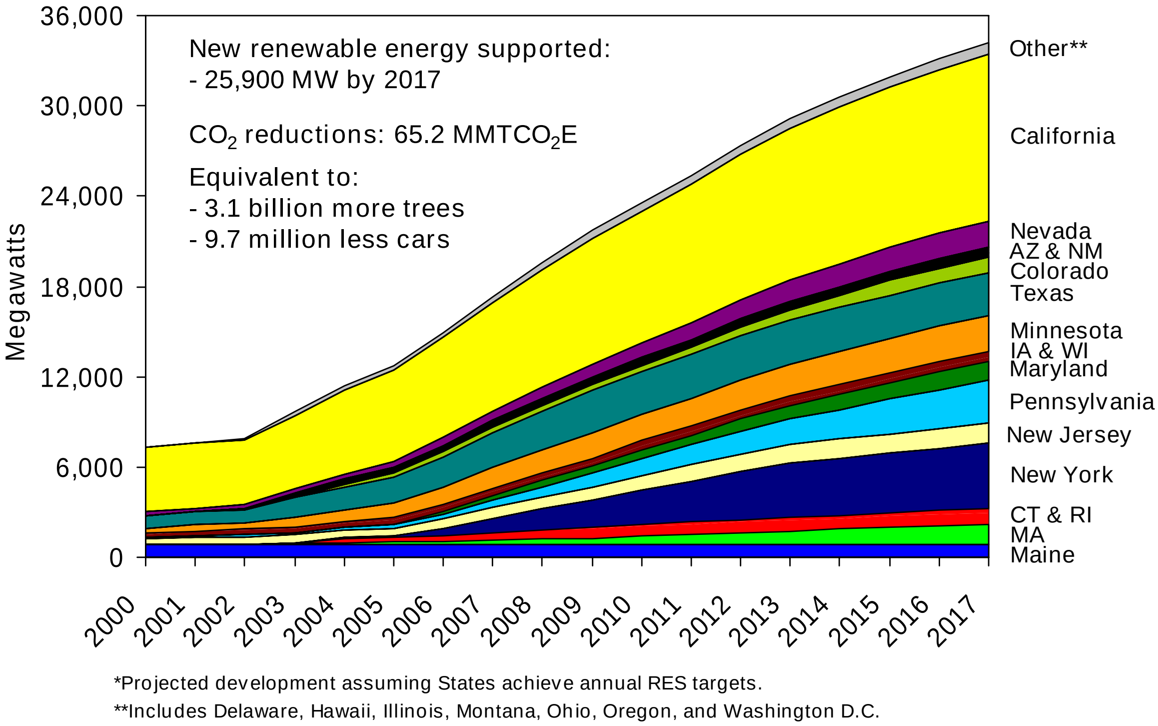

Fig. 14: Prediction of new Renewables from State Standards and Renewable Energy Funds
Figure © Union of Concerned Scientists [Uni 2005b]

So far, Texas has the most successful State RPS initiative. In 1999 a renewable energy standard was adopted that requires 2,000 MW of additional renewable generating capacity to be installed by 2009. Then-Governor George W. Bush signed the RPS into law and Federal Energy Regulatory Commission Chairman, Pat Wood, a former Texas utility regulator, implemented it. At the beginning of 2005, more than 1,100 MW additional renewable energy generation capacity have been installed, which is well ahead of the 850 MW required for 2005. The success of the Texas standard is a combination of the availability of good renewable energy resources in the State and the inclusion of the following key provisions in the RPS legislation:

- New renewable energy requirements are high enough to trigger market growth in the State;
- Requirements apply across the Board to all electricity providers;
- Requirements can be met using tradable renewable energy credits;
- Retail providers that do not comply with the RPS target must pay significant financial penalties.

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.

2006 Goals:

1) Basic University Research
   - Experimentally validate theoretical understanding for doping high-bandgap PV materials.
   - Demonstrate feasibility of third-generation PV devices such as hot-carrier and impact-ionization concepts.

- Evaluate university fundamental R&D programmes and new solar cell options and make decisions on research areas and pathways.
- Assess dye-sensitized solar cell options involving solid-state electrolytes.

2) Measurements and Characterisation
   - Initiate partnerships with university/industry to develop next-generation process diagnostics necessary to enhance yield and throughput.
   - Provide assessment of PV technology measurement, characterisation, and test requirements (inventory current critical requirements and new projected techniques and needs) for input to DOE Multi-Year Technical Plan and PV Industry Roadmap.
3) High Performance and Concentrator Research
   - Fabricate dual-junction polycrystalline thin-film cell of 15% efficiency.
   - Test high-efficiency (35%) concentrator cell array in concentrating solar power dish system
4) Crystalline Silicon
   - Assist industry in demonstrating 19%-efficient, large-area multicrystalline silicon solar cell using commercial processes.
   - Select university centre of excellence for crystalline silicon PV research and education.
5) Thin Films
   - Support a-Si industry adoption of higher-deposition-rate process (5 Å/s).
   - Implement process integration tools to demonstrate the deposition of CIGS with predictable properties.
6) Manufacturing Research and Development
   - Achieve module manufacturing processes capable of $ 1.50/watt direct module manufacturing costs with 500 MW production capacity.
7) Module Performance and Reliability
   - Facilitate improved and cost-reduced standardised qualification test protocols for technologies that are being commercialised.
   - Evaluate accelerated environmental and field reliability test protocols for concentrator module technologies.
8) System Engineering and Reliability
   - Document progress toward 25-year system lifetimes.
   - Designate centre(s) of excellence for PV systems studies.
   - Complete High-Reliability Inverter Initiative.
   - Demonstrate advanced inverter concepts.
9) Partnerships for Technology Introduction
   - Assess international partnering activities facilitating market acceptance of US PV products.
10) Programme Integration and Facilities
    - Start operations of NREL Science and Technology Facility.

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.

5.3 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, dramatically grow markets, 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 leverage 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 making 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 are now and near, 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.

Compared to the 2001 scenario, the new update emphasises the importance of a strong home market in order to develop the local industry in the long term. This is in contrast to the earlier assumption that US PV-Industry Roadmap could depend on 70% export rate of their annual production. A strong home market like in Japan, where it accelerated the expansion of production capacities, is still missing in the United States. This might be one of the reasons why 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.

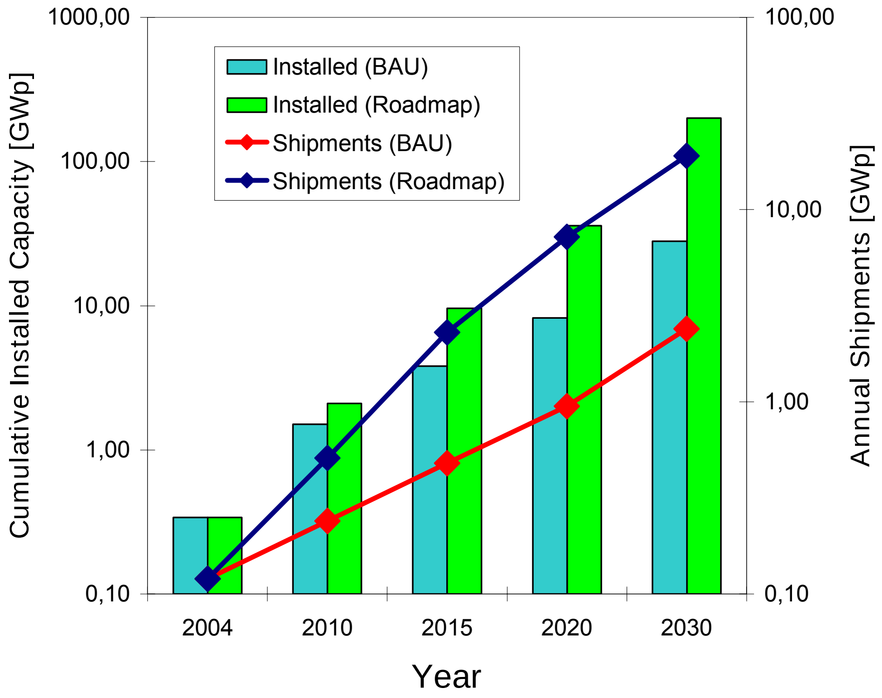

Fig. 15: US PV-Industry Roadmap [Sei 2004]

5.4 Solar Companies

In the following chapter most of the 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. A lot of the data was collected from the companies' web-sites.

5.4.1 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 7 in 2005 with 90 MW. BP Solar has 5 solar cell plants located in Madrid, Spain (Tres Cantos: 17 MW, c-Si Saturn solar cells), Sydney-Homebush Bay, Australia (35 MW, mc-Si and c-Si Saturn solar cells), Bangalore, India (14 MW, mc-Si), and Frederick, Maryland (23 MW mc-Si). BP Solar operates joint ventures in India, Malaysia, Saudi Arabia, South Africa, Thailand and Indonesia.

At present the Frederick plant is BP Solar's biggest polycrystalline wafer production site, with an annual capacity of approx. 50 MW/a and a solar cell line of 40 MW/a. The rest of the wafers are shipped to Australia and India for cell manufacturing. The expansion of the wafer production to 60 MW/a capacity is under way and cell production will be expanded as well. In 2006 BP Solar plans to increase the production capacity of the Madrid (Tres Cantos) plant from 30 to 80 MW/a and of the Bangalore plant from 27 to 43 MW. Expansion of the Homebush Bay plant to 50 MW was announced for 2005.

5.4.2 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 expects to exploit its proprietary and patented technology known as 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. Compared to 2004, sales in 2005 more than doubled again and were 14 MW. Future expansion plans are in the order of 140 MW in 2007 [Rog 2005].

Evergreen Solar formed a joint venture *"EverQ"* with Q-cells, Germany, to develop a 30 MW silicon ribbon solar wafer, cell and module manufacturing plant in Thalheim, Germany, which is located approximately 80 miles from Berlin. [Eve 2005]. November 2005 the Norwegian company Renewable Energy Corporation ASA (REC) joined the joint venture and took over a 15 % share, reducing Q-Cells' share to 21 %, and Evergreen's share to 64 %. REC and Q-Cells have the option of increasing their share to 33.3 % under the terms of the joint venture agreement. This option is available to REC only in connection with higher silicon deliveries. The factory was officially opened on 20 June 2006 and already has a work-force of 260 [Eve 2006]. Groundbreaking for a second integrated wafer, cell and module manufacturing plant – with a capacity of 50 MW – is expected later this year. EverQ plans to increase its current production capacity from 30 MW to approximately 300MW by 2010.

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.

5.4.3 First Solar LLC.

First Solar, LLC is one of the few 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 throughput 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 [Eet 2006]. In March 2005 First Solar announced the tripling of production capacity to approximately 75 MW at their manufacturing facility in Perrysburg (OH), which was scheduled for August 2006 [Fir 2005]. In addition, the company has started the construction of a plant in Frankfurt/Oder, Germany, with a planned capacity of 100 MW scheduled to be finished in the second half of 2007. The company is confident to ramp up production according to plan and more than tripled its 2004 sales of 6 MW in 2005 with 20 MW.

5.4.4 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 25 MW in 2004, but dropped again in 2005 to 18 MW.

Ali Iz, the head of GE Energy's solar business said in an interview in July 2004 "We certainly hope that solar be a billion dollar-plus business for us" and added that this could be achieved by the end of this decade. Under the assumption of a price reduction to $ 2 per Wp by 2010, this implies that GE Energy could build up production capacities of 500 MW or more by then.

5.4.5 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 2006a]. To realise this, a second 25 MW production facility is under construction in Auburn Hills, which is scheduled to start operation in 2006. The construction for a third production line with 50 MW started in April 2006 in Greenville, Michigan, with planned production start in the second half of 2007. Additional expansion is planned in China where a Memorandum of Understanding with Tianjin Jinneng Investment Company (TJIC) to form a joint venture to establish a 25-megawatt (MW) thin-film triple-junction amorphous silicon photovoltaic module manufacturing operation in Tianjin, was signed in September 2005 [Uni 2005a]. Sales in 2005 increased to 22 MW more than 3 times the volume compared to 2003.

5.4.6 SunPower Corporation

SunPower is a majority owned subsidiary of Cypress Semiconductor Corp. founded in 1988 by Richard Swanson and Robert Lorenzini to commercialise proprietary high-efficiency silicon solar cell technology. 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. Pegasus is based on an adaptation of the concentrating cell technology for flat-plate applications, and is the highest-efficiency non-concentrating silicon solar cell commercially available. Besides solar cells, the company manufactures solar modules and inverters.

SunPower conducts its main R&D activity in Sunnyvale, California and has its cell manufacturing plant outside of Manila in the Philippines, which was inaugurated in March 2004 with space for approximately 100 MW annual production. Current production capacity is given with 75 MW. An expansion to 108 MW is under way and should be operational at the end of 2006. On 13 July 2006 the company announced its plans for a second plant with an incremental production capacity of 300 MW [Sun 2006].

In order to secure the necessary silicon supply for its expansion plans, the company signed a multi-year polysilicon agreement with the newcomer DC Chemicals Co. Ltd., Korea [Sun 2006a]. DC Chemicals is constructing a new polysilicon plant and is expecting to produce 3,000 tons per year from 2008 on.

On 15 August 2006, SunPower inaugurated its automated solar panel manufacturing plant, located in the Philippines near to the company's SPML solar cell factory [Sun 2006b]. SunPower expects to produce up to 30 MW of solar panels per year from its first manufacturing line in the new plant. The production facility has sufficient space to expand capacity to 90 MW per year.

5.4.7 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 2005, 1 MW production was reported [Pvn 2006].

- Nanosolar was founded in 2001 and is based in Paolo 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 [Nan2006].

5.4.8 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.

5.4.9 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 24 August 2006, the company announced that it had awarded a contract for the planning and design of their polysilicon plant to CH2M Hill [Hok 2006]. A week later the company announced that id had chosen Idaho as the location for their solar module and polysilicon business [Hok 2006a]. The company plans to commence manufacturing of solar modules and polysilicon in the second halves of 2007 and 2008, respectively.

5.4.10 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 2005 is given with 4,000 tons and the company plans to double production by 2008 [Pvn 2006c].

On 26 July the company announced that it has signed a 10-year supply agreement with Suntech, PRC. [Mem 2006]. Under the terms of the definitive agreement, MEMC will supply solar wafers to Suntech over a 10-year period, with pre-determined pricing, on a take-or-pay basis, beginning in the first quarter of 2007. Sales of the wafers over the 10-year period would generate between $5 billion and $6 billion in revenue for MEMC. As part 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 partner to make silane gas and polysilicon in China [Eet 2006a].

6. THE EUROPEAN UNION

Due to the political structure in Europe with 25 Member States in the European Union, there is no unified approach towards renewable energies yet. Despite this, the European Union has set targets 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 are that renewable energies will provide 12% of the total and 21% of electric energy in the European Union by 2010 (Fig. 16 and 17), in order to meet the obligations of CO_2-reductions pledged in the Kyoto Protocol and lower the dependence on energy imports.

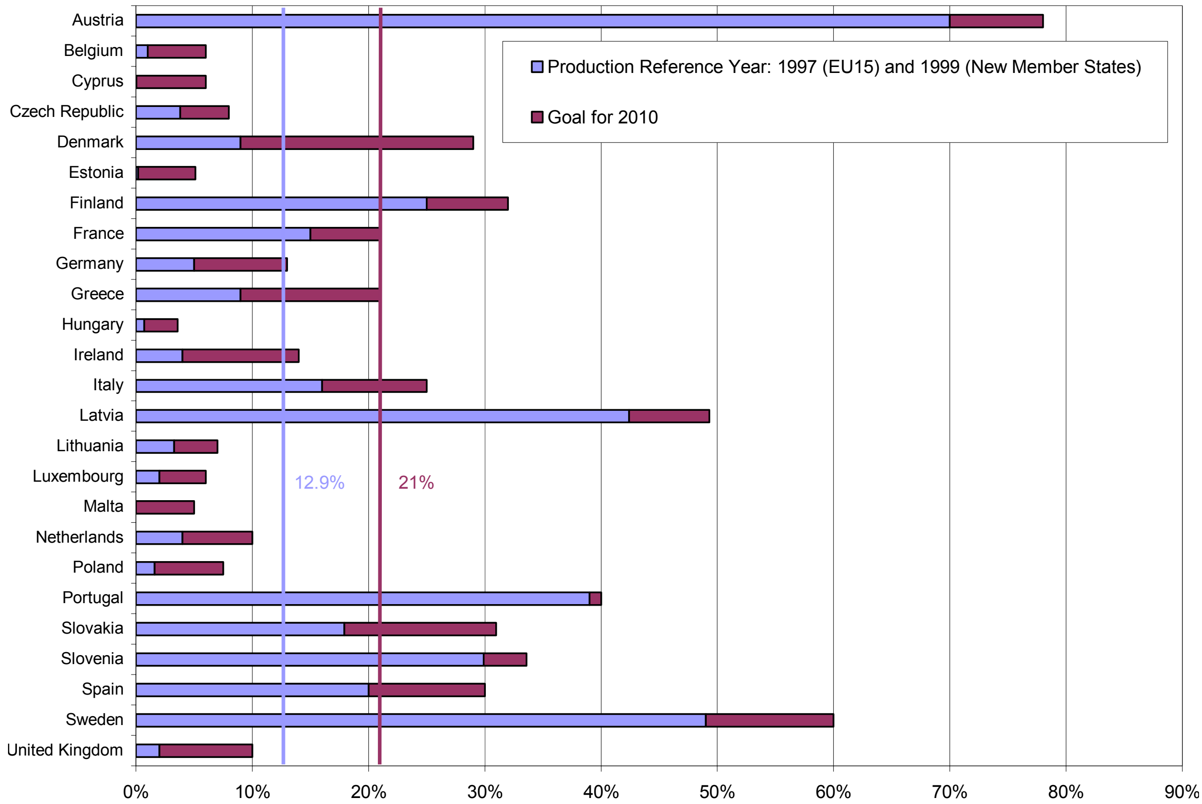

Fig. 16: Share of renewable energies of total European Union electricity production

For this purpose, targets were set in the European Renewable Grid Directive [EU 2001] for the Member States. Indicative targets for the share of Electricity from Renewable Energy Sources (RES-E) were set for each Member State (Fig. 16 and 17). 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 10 New Member States have also committed to national targets in their Accession Treaties in April 2004. Consequently, these national targets are, on the whole, also sufficiently ambitious to achieve the EU-25 target of a 21% RES-E share by 2010.

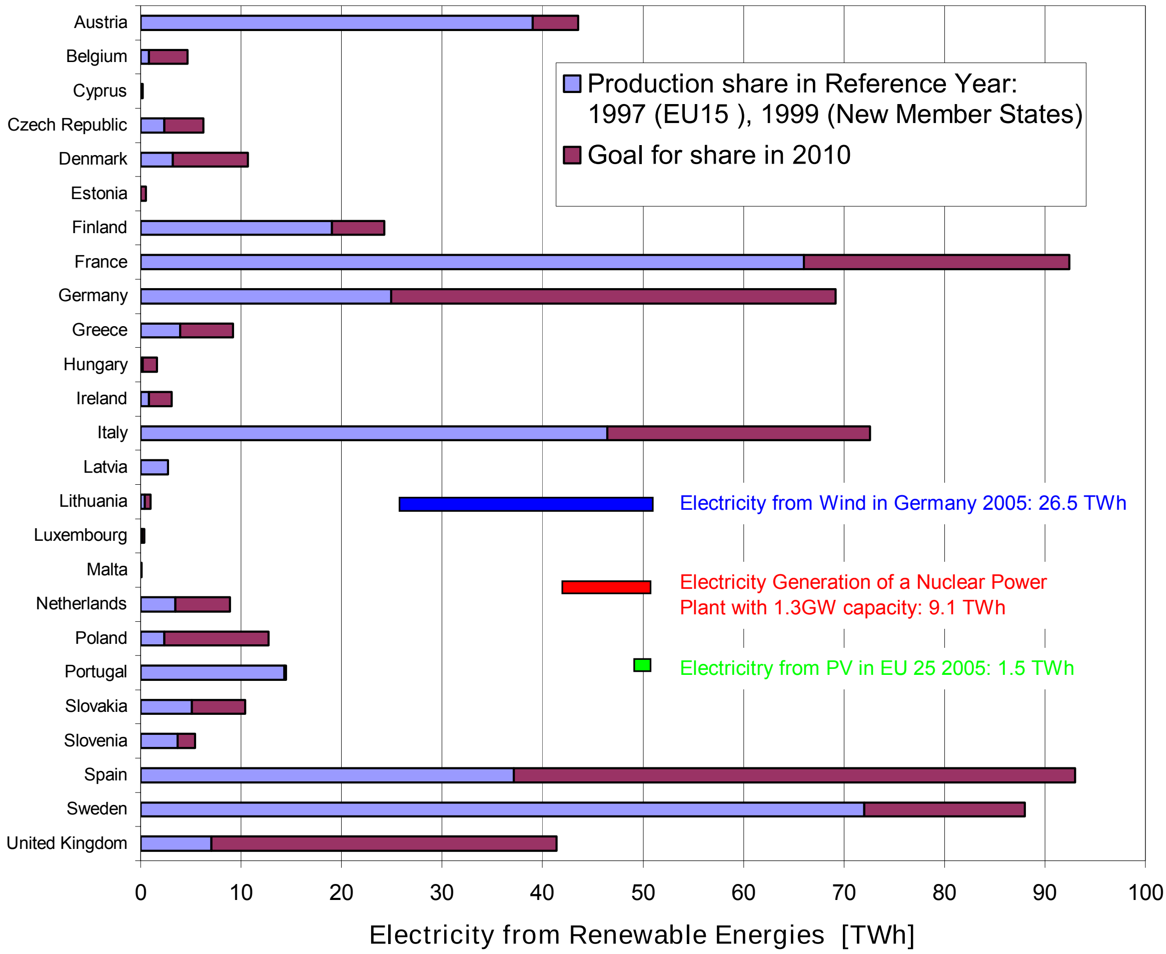

Fig. 17: Electricity generation from renewable energies in the European Union

The target for the cumulative photovoltaic systems capacity installed in the European Union by 2010 is 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 2005, installations of Photovoltaic systems in the European Union increased six fold to reach almost 1.8 GW cumulative installed capacity at the end of 2005 (Fig. 18) [Sys 2006].

In 2005, like in 2004, Germany was the largest single market with 603 MW, followed by Spain with 20.2 MW and France with a little over 6.3 MW [Sys 2006]. The revised German Feed-in Law [EEG 2004] went into force on 1 August 2004. The transitional arrangement before and the revision itself resulted in a dramatic increase in PV installations. For 2005 the German Solar Industry Association estimates that new grid connected systems with a capacity of about 600 MW were installed. Photon reported systems installations with a total of about 710 MW [Pho 2006a]. Even with the more conservative 603 MW installed photovoltaic systems (including off grid installations) Germany accounted for more than 93% of the EU 25 (Fig. 18).

Spain almost doubled from 2004, and for 2006 and 2007 projects with about 200 MW are already under construction or planned [Pho 2006b]. On 26 August 2005, the Spanish Government approved the *Plan de Energías Renovables en España* (PER) for 2005 – 2010. 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.

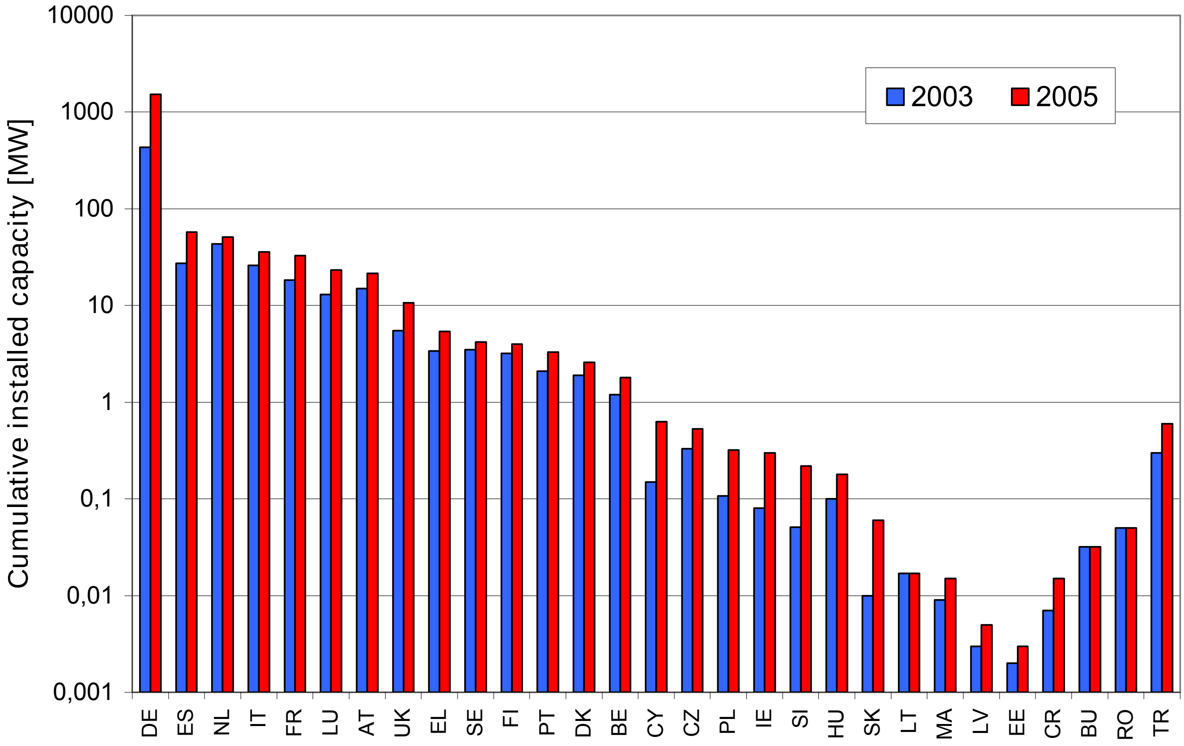

Fig. 18: Cumulative installed grid connected PV capacity in EU + CC 2003 and 2005; Note that capacities do not seem to correlate with solar resources

The new Italian feed-in tariffs, agreed on in July 2005, led to a steep rise in applications in the second half of 2005 and the first half of 2006, but no considerable increase in the amount of new systems capacity could be observed in 2005. 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, but it is estimated that between 50 and 80 MW might be installed at most this year.

France is the latest of the large European Member States to introduce an attractive and cost competitive feed-in tariff for PV installations integrated in a building. The new feed-in tariffs have been in force since 26 July 2006, but is only valid for new installations. 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 digression for new installations was cancelled. All tariffs (old and new) will be adjusted annually in accordance to the inflation during their duration.

With a three year-programme from 2002 to 2004, Luxembourg propelled itself to World Champion and leads the statistics in terms of installed PV with 52.4 Wp per capita. Due to a new legal situation there was no significant addition of PV capacity in 2005. Nevertheless, if the enlarged European Union as a whole would have the same PV quota per capita as Luxembourg, 26.4 GWp installed PV or about 26.4 TWh (0.93% of total EU energy consumption in 2002) per year could be achieved.

Despite the fact that the European PV production grew again by 50% and reached 470 MW, the extreme growth 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. In February 2006 SolarWorld announced it would take over the silicon wafer based solar business of Shell Solar [Sol 2006].

The question regarding the number of photovoltaic systems installed where is getting more and more difficult to answer. Already last year the reported figures for the German installations in 2004 varied from an initial 360 MW reported by the German Solar Industry Association (BSW), and then revised to 500 MW, whereas Photon International reported up to 770 MW [Pho 2005].

The problem started with the end of the German interest reduced loan programme in June 2003. No method was in place to register the number of PV systems installed and the dramatic increase of installations after the revision of the German feed-in law, took everybody by surprise. 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 either, as it is not available before 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.

For 2004 VDN reported 556.5 GWh of electricity generated from photovoltaic electricity systems. To calculate the new installation from the actual electricity generated, the following assumptions are made:

1) The average production of a 1 kWp system is 800 kWh (850 kWh) per year.
2) The 2003 figures of 408 MW grid connected are correct.
3) In 2005 the system installations were equally distributed during the year. This means that for the calculation each kWp installed in 2004 contributes with 400 kWh (425 kWh) to the calculation.

The calculation therefore looks as follows:

The 408 MW installed at the end of 2003 produced	326.4 GWh	(346.8 GWh).
The new systems installed in 2004 have produced	230 GWh	(209.7 GWh)
which translates to	575 MW	(494 MW)

of new installations.

This calculation indicates that it is very likely that the revised BSW numbers are close to the actual installations but still have an uncertainty margin.

An updated list of support measures for Photovoltaics in the European Union Member States is 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) was passed the Parliament on 23 May 2006 and went into force on 1 July 2006. But the tariff negotiations are still ongoing. It is expected that they will be decided in October 2006. Key elements of the Law are: Electricity from all renewable energy sources will be 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. 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.
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 2006: Systems commissioned after 01/01/06: 13.2 CZK/kWh (0.466 €/kWh) Systems commissioned before 01/01/06: 6.28 CZK/kWh (0.222 €/kWh) • Market price + Green Bonus; Green Bonus for 2006 Systems commissioned after 01/01/06: 12.59 CZK/kWh (0.445 €/kWh) Systems commissioned before 01/01/06: 5.67 CZK/kWh (0.200 €/kWh) From 2007 onwards the annual price decrease for new installations should be 5% maximum.
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).
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 2006: Free standing systems: 0.406 €/kWh Systems on buildings and sound barriers: 0.518 €/kWh < 30 kWp, 0.4928 €/kWh > 30 kWp and 0.4874 €/kWh > 100 kWp. For façade integration there is an additional bonus of 0.05 €/kWh.
Greece	New feed-in tariff since June 2006: 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	No PV specific measure, but feed-in tariffs for RES were set through the Electricity Act, which entered into force on 1st 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. There is no differentiation between the renewable sources. The current feed-in tariffs are: • Peak: 25,30 HUF/kWh (0,1 Euro) • Off Peak: 15,80 HUF/kWh (0,063 Euro) • Average: 19,36 HUF/kWh (0,077 Euro) • Average over the year: 18,35 HUF (0,073 Euro)

Ireland	The Alternative Energy Requirement (AER) tender scheme was replaced by a new Renewable Energy Feed in Tariff (ReFIT) scheme in 2006. However, PV is not included.
Italy	Feed-in tariff: guaranteed for 20 years. The tariffs for 2005 and 2006 are listed below, after that there is a 5% decrease for new systems each year, but tariffs and digression will be corrected according to inflation (ISTAT). The original cap of 100 MW to be reached in 2012 was raised to 500 MW (Ministerial Degree 6 February 2006). 1) up to 20 kW: 0.445 €/kWh + "net metering", i.e. each kWh used at home, is deducted from the electricity bill. (1 and 2 together have a cap of 60 annually) 2) between 20 kW and 50 kW: 0.46 €/kWh 3) between 50 kW and 1 MW: 49 €/kWh (cap of 25 MW annually)
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).
Slovakia	Feed-in tariff set by regulator each year. 8 SKK/kWh (ca. 0.206 €/kWh) for 2006. 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 0.375 €/kWh — 0.346 €/kWh
Spain	Feed-in tariff with cap of 150 MW: • 0.44 €/kWh < 100 kWp for 25 years (575% of average electricity price). After 25 years 460% of average electricity price. • > 100 kWp 0.23 €/kWh 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 of 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 25 Member States already have introduced feed-in tariffs. However, the efficiency of this measure to increasingly exploit these countries' PV-potential varies considerably in function of the details in each national regulation. In those States where the tariff does not cover the expenses, impact is very limited. In some other States, there is a motivating tariff, but its effectiveness is limited due to

- 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. 19).

Since the introduction of the feed-in law in Germany, employment in the renewable energy sector has more than doubled compared to 1998. The latest figures given by the German Environment Ministry in May 2006 count more than 157,000 people employed in this sector (including Services and R&D) in 2004 and estimate 170,000 jobs in 2005 [BMU 2006]. The Photovoltaic industry accounted for approximately 30,000 jobs in 2005 [Bsw 2006]. According to an 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 2005 Photovoltaics accounted for a turnover in Germany of € 3 billion and 70% of the added value remained inside Germany.

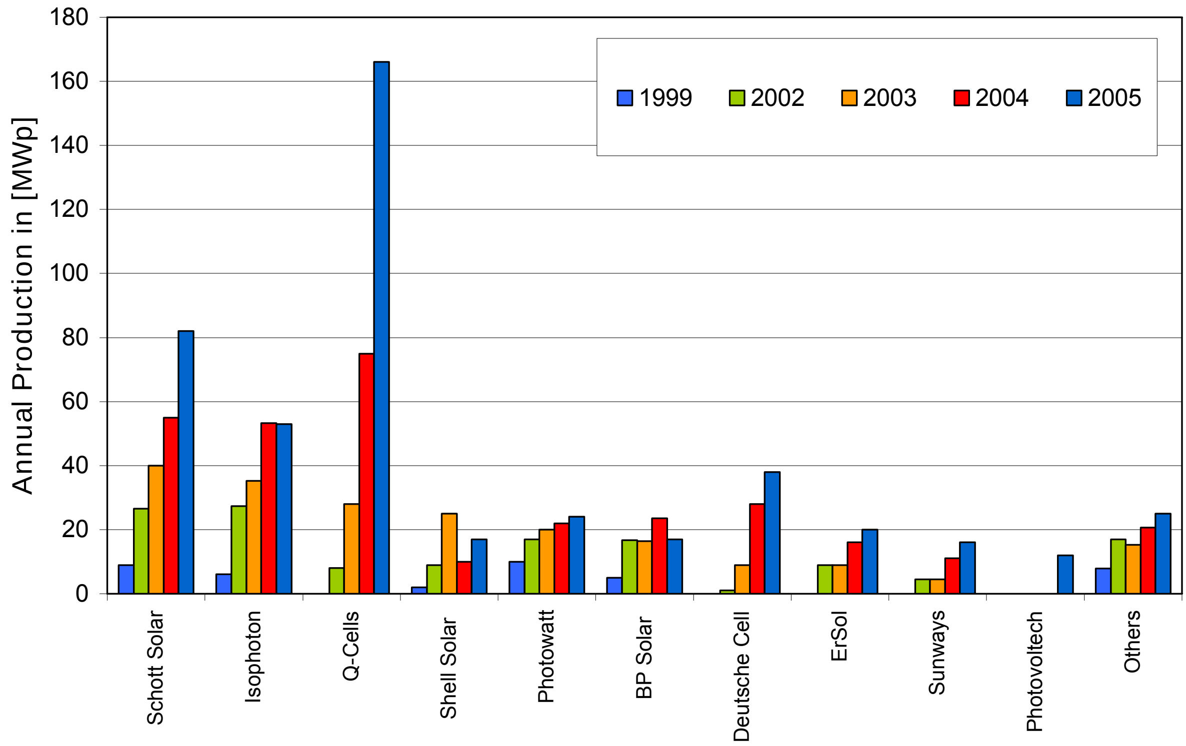

Fig. 19: Annual production of the European PV manufacturers with sales larger than 10 MWp in 2005 [Pvn 2006]

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 offer the most stable and realistic legal framework conditions for citizens investing in a PV system. In 2005 the employment figures in Photovoltaics for the European Union is estimated to be 40,000 to 42,000. These figures are estimated from the already 30,000 jobs reported for Germany [Bsw 2006] and 6,300 for Spain [IEA 2006].

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, 70% of the added value stay within the German economy [Bsw 2006].

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 already quoted impact assessment 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[10] [IEA 2006] 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.

The continuous expansion of the production capacities for solar cells is of particular importance in 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

10 Crude oil prices went up from US$26/bbl (June 2003) to over US$60 (August 2005), source: IEA

market. In June 2004 the European Photovoltaic Industry Association (EPIA) published its recent 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 later jobs are mostly located on a regional level near to the final customer. The goals set by EPIA in its roadmap are cumulative installed photovoltaic systems with 3.6 GWp electricity generation capacity in Europe by 2010 and the respective job numbers mentioned above would correspond to roughly 1.2 GW per year production capacity of cells and systems in the first case and roughly double in the export case. These figures look quite realistic if the planned expansions of production capacities in the order of 900 MW for 2006/7 in Europe are added to the realised production of 470 MW in 2005.

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.

The European Union is on track to fulfil its own target of 3 GWp in terms of Renewable Electricity from Photovoltaics for 2010 – compared to Japan, which seeks to achieve 4.8 GWp (approx. 38 Wp per capita), however, this is not very ambitious. If the growth rates realised in the installation of PV systems between 2001 and 2005 could be maintained in the next years, the White Paper target would already be achieved in 2007 (Fig. 20).

In 2010, total installations would then exceed 10 GWp or approx. 22 Wp per capita, which would still be less than the Japanese target of 38 Wp per capita. The adoption of the Japanese target would result in 17.25 GWp installed in 2010, which would generate around 17.25 TWh or 0.61% of total EU electricity consumption in 2002. 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 next 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.

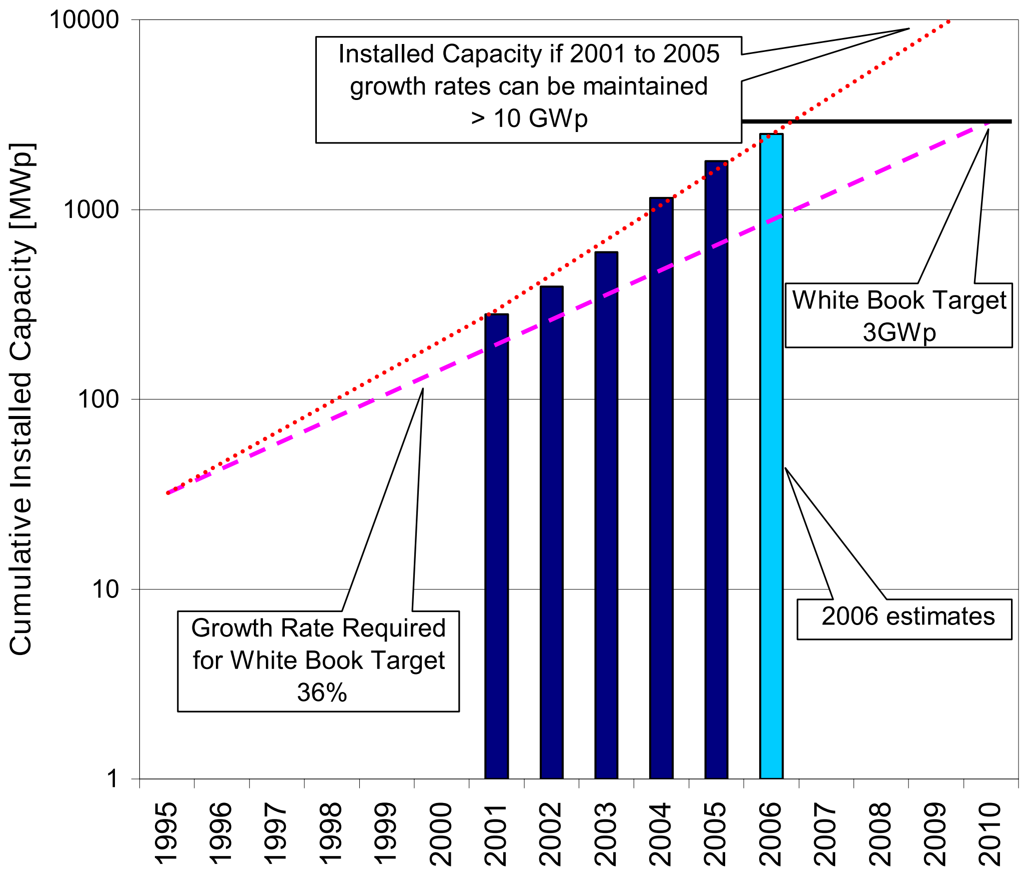

Fig. 20: White Paper target growth rate and estimates based on 2001 to 2005 installations

6.2 PV Research in Europe

In addition to the 25 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 the European PV industry is much more fragmented than competitors in the US and Japan (Fig. 21). 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.

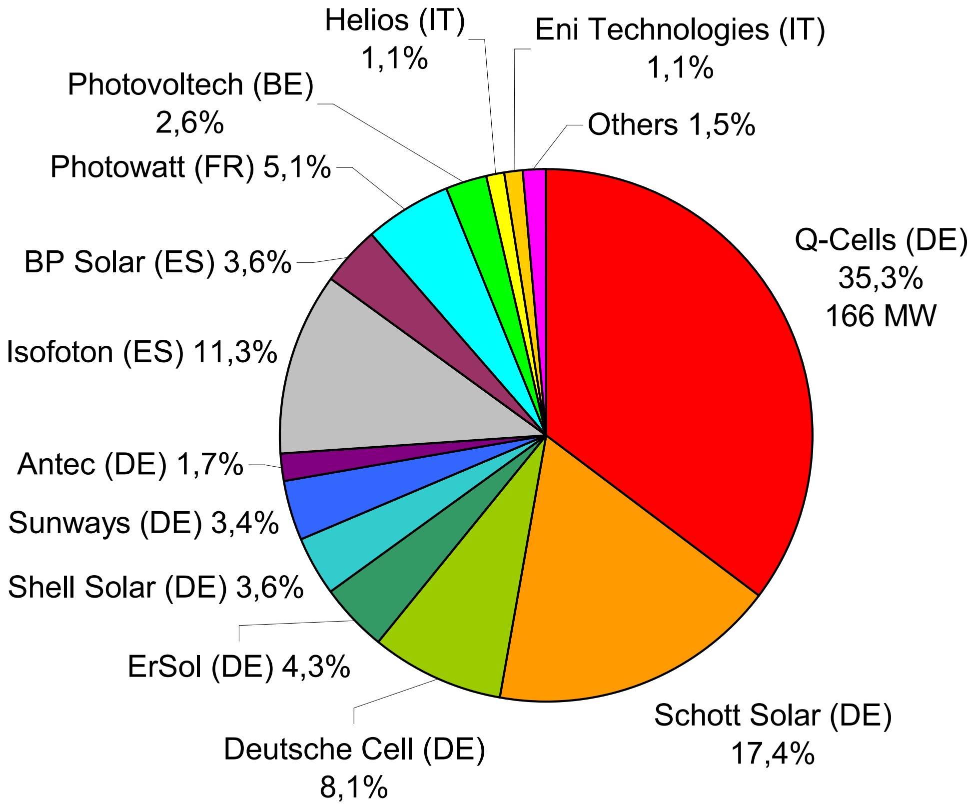

Fig. 21: Shares of the European PV companies in European production
(2005: 470 MW, this corresponds to 26.7% of the world-wide sales) [Pvn 2006]

In the current 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. A report presented at the 21st PVSEC in Dresden in September 2006 stated that up to now € 94.8 million have been awarded to photovoltaic projects [Men 2006]. This represents a share of roughly 11.7 % 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
- Two additional STREPs on the topic of transfer of laboratory results to the production line and solar grade silicon feedstock are under negotiation.

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): (under negotiation), Roll-to-roll manufacturing technology for high efficient multi-junction thin film silicon flexible photovoltaic modules
  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 (Coordination Action) (under negotiation): Coordination Action towards stable and low-cost organic solar cell technologies and their application
  Co-ordinator: IMEC, Leuven, Belgium,
- NANOPHOTO (STREP): Nanocrystalline silicon films for *photovoltaic* and optoelectronic applications
  EU funding: € 1.7 million – Co-ordinator: University of Milano-Bicocca, Milano, Italy
- Another STREP on the topic of manufacturing technology for flexible solar cells is under negotiation.

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 the 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
- Another STREP on the topic of polygeneration of electricity with solar energy is under negotiation.
- 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
  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*).
  Project Funding: € 2.57 million, Co-ordinator: Forschungszentrum Jülich GmbH; Project Management Group "Energy - Technology- Sustainability" (PT-ETN).
- Another Co-ordination Action on the topic of strengthening the European PV sector is under negotiation.

In addition to these technology-oriented research projects, there are some Marie Curie Fellowships and the "Intelligent Energy - Europe" (EIE) Programme.

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. All four of its planned calls for proposals have been launched and the last has a deadline for submitting proposals on 31 October 2006 [IEE 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 *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 € 541.448 (50%).

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.

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 is 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.

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. The COOPENER field is not open in the final IEE Call, but proposals for similar types of action, as well as other sustainable energy projects and infrastructure investments in Africa, Caribbean and Pacific countries have been invited under the ACP-EC Energy Facility Call for proposals, which has a deadline of 6 October 2006 [Acp 2006].

6.3 Solar Companies

In the following, most of the solar cell manufacturers in Europe are described briefly. This listing does not claim to be complete, especially due to the fact that information or data for some companies is very fragmented. 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 it's headquarter 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 2005 was reported with 8 MW [Pvn 2006].

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 will be ramped-up towards an annual capacity of 10 MW by mid year. By end 2006, after the commissioning of the second, CSG-2 stage, production capacity at Thalheim is expected to approach full annual capacity of 20 - 25 MW operating 365 days per year. CSG Solar now has 50 highly skilled employees and plans to have 120 employees to support full-scale CSG-2 operations.

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 photovoltaics products. Its core business is the production and distribution of moncrystalline and multicrystalline solar cells. In 2005 the company had sales of 20 MW and is planning to expand their production capacity from 45 MW to 220 MW by the end of 2009 [Ers 2006].

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. On 8 June 2006 ErSol New technologies was renamed ErSol Thin Films GmbH [Ers 2006a]. This name change is following ErSol's entry into thin-film module production. The ground-breaking ceremony for ErSol Thin Film GmbH's new production plant for silicon thin-film modules was held on 7 July 2006 [Ers 2006b]. In the period up to 2008 the ErSol Group is planning step-by-step expansion, initially according to milestones, up to a production capacity of 40 MWp per annum. For this purpose over € 80 million will be invested in thin-film module production and more than 120 permanent jobs created at the Erfurt site. The medium-term annual capacity target is 100 MWp.

6.3.4 Isofotón

Isofotón, a private owned company, was set up in Malaga to produce silicon solar cells by Professor D. Antonio Luque from the Universidad Politécnica de Madrid. In 1985, Isofotón expanded their activities in the solar sector and also started to fabricate solar collectors. In 2005 Isofotón was the third largest manufacturer of solar cells in Europe with 53 MW. Most of the production is exported, with Germany as the biggest market. It was planned to ramp up to production capacity 100 MW in 2005.

Isofotón teamed up with the utility Endesa and together with the Andalusian Department of Innovation, Science and Business they plan to build the first polysilcon plant in Spain [Sol

2006b]. The plant will be built in Los Barrios, Cadiz province of Andalucía, Southern Spain with a production capacity of 2,500 tons of solar grade polysilicon.

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. The company plans to manufacture 5 MW of concentrator cells by early 2007.

6.3.5 Photowatt

Photowatt was set up in 1979 and relocated to Bourgoin-Jallieu in 1991, where the company converts silicon waste into the raw material used for the manufacturing of solar energy cells. At the beginning of 1997, Matrix Solar Technologies, a subsidiary of the Canadian company, ATS (Automation Tooling Systems), acquired Photowatt International and started to expand the production capacities. 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 2005 Photowatt had sales of 24 MW and is planning a production capacity increase to 60 MW by 2006 [Pvn 2006, Ins 2005].

6.3.6 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 2005 the company had sales of 12 MW of polycrystalline solar cells [Pvn 2006].

6.3.7 Q-Cells AG

Q-Cells AG was founded at the end of 1999 and is based in Thalheim, Sachsen-Anhalt, Germany. Solar cell production started mid 2001 with a 12 MWp production line. In the 2005

Annual Report, the company stated, that the capacity increase to 350 MW should be done by mid 2006 [Qce 2006]. Sales in 2005 were 166 MW, propelling it to second place world-wide. On 14 August 2006, Q-Cells AG presented its report for the first half of 2006 and announced that it expects to reach 255 MW production in 2006 [Qce 2006a].

For Q-Cells the cell efficiency is the key issue. The company was one of the first European industrial producers to offer solar cells exceeding 15 % efficiency to its customers. Technologically, their medium-term objective is to improve cell efficiencies up to the current potential of around 17 % for polycrystalline material and around 20 % for monocrystalline material. After the introduction of the Q6 solar cell (6-Inch-Format/150 x 150 mm) in 2002, the company plans to start the mass production of their 8-inch solar cell Q8 with a power output of approximately 6.4 W in 2005.

Q-Cells is one of the investors and co-founders of CSG Solar AG based in Thalheim, Germany [Csg 2004]. CSG Solar opened its first factory on 15 March 2006 and expects to reach the full capacity of 20 – 25MW at the end of 2006 [Csg 2006].

As already mentioned, Q-cells formed a joint venture with Evergreen Solar, USA, EverQ to develop and build a 30 MW solar wafer, cell and module manufacturing plant in Thalheim, Germany, based on the Evergreen ribbon technology [Qce 2005]. In November 2005 the Norwegian company Renewable Energy Corporation ASA (REC) joined the joint venture and took over a 15 % share, reducing Q-Cells' share to 21 % and Evergreen's share to 64 %. In June 2006 REC and Q-Cells executed their option of increasing their share to 33.3 % [Qce 2006b]. To REC this option was only available in connection with higher silicon deliveries. The factory was officially opened on 20 June 2006 and already has a workforce of 260 [Eve 2006]. Groundbreaking for a second integrated wafer, cell and module manufacturing plant – with a capacity of 50 MW – is expected later this year. EverQ plans to increase its current production capacity from 30 MW to approximately 300MW by 2010.

The latest Q-Cell diversification is its investment in thin film technology company VHF-Technologies SA ("flexcell") in Switzerland [Qce 2006c]. VHF-Technologies produces flexible solar modules on a thin-film silicon basis. Q-Cells has an initial stake of 15.5 % in VHF-Technologies, with the option of a gradual increase to 51 %.

6.3.8 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 2005, the company had sales of 95 MW (82 MW from

Germany, 13 MW from US) sales of € 285 million with 900 employees and a production capacity of 130 MW. It has five locations:

- Alzenau, Germnay: Headquarters, SmartSolarFab®, marketing for Europe, Asia, Africa for cells, modules, systems and building integration
- Putzbrunn, Germany: Phototronics Division
- Valašské, Czech Republic: Module manufacturing
- Billerica, USA: Silicon Octagon Wafer, cell and module production, marketing of modules for North and South America.
- Rocklin (CA), USA: planning, marketing and installation of PV systems for North and South America.

Schott Solar uses silicon wafers grown by Edge-Defined, Film-Fed Growth (EFG). The development of EFG dates back to 1974 when Tyco Laboratories and Mobil Corporation joined forces to begin developing advanced silicon solar cells. Although 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 2006].

6.3.9 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 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]. According to the company, solar cell production at SolarWorld Industries America in Camarillo/California has gone up significantly. For the second half of the year 2006, SolarWorld expects to double US solar cell production over that of the previous year. 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. With the takeover, the following Shell sites were transferred to Solar World:

- Research and Development in Munich, Germany
- Ingot growing and wafers in Vancouver, WA, USA
- Mono-crystalline cells and modules in Camarillo, CA, USA
- CIS thin film modules in Camarillo, CA, USA
- Multi-crystalline cells in Gelsenkirchen, Germany
- Silicon Research and Development in Munich, Germany

The production in 2005 was 160 MWp wafers, module fabrication of more than 43 MW and 37 MWp solar cells [Sol 2006]. The planned fabrication capacities expansions in Europe without the former Shell Solar capacities, can be summarised as follows: wafer from 120 MW to 220 MW, solar cell from 60 MW to 160 MW and modules from 60 to 120 MW. The takeover of the Shell Solar activities adds in the current year about 50 MW of wafer and raw material capacity, 80 MW cell capacity and 25 MW module capacity.

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.

6.3.10 Shell Solar

Shell Solar was established to develop commercial opportunities in solar energy. In 2001, subject to economic review, Shell committed to invest 0.5 to 1 billion $ in solar photovoltaics (PV) and wind energy in the period from 2001 to 2006. Shell Solar sold its silicon related solar business to Solar World at the beginning of 2006 and is now focussing on the development of the copper indium selenide (CIS) technology together with Saint Gobain [She 2006].

6.3.11 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. At the end of 2005, the company had 213 employees. Sales in 2005 were 16 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.

Sunways moves to diversify its portfolio and expand its product range by branching out into thin film technology. For this purpose the company signed a co-operation agreement with

Unaxis AG, Liechtenstein [Sun 2005a]. The goal of this agreement is to jointly construct a production unit for the manufacturing of solar cells based on thin film technology within two years.

6.3.12 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.

During the Annual Results Press Conference, the chairman of the Würth Group Advisory Board, Prof. Dr. h.c. Reinhold Würth announced the construction of a new production facility for CIS photovoltaic modules with an investment volume of around € 55 million [Wür 2005]. The planned production capacity with a staff of 125 is 14.8 MW (2007), corresponds to a manufacturing volume of 200,000 CIS modules. The schedule is as follows:

- Move into production hall in 3rd quarter 2006
- Start production: 4th quarter 2006

Würth Solar currently has 1.3 megawatt of production capacity at its Marbach/Neckar site, corresponding to around 20,000 modules in 2004. A staff of 67 generated sales of € 3.9 million in 2004. The production facilities of the Marbach pilot factory will be integrated into the new CIS factory.

6.3.13 Additional Solar Cell Companies

- Eni Technologies is a subsidiary of Eni SpA. The company has been in the photovoltaic business since the early '80s and is the only Italian industry to operate with a vertically integrated cycle, from raw material to systems. Eni Technologies produces standard mono and multi-crystalline PV modules with sales of 5 MW in 2005.

- 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 2005 [Pvn 2006].

- 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 groundbreaking ceremony for the production plant took place on 16 April 2006 and it is planned to start production at the beginning of 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. A pilot plant with 10 MW capacity is planned to come online in 2008 and should then be expanded to 250 MW at the end of the decade.

- SOLARTEC was established in 1993 and is located in industrial area of Roznov pod Radhostem, in the eastern part of Czech Republic. The company is a producer of solar cells and modules as well as a PV system integrator. In 2005 the company had a production capacity of about 1.8 MW and produces 1 MW of solar cells.

- 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 for 2006 the company plans to increase its production capacity to 5 MW.

6.3.14 PV Crystalox Solar AG

PV Crystalox Solar AG 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 2004, it increased its capacity to 185 MW [Aul 2004] and had a turnover larger than € 100 million. The company plans to increase its market share of currently approximately 20% and expand to 500 MW in the future.

6.3.15 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. 2004 Elkem acquired a 23% share in 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 2,000 to 3,000 tons of solar grade silicon in 2007, ramping up to 10,000 tons in 2010 [Pvn 2006c].

6.3.16 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 Renewable Energy Corporation ASA (REC). The company is specializing 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 (southeast France) is the preferred site for the plant but the consortium is also considering other possible locations in Europe.

6.3.17 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”). On 11 October 2005, REC then 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 9,000 tons production capacity in 2009 and close to 13,000 tons by 2010 [Rec 2006a]. REC produced 5,200 tons of polysilicon in 2005 [Pvn 2006c].

Since 28 June 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 2005, REC Wafer’s plants produced wafers of approximately 220 MWp. The run rate at the end of 2005 was approximately 250 MWp. In 2005, significant expansion projects were initiated at both Herøya and in Glomfjord, which will, together with product mix optimisations and productivity improvements, more than double REC Wafer’s capacity to approximately 550 MWp.

REC ScanCell is located in Narvik, producing solar cells. From the start-up in 2003, the factory has been continuously expanding and during summer 2006 the capacity will be 45 MWp of solar cells per year.

6.3.18 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 2005 Wacker produced 5,800 tons of polysilicon [Pvn 2006c]. 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].

6.3.19 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. The milestones were quite ambitious:

- Mid 2004: a-Si cell on 1.4 m^2
- Mid 2005: μc-Si cell on 1.4 m^2
- 2005: First KAI Production System going into mass production

In the meantime Oerlikon Solar has sold a number of their deposition machines to various solar cell companies.

7. OUTLOOK

In 2005 Japan again had the major market share in photovoltaic device production, with four companies in the top ten manufacturers (Sharp Nº1, Kyocera Nº3, Sanyo Nº4, Mitsubishi Electric Nº5), followed by one European company (Q-Cells Nº2), three with production capacities in more than one continent (Schott Solar Nº6, BP Solar Nº7, Shell Solar Nº10) and one Chinese and one Taiwanese company (Suntech Nº8, Motech Nº9). Since 1999 the European PV production grew on average by 50% per annum and reached about 470 MW in 2005. European market share rose in the same time from 20% to 26%, whereas the US share decreased due to a weak home market, while the Japanese share increased close to 50%.

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 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. Despite the difficult economic situation, a further increase in production capacities for solar cells can be expected in Japan. The reason for this is the fact that METI, together with the Japanese industry, views PV manufacturing as a "key industry" at the beginning of the 21st century. This shift in the evaluation of future perspectives of the PV industry has resulted in the fact that traditional heavy industry companies like Mitsubishi Heavy, or car makers like Honda, have started a solar cell business.

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 30% annually during the last years and reached a volume of 1.7 GWp or € 8 billion in 2005.

The German market was very strong again in 2005 and installations were in the range of 600 MW [Sys 2006]. A further increase of the market is expected in 2006. However, due to the limited availability of solar modules and the increasing demand in countries like Spain and Italy, the increase is expected to be "only" in the range of 10 to 15% or 660 to 700 MW.

The current temporary shortage in silicon feedstock, triggered by the extremely high growth rates of the photovoltaics industry over the last years, is showing its effects. Advanced 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 commitments made at the International Conference on Renewable Energies, Bonn in June 2004, will continue to keep the demand for solar systems high. In the long-term, the growth rates for photovoltaics will continue to be high, even if the economic frame conditions can lead to a short-term slow-down of growth rates. 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 2010 [Cib 2005] or even exceed it, as stated by Matthew Simmons, member of the Energy Task force of US Vice-President Dick Cheney.

If Oil-futures for 2012 and 10 year US treasury bonds (4.88%) are taken as a benchmark, the oil price will rise to at least $ 90/bbl (€ 72) in 2012. Otherwise Oil-futures will be 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.

Figure 22 shows the world-wide potential of renewable energies, mainly geothermal and solar, which is sufficient to supply a world population of 10 billion people with approx. 300 GJ of energy per capita. Only Europe and Asia, whose potential is just 100 GJ/capita, would need to import energy.

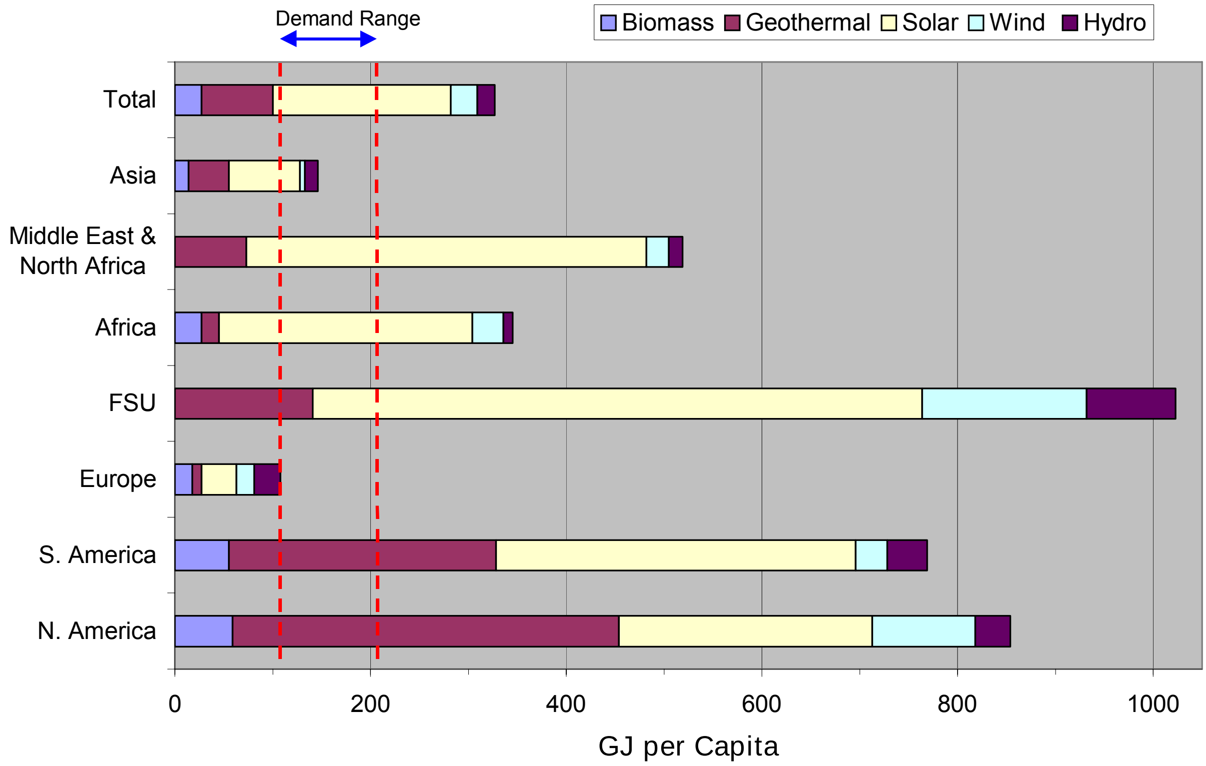

Fig. 22: Potential of usable renewable energies calculated for a world population of 10 billion people [She 2000]

In the run-up to the UN Johannesburg Summit for Sustainable Development in August 2002, the then-president of BP Solar, Harry Shimp, declared in an interview with Reuters:

"Ultimately the world has to move toward renewable power. In 20-25 years the reserves of liquid hydrocarbons are beginning to go down so we have this window of time to convert over to renewables." [Reu 2002]. These remarks are in line with the energy scenario of the oil company Royal Dutch Shell, which predicts high growth rates for renewable energies in the coming decades [She 2000].

It can be observed that for all big OECD economies, growing energy import dependency has become a main driver in political argumentation for RE, probably because the negative consequences (trade balance, risk increase for economic and geo-strategic stability) are more tangible in the short-term than for instance global consequences of substantial climate change. This goal is notably similar to the final Declaration of the EC-organised European Conference for Renewable Energy "Intelligent Policy Options" held in January 2004 in Berlin. Also there, the recommendations to the EU institutions were to achieve 20% of renewable energy in overall EU consumption by 2020 [Ber 2004].

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 is on track to fulfil its 2010 targets. 2005 saw yet again a 50% growth of production volume in Europe and additional production capacities will become available over the next years. Japan is increasing its capacities at a similar pace. Should the current trend in the field of world-wide production capacity increase continue, Europe will only be able to increase its market share slightly from 26 to 29% even with 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 Japan will still dominate the PV world-market with about 50% market share, but it is already obvious that China becomes a driving force in the photovoltaic manufacturing and will probably be close to reaching a 20% market share (Fig. 23).

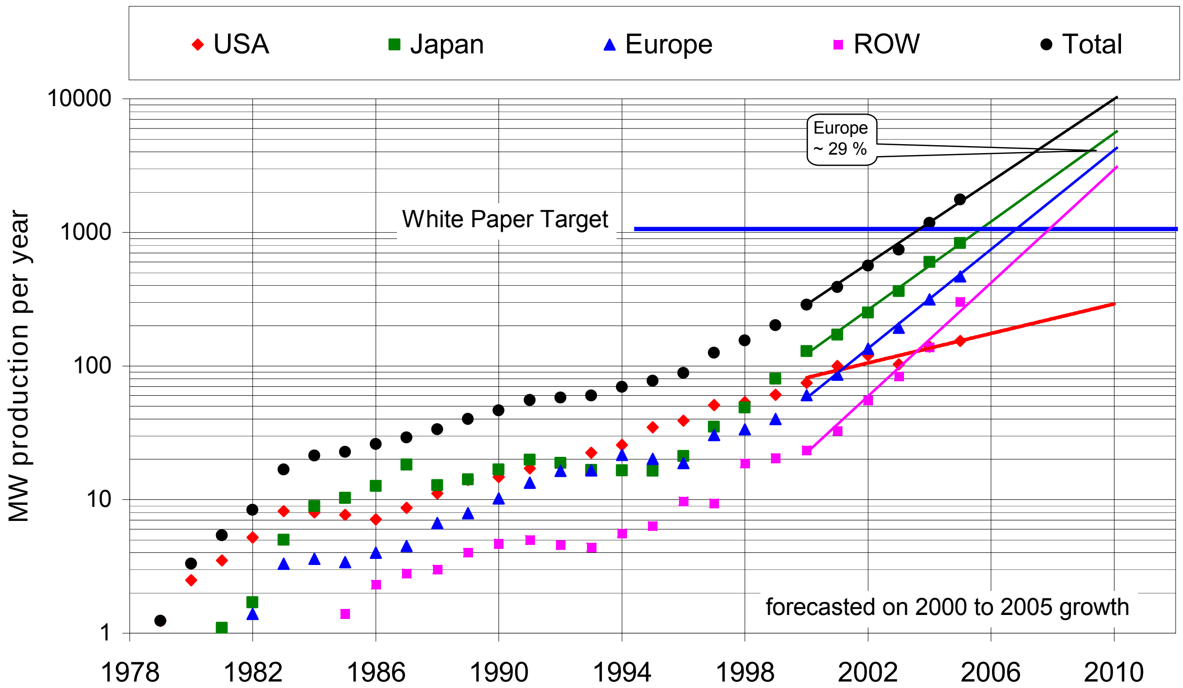

Fig. 23: Extrapolated increase of production capacities up until 2010 using the growth rates from 2000 to 2005 (Data source: PV News [Pvn 2006])

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 until 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.

It is still true that Photovoltaics need significant initial investment, as was the case for the other energy sources, such as coal, oil and nuclear energy. It should not be forgotten that most of these investments were either made by public companies or secured by public credit guarantees. The European Environment Agency reported that the total energy subsidies in the European Union (EU15) were more than € 29 billiuon in 2001 [EEA 2004]. About 18% or € 5.3 billion were given to renewable energies, whereas the rest went to coal, oil, gas and nuclear. These figures exclude external costs and for nuclear exclude the cost of not having to pay for full-liability insurance cover. In addition, the fact that some of Europe’s nuclear companies are still state owned or controlled and arising liabilities will eventually have to be covered, or are actually being covered by the taxpayers, are not taken into account either.

At the current time we can observe a continuous 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. However, apart from conventional energy sources, renewable energies are the only ones to offer a reduction of prices instead of an increase in the future.

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