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PV STATUS REPORT 2011

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PV Status Report 2011

Research, Solar Cell Production and Market Implementation of Photovoltaics

July 2011

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Preface

Three years after the spiking oil prices at $ 147.27 per barrel in July 2008, we became accustomed to seeing oil prices around $ 100 per barrel as standard price, and it is only a question of time before the next price hikes will come and reach $ 200 per barrel. During the same time, residential PV electricity system prices have decreased by more than 40% in the most competitive markets and the gap between residential electricity retail prices and the cost of PV-generated electricity is closing fast.

Almost 40 years after the first oil price shock, and 25 years after the Chernobyl accident, the discussion as to how to transform the world-wide energy supply into a less price volatile and disruptive, as well as a sustainable, is still ongoing, despite the fact that the technology solutions are already well known. The question is not if a 100% Renewable Energy supply is possible, but rather in which timeframe can it be realised, with what renewable energy source mix and at what costs.

Another nuclear accident which was classified as a Level 7 event on the International Nuclear Event Scale (INES), the same as Chernobyl took place in Fukujima in March 2011 and demonstrated that the *residual risk* of nuclear incidents, which predicted such accidents only every thousand years, is more real than predicted. The consequences of the Fukujima incident led to decisions in three European countries, namely Italy, Germany and Switzerland, not to restart or to phase out nuclear electricity generation within the next 10 to 25 years.

In June 2009, the European Directive on the "Promotion of the Use of Energy from Renewable Sources" went into force and does not only set mandatory targets for the Member States in 2020, but also gives a trajectory how to reach them. The aim of the Directive is to provide the necessary measures for Europe to reduce its green-house gas emissions by 20% in 2020, in order to support the world-wide stabilisation of the atmospheric gases in the 450 to 550 ppm range.

The IEA estimated that the additional costs, compared to the Reference Scenario of $ 26 trillion (€ 20 trillion), would be $ 4.1 trillion (€ 3.15 trillion) and US 9.2 trillion (€ 7.01 trillion) for the 550 ppm and 450 ppm scenarios respectively. At first sight, this looks like a lot of additional investment, but it is much less than the continuation of the 2008 annual fossil energy subsidies of around $ 650 billion (€ 500 billion) over the same time period, which would amount to $ 13 trillion (€ 10 trillion). Compared to these figures, subsidies to renewable energy are small, quoted with $ 27 billion (€ 20.8 billion) for renewable electricity, without hydro power, and $ 20 billion (€ 15.4 billion) for biofuels. During this year, the Commission will present its Energy Roadmap 2050 and the discussion about renewable energy targets for 2030 is heating up. The European Renewable Energy Council (EREC) already presented its request to set a 45% renewable energy target for the European Union for 2030.

Photovoltaics is a key technology option to realise the shift to a decarbonised energy supply. The solar resources in Europe and world-wide are abundant and cannot be monopolised by one country. Regardless why, and how fast the oil price and energy prices increase in the future, photovoltaics and other renewable energies are the only ones to offer a reduction of prices, rather than an increase in the future.

In 2010, the photovoltaic industry production more than doubled and reached a world-wide production volume of 23.5 GWp of photovoltaic modules. Yearly growth rates over the last decade were in average more than 40%, which makes photovoltaics one of the fastest growing industries at present. Business analysts predict that investments in PV technology could double from € 35-40 billion in 2010 to over € 70 billion in 2015, while prices for consumers are continuously decreasing at the same time.

The Tenth Edition of the "PV Status Report" tries to give an overview about the current activities regarding Research, Manufacturing and Market Implementation. Over the last ten years, the photovoltaic industry has grown from a small group of companies and key players, which were more or less personally known to me, into a global business where information gathering is getting more and more complex. I am aware that not every country and development is treated with the same attention, but this would go beyond the scope of this report. Nevertheless, I hope that this report will provide a useful overview about the situation world-wide. Any additional information is highly welcome and will be used for the update of the report.

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, July 2011

Arnulf Jäger-Waldau
European Commission
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1. Introduction

Production data for the global cell production[1] in 2010 vary between 18 GW and 27 GW. The significant uncertainty in the data for 2010 is due to the highly competitive market environment, as well as the fact that some companies report shipment figures, others report sales and again others report production figures. In addition, the difficult economic conditions and increased competition led to a decreased willingness to report confidential company data. The previous tight silicon supply situation reversed due to massive production expansions, as well as the economic situation. This led to a price decrease from the 2008 peak of around 500 $/kg to about 50–55 $/kg at the end of 2009, with a slight upwards tendency throughout 2010 and early 2011.

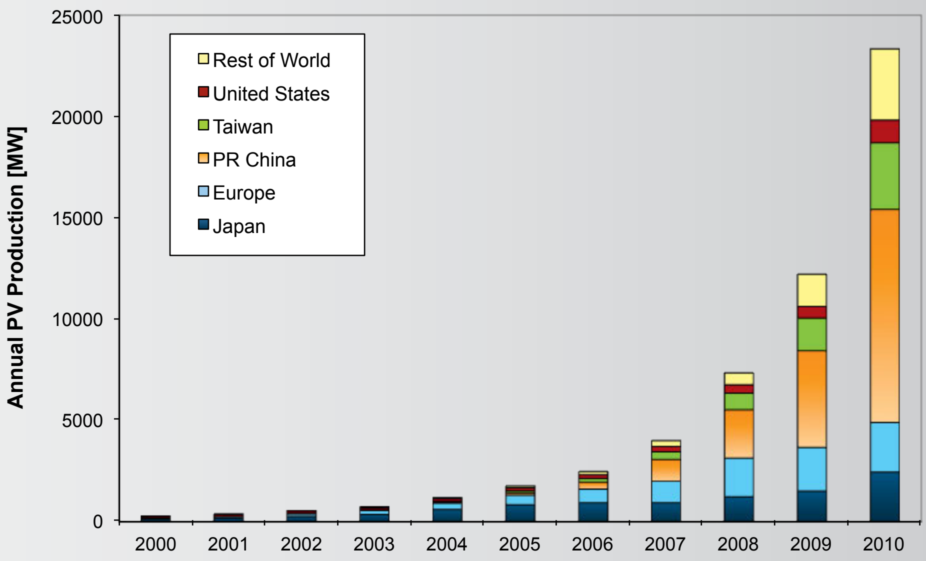
The data, collected from various companies and colleagues were compared to various data sources and thus led to an estimate of 23.5 GW (Fig. 1), representing a doubling of production compared to 2009.

Since 2000, total PV production increased almost by two orders of magnitude, with annual growth rates between 40% and 90%. The most rapid growth in annual production over the last five years could be observed in Asia, where China and Taiwan together now account for almost 60% of world-wide production.

Public-traded companies manufacturing solar products, or offering related services, have attracted a growing number

[1] **Solar cell production capacities mean:**
- In the case of wafer silicon based solar cells only the cells
- In the case of thin-films, the complete integrated module
- Only those companies which actually produce the active circuit (solar cell) are counted
- Companies which purchase these circuits and make cells are not counted

Fig. 1: World PV Cell/Module Production from 2000 to 2010
(data source: Navigant [Min 2010, 2011], Photon International [Pho 2011], PV News [Pvn 2011] and own analysis)



of private and institutional investors. In 2010 world-wide new investments into the renewable energy and energy efficiency sectors increased to a new record of $ 243 billion (€ 187 billion[2]), up 30% from 2009 and for the third year in a row solar power attracted, behind wind, the second largest amount of new investments into renewable energies [Wor 2011]. Europe was still the leading region in terms of renewable energy investments, totalling $ 94.4 billion (€ 72.6 billion), followed by Asia/Oceania with $ 82.8 billion (€ 63.7 billion) and the Americas with $ 65.8 billion (€ 50.6 billion) [Pew 2011].

Europe's leadership position was vested through a more than doubling of the investments in small-scale solar installations in Germany and Italy. However, renewable energy investments in the Asia/Oceania region grew faster than in Europe, mainly through the 39% increase in private investment in China's renewable energy sector to $ 54.4 billion (€ 41.8 billion), moving Asia to become the world's leading destination for renewable energy finance investments [Pew 2011].

At the end of 2010 about 48% or $ 94.8 billion (€ 72.9 billion) of the $ 194.3 billion (€ 149.5 billion) global "green stimulus" money from governments, aimed to help relieve the effect of the recession, had reached the markets [Wor 2011]. For 2011 another $ 68 billion (€ 52.3 billion) are expected.

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

Business analysts are confident that the industry fundamentals as a whole remain strong and that the overall photovoltaics sector will continue to experience a significant long-term growth. Following the stock market decline, as a result of the financial turmoil, the PPVX[3] (Photon Pholtovoltaic Stock Index) fell from its high at over 6,500 points at the beginning of 2008 to 2,095 points at the end of 2008. At the beginning of July 2011 the index stood at 2,107 points and the market capitalisation of the 30-PPVX companies[4] was € 36,4 billion.

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

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

Market predictions for the 2011 PV market vary between 17.3 GW by the Navigant Consulting conservative scenario [Min 2011], 19.6 GW by Macquarie [Mer 2011] and 24.9 GW by iSuppli [iSu 2011], with a consensus value in the 18 to 19 GW range. Massive capacity increases are underway or announced and if all of them are realised, the world-wide production capacity for solar cells would exceed 80 GW at the end of 2012. This indicates that even with the optimistic market growth expectations, the planned capacity increases are way above the market growth. The consequence would be the continuation of the low utilisation rates and therefore a continued price pressure in an oversupplied market. Such a development will accelerate the consolidation of the photovoltaics industry and spur more mergers and acquisitions.

The current solar cell technologies are well established and provide a reliable product, with sufficient efficiency and energy output for at least 25 years of lifetime. This reliability, the increasing potential of electricity interruption from grid overloads, as well as the rise of electricity prices from conventional energy sources, add to the attractiveness of photovoltaic systems.

About 80% of the current production uses wafer-based crystalline silicon technology. A major advantage of this technology is that complete production lines can be bought, installed and be up and producing within a relatively short time-frame. This predictable production start-up scenario constitutes a low-risk placement with calculable return on investments. However, the temporary shortage in silicon feedstock and the market entry of companies offering turn-key production lines for thin-film solar cells led to a massive expansion of investments into thin-film capacities between 2005 and 2009. More than 200 companies are involved in the thin-film solar cell production process ranging from R&D activities to major manufacturing plants.

[2] Exchange rate: 1 € = 1.30 US$

Projected silicon production capacities available for solar in 2012 vary between 250,000 metric tons [Ber 2010] and 396,650 metric tons [Ikk 2011]. The possible solar cell production will in addition depend on the material used per Wp. Material consumption could decrease from the current 7 to 8 g/Wp down to 5 to 6 g/Wp, but this might not be achieved by all manufacturers.

Similar to other technology areas, new products will enter the market, enabling further cost reduction. Concentrating Photovoltaics (CPV) is an emerging market. There are two main tracks – either high concentration > 300 suns (HCPV), or low to medium concentration with a concentration factor of 2 to approx. 300. In order to maximise the benefits of CPV, the technology requires high Direct Normal Irradiation (DNI) and these areas have a limited geographical range – the "Sun Belt" of the Earth. The market share of CPV is still small, but an increasing number of companies are focusing on CPV. In 2008 about 10 MW of CPV were produced, market estimates for 2010 are in the 10 to 20 MW range and for 2011 about 100 to 200 MW are expected. In addition, dye-cells are getting ready to enter the market as well. The growth of these technologies is accelerated by the positive development of the PV market as a whole.

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

- Continuation to expand solar grade silicon production capacities in line with solar cell manufacturing capacities;
- Accelerated reduction of material consumption per silicon solar cell and Wp, e.g. higher efficiencies, thinner wafers, less wafering losses, etc.;
- Accelerated ramp-up of thin-film solar cell manufacturing;
- Accelerated CPV introduction into the market, as well as capacity growth rates above the normal trend.

Further photovoltaic system cost reductions will depend not only on the technology improvements and scale-up benefits in solar cell and module production, but also on the ability to decrease the system component costs, as well as the whole installation, projecting, operation, permitting and financing costs.

2. The Photovoltaic Market

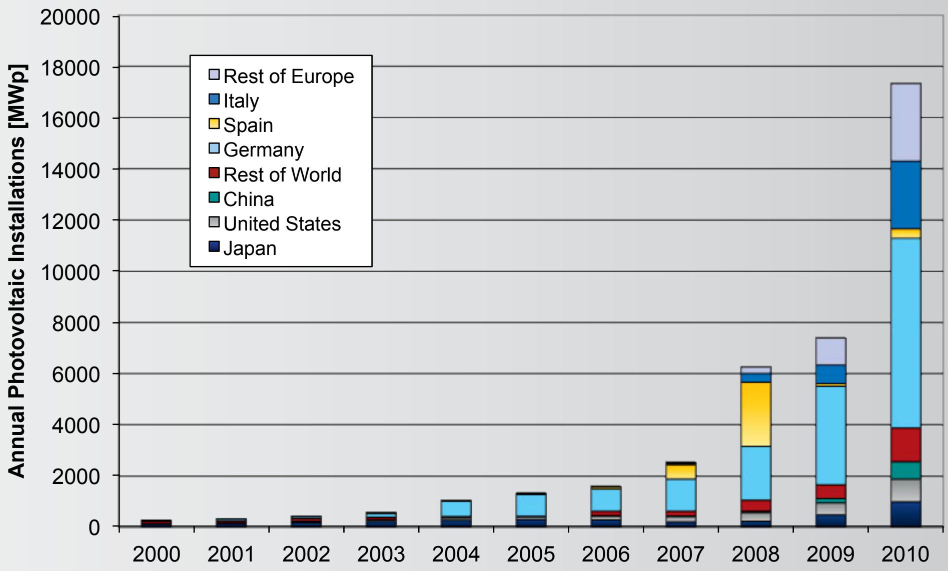
In 2010, the world-wide photovoltaic market more than doubled, driven by major increases in Europe. For 2010 the market volume of newly installed solar photovoltaic electricity systems varies between 17 and 19 GW, depending on the reporting consultancies (Fig.2). This represents mostly the grid-connected photovoltaic market. To what extent the off-grid and consumer product markets are included is not clear, but it is believed that a substantial part of these markets are not accounted for, as it is very difficult to track them. A conservative estimate is that they account for approx. 400 to 800 MW (approx. 1-200 MW off-grid rural, approx. 1-200 MW communication/signals, approx. 100 MW off-grid commercial and approx. 1-200 MW consumer products).

With a cumulative installed capacity of over 29 GW, the European Union is leading in PV installations with a little more than 70% of the total world-wide 39 GW of solar photovoltaic electricity generation capacity at the end of 2010.

2.1 Asia & Pacific Region

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

Fig. 2: Annual Photovoltaic Installations from 2000 to 2010 (data source: EPIA [Epi 2011], Eurobserver [Sys 2011] and own analysis)



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

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

The Asian Development Bank (ADB) launched an Asian Solar Energy Initiative (ASEI) in 2010, which should lead to the installation of 3 GW of solar power by 2012 [ADB 2011]. In their report, ADB states: *Overall, ASEI aims to create a virtuous cycle of solar energy investments in the region, toward achieving grid parity, so that ADB developing member countries optimally benefit from this clean, inexhaustible energy resource.*

Three interlinked components will be used to realise the ASEI target:

Knowledge management: Development of a regional knowledge platform dedicated to solar energy in Asia and the Pacific.

Project development: ADB will provide $ 2.2[5] billion5 (€ 1.73 billion) to finance the project development, which is expected to leverage an additional $ 6.75 billion (€ 5.19 billion) in solar power investments over the period.

Innovative finance instruments: A separate and targeted Asia Accelerated Solar Energy Development Fund is set up to mitigate risks associated with solar energy. The fund will be used for a *buy down* programme to reduce the up-front costs of solar energy for final customers. ADB aims to raise $ 500 million (€ 385 million) and design innovative financing mechanisms in order to encourage commercial banks and the private sector to invest in solar energy technologies and projects.

Innovative finance instruments: Setting up of a separate and targeted Asia Accelerated Solar Energy Development Fund to mitigate risks associated with solar energy and buy down the up-front costs of solar energy. ADB aims to raise $ 500 million (€ 385 million) and design innovative financing mechanisms in order to encourage commercial banks and the private sector to invest in solar energy technologies and projects.

2.1.1 Australia

In 2010, 383 MW of new solar photovoltaic electricity systems were installed in Australia, bringing the cumulative installed capacity of grid-connected PV systems to 571 MW [Apv 2011]. The 2010 market was dominated by the increase of grid-connected distributed systems, which increased from 67 MW in 2009 to 378 MW in 2010. The newly installed PV electricity generation capacity in Australia accounted for 20% of the new electricity generation capacity in 2010.

Most installations took advantage of the incentives under the Australian Government's Solar Homes and Communities Plan (SHCP), Renewable Energy Target (RET) mechanisms and feed-in tariffs in some States or Territories. At the beginning of 2010, eight out of the eleven Australian Federal States and Territories had introduced some kind of feed-in tariff scheme for systems smaller than 10 kWp. All of these schemes have built-in caps which were partly reached that year so that in 2011 only five State schemes are still available for new installations and additional changes are expected in the course of this year.

2.1.2 India

For 2010, market estimates for solar PV systems vary between 50 to 100 MW, but most of these capacities are for off-grid applications. The Indian National Solar Mission was launched in January 2010, and it was hoped that it would give impetus to the grid-connected market, but only a few MW were actually installed in 2010. The majority of the projects announced will come on-line from 2011 onwards.

The National Solar Mission aims to make India a global leader in solar energy and envisages an installed solar generation capacity of 20 GW by 2020, 100 GW by 2030 and 200 GW by 2050. The short-term outlook up until 2013 was improved as well when the original 50 MW grid-connected PV system target in 2012 was changed to 1,000 MW for 2013.

2.1.3 Japan

In 2010, the Japanese market experienced a high growth, doubling its volume to 990 MW, bringing the cumulative installed PV capacity to 3.6 GW. In 2009 a new investment incentive of ¥ 70,000 per kW for systems smaller than 10 kW, and a new surplus power purchase scheme, with a purchase price of ¥ 48 per kWh for systems smaller than 10 kW, was introduced and the start of the discussion about a wider feed-in tariff.

In April 2011, METI (Ministry for Economy, Trade and Industry) announced a change in the feed-in tariffs and increased the tariff for commercial installations from ¥ 20 to 40 per kWh and decreased the tariff for residential installations to ¥ 42 per kWh.

[5] Exchange rate: 1 € = 1.30 $

As a consequence of the accident at the Fukujima Daiichi Nuclear Power Plant, Prime Minister Naoto Kan announced an overall review of the country's Basic Energy Plan. At the G8 Summit held in Deauville, France, on 26 May 2011, he announced that Japan plans to increase the share of renewable energy in total electricity supply to over 20% in the 2020s. One measure to achieve this goal is to install a PV system on some 10 million houses suitable for it.

2.1.4 People's Republic of China

The 2010 Chinese PV market estimates are between 530 to 690 MW, bringing the cumulative installed capacity to about 1 GW. This is a significant increase from the 160 MW in 2009, but still only 5 to 7 % of the total photovoltaic production. This situation will change because of the revision of the PV targets for 2015 and 2020. According to press reports, the National Energy Administration doubled its capacity target for installed photovoltaic electricity systems to 10 GW in 2015 and further up to 50 GW in 2020 [Reu 2011].

According to the 12th Five-Year Plan, which was adopted on 14 March 2011, China intends to cut its carbon footprint and be more energy efficient. The targets are 17% less carbon dioxide emissions and 16% less energy consumption unit of GDP. The total investment in the power sector under the 12th Five-Year Plan is expected to reach $ 803 billion (€ 618 billion), divided into $ 416 billion (€ 320 billion), or 52 %, for power generation, and $ 386 billion (€ 298 billion) to construct new transmission lines and other improvements to China's electrical grid.

Renewable, clean, and nuclear energy are expected to contribute to 52 % of the increase and it is planned to increase power generation capacity from non-fossil fuels to 474 GW by 2015.

The investment figures necessary are in-line with a World Bank report stating that China needs an additional investment of $ 64 billion (€ 49.2 billion) annually over the next two decades to implement an "energy-smart" growth strategy [WoB 2010]. However, the reductions in fuel costs through energy savings could largely pay for the additional investment costs according to the report. At a discount rate of 10 %, the annual net present value (NPV) of the fuel cost savings from 2010 to 2030 would amount to $145 billion (€ 111.5 billion), which is about $ 70 billion (€ 53.8 billion) more than the annual NPV of the additional investment costs required.

2.1.5 South Korea

In 2010, about 180 MW of new PV systems were installed in South Korea, about the same as the year before, bringing the cumulative capacity to a total of 705 MW. The Korean PV industry expects a moderate increase for 2011, due to the fact that the feed-in tariff scheme is in its final year and the Korean Government continues its "One Million Green Homes" Project, as well as other energy projects in the provinces. The implementation of the Renewable Portfolio Standard in 2012 has additional consequences, as systems will need to be installed by the end of 2011 to generate electricity.

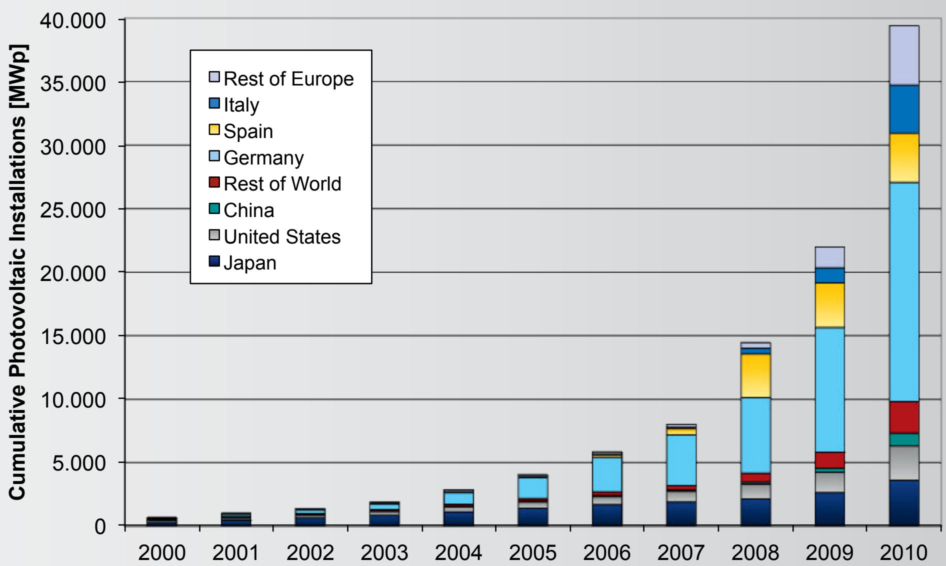


Fig. 3: Cumulative Photovoltaic Installations from 2000 to 2009 (data source: EPIA [Epi 2010], Eurobserver [Sys 2010] and own analysis)

In January 2009, the Korean Government had announced the Third National Renewable Energy Plan, under which renewable energy sources will steadily increase their share of the energy mix between now and 2030. The Plan covers such areas as investment, infrastructure, technology development and programmes to promote renewable energy. The new Plan calls for a renewable energies share of 4.3% in 2015, 6.1% in 2020 and 11% in 2030.

2.1.6 Taiwan

In June 2009, the Taiwan Legislative Yuan gave its final approval to the Renewable Energy Development Act, a move that is expected to bolster the development of Taiwan's green energy industry. The new law authorises the Government to enhance incentives for the development of renewable energy via a variety of methods, including the acquisition mechanism, incentives for demonstration projects and the loosening of regulatory restrictions. The goal is to increase Taiwan's renewable energy generation capacity by 6.5 GW to a total of 10 GW within 20 years. In January 2011, the Ministry of Economic Affairs (MOEA) announced the revised feed-in tariffs for 2011. In 2011, the price paid by the state-owned monopoly utility, Taiwan Power, will fell 30% from 11.12 NT$[6]/kWh (0.264 €/kWh) to 7.33 NT$/kWh per kWh (0.175 €/kWh) for solar installations, with an exception for rooftop installations which are eligible for rates of 10.32 NT$/kWh (0.246 €/kWh).

Despite the favourable feed-in tariff, the total installed capacity at the end of 2010 was only between 19 and 20 MW and the annual installation of about 7 to 8 MW was far less than 1% of the 3.2 GW solar cell production in Taiwan that year.

2.1.7 Thailand

Thailand enacted a 15-year Renewable Energy Development Plan (REDP) in early 2009, setting the target to increase the Renewable Energy share to 20% of final energy consumption of the country in 2022. Besides a range of tax incentives, solar photovoltaic electricity systems are eligible for a feed-in premium or "Adder" for a period of 10 years. However, there is a cap of 500 MW eligible for the original 8 THB[7]/kWh (0.182 €/kWh) "Adder" (facilities in the 3 Southern provinces and those replacing diesel systems are eligible for an additional 1.5 THB/kWh (0.034 €/kWh)), which was reduced to 6.5 THB/kWh (0.148 €/kWh) for those projects not approved before 28 June 2010.

As of October 2010, applications for 1.6 GW, under the Very Small Power Producer Programme (VSPP), and 477 MW, under the Small Power Producer Programme (SPP), were submitted. In 2010 it is estimated that between 20 and 30 MW were actually added, increasing the total cumulative installed capacity to 60 to 70 MW.

2.1.8 Emerging Markets

- **Bangladesh:** In 1997, the Government of Bangladesh established the Infrastructure Development Company Limited (IDCOL) to promote economic development in Bangladesh. In 2003, IDCOL started its Solar Energy Programme to promote the dissemination of solar home systems (SHS) in the remote rural areas of Bangladesh, with the financial support from the World Bank, the Global Environment Facility (GEF), the German Kreditanstalt für Wiederaufbau (KfW), the German Technical Cooperation (GTZ), the Asian Development Bank and the Islamic Development Bank. Since the start of the programme, more than 950,000 SHS, with an estimated capacity of 39 MW, have been installed in Bangladesh by May 2011.
  According to a press report, the Government plans to implement a mega project of setting up 500 MW of PV electrical power generation and the Asian Development Bank (ADB) has, in principal, agreed to provide financial support to Bangladesh for implementing the project within the framework of the Asian Solar Energy Initiative [Dai 2011, Unb 2011].

- **Indonesia:** The development of renewable energy is regulated in the context of the national energy policy by Presidential Regulation No.5/2006 [RoI 2006]. The decree states that 11% of the national primary energy mix in 2025 should come from renewable energy sources. The target for solar PV is 870 MW by 2024. At the end of 2010 about 20 MW of solar PV systems were installed, mainly for rural electrification purposes.

- **Malaysia:** The Malaysia Building Integrated Photovoltaic (BIPV) Technology Application Project was initiated in 2000 and at the end of 2009 a cumulative capacity of about 1 MW of grid-connected PV systems has been installed.
  The Malaysian Government officially launched their GREEN Technology Policy in July 2009 to encourage and promote the use of renewable energy for Malaysia's future sustainable development. By 2015, about 1 GW must come from Renewable Energy Sources according to the Ministry of Energy, Green Technology and Water (KETHHA). The Malaysian Photovoltaic Industry Association (MPIA) proposed a five-year programme to increase the share of electricity generated by photovoltaic systems to 1.5% of the national

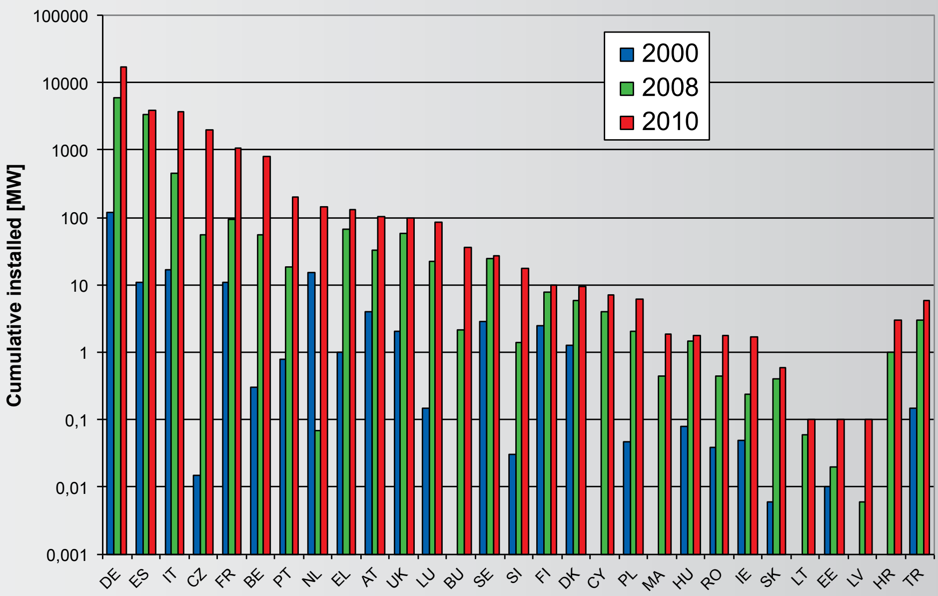
[6] Exchange Rate 1 € = 42 NT$
[7] Exchange Rate 1 € = 44 THB

demand by 2015. This would translate into 200 MW grid-connected and 22 MW of grid systems. In the long-term beyond 2030, MPIA is calling for a 20% PV share. Pusat Tenaga Malaysia (PTM), and its IEA international consultant, estimated that 6,500 MW power can be generated by using 40% of the nation's house rooftops (2.5 million houses) and 5% of commercial buildings alone. To realise such targets, a feed-in tariff is still under discussion and it is hoped to be under way in the second half of 2011.
First Solar (USA), Q Cells (Germany) and Sunpower (USA) have started to set up manufacturing plants in Malaysia, with a total investment of RYM 12 billion (€ 2.80 billion[8]) and more than 2 GW of production capacities. Once fully operational, these plants will provide 11,000 jobs and Malaysia will be the world's sixth largest producer of solar cells and modules.

- **The Philippines:** The Renewable Energy Law was passed in December 2008 [RoP 2008]. Under the Law, the Philippines has to double the energy derived from Renewable Energy Sources within 10 years. On 14 June 2011, Energy Secretary, Rene Almendras. unveiled the new Renewable Energy Roadmap, which aims to increase the share of renewables to 50% by 2030. The programme will endeavour to boost renewable energy capacity from the current 5.4 GW to 15.4 GW by 2030.
Early 2011, the country's Energy Regulator National Renewable Energy Board (NREB) has recommended a target of 100 MW of solar installations that will be constructed in the country over the next three years.
A feed-in tariff of 17 PHP/kWh (0.283 €/kWh)[8] was suggested, to be paid from January 2012 on. The initial period of the programme is scheduled to end on 31 December 2014.
At the end of 2010, about 10 MW of PV systems were installed, mainly off-grid.
SunPower has two cell manufacturing plants outside of Manila. Fab. No 1 has a nameplate capacity of 108 MW and Fab. No 2 adds another nameplate capacity of 466 MW.

- **Vietnam:** In December 2007, the National Energy Development Strategy of Vietnam was approved. It gives priority to the development of renewable energy and includes the following targets: increase the share of renewable energies from negligible to about 3% (58.6 GJ) of the total commercial primary energy in 2010, to 5% in 2020, 8 % (376.8 GJ) in 2025, and 11 % (1.5 TJ) in 2050.
The Indochinese Energy Company (IC Energy) broke ground for the construction of a thin-film solar panel factory with an initial capacity of 30 MW and a final capacity of 120 MW in the central coastal Province of Quang Nam on 14 May 2011.
In March 2011, First Solar broke ground on its four-line photovoltaic module manufacturing plant (250 MW) in the Dong Nam Industrial Park near Ho Chi Minh City.

Fig. 4: Cumulative installed grid-connected PV capacity in EU + CC
Note that the installed capacities do not correlate with solar resources.



[8] Exchange rate: 1 € = 4,29 MYR
Exchange rate: 1 € = 60 PHP

2.2 Europe and Turkey

Market conditions for photovoltaics differ substantially from country to country. This is due to different energy policies and public support programmes for renewable energies and especially photovoltaics, as well as the varying grades of liberalisation of domestic electricity markets. Within one decade, the solar photovoltaic electricity generation capacity has increased 160 times from 185 MW in 2000 to 29.5 GW in 2010 (Fig. 4) [Bun 2011, Epi 2011, Ges 2011, Sys 2011].

A total of about 58.8 GW of new power capacity was constructed in the EU last year and 2.5 GW were decommissioned, resulting in 56.3 GW of new net capacity (Fig. 5) [Ewe 2011, Sys 2011]. Gas-fired power stations accounted for 28.3 GW, or 48% of the newly installed capacity. However, in the recent years about 30 GW of additional gas-fired power station projects were suspended or cancelled according to Platts [Pla 2011]. Solar photovoltaic systems moved to the second place with 13.5 GW (23%), followed by 9.4 GW (16%) wind power; 4.1 GW (7%) MW coal-fired power stations; 570 MW (> 1%) biomass; 450 MW (> 1%) CSP, 210 MW (> 1%) hydro, 230 MW (> 1%) peat and 150 MW (> 1%) waste. The net installation capacity for oil-fired and nuclear power plants was negative, with a decrease of 245 MW and 390 MW respectively. The renewable share of new power installations was 40% in 2010.

2.2.1 Belgium

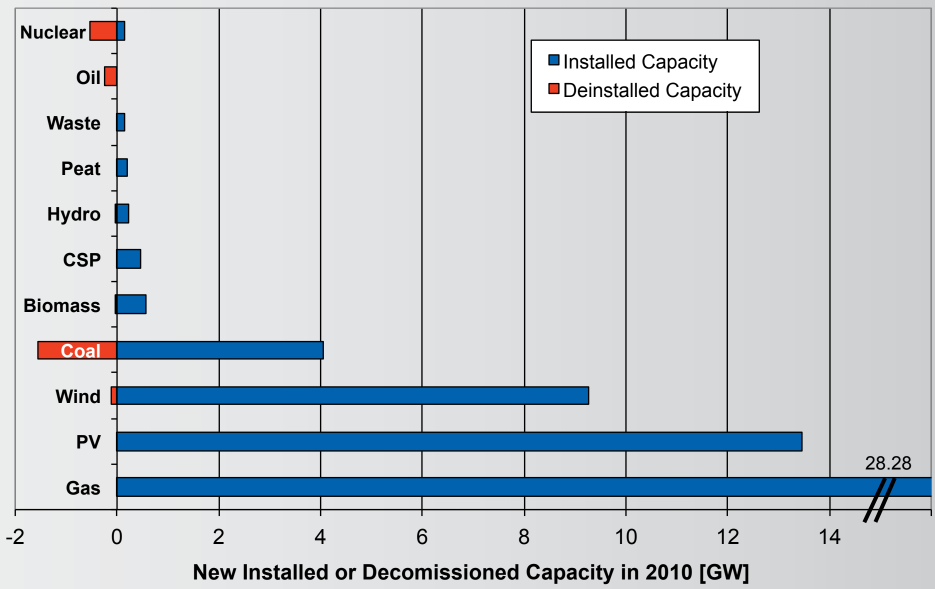
Belgium showed another strong market performance year in 2010, with new photovoltaic system installations of 420 MW bringing the cumulative installed capacity to 790 MW. However, most of the installations were done in Flanders, where since 1 January 2006 Green Certificates exist with 0.45 €/kWh for 20 years. In Brussels and Wallonia, the Green Certificates have a guaranteed minimum price between 0.15 – 0.65 €/kWh, depending on the size of the systems and region (Brussels 10 years, Wallonia 15 years).

2.2.2 Czech Republic

In the Czech Republic, photovoltaic systems with about 1.5 GW capacity, were installed in 2010, bringing the cumulative nominal capacity to 1.95 GW exceeding their own target of 1.65 GW set in the National Renewable Action Plan for 2020. The Law on the Promotion of Production of Electricity from Renewable Energy Sources went into effect on 1 August 2005 and guarantees a feed-in tariff for 20 years. The annual prices are set by the Energy Regulator. The electricity producers can choose from two support schemes, either fixed feed-in tariffs or market price + Green Bonus. The 2010 feed-in rate in the Czech Republic was CZK[9] 12.25 per kilowatt hour (0.48 €/kWh).

On 3 February 2010, the Czech transmission system operator, EPS, requested all main distribution system operators (EZ, E-ON, PRE) to stop permitting new renewable energy power plants, due to a virtual risk of instability of the electricity grid caused by intermittent renewable sources, especially photovoltaic and wind. Distribution System Operators (DSO) met the requirement on 16 February 2011. The moratorium still exists and SRES (Czech Association of Regulated Energy Companies) announced that the moratorium will continue until at least September.

Fig. 5: New installed or decommissioned electricity generation capacity in Europe in 2010



[9] Exchange Rate 1 € = 25.52 CZK

A number of legislative changes took place in the second half of the year, which resulted in a lower feed-in tariff for systems larger than 30 kW (5.5 CZK/kWh or 0.216 €/kWh), the phase-out of ground-mounted PV systems from 1 March 2011 onwards and the introduction of a retroactive tax on benefits generated by PV installations.

2.2.3 France

In 2010, 720 MW of PV systems were connected to the grid in France, including about 100 MW which were already installed in 2009. This led to an increase of the cumulative installed capacity to 1.05 GW. However, this positive development came to a sudden stop when the French Prime Minister declared a three-month moratorium on new PV installations above 3 kW and a suspension of projects waiting for grid connection in December 2010.

This rapid growth led to a revision of the feed-in scheme in February 2011, setting a cap of 500 MW for 2011 and 800 MW for 2012 [MEI 2011]. The new tariff levels only apply to rooftop systems up to 100 kW in size. In addition, those installations are divided into three different categories: residential; education or health; and other buildings with different feed-in tariffs, depending on the size and type of installation. The tariffs for these installations range between 0.2883 €/kWh and 0.46 €/kWh. All other installations up to 12 MW are just eligible for a tariff of 0.12 €/kWh.

2.2.4 Germany

Germany had the biggest market with 7.4 GW [Bun 2011]. The German market growth is directly correlated to the introduction of the Renewable Energy Sources Act or *"Erneuerbare Energien Gesetz"* (EEG) in 2000 [EEG 2000]. This Law introduced a guaranteed feed-in tariff for electricity generated from solar photovoltaic systems for 20 years and already had a fixed built in annual decrease, which was adjusted over time to reflect the rapid growth of the market and the corresponding price reductions. Due to the fact that until 2008 only estimates of the installed capacity existed, a plant registrar was introduced from 1 January 2009 on.

The German market showed two installation peaks during 2010. The first one was in June, when more than 2.1 GW were connected to the grid prior to the 13% feed-in cut which took effect on 1 July 2010. The second peak was in December with almost 1.2 GW just before the scheduled tariff reduction of another 13% on 1 January 2011. Compared to 2009, the feed-in tariff has been reduced by 33 to 36% depending on the system size and classification. In June 2011 the Bundesnetzagentur (German Federal Network Agency) announced the results of the PV system installation projection required under the Renewable Energy Sources Act (EEG) in order to determine the degression rates for the feed-in tariffs [Bun 2011a]. According to the Agency approx. 700 MW of PV systems were commissioned between March and May 2011 resulting in a projected annual growth of 2.8 GW, which is below the 3.5 GW threshold set for an additional reduction of the tariffs starting July 2011.

2.2.5 Greece

Greece introduced a new feed-in tariff scheme on 15 January 2009. The tariffs remained unchanged until August 2010 and are guaranteed for 20 years. However, if a grid-connection agreement was signed before that date, the unchanged FIT was applied if the system is finalised within the next 18 months. For small rooftop PV systems, an additional programme was introduced in Greece on 4 June 2009. This programme covers rooftop PV systems up to 10 kWp (both for residential users and small companies). In 2011, the tariffs decreased by 6.8% to 8.5%, depending on the size and location of the installation. In 2010, about 150 MW of new installations were carried out, bringing the total capacity to about 205 MW.

2.2.6 Italy

Italy again took the second place, with respect to new installations and added a capacity of about 2.5 GW, bringing cumulative installed capacity to 3.7 GW at the end of 2010 [Ges 2011]. At the beginning of July 2011, the total connected PV capacity has surpassed 7 GW [Gse 2011a]. The *Quarto Conto Energia* (Fourth Energy Bill) was approved by the Italian Council of Ministers on 5 May 2011 [Gaz 2011]. The Bill introduced monthly reductions of the tariffs, starting from June 2011 until January 2012 and then another one in July 2012. In addition, the new Bill limits the feed-in tariffs for new systems up until the end of 2016, or until a cap of 23 GW is reached. In addition, separate caps for large systems are set for the second half of 2011 (1.35 GW) and 2012 (1.75 GW).

2.2.7 Spain

Spain is second regarding the total cumulative installed capacity with 3.9 GW. Most of this capacity was installed in 2008 when the country was the biggest market, with close to 2.7 GW in 2008 [Epi 2011]. This was more than twice the expected capacity and was due to an exceptional race to install systems before the Spanish Government introduced a cap of on the yearly installations in the autumn of 2008. Royal Decree 1758/2008 set considerably lower feed-in tariffs for new systems and limited the annual market to 500 MW, with the provision that two thirds are rooftop mounted and no longer free-field systems. These changes resulted in a new installed capacity of about

100 MW in 2009 and about 380 MW in 2010.
In 2010, the Spanish Government passed the Royal Decrees 1565/10 [GoS 2010] and RD-L 14/10 [GoS 2010a]. The first one limits the validity of the feed-in tariffs to 28 years, while the latter reduces the tariffs by 10% and 30% for existing projects until 2014. Both Bills are "retroactive" and the Spanish Solar Industry Association (ASIF) [Asi 2011] has already announced taking legal actions against them.

2.2.8 United Kingdom

The United Kingdom introduced of a new feed-in tariff scheme in 2010, which led to the installation of approximately 55 MW, bringing the cumulative installed capacity to about 85 MW. However, in March 2011, the UK Government proposed significant reductions of the tariffs, especially for systems larger than 50 kW.

2.2.9 Other European Countries and Turkey

Despite high solar radiation, solar photovoltaic system installation in **Portugal** has only grown very slowly and reached a cumulative capacity of 130 MW at the end of 2010.
The market in **Slovakia** showed an unexpected growth from less than 1 MW installed at the end of 2009 to about 144 MW at the end of 2010. In December 2010, the Slovak Parliament adopted an Amendment to the Renewable Energy Sources (RES) Promotion Act, decreasing the feed-in tariffs and from 1 February 2011 on only solar rooftop facilities or solar facilities on the exterior wall of buildings, with capacity not exceeding 100 kW, are eligible for the feed-in tariff. As a result, larger new solar projects in Slovakia are on hold.

In **Turkey** in March 2010, the Energy Ministry unveiled its 2010 – 2014 Strategic Energy Plan. One of Government's priorities is to increase the ratio of renewable energy resources to 30 % of total energy generation by 2023.
At the beginning of 2011, the Turkish Parliament passed a Renewable Energy Legislation which defines new guidelines for feed-in tariffs. The feed-in tariff is 0.133 $/kWh (0.10 €/kWh) for owners commissioning a PV system before the end of 2015. If components *'Made in Turkey'* are used, the tariff will increase by up to $ 0.067 (€ 0.052), depending on the material mix. Feed-in tariffs apply to all types of PV installations, but large PV power plants will receive subsidies up to a maximum size of 600 MWp.

2.3 North America

2.3.1 Canada

In 2010, Canada more than tripled its cumulative installed PV capacity to about 420 MW, with 300 MW new installed systems. This development was driven by the introduction of a feed-in tariff in the Province of Ontario, enabled by the *"Bill 150, Green Energy and Green Economy Act, 2009"*. On the Federal level, only an accelerated capital cost allowance exists under the Income Tax Regulations. On a Province level, nine Canadian Provinces have Net Metering Rules, with solar photovoltaic electricity as one of the eligible technologies, Sales Tax Exemptions and *Renewable Energy Funds* exist in two Provinces and *Micro Grid Regulations* and *Minimum Purchase Prices* each exist in one Province.
The Ontario feed-in tariffs were set in 2009 and depend on the system size and type, as follows:

- Rooftop or ground-mounted ≤ 10 kW
  80.2 ¢/kWh (0.59 €/kWh[10])
- Rooftop > 10 kW ≤ 250 kW
  71.3 ¢/kWh (0.53 €/kWh)
- Rooftop > 250 kW ≤ 500 kW
  63.5 ¢/kWh (0.47 €/kWh)
- Rooftop > 500 kW
  53.9 ¢/kWh (0.40 €/kWh)
- Ground-mounted[11]* >10 kW ≤ 10 MW
  44.3 ¢/kWh (0.33 €/kWh)

The feed-in tariff scheme has a number of special rules, ranging from eligibility criteria, which limit the installation of ground-mounted PV systems on high-yield agricultural land to domestic content requirements and *additional "price adders" for Aboriginal and community-based projects.* Details can be found in the Feed-in Tariff Programme of the Ontario Power Authority [Ont 2009].

2.3.2 United States of America

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

PV projects with Power Purchase Agreements (PPAs), with a total capacity of 6.1 GW, are already under contract and to be completed by 2014 [Enf 2011]. If one adds those 10.5 GW of projects which are already publicly announced, but PPAs have yet to be signed, this make the total "pipeline" more than 16.6 GW.

[10] Exchange Rate 1 € = 1.35 CAD
[11] Eligible for Aboriginal or community adder

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 (such as tax credits). 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) gives information on State, local, utility, and selected Federal incentives that promote renewable energy ans lists all the different support schemes.

3. The Photovoltaic Industry

In 2010, the photovoltaic world market doubled in terms of **production** to 23 to 24 GW as well for installed systems where 16 to 18 GW 16 and 18 GW were reported by various consultancies and institutions. This mainly represents the grid-connected photovoltaic market. To what extent the off-grid and consumer-product markets are included is unclear. The difference of roughly 6 to 7 GW has therefore to be explained as a combination of unaccounted off-grid installations (approx. 1-200 MW off-grid rural, approx. 1-200 MW communication/signals, approx. 100 MW off-grid commercial), consumer products (ca. 1-200 MW) and cells/modules in stock.

In addition, the fact that some companies report shipment figures, whereas others report production figures, add to the uncertainty. The difficult economic conditions contributed to the decreased willingness to report confidential company data. Nevertheless, the figures show a significant growth of the production.

The announced production capacities, based on a survey of more than 350 companies world-wide, increased, even with difficult economic conditions. Despite the fact that a number of players announced a scale-back or cancellation of their expansion plans for the time being, the number of new entrants into the field, notably large semiconductor or energy-related companies overcompensated this. At least on paper the expected production capacities are increasing. Only published announcements of the respective companies and no third source info were used. The cut-off date of the info used was June 2011.

It is important to note that production capacities are often announced, taking into account different operation models, such as number of shifts, operating hours per year, etc. In addition, the announcements of the increase in production capacity do not always specify when the capacity will be fully ramped up and operational. This method has of course the setback that a) not all companies announce their capacity increases in advance and b) that in times of financial tightening, the announcements of the scale-back of expansion plans are often delayed, in order not to upset financial markets. Therefore, the capacity figures just give a trend, but do not represent final numbers.

If all these ambitious plans can be realised by 2015, China will have about 46.3% of the world-wide production capacity of 102 GW, followed by Taiwan (15.8%), Europe (9.5%) and Japan (6.9%) (Fig. 6).

All these ambitious plans to increase production capacities, at such a rapid pace, depend on the expectations that markets will grow accordingly. This, however, is the biggest uncertainty, as the market estimates for 2011 vary between 17 GW and 24 GW, with a consensus value in the 19 GW range. In addition, most markets are still dependent on public support in the form of feed-in tariffs, investment subsidies or tax-breaks.

Already now, electricity production from photovoltaic solar systems has shown that it can be cheaper than peak prices in the electricity exchange. In the second quarter of 2011, the German average price index, for rooftop systems up to 100 kWp, was given with € 2,422 per kWp without tax or half the price of five years ago [Bsw 2011]. With such investment costs, the electricity generation costs are already at the level of residential electricity prices in some countries, depending on the actual electricity price and the local solar radiation level. But only if markets and competition continue to grow, prices of the photovoltaic systems will continue to decrease and make electricity from PV systems for consumers even cheaper than from conventional sources. In order to achieve the price reductions and reach grid-parity for electricity generated from photovoltaic systems, public support, especially on regulatory measures, will be necessary for the next decade.

3.1 Technology Mix

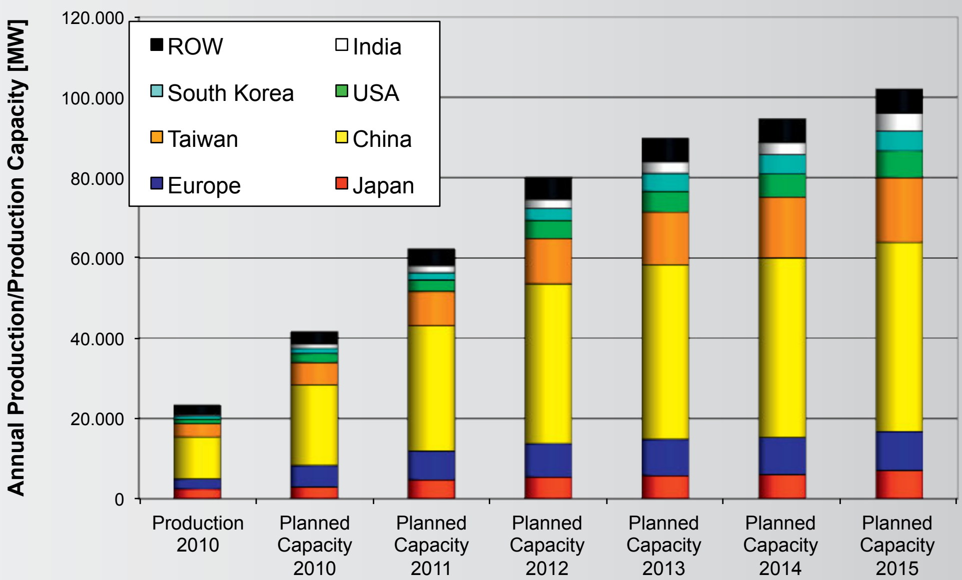
Wafer-based silicon solar cells is still the main technology and had around 85% market shares in 2010. Commercial module efficiencies are within a wide range between 12 and 20%, with monocrystalline modules between 14% – 20%, and polycrystalline modules between 12% – 17%. The massive manufacturing capacity increases for both technologies are followed by the necessary capacity expansions for polysilicon raw material.

More than 200 companies are involved in thin-film solar cell activities, ranging from basic R&D activities to major manufacturing activities and over 120 of them have announced the start or increase of production. In 2005, for the first time, production of thin-film solar modules reached more than 100 MW per annum. The first 100 MW thin-film factories became operational in 2007, followed by the first 1 GW factory in 2010. If all expansion plans are realised in time, thin-film production capacity could be 17 GW, or 21% of the total 80 GW in 2012 and 27 GW, or 26%, in 2015 of a total of 102 GW (Fig. 7).

One should bear in mind that only one third of the over 120 companies, with announced production plans, have produced thin-film modules of 10 MW or more in 2010.

More than 70 companies are silicon-based and use either amorphous silicon or an amorphous/microcrystalline silicon structure. Thirty-six companies announced using

Fig. 6: World-wide PV Production 2010 with future planned production capacity increases



$Cu(In,Ga)(Se,S)_2$ as absorber material for their thin-film solar modules, whereas nine companies use CdTe and eight companies go for dye and other materials.

Concentrating Photovoltaics (CPV) is an emerging technology which is growing at a very high pace, although from a low starting point. Over 50 companies are active in the field of CPV development and almost 60% of them were founded in the last five years. Over half of the companies are located either in the United States of America (primarily in California) and Europe (primarily in Spain).

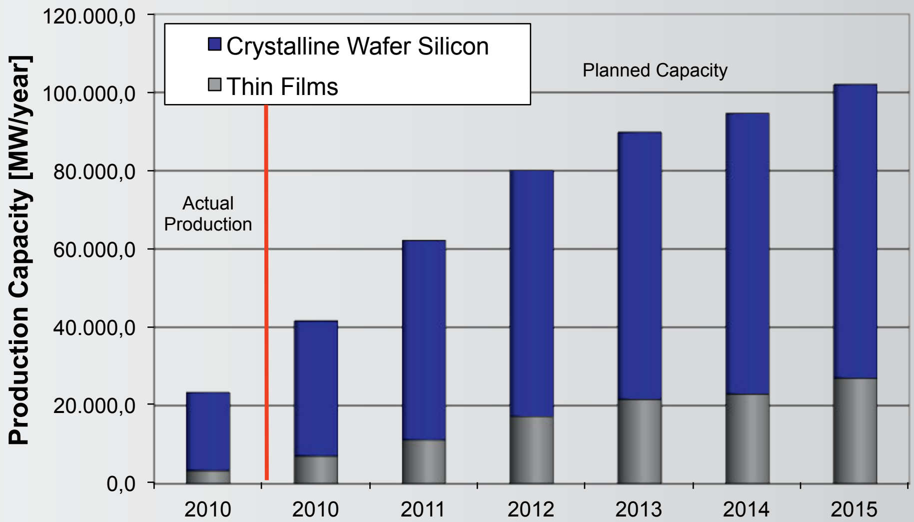
Within CPV there is a differentiation according to the concentration factors[12] and whether the system uses a dish (Dish CPV) or lenses (Lens CPV). The main parts of a CPV system are the cells, the optical elements and the tracking devices. The recent growth in CPV is based on significant improvements in all of these areas, as well as the system integration. However, it should be pointed out that CPV is just at the beginning of an industry learning curve, with a considerable potential for technical and cost improvements. The most challenging task is to become cost-competitive with other PV technologies quickly enough, in order to use the window of opportunities for growth.

With market estimates for 2010 in the 10 to 20 MW range, the market share of CPV is still small, but analysts forecast an increase to more than 1,000 MW globally by 2015. At the moment, the CPV pipeline is dominated by just three system manufacturers: Concentrix Solar, Amonix, and SolFocus.

The existing photovoltaic technology mix is a solid foundation for future growth of the sector as a whole. No single technology can satisfy all the different consumer needs, ranging from mobile and consumer applications, with the need for a few watts to multi MW utility-scale power plants. The variety of technologies is an insurance against a roadblock for the implementation of solar photovoltaic electricity if material limitations or technical obstacles restrict the further growth or development of a single technology pathway.

[12] High concentration > 300 suns (HCPV), medium concentration 5 < x < 300 suns (MCPV), low concentration < 5 suns (LCPV).

Fig. 7: Annual PV Production capacities of Thin-Film and Crystalline Silicon based solar modules.



3.2 Solar Cell Production[13] Companies

World-wide, more than 350 companies produce solar cells. The following chapter gives a short description of the 20 largest companies, in terms of actual production/shipments in 2010. More information about additional solar cell companies and details can be found in various market studies and in the country chapters of this report. The capacity, production or shipment data are from the annual reports or financial statements of the respective companies or the cited references.

3.2.1 Suntech Power Co. Ltd. (PRC)

Suntech Power Co. Ltd. (www.suntech-power.com) 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. For 2010, Suntech reported shipments of 1,507 MW, taking the top rank amongst the solar cell manufacturers. The annual production capacity of Suntech Power was increased to 1.8 GW by the end of 2010, and the company plans to expand its capacity to 2.4 GW in 2011.

3.2.2 JA Solar Holding Co. Ltd. (PRC)

JingAo Solar Co. Ltd. (www.jasolar.com) was established in May 2005 by the Hebei Jinglong Industry and Commerce Group Co. Ltd., the Australia Solar Energy Development Pty. Ltd. and Australia PV Science and Engineering Company. Commercial operation started in April 2006 and the company went public on 7 February 2007. According to the company, the production capacity should increase from 1.9 GW at the end of 2010 to 2.5 GW in 2011. For 2010, shipments of 1,460 MW are reported.

3.2.3 First Solar LLC. (USA/Germany/Malaysia)

First Solar LLC (www.firstsolar.com) is one of the few companies world-wide to produce CdTe-thin-film modules. The company has currently three manufacturing sites in Perrysburg (USA), Frankfurt/Oder (Germany) and in Kulim (Malaysia), which had a combined capacity of 1.5 GW at the end of 2010. The second Frankfurt/Oder plant, doubling the capacity there to 512 MW, became operational in May 2011 and the expansion in Kulim is on track to increase the production capacity to 2.3 GW at the end of 2011. Further expansions are under way in Meze (AZ), USA, and Dong Nam Industrial Park, Vietnam, to increase the production capacity to 2.9 GW at the end of 2012. The new factory planned in the framework of a joint venture with EdF Nuovelles in France is currently on hold. In 2010, the company produced 1.4 GW and currently sets the production cost benchmark with 0.75 $/Wp (0.58 €/Wp) in the first quarter of 2011.

3.2.4 Sharp Corporation (Japan/Italy)

Sharp (www.sharp-world.com) started to develop solar cells in 1959 and commercial production got under way 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.
In 2010, Sharp had a production capacity of 1,070 MWp/year, and shipments of 1.17 GW were reported [Ikk 2011]. Sharp has two solar cell factories in Japan, Katsuragi, Nara Prefecture, (550 MW c-Si and 160 MW a-Si their triple-junction thin-film solar cell) and Osaka (200 MW c-Si and 160 MW a-Si), one together with Enel Green Power and ST-Microelectronics in Catania, Italy (initial capacity 160 MW at the end of 2011), six module factories and the Toyama factory to recycle and produce silicon. Three of the module factories are outside Japan, one in Memphis, Tennessee, USA with 100 MW capacity, one in Wrexham, UK, with 500 MW capacity and one in Nakornpathom, Thailand.

3.2.5 Trina Solar Ltd, PRC (PRC)

Trina Solar (www.trinasolar.com) was founded in 1997 and went public in December 2006. The company has integrated product lines, from ingots to wafers and modules.
In December 2005, a 30 MW monocrystalline silicon wafer product line went into operation. According to the company, the production capacity was 750 MW for ingots and wafers and 1.2 GW for cells and modules at the end of 2010.
For 2011, it is planned to expand the capacities to 1.2GW for ingots and wafers and to 1.9 GW for cells and modules.
For 2010, shipments of 1.06 GW were reported.
In January 2010, the company was selected by the Chinese Ministry of Science and Technology to establish a State Key Laboratory to develop PV technologies within the Changzhou Trina PV Industrial Park. The laboratory is established as a national platform for driving PV technologies in China. Its mandate includes research into PV-related materials, cell and module technologies and system-level performance. It will also serve as a platform to bring together technical capabilities from the company's strategic partners, including customers and key PV component suppliers, as well as universities and research institutions.

[13] **Solar cell production capacities mean:**
- In the case of wafer silicon based solar cells, only the cells
- In the case of thin-films, the complete integrated module
- Only those companies which actually produce the active circuit (solar cell) are counted
- Companies which purchase these circuits and make cells are not counted.

3.2.6 Yingli Green Energy Holding Company Ltd. (PRC)
Yingli Green Energy (www.yinglisolar.com/) went public on 8 June 2007. The main operating subsidiary, Baoding Tianwei Yingli New Energy Resources Co. Ltd., is located in the Baoding National High-New Tech Industrial Development Zone. The company deals with the whole set, from solar wafers, cell manufacturing and module production. According to the company, production capacity reached 1 GW in July 2010. A further expansion project to 1.7 GW is ongoing and should be operational at the end of 2011. The financial statement for 2010 gave shipments of 1.06GW.
In January 2009, Yingli acquired Cyber Power Group Limited, a development stage enterprise designed to produce polysilicon. Through its principle operating subsidiary, Fine Silicon, the company started trial production of solar-grade polysilicon in late 2009 and is expected to reach its full production capacity of 3,000 tons per year by the end of 2011.
In January 2010, the Ministry of Science and Technology of China approved the application to establish a national-level key laboratory in the field of PV technology development, the State Key Laboratory of PV Technology at Yingli Green Energy's manufacturing base in Baoding.

3.2.7 Q-Cells AG (Germany/Malaysia)
Q-Cells SE (www.qcells.de) was founded at the end of 1999 and is based in Thalheim, Sachsen-Anhalt, Germany. Solar cell production started in mid 2001, with a 12 MWp production line. In the 2010 Annual Report, the company stated that the nominal capacity was 1.1 GW by the end of 2010, 500 MW in Germany and 600 MW in Malaysia. In 2010, production was 936 MW, 479 MW in Germany and 457 MW in Malaysia.
In the first half of the last decade, Q-Cells broadened and diversified its product portfolio by investing in various other companies, or forming joint ventures. Since the first half of 2009, Q-Cells has sold most of these holdings and now has one fully-owned solar cell manufacturing subsidiary, Solibro (CIGS) with a 2010 production of 75 MW.

3.2.8 Motech Solar (Taiwan/PRC)
Motech Solar (www.motech.com.tw) 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 850 MW in 2010. In 2009, Motech started the construction of a factory in China which should reach its nameplate capacity of 500 MW in 2011. Production capacity at the end of 2010 was given as 1.2 GW (860 MW in Taiwan and 340 MW in China).
In 2007, Motech Solar's Research and Development Department was upgraded to Research and Development Centre (R&D Centre), with the aim not only to improve the present production processes for wafer and cell production, but to develop next generation solar cell technologies.
At the end of 2009, the company announced that it acquired the module manufacturing facilities of GE in Delaware, USA.

3.2.9 Gintech Energy Corporation (Taiwan)
Gintech (www.gintech.com.tw/) was established in August 2005 and went public in December 2006. Production at Factory Site A, Hsinchu Science Park, began in 2007 with an initial production capacity of 260MW and increased to 930 MW at the end of 2010. The company plans to expand capacity to 1.5GW in 2011. In 2010, the company had a production of 827 MW [Pvn 2011].

3.2.10 Kyocera Corporation (Japan)
In 1975, Kyocera (www.global.kyocera.com/prdct/solar/) 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 started as the first Japanese company to sell home PV generation systems.
Besides the solar cell manufacturing plants in Japan, Kyocera has module manufacturing plants in China (joint venture with the Tianjin Yiqing Group (10% share) in Tianjin since 2003), Tijuana, Mexico (since 2004) and in Kadan, Czech Republic (since 2005).
In 2010, Kyocera had a production of 650 MW and is also marketing systems that both generate electricity through solar cells and exploit heat from the sun for other purposes, such as heating water. The Sakura Factory, Chiba Prefecture, is involved in everything from R&D and system planning to construction and servicing and the Shiga Factory, Shiga Prefecture, is active in R&D, as well as the manufacturing of solar cells, modules, equipment parts, and devices, which exploit heat. Like solar companies, Kyocera is planning to increase its current capacity of 650 MW in 2010 to 800 MW in 2011 and 1 GW in 2012.

3.2.11 SunPower Corporation (USA/Philippines/Malaysia)
SunPower (www.us.sunpowercorp.com/) was founded in 1988 by Richard Swanson and Robert Lorenzini to commercialise proprietary high-efficiency silicon solar cell technology. The company went public in November 2005. SunPower designs and manufactures high-performance silicon solar cells, based on an inter-digitated rear-contact design for commercial use. The initial products, introduced in 1992, were high-concentration solar cells with an efficiency of

26%. SunPower also manufactures a 22% efficient solar cell, called Pegasus, that is designed for non-concentrating applications.
SunPower conducts its main R&D activity in Sunnyvale, California, and has its cell manufacturing plant outside of Manila in the Philippines, with 590 MW capacity (Fab. No 1 and No 2). Fab. No. 3, a joint venture with AU Optronics Corporation (AUO), with a planned capacity of 1.4 GW, is currently under construction in Malaysia. Production in 2010 was reported at 584 MW.

3.2.12 Canadian Solar Inc. (PRC)

Canadian Solar Inc. was founded in Canada in 2001 and was listed on NASDAQ in November 2006. CSI has established six wholly-owned manufacturing subsidiaries in China, manufacturing ingot/wafer, solar cells and solar modules. According to the company, it had 200 MW of ingot and wafer capacity, 800 MW cell capacity and 1.3 GW module manufacturing capacity in 2010. The company reports that it is on track to expand their solar cell capacity to 1.3 GW and the module manufacturing capacity to 2 GW, including 200 MW in Ontario, Canada, in 2011. For 2010, the company reported production of 522 MW solar cells and sales of 803 MW of modules.

3.2.13 Hanwah Solar One (PRC/South Korea)

Hanwah Solar One (www.hanwha-solarone.com) was established in 2004 as Solarfun Power Holdings, by the electricity meter manufacturer, Lingyang Electronics, the largest Chinese manufacturer of electric power meters.
In 2010, the Korean company, Hanwha Chemical, acquired 49.99% of the shares and a name change was performed in January 2011. The company produces silicon ingots, wafers, solar cells and solar modules. The first production line was completed at the end of 2004 and commercial production started in November 2005. The company went public in December 2006 and reported the completion of its production capacity expansion to 360 MW in the second quarter of 2008.
As of 30 April 2011, the company reported the following capacities: 1 GW PV module production capacity, 700 MW of cell production capacity, 415 MW of ingot production capacity and 500 MW of wire sawing capacity. It is planned to expand the module production capacity to 1.5 GW, cell production capacity to 1.3 GW and ingot and wafer production capacity to 1 GW by the end of 2011.
The 2010 annual production was reported with 360 MW ingots, 387 MW wafers, 502 MW solar cells and 759 modules.

3.2.14 Neo Solar Power Corporation (Taiwan)

Neo Solar Power (www.neosolarpower.com/) was founded in 2005 by PowerChip Semiconductor, Taiwan's largest DRAM company, and went public in October 2007. The company manufactures mono- and multicrystalline silicon solar cells and offers their SUPERCELL multicrystalline solar-cell brand with 16.8% efficiency. Production capacity of silicon solar cells at the end of 2010 was 820 MW and the expansion to more than 1.3 GW is planned for 2011. In 2010, the company had shipments of about 500 MW.

3.2.15 Renewable Energy Corporation AS (Norway/Singapore)

REC's (www.recgroup.com/) 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.
REC ScanCell is located in Narvik, producing solar cells. From the start-up in 2003, the factory has been continuously expanding. In 2010, production of solar cells was 452 MW, with a capacity at year end of 180 MWp in Norway and 550 MW in Singapore.

3.2.16 Solar World AG (German/USA)

Since its founding in 1998, Solar World (www.solarworld.de/) has changed from a solar system and components dealer to a company covering the whole PV value chain, from wafer production to system installations. The company now has manufacturing operations for silicon wafers, cells and modules in Freiberg, Germany, and Hillsoboro (OR), USA. Additional solar module production facilities exist in Camarillo (CA), USA, and since 2008 with a joint venture between Solarworld and SolarPark Engineering Co. Ltd. in Jeonju, South Korea.
For 2010, solar cell production capacities in Germany were reported at 250 MW and 500 MW in the USA. Total cell production in 2010 was 451 MW, with 200 MW coming from Germany and 251 MW form the USA.
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.

3.2.17 Sun Earth Solar Power Co. Ltd. (PRC)

Sun Earth Solar Power (www.nbsolar.com/), or NbSolar, has been part of China's PuTian Group since 2003. The company has four main facilities for silicon production, ingot manufacturing, system integration and solar system production. According to company information, Sun Earth

has imported solar cell and module producing and assembling lines from America and Japan.
In 2007, Sun Earth Solar Power relocated to the Ningbo high-tech zone, with the global headquarters of Sun Earth Solar Power. There the company produces wafers, solar cells and solar modules. The second phase of production capacity expansion to 350 MW was completed in 2009. Further expansion is planned from 450 MW in 2010, 700 MW in 2011 and 1 GW in 2012. For 2010, shipments of 421 MW were reported [Pvn 2011].

3.2.18 E-TON Solartech Co. Ltd. (Taiwan)

E-Ton Solartech (www.e-tonsolar.com) was founded in 2001 by the E-Ton Group; a multinational conglomerate dedicated to producing sustainable technology and energy solutions and was listed on the Taiwan OTC stock exchange in 2006. At the end of 2010, the production capacity was 560 MW per annum and a capacity increase to 820 MW is foreseen for 2011. Shipments of solar cells were reported at 420 MW for 2010.

3.2.19 SANYO Electric Company (Japan)

Sanyo (www.sanyo.com/solar/) commenced R&D for a-Si solar cells in 1975. 1980 marked the beginning of Sanyo's a-Si solar cell mass productions for consumer applications. Ten years later in 1990, research on the HIT (Heterojunction with Intrinsic Thin Layer) structure was started. In 1992, Dr. Kuwano (former president of SANYO) installed the first residential PV system at his private home. Amorphous Silicon modules for power use became available from SANYO in 1993 and in 1997 the mass production of HIT solar cells started. In 2010, Sanyo produced 405 MW solar cells [Pvn 2011]. The company announced increasing its 2009 production capacity of 500 MW HIT cells to 650 MW by 2011.
At the end of 2002, Sanyo announced the start of module production outside Japan. The company now has a HIT PV module production 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. In 2005, it opened its module manufacturing plant in Dorog, Hungary.
Sanyo has set a world record for the efficiency of the HIT solar cell, with 23% under laboratory conditions [Tag 2009]. The HIT structure offers the possibility to produce double-sided solar cells, which has the advantage of collecting 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.

3.2.20 China Sunergy

China Sunergy was established as CEEG Nanjing PV-Tech Co. (NJPV), a joint venture between the Chinese Electrical Equipment Group in Jiangsu and the Australian Photovoltaic Research Centre in 2004. China Sunergy went public in May 2007. At the end of 2008, the Company had five selective emitter (SE) cell lines, four HP lines, three capable of using multicrystalline and monocrystalline wafers, and one normal P-type line for multicrystalline cells, with a total nameplate capacity of 320 MW. At the end of 2010, the company had a cell capacity of 400 MW and a module capacity of 480 MW. For 2011, a capacity increase to 750 MW cells and 1.2 GW of modules is foreseen. For 2010, a production of 347 MW was reported.

3.3 Polysilicon supply

The rapid growth of the PV industry since 2000 led to the situation where, between 2004 and early 2008, the demand for polysilicon outstripped the supply from the semiconductor industry. Prices for purified silicon started to rise sharply in 2007 and in 2008 prices for polysilicon peaked around 500 $/kg and consequently resulted in higher prices for PV modules. This extreme price hike triggered a massive capacity expansion, not only of established companies, but many new entrants as well. In 2009, more than 90% of total polysilicon, for the semiconductor and photovoltaic industry, was supplied by seven companies: Hemlock, Wacker Chemie, REC, Tokuyama, MEMC, Mitsubishi and Sumitomo. However, it is estimated that now about seventy producers are present in the market.
The massive production expansions, as well as the difficult economic situation, led to a price decrease throughout 2009, reaching about 50–55 $/kg at the end of 2009, with a slight upwards tendency throughout 2010 and early 2011.

For 2010, about 140,000 metric tons of solar grade silicon production were reported, sufficient for around 20 GW, under the assumption of an average materials need of 7 g/Wp [Ici 2011]. China produced about 45,000 metric tons, or 32%, capable of supplying about 75% of the domestic demand [Sem 2011]. According to the Semi PV Group Roadmap, the Chinese production capacity rose to 85,000 metric tons of polysilicon in 2010.
In January 2011, the Chinese Ministry of Industry and Information Technology tightened the rules for polysilicon factories. New factories must be able to produce more than 3,000 metric tons of polysilicon a year and meet certain efficiency, environmental and financing standards. The maximum electricity use is 80 kWh/kg of polysilicon produced a year, and that number will drop to 60 kWh at

the end of 2011. Existing plants that consume more than 200 kWh/kg of polysilicon produced at the end of 2011 will be shut down.
Projected silicon production capacities available for solar in 2012 vary between 250,000 metric tons [Ber 2010] and 410,665 metric tons [Ikk 2011]. The possible solar cell production will in addition depend on the material use per Wp. Material consumption could decrease from the current 7 to 8 g/Wp down to 5 to 6 g/Wp, but this might not be achieved by all manufacturers.

3.3.1 Silicon production processes

The high growth rates of the photovoltaic industry and the market dynamics forced the high-purity silicon companies to explore process improvements, mainly for two chemical vapour deposition (CVD) approaches — an established production approach known as the Siemens process, and a manufacturing scheme based on fluidised bed (FB) reactors. Improved versions of these two types of processes will very probably be the work-horses of the polysilicon production industry for the near future.

Siemens process – In the late 1950s, the Siemens reactor was developed and has been the dominant production route ever since. About 80% of total polysilicon manufactured world-wide was made with a Siemens-type process in 2009. The Siemens process involves deposition of silicon from a mixture of purified silane or trichlorosilane gas, with an excess of hydrogen onto high-purity polysilicon filaments. The silicon growth then occurs inside an insulated reaction chamber or "bell jar", which contains the gases. The filaments are assembled as electric circuits in series and are heated to the vapour deposition temperature by an external direct current. The silicon filaments are heated to very high temperatures between 1,100 – 1,175°C at which trichlorsilane, with the help of the hydrogen, decomposes to elemental silicon and deposits as a thin-layer film onto the filaments. Hydrogen Chloride (HCl) is formed as a by-product.

The most critical process parameter is temperature control. The temperature of the gas and filaments must be high enough for the silicon from the gas to deposit onto the solid surface of the filament, but well below the melting point of 1,414°C, that the filaments do not start to melt. Second, the deposition rate must be well controlled and not too fast, because otherwise the silicon will not deposit in a uniform, polycrystalline manner, making the material unsuitable for semiconductor and solar applications.
Fluidised bed process — A number of companies develop polysilicon production processes based on fluidised bed (FB) reactors. The motivation to use the FB approach is the potentially lower energy consumption and a continuous production, compared to the Siemens batch process. In this process, tetrahydrosilane or trichlorosilane and hydrogen gases are continuously introduced onto the bottom of the FB reactor at moderately elevated temperatures and pressures. At a continuous rate, high-purity silicon seeds are inserted from the top and are suspended by the upward flow of gases. At the operating temperatures of 750°C, the silane gas is reduced to elemental silicon and deposits on the surface of the silicon seeds. The growing seed crystals fall to the bottom of the reactor where they are continuously removed.

MEMC Electronic Materials, a silicon wafer manufacturer, has been producing granular silicon from silane feedstock, using a fluidised bed approach for over a decade. Several new facilities will also feature variations of the FB. Several major players in the polysilicon industry, including Wacker Chemie and Hemlock, are developing FB processes, while at the same time continuing to produce silicon using the Siemens process as well.

Upgraded metallurgical grade (UMG) silicon was seen as one option to produce cheaper solar grade silicon with 5- or 6-nines purity, but the support for this technology is waning in an environment where higher-purity methods are cost-competitive. A number of companies delayed or suspended their UMG-silicon operations as a result of low prices and lack of demand for UMG material for solar cells.

3.4 Polysilicon Manufacturers

World-wide more than 100 companies produce or start up polysilicon production. The following chapter gives a short description of the ten largest companies in terms of production capacity in 2010. More information about additional polysilicon companies and details can be found in various market studies and the country chapters of this report.

3.4.1 Hemlock Semiconductor Corporation (USA)

Hemlock Semiconductor Corporation (www.hscpoly.com) is based in Hemlock, Michigan. The corporation is a joint venture of Dow Corning Corporation (63.25%) and two Japanese firms, Shin-Etsu Handotai Company, Ltd. (24.5%) and Mitsubishi Materials Corporation (12.25%). The company is the leading provider of polycrystalline silicon and other silicon-based products used in the semiconductor and solar industry.
In 2007, the company had an annual production capacity of 10,000 tons of polycrystalline silicon and production at

the expanded Hemlock site (19,000 tons) started in June 2008. A further expansion at the Hemlock site, as well as a new factory in Clarksville, Tennessee, was started in 2008 and brought total production capacity to 36,000 tons in 2010. A further expansion to 40,000 tons in 2011 and 50,000 tons in 2012 is planned [Ikk 2011].

3.4.2 Wacker Polysilicon (Germany)
Wacker Polysilicon AG (www.wacker.com), is one of the world's leading manufacturers of hyper-pure polysilicon for the semiconductor and photovoltaic industry, chlorosilanes and fumed silica. In 2010, Wacker increased its capacity to over 30,000 tons and produced 30,500 tons of polysilicon. The next 10,000 tons expansion in Nünchritz (Saxony), Germany, started production in 2011. In 2010, the company decided to build a polysilicon plant in Tennessee with 15,000 tons capacity. The groundbreaking of the new factory was in April 2011 and the construction should be finished at the end of 2013.

3.4.3 OCI Company (South Korea)
OCI Company Ltd. (formerly DC Chemical) (www.oci.co.kr/) is a global chemical company with a product portfolio spanning the fields of inorganic chemicals, petro and coal chemicals, fine chemicals, and renewable energy materials. In 2006, the company started its polysilicon business and successfully completed its 6,500 metric ton P1 plant in December 2007. The 10,500 metric ton P2 expansion was completed in July 2009 and P3 with another 10,000 metric tons brought the total capacity to 27,000 metric tons at the end of 2010. The debottlenecking of P3, foreseen in 2011, should then increase the capacity to 42,000 tons at the end of the year. Further capacity expansions P4 (20,000 tons by 2012) and P5 (24,000 tons by 2013) have already started (P4) or will commence in the second half of this year (P5).

3.4.4 GCL-Poly Energy Holdings Limited (PRC)
GCL-Poly (www.gcl-poly.com.hk) was founded in March 2006 and started the construction of their Xuzhou polysilicon plant (Jiangsu Zhongneng Polysilicon Technology Development Co. Ltd.) in July 2006. Phase I has a designated annual production capacity of 1,500 tons and the first shipments were made in October 2007. Full capacity was reached in March 2008. At the end of 2010, polysilicon production capacity had reached 21,000 tons and further expansions to 46,000 tons in 2011 and 65,000 tons in 2012 are underway. For 2010, the company reported a production 17,850 metric tons of polysilicon.
In August 2008, a joint-venture, Taixing Zhongneng (Far East) Silicon Co. Ltd., started pilot production of trichlorsilane. Phase I will be 20,000 tons, to be expanded to 60,000 tons in the future.

3.4.5 MEMC Electronic Materials Inc. (USA)
MEMC Electronic Materials Inc. (www.memc.com/) has its headquarters 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 aluminium tetraflouride (SAF). MEMC's production capacity in 2008 was increased to 8,000 tons and 9,000 tons in 2009 [Ikk 2011].

3.4.6 Renewable Energy Corporation AS (Norway)
REC's (www.recgroup.com/) 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.
In 2005, Renewable Energy Corporation AS ("REC") took over Komatsu's US subsidiary, Advanced Silicon Materials LLC ("ASiMI"), and announced the formation of its silicon division business area, "REC Silicon Division", comprising the operations of REC Advanced Silicon Materials LLC (ASiMI) and REC Solar Grade Silicon LLC (SGS). Production capacity at the end of 2010 was around 17,000 tons [Ikk 2011] and according to the company, 11,460 tons electronic grade silicon was produced in 2010.

3.4.7 LDK Solar Co. Ltd. (PRC)
LDK (www.ldksolar.com/) was set up by the Liouxin Group, a company which manufactures personal protective equipment, power tools and elevators. With the formation of LDK Solar, the company is diversifying into solar energy products. LDK Solar went public in May 2007. In 2008, the company announced the completion of the construction and the start of polysilicon production in its 1,000 metric tons polysilicon plant. According to the company, the total capacity was 12,000 metric tons at the end of 2010 which will be increased to 25,000 tons in 2011. In 2010, polysilicon production was reported at 5,050 tons.

3.4.8 Tokuyama Corporation (Japan/Malaysia)
Tokuyama (www.tokuyama.co.jp/) is a chemical company involved in the manufacturing of solar-grade silicon, the base material for solar cells. The company is one of the world's leading polysilicon manufacturers and produces roughly 16% of the global supply of electronics and solar grade silicon. According to the company, Tokuyama had an annual production capacity of 5,200 tons in 2008 and has

expanded this to 9,200 tons in 2010. In February 2011, the company broke ground for a new 20,000 ton facility in Malaysia. The first phase with 6,200 tons should be finished in 2013.
A verification plant for the vapour to liquid-deposition process (VLD method) of polycrystalline silicon for solar cells has been completed in December 2005. According to the company, steady progress has been made with the verification tests of this process, which allows a more effective manufacturing of polycrystalline silicon for solar cells. Tokuyama has decided to form a joint venture with Mitsui Chemicals, a leading supplier of silane gas. The reason for this is the increased demand for silane gas, due to the rapid expansion of amorphous/microcrystalline thin-film solar cell manufacturing capacities.

3.4.9 Kumgang Korea Chemical Company (South Korea)

Kumgang Korea Chemical Company (KCC) was established by a merger of Kumgang and the Korea Chemical Co. in 2000. In February 2008, KCC announced its investment in the polysilicon industry and began to manufacture high-purity polysilicon with its own technology at the pilot plant of the Daejuk factory in July of the same year. In February 2010, KCC started to mass-produce polysilicon, with an annual capacity of 6,000 tons.

3.4.10 Mitsubishi Materials Corporation (Japan)

Mitsubishi Materials (www.mmc.co.jp) was created through the merger Mitsubishi Metal and Mitsubishi Mining & Cement in 1990. Polysilicon production is one of the activities in their Electronic Materials & Components business unit. The company has two production sites for polysilicon, one in Japan and one in the USA (Mitsubishi Polycrystalline Silicon America Corporation) and is a shareholder (12.25%) in Hemlock Semiconductor Corporation. With the expansion of the Yokkachi, Mie, Japan, polysilicon plant, by 1,000 tons in 2010, total production capacity was increased to 4,300 tons.

4. The European Union

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

In order to meet the new targets, the European Council called for an overall coherent framework for renewable energies, which resulted in the Directive on the "Promotion of the Use of Energy from Renewable Sources" [EC 2009]. The Directive 2009/28/EC, which went into force on 25 June 2009, amends and subsequently repeals the Directives 2001/77/EC and 2003/30/EC [EC 2001, EC 2003].

The main points of the Directive are:

- Mandatory national overall targets and measures for the use of energy from renewable sources, as well as an indicative trajectory how to reach the targets;
- National Action Plans containing targets for transport, electricity and heating and cooling in 2020;
- Member States shall provide for either priority access or guaranteed access to the grid-system for electricity produced from renewable energy sources;
- Each Member State has to submit a report to the Commission on progress in the promotion and use of energy from renewable energy sources by 31 December 2011, and every two years thereafter. The sixth report to be delivered on 31 December 2021;
- Criteria and provisions to ensure sustainable production and use of bioenergy and to avoid conflicts between different uses of biomass.

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

The White Paper target for the cumulative photovoltaic systems capacity installed in the European Union by 2010 was 3,000 MW or a 100-fold increase of the capacity in 1995. It was assumed that 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. The target was already achieved in 2006 and the cumulative installed capacity at the end of 2010 was over 29 GW, almost ten times the original target.

As depicted in Figure 8, the overall progress of the European Union towards the 2010 targets was very positive, with about 20% of the Union's total net electricity generation coming from renewable energy sources. However, it should be noted that this development fell short of the 21% needed, and after a 5% decrease of the electricity demand in 2009 compared to 2008, due to the economic crisis, electricity consumption in 2010 increased by 3.2% again. In addition, the development in the different Member States is quite diverse, as nine Member States have exceeded their targets, whereas some others are lagging behind.

The 2009 Directive indicates the overall percentage of renewable energies for the different Member States (Fig. 9), as well as the indicative trajectory (Fig. 10) how to reach it [EC 2009]. The decision on what kind of technologies to utilise in order to reach the national targets, is left to the Member States. By 30 June 2010, the Member States had to notify the Commission about their National Renewable Energy Action Plans (NRAPs). As stated in the Directive, the aim of these plans is *that all Member States, including those which so far have made very limited progress towards agreed EU objectives, will have to establish a clear plan as to how they intend to achieve their targets for renewable energy and for renewable energy in transport. They will have to explain how they intend to reform building codes and planning regimes to increase the use of renewable energy and to improve access conditions to the electricity grid. They will have to set out national sectoral targets, the measures and support schemes to be used to reach the targets, the specific measures for the promotion of the use of energy from biomass, the intended use of (statistical) transfers of renewable energy from other Member States and their assessment of the role different technologies will play in reaching the targets. Moreover, they will have to implement and monitor biofuel sustainability criteria to ensure biofuels clearly contribute to our environmental objectives.*

Fig. 8: Electricity generation in TWh from renewable energies in the European Union [Est 2011]

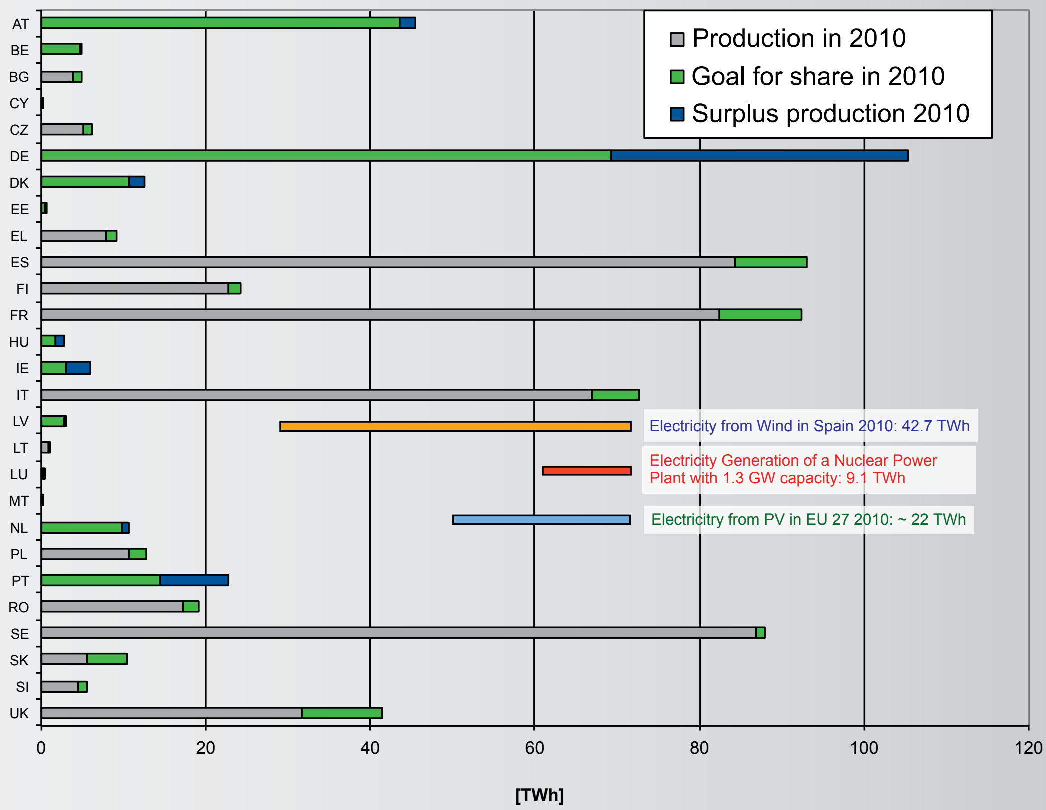


Fig. 9: Fig. 9: Share of renewable energies in the European Union in 2020

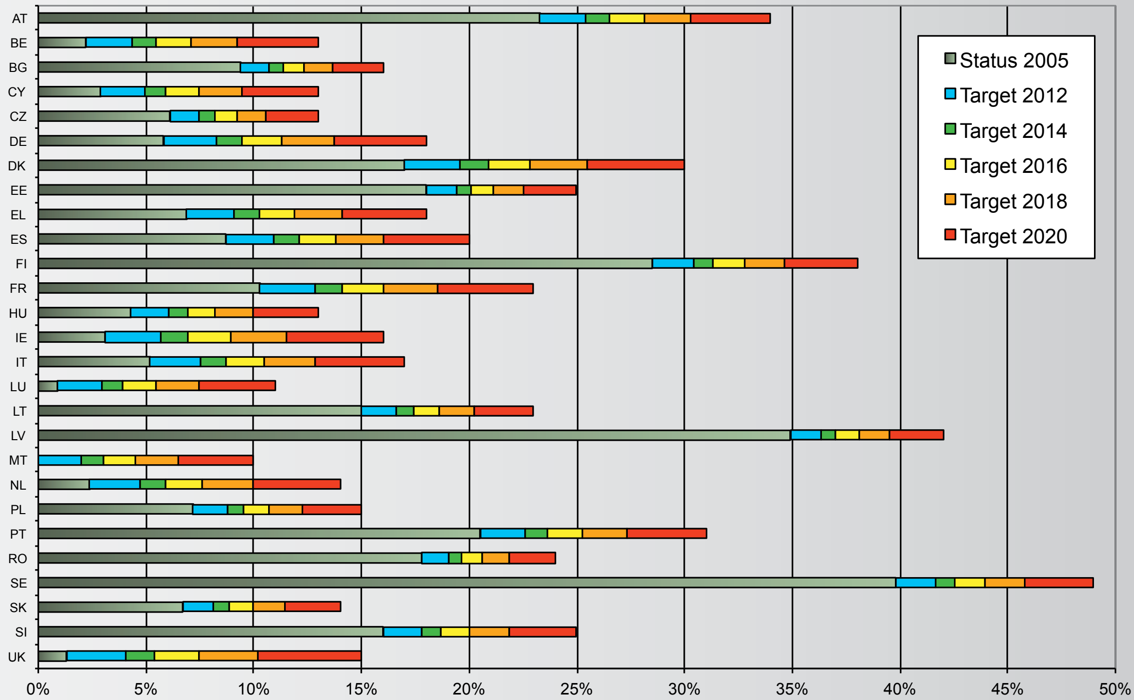
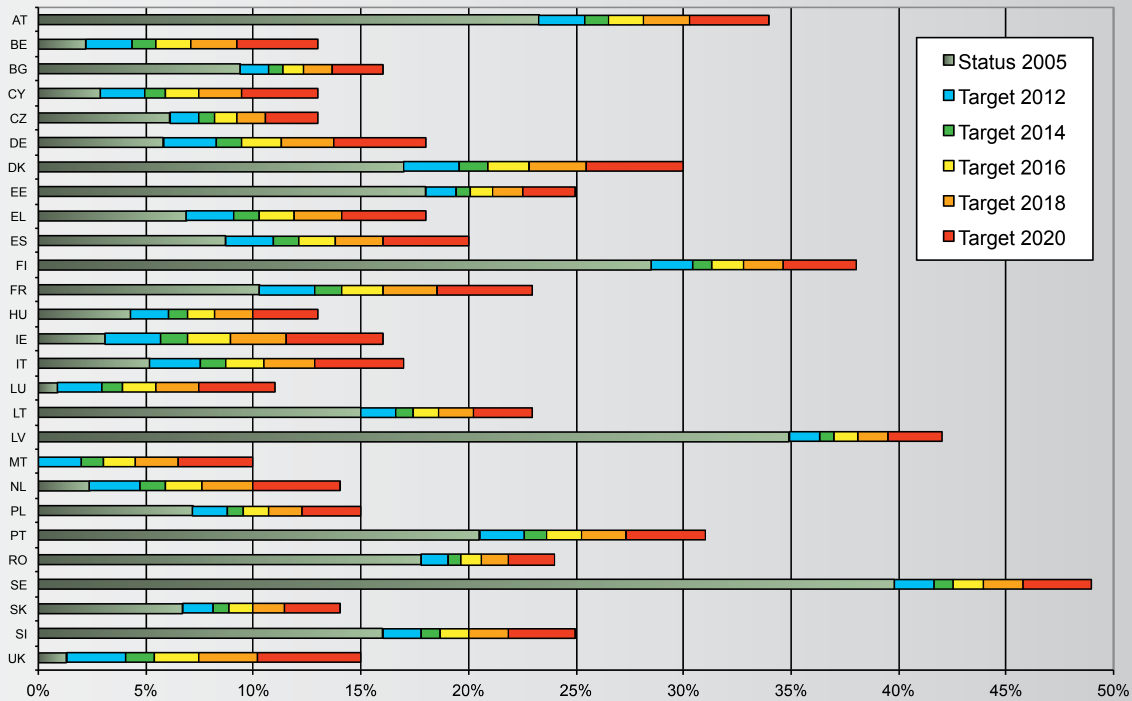


Fig. 10: Trajectory to reach the share of renewable energies in the European Union in 2020



In January 2011, the European Commission published a Communication to the European Parliament and the Council entitled ***"Renewable Energy: Progressing towards the 2020 target"*** [EC 2011]. In this Communication the progress of the Member States towards achieving the Renewable Electricity Directive 2001/77/EC was cited as:

Only a few Member States, namely Denmark, Germany, Hungary, Ireland, Lithuania, Poland and Portugal expect to achieve their 2010 targets for renewable energy in electricity generation.

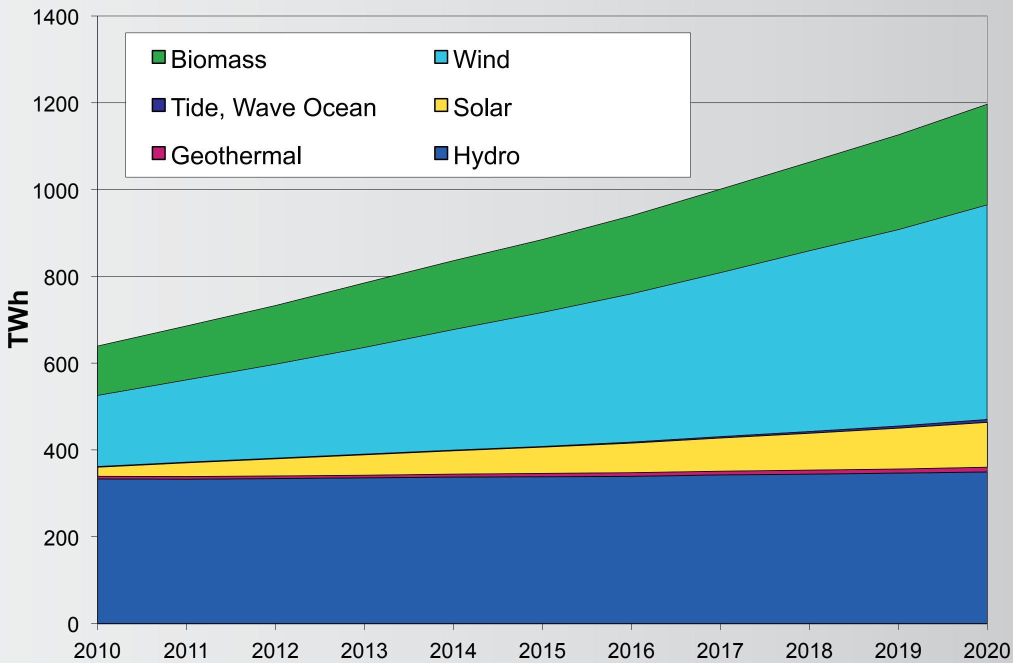
The communication further pointed out: *Based on Member States' plans, renewable energy should constitute 37% of Europe's electricity mix by 2020. … The Energy 2020 Strategy highlighted how the rise of electricity produced from renewable sources also has implications for the electricity market as a whole. Multiple, flexible, smaller scale distributed forms of electricity generation need different grid and market design rules compared to traditional large, centralised power sources.*

As a consequence, the Communication calls for a new priority in renewable energy: *As the new EU Energy Strategy notes[14], priority should be given to renewable electricity investments – achieving levels higher than the 62% of all new power installations in 2009. Further analysis undertaken for the Commission suggests that **whilst annual capital investment in renewable energy today averages €35bn, this would need to rapidly double to €70bn** to ensure we achieve our goals[15]. Such outlays must be funded, as they are today, chiefly through private sector investment, financed finally by energy consumers.*

4.1 Implementation of Photovoltaics 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 grades of liberalisation of domestic electricity markets. The legal framework for the overall increase of renewable energy sources was set with the Directive 2009/28/EC, and in their National Renewable Energy Action Plans (NREAPs), 26 Member States have set specific photovoltaic solar energy targets, adding up to 84.5 GW in 2020 (Fig. 11). However, 51.7 GW will come from Germany alone, which

Fig. 11: Planned European electricity production according to the National Renewable Energy Action Plans



[14] COM(2010)639/3 Energy 2020: a strategy for competitive sustainable and secure energy, p6
[15] ECOFYS, Ernst & Young, Fraunhofer ISI, TU Vienna, 2010. The least cost electricity investment component of this, consistent with the analysis of COM(2010)677 ranges from €310bn-370bn.

makes the balance even more uneven. Especially the sun-rich Mediterranean countries only pledged 24.6 GW (8.4 GW Spain, 8 GW Italy, 4.8 GW France, 2.2 GW Greece, 1.0 GW Portugal, and Cyprus and Malta together 220 MW) is far below (factor 2 to 6) the anticipated contribution of these sun-rich countries in order to reach 6% of solar electricity by 2020, where a cumulative installed capacity of about 200 GW in Europe would be needed [Epi 2009]. However, the latest development in Italy, where a limit of support for 23 GW of PV installations by the end of 2017 was given in the 4th Conto Energia [Gaz 2011], indicates that the targets set in the NREAPs should be seen as the guaranteed minimum and not the overall goal.

The tremendous growth of the European PV Market to 5.8 GW in 2009, and 13.6 GW in 2010, did not result in a similar growth of the European PV solar cell production, which reached about 3 GW. Further capacity expansions and technology progress are necessary to change this in the future and to secure a leading role of the European PV solar cell industry.

However, looking only at the cell production does not grasp the whole picture of the whole PV value chain. Besides the manufacturing of solar cells, the whole upstream industry (e.g. materials, polysilicon production, equipment manufacturing), as well as the downstream industry (e.g. inverters, BOS components, system development, installations) has to be looked at as well. It is worthwhile remembering that despite the fact that more than two-thirds of the solar cells which are installed in Germany are not produced there, about 60% of the added value remains within the German economy.

The dominating support measures for photovoltaics in the European Union Member States and Switzerland are feed-in tariffs. The rapid decrease of photovoltaic system prices led to a number of sometimes drastic revisions in the feed-in schemes. The existing support schemes are listed in Table 1.

Table 1: Support mechanisms for photovoltaics in the European Union and Switzerland

Austria	The Ökostromverordnung 2011 (eco electricity degree) set the following new tariffs for 2011 (only for PV systems covered by the Ökostromgesetz (Eco Electricty Law). Systems on buildings or noise barriers: ■ System size between 5 and 20 kWp: 0.38 €/kWh ■ System size > 20 kWp: 0.33 €/kWh Free-standing systems: ■ System size between 5 and 20 kWp: 0.35 €/kWh ■ System size > 20 kWp: 0.25 €/kWh For systems smaller than 5 kWp, the Climate & Energy Fund, which has in 2011 a budget of € 35 million, offered an investment subsidy to private persons. Applications on a first come first serve base were possible between 4 and 30 April 2011 For 2011, the investment subsidies were as follows: ■ Rooftop and free-standing systems: 1,100 €/kWp ■ Building integrated system: 1,450 €/kWp Some of the Federal States have additional investment support schemes.
Belgium	Green Certificates (with guaranteed minimum price): ■ Brussels: 0.15 – 0.65 €/kWh depending on size (10 years) ■ Wallonia: 0.15 – 0.70 €/kWh depending on size and actual GC value (15 years) ■ Flanders from 1 January 2010: 0.35 €/kWh and from 1 January 2011: 0.33 €/kWh for 20 years. Net meeting possible for systems smaller than 10 kWp Tax reduction available

Bulgaria

In November 2008 the duration of FIT payments was changed from 12 to 25 years and from 1 April 2009 on only systems with a capacity of a maximum of 10 MW are eligible for the tariff. The tariffs for 2011 were set by the regulator on 31 March 2011:

- 0.760 BGN/kWh (0.389 €/kWh)[16] for systems up to 5 kW
- 0.699 BGN/kWh (0.3572 €/kWh) for systems < 5 kW and ≥ 10 MW

However, a new proposal was published by the State Energy and Water Regulation Commission on 16 May 2011 to change the tariffs as follows:

- 0.576 BGN/kWh (0.294 €/kWh) for systems up to 30 kW
- 0.567 BGN/kWh (0.290 €/kWh) for systems between 30 kW and2 MW
- 0.486 BGN/kWh (0.248 €/kWh) for systems over 2 MW

Up to 15%, or a maximum of € 2.5 million of the project investment, can be financed with a reduced interest loan from the Bulgarian Energy Efficiency and Renewable Energy Credit Line (BEERECL), credit facility offered by the European Bank for Reconstruction and Development (EBRD), the Bulgarian Government and the European Union.

[16] Exchange rate: 1 € = 1.956 BGN

Cyprus

At the moment, there are three grant schemes to support renewable electricity generation in Cyprus.
Feed-in Tariff: The tariff consists of the purchase price and an additional flexible payment to cover the difference between the purchase price and the guaranteed tariff. It is linked to the oil price and set by the Cyprus Energy Regulatory Authority (CERA).

- Large-scale PV systems (21 to 150 kW): 0.34 €/kWh
- Small PV systems (up to 20 kW): 0.36 €/kWh

SSEEA I (2010): Support Scheme for Energy Conservation and the Promotion of Renewable Energy Sources (RES) for natural persons and public entities for 2009 – 2013. The amount of grant is a certain percentage of the amount invested.

- **Solar energy systems of up to 20 kW:** 55% of the total investment (subject to a maximum of 33,000 € for on-grid systems and 44,000 € for off-grid PV systems). (ch. 5 in connection with ch. 4 par. 3 and ch. 4.2 of SSEEA I (2010)).

SSEEA II: Grants are allocated to incentivise the installation of renewable energy systems. The scheme applies to private entities.

- **De-minimis grant:**
    - 40% of the total investments in building-integrated systems (subject to a maximum of 36,000 €)
    - 40% of the total investments in ground-mounted systems (subject to a maximum of 50,000 €).
- **Grant for less developed regions according to company size:** 15%, 25% or 35% of total investments (subject to a maximum of 50,000 €).

Czech Republic

Feed-in tariff for 20 years.
Annual prices are set by the Energy Regulator.
Producers of electricity can choose from two support schemes:

- Fixed feed-in tariff 2011:
  Systems commissioned after 01/01/11:
  ≤ 30 kW: 7.5 CZK/kWh (0.311 €/kWh)[17]
  > 30 kW and ≤ 100kW: 5.9 CZK/kWh (0.245 €/kWh)
  > 100 kW: 5.5 CZK/kWh (0.228 €/kWh)

- Market price + Green Bonus; Green Bonus 2011
  Systems commissioned after 01/01/10:
  ≤ 30 kW: 6.5 CZK/kWh (0.270 €/kWh)
  > 30 kW and ≤ 100kW: 4.9 CZK/kWh (0.203 €/kWh)
  > 100 kW: 4.5 CZK/kWh (0.187 €/kWh)

From 1 January 2011 on, for PV systems put into operation between 1 Jan 2009 and 31 Dec 2010 the feed-in tariff is subject to a tax of 26% and the green bonus is subject to 28% tax. Exception: Roof-top and facade-integrated systems with a capacity of up to 30 kW.

[17] Exchange rate: 1 € = 24.11 CZK

Denmark

No specific PV programme, but settlement price for green electricity (bonus) 60 Øre[18]/kWh (0.08 €/kWh) for 10 years, then 10 more years 40 Øre/kWh.

[18] Exchange Rate: 1 € = 7.45 DKK

Estonia

No specific PV programme, but Renewable Portfolio Standard and tax relief.
Feed-in tariff for 12 years for electricity produced out of RES, except wind, is:

- 1.16 EEK/kWh (0.074 €/kWh)[19] for systems with start of operation 2007 – 2009.
- 0.85 EEK/kWh (0.054 €/kWh) for systems with start of operation 2010 and after.

[19] Exchange rate: 1 € = 15.64 EEK

Finland

No PV programme, but investment subsidy up to 40% and tax/production subsidy for electricity from renewable energy sources (6.9 €/MWh).

France

Feed-in tariff for 20 years
In February the tariffs were changed as follows:

Residential:

BIPV:	≤ 9kWp	0.46 €/kWh
	9 < P ≤ 36 kWp	0.403 €/kWh
Simplified BIPV:	≤ 9kWp	0.304 €/kWh
	9 < P ≤ 36 kWp	0.288 €/kWh

Health Care Institutions:

BIPV:	≤ 36 kWp	0.406 €/kWh
Simplified BIPV:	≤ 9kWp	0.304 €/kWh
	9 < P ≤ 36 kWp	0.288 €/kWh

Other Buildings:

BIPV:	≤ 9kWp	0.352 €/kWh
Simplified BIPV:	≤ 9kWp	0.304 €/kWh
	9 < P ≤ 36 kWp	0.288 €/kWh

All Other Installations:	≤ 12 MWp	0.120 €/kWh

Germany

Feed-in tariff for 20 years.
Tariffs for new installations from 1 January 2011 on:

Roof-top and noise barriers:

■ System size < 30 kW:	0.287 €/kWh
■ System size 30 to 100 kW:	0.273 €/kWh
■ System size 100 kW to 1 MW:	0.259 €/kWh
■ System size > 1 MW:	0.216 €/kWh

Roof-top with auto consumption:

■ System size < 30 kW:	up to 30%	0.124 €/kWh
	more than 30%	0.167 €/kWh
■ System size 30 to 100 kW:	up to 30%	0.110 €/kWh
	more than 70%	0.153 €/kWh
■ System size 100 to 500 kW:	up to 30%	0.095 €/kWh
	more than 70%	0.139 €/kWh

Ground-mounted installations: 0.211 €/kWh
Ground-mounted installations in redevelopment areas: 0.227 €/kWh

In 2012 the feed-in tariffs o for all new systems is reduced by 9%.
In addition, there is an automatic increase or decrease of the degression rate if the installed capacity is above or below certain values in the year before. In order to monitor this, all new systems which become operational after 1 January 2009, have to be registered in a central PV system register. The degression rates will be lowered or increased in the next year if the following installed capacities are undercut or exceeded:
Installations in 2011 and resulting degression in 2012:

■ > 3,500 MW	+ 3%	< 2,500 MW	– 2.5%
■ > 4,500 MW	+ 6%	< 2,000 MW	– 5%
■ > 5,500 MW	+ 9%	< 1,500 MW	– 7.5%
■ > 6,500 MW	+ 12%		
■ > 7,500 MW	+ 15%		

Greece

Since 4 June 2009:
Roof-top PV systems up to 10 kWp (both for residential users and small companies) receive 0.55 €/kWh.
Annual degression of 5% is foreseen for newcomers as of 2012.
Photovoltaic systems are eligible for the following feed-in tariffs (Art. 15 Par. 1 Law No. 3486/2006).

	≤100 kW, off-grid systems and islands	>100 kW
From 02/11:	0.419 €/kWh	0.373 €/kWh
From 08/11:	0.395 €/kWh	0.351 €/kWh
From 02/12:	0.376 €/kWh	0.334 €/kWh
From 08/12:	0.354 €/kWh	0.314 €/kWh
From 02/13:	0.336 €/kWh	0.299 €/kWh
From 08/13:	0.317 €/kWh	0.281 €/kWh
From 02/14	0.303 €/kWh	0.269 €/kWh
From 08/14:	0.294 €/kWh	0.261€/kWh

Hungary

Support for RES is regulated through the Electricity Act, which entered into force on 1 January 2003.
From January 2011 onwards the feed-in tariff for PV is: 29.84 HUF/kWh (0,111 €/kWh[20])

[20] Exchange rate: 1 € = 268 HUF

Ireland

The Alternative Energy Requirement (AER) Tender Scheme was replaced by a new Renewable Energy Feed-in Tariff (ReFIT) scheme in 2006. In 2009 a microgeneration scheme was introduced by the Irish Electricity Supply Board (ESB) which offered a guaranteed buying price of 0.09 €/kWh and a bonus for 5 years for up to 3,000 kWh generated by solar systems smaller than 11 kWp.

Italy

Feed-in tariff guaranteed for 20 years. 2% decrease for new systems each year. The 4th Conto Energia was passed in May 2011 [Gaz 2011]. The decree applies to plants connected after 31 May 2011 and before 31 December 2016.
In 2011 the tariffs are being reduced on a monthly base from June onwards:

	System size [kWp]	Systems on buildings	other installations
June 2011:	1 ≤ P ≤ 3	0.387 €/kWh	0.344 €/kWh
	3 < P ≤ 20	0.356 €/kWh	0.319 €/kWh
	20 < P < 200	0.338 €/kWh	0.306 €/kWh
	200 < P < 1 MW	0.325 €/kWh	0.291 €/kWh
	1 MW < P < 5 MW	0.314 €/kWh	0.277 €/kWh
	P > 5 MW	0.299 €/kWh	0.264 €/kWh
July 2011:	1 ≤ P ≤ 3	0.379 €/kWh	0.337 €/kWh
	3 < P ≤ 20	0.349 €/kWh	0.312 €/kWh

	20 < P < 200	0.331 €/kWh	0.300 €/kWh
	200 < P < 1 MW	0.315 €/kWh	0.276 €/kWh
	1 MW < P < 5 MW	0.298 €/kWh	0.264 €/kWh
	P > 5 MW	0.284 €/kWh	0.251 €/kWh
August 2011:	1 ≤ P ≤ 3	0.368 €/kWh	0.327 €/kWh
	3 < P ≤ 20	0.339 €/kWh	0.303 €/kWh
	20 < P < 200	0.321 €/kWh	0.291 €/kWh
	200 < P < 1 MW	0.303 €/kWh	0.263 €/kWh
	1 MW < P < 5 MW	0.280 €/kWh	0.250 €/kWh
	P > 5 MW	0.269 €/kWh	0.238 €/kWh
September2011:	1 ≤ P ≤ 3	0.361 €/kWh	0.316 €/kWh
	3 < P ≤ 20	0.325 €/kWh	0.289 €/kWh
	20 < P < 200	0.307 €/kWh	0.271 €/kWh
	200 < P < 1 MW	0.298 €/kWh	0.245 €/kWh
	1 MW < P < 5 MW	0.278 €/kWh	0.243 €/kWh
	P > 5 MW	0.264 €/kWh	0.231 €/kWh
October 2011:	1 ≤ P ≤ 3	0.345 €/kWh	0.302 €/kWh
	3 < P ≤ 20	0.310 €/kWh	0.276 €/kWh
	20 < P < 200	0.293 €/kWh	0.258 €/kWh
	200 < P < 1 MW	0.285 €/kWh	0.233 €/kWh
	1 MW < P < 5 MW	0.256 €/kWh	0.223 €/kWh
	P > 5 MW	0.243 €/kWh	0.212 €/kWh
November 2011:	1 ≤ P ≤ 3	0.320 €/kWh	0.281 €/kWh
	3 < P ≤ 20	0.288 €/kWh	0.256 €/kWh
	20 < P < 200	0.272 €/kWh	0.240 €/kWh
	200 < P < 1 MW	0.265 €/kWh	0.210 €/kWh
	1 MW < P < 5 MW	0.233 €/kWh	0.201 €/kWh
	P > 5 MW	0.221 €/kWh	0.191 €/kWh
December 2011:	1 ≤P ≤ 3	0.289 €/kWh	0.261 €/kWh
	3 < P ≤ 20	0.268 €/kWh	0.238 €/kWh
	20 < P < 200	0.253 €/kWh	0.224 €/kWh
	200 < P < 1 MW	0.246 €/kWh	0.189 €/kWh
	1 MW < P < 5 MW	0.212 €/kWh	0.181 €/kWh
	P > 5 MW	0.199 €/kWh	0.172 €/kWh

In 2012 a half-yearly reduction is foreseen.

1stH 2012:	1 ≤ P ≤ 3	0.274 €/kWh	0.240 €/kWh
	3 < P ≤ 20	0.247 €/kWh	0.219 €/kWh
	20 < P < 200	0.233 €/kWh	0.206 €/kWh
	200 < P < 1 MW	0.224 €/kWh	0.172 €/kWh
	1 MW < P < 5 MW	0.182 €/kWh	0.156 €/kWh
	P > 5 MW	0.171 €/kWh	0.148 €/kWh
2nd H 2012:	1 ≤ P ≤ 3	0.252 €/kWh	0.221 €/kWh
	3 < P ≤ 20	0.227 €/kWh	0.202 €/kWh
	20 < P < 200	0.214 €/kWh	0.189 €/kWh
	200 < P < 1 MW	0.202 €/kWh	0.155 €/kWh
	1 MW < P < 5 MW	0.164 €/kWh	0.140 €/kWh
	P > 5 MW	0.154 €/kWh	0.133 €/kWh

Italy (part 2)

2011 and 2012 tariffs for CPV systems:

[kWp]	2011	1H2012	2H2012
1 ≤ P ≤ 3	0.359 €/kWh	0.352 €/kWh	0.345 €/kWh
20 < P < 200	0.310 €/kWh	0.304 €/kWh	0.298 €/kWh
P > 200	0.272 €/kWh	0.266 €/kWh	0.261 €/kWh

The following additions exist:

- Up to 30% premium for roof-top systems installed in conjunction with energy efficiency measures
- 5% premium for ground-mounted systems on garbage dumps, contained sites or similar.
- 5% bonus for smaller systems in communities with less than 5,000 inhabitants.
- 0.05 €/kWh bonus for roof-top systems with removal of asbestos cement or similar material.

Latavia

Feed-in tariff for RES, but not PV specific:
Licensed before 01.06.2001: double the average sales price (~ 0.101 €/kWh) for eight years, then reduction to normal sales price.
Licensed after 01.06.2001: Regulator sets the price
The feed-in system has been amended through Regulation N°. 503 on Electricity Production from RES (in force since August 2007), but without PV provisions.
A national investment programme for RES has been running since 2002. Net metering for electricity from PV systems. The average domestic electricity price Net

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 had a cap of 3 MW by 2007. The feed-in tariffs have been amended in February 2008 and a new cap of 5 MW has been set. Tariffs are guaranteed over 15 years with simpler administrative procedures. They are differentiated according to technology and capacity. Some tariffs are degressive. In the case ofphotovoltaics only roof-top systems are eligible and the tariff for 2011 is set as follows:

- System size ≤ 30 kW:0.382 €/kWh
- System size 30 < P ≤ 1 MW: 0.337 €/MWh

In addition, investment subsidies (environmental grants of max 50% of the investments in the case of self-consumption purposes) are available to private companies.
For local authority buildings, investment grants of up to 15% of the investment cost (max 900 €/kWp) are available.
For private households, investment grants up to 30% of the investment for roof or façade systems up to 30 kWp (max 1,650 €/kWp) are available.

Malta

Net metering for electricity from PV systems. The average domestic electricity price for 2011 is given with 0.158 €/kWh.
Surplus exported to the grid: 0.07 €/kWh.
Grant for roof-top PV installations for systems between 1 and 3.7 kWp.

Netherlands

In October 2007, the Dutch Government published a new regulation for a feed-in premium for renewable energy. The new support mechanism, called SDE ('Stimuleringsregeling duurzame energieproductie') resembles the old MEP premium system. Producers will get a premium covering extra costs on top of the wholesale energy price for a number of years. The programme has annual caps with a total of 75 MW between 2008 and 2011.
For 2010 the feed-in tariff and caps for new systems were set as:

- System size 0.6 – 15 kWp: 0.2441 €/kWh 20 MW CAP
- System size 15 – 100 kWp: 0.351 €/kWh 5 MW CAP.

Investment subsidies are available, administered with yearly calls.
Tax reductions are available.

Poland

No specific PV programme. In January 2007, changes in the Energy Law Act were made, resulting in the requirement of an energy generation licence regardless of the power installed (previously required only > 50 MW).
An excise tax exemption on RES-E was introduced in 2002. It amounts to 0.02 PLN/kWh (0.483 €cent/kWh)[21].
Green Certificates are available for all RE technologies. They have a value of about 0.25 PLN/kWh (0.060€/kWh)

[20] Exchange rate: 1 € = 4.137 PLN

Portugal

In November 2007 the micro-generation scheme was launched and has been fully operational since March 2008. There are two regimes:

- General Regime: this is available to any type of microgeneration source, with a maximum capacity of 5.75 kW. The FIT is the same as the regulated tariff (true net-meeting) set annually by the regulator.
- Special Regime: only for renewable energy sources with a capacity up to 3.68 kW.

In October 2010 a feed-in tariff for small systems [Dia 2010] and in March 2011 for medium sized systems [Dia 2011], was introduced.

Small systems (up to 3.68 kW and 11.04 kW for condominiums):

- 0.40 €/kWh for the first eight years and 0.25 €/kWh for the next seven years.

The annual electricity amount is limited to 2.4 MWh/a per kW installed and an annual cap of 25 MW for new installations is in place. An annual reduction of 0.02 €/kWh for new systems is foreseen.

Medium-sized systems (up to 250 kW):

- 0.25 €/kWh for 15 years and the tariff for new systems decreases 7% each

year. The annual electricity amount is limited to 2.6 MWh/a per kW installed and

Portugal (part 2)

an annual cap of 50 MW for new installations is in place.
Reduction of VAT rate from 21 % to 12 % on renewable equipment, custom duties exemption and income tax reductions (up to € 777 for solar equipment).
Investment subsidies are available for SMEs.

Romania

No specific programme for PV. For the promotion of the production of electricity from Renewable Energy Sources, a system of Tradable Green Certificates is in place. For PV systems 1 MWh produced receives 4 GC.
For the period 2005-2012, the annual maximum and minimum value for Green Certificates trading is 27 € per certificate, respectively 55 € per certificate, calculated at the exchange rate established by the Romanian National Bank, for the last working day of December of the previous year.
The penalty level is 0.84 €/kWh.

Slovakia

In December 2010, the Slovak Parliament adopted an Amendment to the Renewable Energy Sources (RES) Promotion Act in order to lower the feed-in tariff by more than 10% in a single year.
From 1 February 2011 on only solar rooftop facilities or solar facilities on the exterior wall of buildings with capacity not exceeding 100 kW are eligible for the feed-in tariff.
Feed-in tariff guaranteed for 12 years is set by the Regulator each year.
2011 feed-in tariff: 0.383 €/kWh
In addition, PV, like all other RES, qualifies for investment subsidies under the framework of the EU Structural Funds.

Slovenia

A revised feed-in tariff scheme went into force in 2009. The main changes were that the guaranteed period changed from 10 to 15 years and that the tariffs were differentiated according to system sizes and type of installations. The tariff was reduced by 20% from 2010 to 2011. There are two schemes, either a guaranteed tariff or an operating support + market price.

2011 tariffs:

Guaranteed Purchase:

Power	roof-top	BIPV	ground-mounted
< 50 kW	0.332 €/kWh	0.382 €/kWh	0.312 €/kWh
50kW < P < 1 MW	0.304 €/kWh	0.350 €/kWh	0.288 €/kWh
1 MW< P < 10MW	0.232 €/kWh	0.290 €/kWh	0.270 €/kWh

Note: Each year only 5 MW of new ground-mounted systems can receive the FIT.

Operating Support:

Power	roof-top	BIPV	ground-mounted
< 50 kW	0.286 €/kWh	0.335 €/kWh	0.266 €/kWh
50kW < P < 1 MW	0.257 €/kWh	0.303 €/kWh	0.241 €/kWh
1 MW < P < 10MW	0.204 €/kWh	0.242 €/kWh	0.184 €/kWh
10 MW < P < 125 MW	0.171 €/kWh	0.205 €/kWh	0.162 €/kWh

Spain

After the introduction of a 500 MW/a cap for new installations in 2008, new major changes were introduced in October and December 2010 with the Royal Decrees 1565/10 [GoS 2010] and RD-L 14/10 [GoS 2010a].
The major changes included a limitation of the period the feed-in tariffs are paid, the introduction of a limit of the maximum annual numbers of hours of operation on a regional scale and a reduction of the tariffs up to 45% depending on the size and type of the system. In addition the decrees are "retroactive" imposing a reduction of the feed-in tariffs between 10% and 30% for existing projects until 2014.

Current tariffs for new projects are:
- 0.289 €/kWh < 20 kWp; building-integrated and roof-top
- 0.204 €/kWh > 20 kWp; building-integrated and roof-top, max. 2 MW
- 0.135 €/kWh ground-mounted systems up to a maximum size of 10 MW

Sweden

In 2009, Regulation N° 2009:689 on State Subsidies for Solar Cells went into force. The support is limited to actions commenced on, or after, 1 July 2009 and completed by 31 December 2011. The aid may not exceed 60% of the eligible costs (planning and labour, material) and for large companies, aid may not exceed 55% of the eligible costs. Generally, the subsidy must not exceed 2 million SEK (€ 0.22 million[22]) per photovoltaic system or solar electricity and solar thermal hybrid systems.

Energy tax exemption.

[22] Exchange rate: 1 € = 9.15 SEKF

Switzerland

New feed-in tariff in 2008 for new PV systems and those which became operational after 1 January 2006. At the end of 2010, due to the 18% reduction in the feed-in tariff, the budget cap was revised and now 10% of the available budget is allocated to PV systems. Tariff guaranteed for 25 years. Annual tariff revision is foreseen depending on cost reduction.

2011 tariffs:

Nominal Power [CHF/kWh (€/kWh)][23]	Ground-mounted	Roof-top	Building-integrated
≤ 10 kWp	0.427 (0.342)	0.483 (0.386)	0.592 (0.474)
10 – 30 kWp	0.393 (0.314)	0.467 (0.374)	0.542 (0.434)
30 – 100 kWp	0.343 (0.274)	0.422 (0.338)	0.459 (0.367)
100kWp – 1 MWp	0.305 (0.244)	0.378 (0.302)	0.415 (0.332)
> 1 MWp	0.289 (0.231)	0.361 (0.289)	0.391 (0.313)

[23] Exchange rate: 1 € = 1.25 CHF

United Kingdom

New feed-in tariff to be paid for 25 years was introduced on 1 April 2010 and adapted in February 2011.

Tariffs from April 2011 on:

Power	
< 4 kW new buildings	0.378 £/kWh[24] (0.445 €/kWh)
< 4 kW retrofit	0.433 £/kWh (0.509 €/kWh)
4 – 10 kW	0.378 £/kWh (0.445 €/kWh)
10 – 100 kW	0.329 £/kWh (0.387 €/kWh)
0.1 – 5 MW	0.307 £/kWh (0.361 €/kWh)

On 9 June 2011, Energy and Climate Change Minister, Greg Barker, announced the outcome of the fast track review on Feed-in Tariff (FIT) levels of large-scale solar [DEC 2011].
The tariffs for systems smaller than 50 kWp remain unchanged, and for larger systems they are changed as follows from 1 August 2011 on:

50 kW < P ≤ 150 kW	0.190 £/kWh (0.224 €/kWh)
150 kW < P ≤ 250 kW	0.150 £/kWh (0.176 €/kWh)
250 kW – 5 MW	0.085 £/kWh (0.100 €/kWh)

[24] Exchange rate: 1 € = 0.85 GBP

As depicted in Table 1, 21 out of 27 Member States, and Switzerland, have already introduced feed-in tariffs. However, the efficiency of this measure to increasingly exploit these countries' PV-potential varies considerably, in function of the details in each national regulation. In those States where the tariff does not cover the expenses, impact is very limited. In some other States, there is a motivating tariff, but its effectiveness is limited, due to

- fulfilling the cap too early,
- too short a period of validity for the guaranteed increased tariff,
- not yet established priority grid access for renewable energy sources and photovoltaics, or
- administrative requirements being too complicated or even obstructive.

The lessons learned over the last 10 years, with regard to feed-in tariffs, clearly show that the design of the tariffs has to follow a number of framing conditions, in order to be successful and lead to a substantial market growth and competitive market development.

- First, the tariff has to be high enough to recuperate the investment cost in a reasonable time, but does not generate short-term windfall profits. The tariff should have an annual reduction, as well as a sunset built in, to enforce realistic price reductions. In addition, it is important that the feed-in tariff design allows adjusting it according to unexpected high growth rates of the regional and global PV markets and the resulting price developments.
- Second, guaranteed access to connect to the grid, in conjunction with simple permitting procedure (especially for small residential systems). Priority to feed into the grid for electricity generated from renewable energy sources.
- Third, predictable long-term design of the scheme to ensure investors' confidence. Avoidance of stop and go policies.

With a few exceptions, 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 [Šúr 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 are 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 manufacturing capacities along the whole value chain, from raw materials to system components. As the PV industry is becoming more and more a global industry, Europe has to realise that just because it is an environmental technology will not protect it from global competition. Like any other industry, world-wide competition is an essential in the PV industry as well, and if Europe wants to safeguard a vital PV industry in Europe it needs to act not in a protectionist way, but to design industry policies, which help and allow European manufactures to be competitive on the world market. So far, a PV Industry Policy is missing on the European, as well as on the national, level.

Despite the fact that the share of European-made solar cells and modules has decreased to less than 15% in 2010, the European PV industry is still very well positioned along the whole value chain, especially in the equipment manufacturing part, as well as the inverter manufacturing and project businesses.

Based on information provided by the industry, Greenpeace and EPIA have assumed in their study *"Solar Generation VI – 2011"* that, on average, 30 full-time equivalent (FTE) jobs are created for each MW of solar power modules produced and installed [Epi 2011a]. This is a significant reduction from the figures (about 45 FTE) a few years ago, which reflects the increased industrialisation of the PV industry. Based on this data, the employment figures in the photovoltaics sector for 2010 are estimated well above 500,000 world-wide and above 300,000 in the European Union.

In March 2011, the European Commission published a Communication to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions entitled ***"A Roadmap for moving to a competitive low carbon economy in 2050"*** [EC 2011a]. In this Communication, the significance of early investments into low-carbon technologies was highlighted:

Investing early in the low carbon economy would stimulate a gradual structural change in the economy and can create in net terms new jobs both in the short- and the medium-term. Renewable energy has a strong track record in job creation. In just 5 years, the renewable industry increased its work force from 230 000 to 550 000.… In the longer-term, the creation and preservation of jobs will depend on the EU's ability to lead in terms of the development of new low carbon technologies through increased education, training, programmes to foster acceptability of new technologies, R&D and entrepreneurship, as well as favourable economic framework conditions for investments. In this context, the Commission has repeatedly emphasised the positive employment benefits if revenues from the auctioning of ETS allowances and CO_2 taxation are used to reduce labour costs, with the potential to increase total employment by up to 1.5 million jobs by 2020.

Electricity generated with photovoltaic systems has additional positive benefits for the European economy in the long run. First, with increasing installations of photovoltaic systems, the electricity generated can help to reduce the import dependency of the European Union on energy imports. The results of an impact assessment of the European Commission on the effectiveness of support measures for renewable energies in the European Union state [EC 2005]:

Rising oil prices and the concomitant general increase in energy prices reveal 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 2005a]. For the European Union, the negative GDP effect would be in the order of € 41.9 billion from 2005 to 2007.

It is obvious that further price increases worsened the situation, and some economic analysts claim that the 2008/2009 economic crisis could be attributed to the rapid increase of the oil prices since 2003 and the spike in July 2008[25] [IEA 2008].

[25] Crude oil prices went up from US$ 26/bbl (june 2003) and spiked at US$ 147.27/bbl (July 2008), source: Oil report IEA

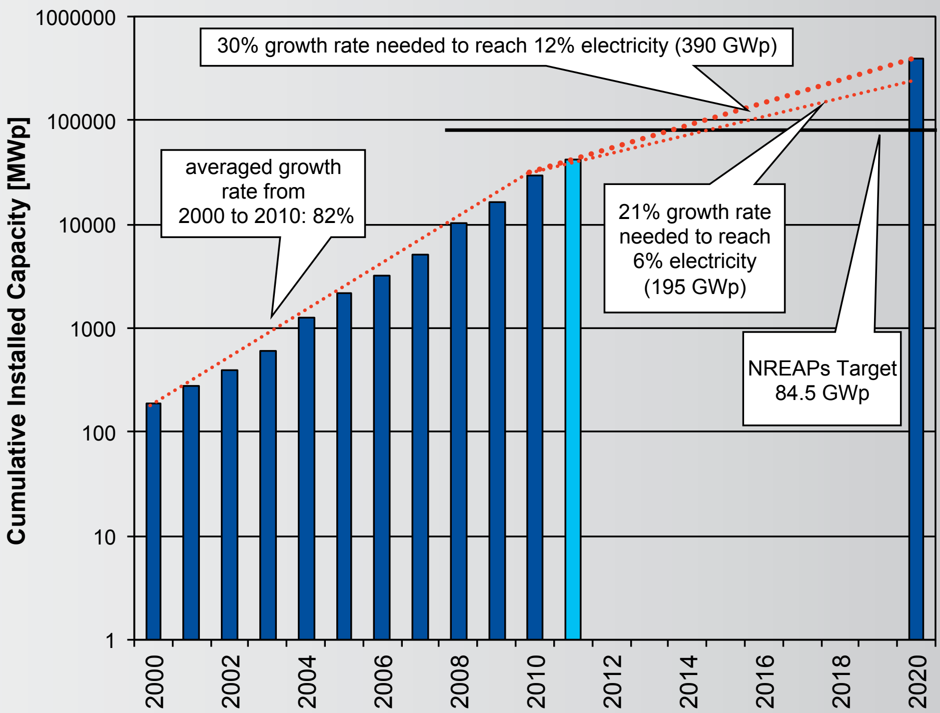
There are several studies that examine the difficult issue of quantifying the effect of the inclusion of RES in an energy portfolio and the reduction in the portfolio energy price. This is in addition to the employment benefits and the economic benefits of avoided fuel costs and external costs (GHG),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

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

In 2006, the European Union already surpassed its own White Paper target of 3 GWp cumulative installed capacity for **Renewable Electricity from Photovoltaics** for 2010. The averaged annual growth rate between 2000 and 2010 was 82%, which is more than double the 30% needed between 2010 and 2020 in order to reach 12% of European electricity supply from solar photovoltaic systems (Fig. 12). The main issue to realise such ambitious targets is not whether or not the PV industry can supply the needed systems, but whether or not the electricity grid infrastructure will be able to absorb and distribute the solar-generated electricity.
The European PV Industry has to continue its impressive growth over the coming years, in order to maintain its market position. This will only be achieved if reliable political framework conditions are created, and maintained, to enable return on investment for PV investors and the industry alike. Besides this political issue, targeted improvements of the solar cell and system technology, as well as competitive manufacturing technologies, are still required.

Fig. 12:
PV growth in the European Union and estimate for 2011.



4.2 PV Research in Europe

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

The European Commission's Research and Development activities are organised in multi-annual Framework Programmes (FP), originally with a duration of 4 years. Support for Photovoltaic Research Projects started in the 1980s. In FP4 (1994 – 1998) 85 projects were supported with a budget of € 84 million. In FP5 (1998 to 2002) the budget was increased to around € 120 million and about 100 projects received funding. In FP6 (2002 to 2006) the budget for PV projects fell to € 107.5 million. An overview about the FP6 funded projects was published by the European Commission in 2009 [EC 2009a].

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

During the 6th Framework Programme, the PV Technology Platform was established. The aim of the Platform is to mobilise all the actors sharing a long-term European vision for photovoltaics. The Platform developed the European Strategic Research Agenda for PV for the next decade(s) and the corresponding implementation plan to ensure that Europe maintains industrial leadership [Ptp 2007, 2009].

For the first time, the **7th EC Framework Programme** for Research, Technological Development has a duration of 7 years and runs from 2007 to 2013. The Commission expects the following impacts from the research activities: *Through technological improvements and economies of scale, the cost of grid-connected PV electricity in Europe is expected to be lowered to a figure in the range of 0.10-0.25 €/kWh by 2020. Research and development should lead to reduced material consumption, higher efficiencies and improved manufacturing processes, based on environmentally sound processes and cycles.*

The following projects have been approved since the publication of the 2010 PV Status Report [Jäg 2010].

Topic ENERGY.2010.2.1-1:
Further development of very thin wafer-based c-Si photovoltaics

- **20plμS:** 20% efficiency on less than 100 μm thick industrially feasible c-Si solar cells

  The overall objective of the current project is a significant contribution to the dissemination of PV, in order to improve the sustainability of the European energy supply and to strengthen the situation of the European PV industry. The approach to reach this overall objective is the development of solar cells which are substantially thinner than today. In more detail the following topics are addressed:

  Wafering from Si ingots, surface passivation, light trapping, solar cell and module processing and handling of the thin wafers The partners of this project form an outstanding consortium to reach the project goals, including four leading European R&D Institutes, as well as four companies with recorded and published expertise in the field of thin solar cells and modules and handling of such. The project is structured in 10 work packages, covering the process chain from wafer to module and the transfer into pilot production already at mid-term, as well as integral eco-assessment and management tasks.
  Total Budget:
  € 7.01 million, EU contribution: € 4.88 million
  Coordinator: Universität Konstanz, Germany
  Project duration: 36 months

- **SUGAR: Silicon Substrates from an Integrated Automated Process:** Since the silicon wafer still accounts for a substantial part of the cost of solar modules, reducing the silicon consumption per watt peak is one of the most effective ways of reducing the overall cost of PV systems. In this project,a methodology is proposed to produce a high-efficiency solar module with a very limited amount of Si. The methodology is based on two technologies: the first one for the fabrication of the solar wafers, the second one for the processing of this new material. For the fabrication of the ultra-thin solar wafers, a material, for instance a metallic material, with a high coefficient of thermal expansion, is deposited on the substrate at high temperature. The system is then cooled down, and the difference of thermal expansion induces some stress in the silicon substrate. When the stress exceeds the mechanical strength of silicon, a crack propagates parallel to the surface, and the top layer (which thickness reaches in this case around 50 μm) of silicon is detached from the parent substrate. The thin silicon layer, and the metal layer, are rolled due to some remaining stress. This stress can be annihilated by dipping the sample in a chemical bath.

The processing of this material into a solar module is not trivial, and the second technology developed in this project proposes to glue the ultra-thin wafer to a definitive glass superstrate. The Si material is then processed into a solar cell, and encapsulated into a module. The module and the solar cell process are integrated and are performed at low temperature (heterojunction-based interdigitated back contact) to be compatible with the glass thermo-mechanical properties. The project directly addresses a core issue of photovoltaic research and proposes an elegant, low-cost and very innovative solution to solve it.
Total Budget:
€ 5.76 million, EU contribution: € 3.72 million
Coordinator: imec, Belgium
Project duration: 36 months

Topic ENERGY.2010.2.1-2 - EU – India Coordinated Call: Development of novel materials, device structures and fabrication methods suitable for thin-film solar cells and TCOs, including organic photovoltaics.

- **LARGECELLS: Large-area Organic and Hybrid Solar Cells:** The task of developing large-area, thin-film solar cells based on polymers, as well as solid-state organic-inorganic (hybrid) systems, will be undertaken. The required novel materials (charge transport polymers, semiconductor surfactants/compatibilisers and inorganic nanoparticles) will be synthesised and the compounds with the most potential will be scaled-up for the purpose of modern fabrication methods, such as roll-to roll (R2R) processing. Additionally, the efficient devices will be tested and analysed in outdoor conditions in India, and under accelerated ageing conditions in Israel, to understand the degradation mechanism. Finally, the basic information from stability studies will be used to design novel materials suitable for highly efficient devices of long-term stability. The programme is intensively intertwined with an Indian consortium, especially in the fields of novel materials, outdoor testing, transfer and exchange of knowledge and methods.
Total Budget:
€ 2.17 million, EU contribution: € 1.65 million
Coordinator: Universität Bayreuth, Germany
Project duration: 36 months

- **AGATHA: Advanced Gratting for Thin Films Solar Cell:** The minority carrier diffusion lengths are small in polycrystalline or amorphous materials used in thin-film solar cells, requiring thin layers to maximise charge collection. This is contradictory for the requirement to maximise solar energy absorption. The optical design, consisting in increasing a solar cell's light-trapping capability is of prime importance. In order to provide total internal reflection, both randomly textured surfaces and regularly patterned surfaces have been investigated. None of these approaches provide optimal light trapping because none are suitable for the broad solar spectrum. Recent approaches, involving new TCO layers, show that double textures provide improved scattering. The AGATHA project aims to realise an advanced light trapping design by combining micro-texturing of glass by hot embossing and nano-texturing of the top TCO layer by etching. The parameters of this modulated surface texture can be adjusted to maximise the light scattering in all the solar spectrum to provide a significant increase in both short-circuit current and EQE. Suitable for high production throughput, the new texturing process chain, developed in AGATHA, fits with the intrinsic low cost nature of thin-film solar cells To demonstrate the efficiency of this optical trapping design, the modulated texture concept will be implemented in a-Si:H based, μ-c-Si:H based and CIGS based thin-film technologies. The objective is to reduce the active material thickness, from 250 nm up to 150 nm for the a-Si:H, from 1.5 μm up to 1 μm for μc-Si:H and from 2.5 μm up to 800 nm for the CIGS, when increasing the short circuit current of 15% The choice of these technologies aims to maximise the impact by addressing 70% of the thin-film market. According to typical solar cell cost structure, a 15 % reduction of the cost/m^2 is achievable. Combined with the Jsc improvement, the implementation of modulated surface texture should result in a 20 % decrease

of the /W indicator.
Total Budget: € 2.43 million, EU contribution: € 1.71 million
Coordinator: CEA, France
Project duration: 36 months

- **ESCORT: Efficient Solar Cells based on Organic and hybrid Technology**: Widespread uptake of inorganic semiconductor solar cells has been limited, with current solar cell arrays only producing between 4 to 7 GW of the 15 TW (<0.04%) global energy demand, despite the terrestrial solar resource being 120,000 TW. The industry is growing at a cumulative rate of over 40% per annum, even with effects of the financial crisis. The challenge facing the photovoltaic industry is cost effectiveness through much lower embodied energy. Plastic electronics and solution-treatable inorganic semiconductors can revolutionise this industry thanks to their relatively easy and low-cost treatment (low embodied energy). The efficiency of solar cells fabricated from these cheap materials, is approaching competitive values, with comparison tests showing better performance for excitonic solar cells with reference to amorphous silicon in typical Northern European conditions. A 50% increase of the output will make these new solar cells commercially dominant in all markets, since they are superior in capturing photons in non-ideal conditions (angled sun, cloud, haze) having a stable maximum power point over the full range of light intensity. The objectives are to exploit the joint leadership of the top European and Indian academic and industrial Institutions to foster the wide-spread uptake of Dye-Sensitised Solar Cells technology, by improving over the current state-of-the-art by innovative materials and processes.
Total Budget: € 1.76 million, EU contribution: € 1.34 million
Coordinator: ENEA, Italy
Project duration: 36 months

Topic ENERGY.2010.10.2-1 Future Emerging Technologies for Energy Applications (FET)

- **MOLESOL:** All-carbon platforms for highly efficient molecular wire-coupled dye-sensitised solar cells.
The proposed project comes with a visionary approach, aiming at the development of a highly efficient molecular-wire charge transfer platform to be used in a novel generation thin-film dye-sensitised solar cell fabricated via organic chemistry routes. The proposed technology combines the assembled dye monolayers, linked with organic molecular wires to semiconducting thin film deposited on optically transparent substrates. Current organic photovoltaic (OPV) cell designs made a significant step towards low cost solar cells technology, however in order to be competitive with Si and CIGs technologies, OPVs have to demonstrate long-term stability and power conversion efficiencies above 10% The highest reported power conversion efficiency for an OPV device, based on bulk heterojunction device with PCBM and low band gap conjugated polymers, is today 6.4%, but this system seems to be reaching its limit. Offsets in the energetics of these systems lead to large internal energy losses. The dye-sensitised solar cells (DSC) reach the efficiency above 11%, but the problems with the stability of the electrolyte are the current bottleneck. The MOLESOL comes with a novel concept of hybrid device combining the advantages of both concepts (i.e. dye coupled with organic molecular wire to a conductive electrode). This concept will lead to stable cells with enhanced conversion efficiency based on: Reduction of critical length for the charge collection generated in the dye monolayer by the inorganic bottom electrode, using short molecular wires compatible with exciton diffusion length. Replacing current inorganic ITO/FTO (n-type) layers by novel transparent wide band p-type semiconductor, with a possibility of engineering the surface work function and leading to perfect matching between HOMO of the dye layer and the valence band of semiconductors, allowing larger Voc.
Project cost: € 3.34 million, EU Contribution: € 2.45 million
Coordinator: IMEC, Belgium
Project duration: 36 months

- **R2M-Si:** Roll to Module processed Crystalline Silicon Thin-Films for higher than 20% efficient modules.
The current technologies to produce photovoltaic modules exhibit features, which prevent cost-reduction to below 0.5 €/Wp: - Sawing/Wafering and Module assembly is costly and material intensive for wafer solar cells - Efficiency is comparatively low for classical thin-film solar cells (CdTe, CIS, a-Si/µc-Si, dye, organic). One approach to avoid both disadvantages is the so-called crystalline Si thin-film lift-off approach, where thin c-Si layers are stripped from a silicon wafer. This approach has the potential to reach > 20% efficient solar cells, however handling issues have hindered quick progress so far. The basic idea of the current project is to enable the use of lift-off films in a nearly handling-free approach, to avoid limitations by handling issues. The technological realisation has the following key features

and steps: - Continuous separation of a very thin (< 10 µm) c-Si foil from the circumference of a monocrystalline silicon ingot - Attachment to a high-temperature stable substrate of large area (e.g. graphite, Sintered Silicon, or ceramics), which can also serve as the rear side of modules. - High-temperature re-organisation of the silicon foil, followed by in-situ epitaxial thickening (~40 µm base thickness) in an in-line chemical vapour deposition reactor, including pn-junction formation - Processing of high-efficiency solar cells and formation of integrated interconnected high-voltage modules - Encapsulating into a module (glass / encapsulant only if needed). The resulting module to be demonstrated in R2M-Si has a cost potential around 0.55 €/Wp, at 18% module efficiency and thus low Balance-of-System cost. Future enhanced R2M-Si modules can exceed even 20% efficiency, at costs below 0.5 €/Wp. The project shall demonstrate the feasibility of the most critical process steps, like continuous layer detachment, bonding to a carrier substrate, high-quality epitaxy, handling-free solar cell processing and module integration. As a deliverable, a mini module of higher than 18% efficiency shall be prepared.
Project cost:
€ 3.9 million, EU Contribution: € 2.83 million
Coordinator: Fraunhofer-Institut für Solare Energiesysteme ISE, Germany
Project duration: 36 months

Topic ENERGY.2011.2.1-1 – EU-Japan Coordinated Call. Ultra-high concentration photovoltaics (CPV), cells, modules and systems

- NGCPV: A new generation of concentrator photovoltaic cells, modules and systems The Project, through collaborative research between seven European and nine Japanese leading research centres, in the field of concentration photovoltaic (CPV), pursues the improvement of present concentrator cell, module and system efficiency. Particular effort will be devoted to the development of multijunction solar cells (by carrying out research on metamorphic, lattice match, inverted and bifacial growth, use of silicon substrates and incorporation of quantum nanostructures) with the objective of approaching the 50 % efficiency goal at cell level and 35% at module level (by incorporating advanced optics, as for example Fresnel-Kohler concentrators). As a means to speed up the progress, the project will also expand the use of characterisation techniques suitable for CPV materials, cells, trackers, modules and systems, by developing new ones, incorporating advanced semiconductor techniques to the field of photovoltaics (such as three dimensional real-time reciprocal space mapping, 3D-RTSM, piezoelectric photo-thermal and optical time resolved techniques) and by deploying a round robin scheme that allows the qualification and standardisation of the results derived from the measurements.

  To support all these studies from a global perspective and, in particular, to ensure an accurate forecast of the energy produced at system level, the project plans to build a 50 kW concentrator plant. To achieve its goals, the project is structured into five RTD work-packages: new materials and device characterisation, development of novel device technologies and quantum nanostructures for CPV, development of advanced CPV cells, development of characterisation tools for CPV cells, modules and systems and development of CPV modules and systems. To strengthen the collaboration between EU and Japan, the proposal also foresees more than 20 interchange visits. NGCPV is an EU coordinated project in the framework of call FP7-ENERGY-2011-JAPAN, foreseeing a simultaneous start with the Japanese coordinated project. Accordingly, the Japanese project should start at the latest within 3 months of the signature of the EU grant agreement.

  Project cost:
  € 6.53 million, EU Contribution: € 5 million
  Coordinator: Universidad Politécnica de Madrid, Spain
  Project duration: 42 months

The following call was launched in 2010, with a closing date of 7 April 2011. The project applications are already evaluated and a short-list established. The contract negotiations are not yet finalised.

Call: ENERGY-2011-2
Topic ENERGY-2011-2.1-3
Productivity and cost optimisation issues for the manufacturing of photovoltaic systems based on concentration

ENERGY.2011.2.1-4:
Development and demonstration of standardised building components

4.2.1 The Strategic Energy Technology Plan

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

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

In June 2009, the European Photovoltaic Industry Association published its study "SET for 2020 – Solar photovoltaic Electricity: A mainstream power source in Europe by 2020" [Epi 2009]. The study explores different deployment scenarios ranging between 4 and 12%.

4.2.2 Solar Europe Industry Initiative

Within the SET-Plan, photovoltaics was identified as one of the key technologies and the SET-Plan calls for six different European initiatives, one of them being solar. The ***Solar Europe Industry Initiative*** (SEII) has two pillars: Photovoltaics and concentrated solar thermal power. The Initiative focuses on large-scale demonstration for both technologies and was officially launched at the beginning of June 2010, under the Spanish Presidency.

The intention of the SET-Plan Initiatives is that they are industry-led, and for this reason the European Photovoltaic Industry Association (EPIA) developed an implementation plan for the first three years of the PV part of the Solar Europe Industry Initiative [Sei 2010].
The implementation plan of the SEII clearly identifies the recommended actions and investment areas, their budgetary implications and the resulting expected measurable benefits for the European society. Within SEII it is envisaged to achieve the following three strategic objectives:

1. SEII will bring PV to cost competitiveness in all market segments (residential, commercial, and industrial) by 2020 (cost reduction);

2. SEII will establish the conditions allowing high penetration of distributed PV electricity within the European electricity system (integration);

3. SEII will facilitate the implementation of large-scale demonstration and deployment projects with a high added value for the European PV sector and society as a whole.

In addition to this, the SEII creates the necessary basis for development beyond 2020 and the 2020 targets, supporting the European industry to also play a leading role in the longer term.

4.3 Solar Companies

In the following, some European solar cell manufacturers, not yet mentioned in Chapter 3, are described briefly. This listing does not claim to be complete, especially concerning the great number of start-up companies. In addition, it has to be noted that information or data for some companies are very fragmented and limited. A lot of the data were collected from the companies' websites.

4.3.1 AVANCIS GmbH & Co KG (Germany)

AVANCIS was founded as a joint venture between Shell and Saint-Gobain in 2006. In 2008, commercial production started in the new factory with an initial annual capacity of 20 MW in Torgau, Germany. In 2009, Saint-Gobain took over the shares of Shell and started the construction of a second CIS factory with a total capacity of 100 MW in Torgau. In October 2010, the company announced the forming of a joint venture with Hyundai Heavy Industries (HHI), in Korea, for the production of CIS solar cells with a production capacity of initially 100 MW. Production in 2010 is reported with 20 MW.

4.3.2 Bosch Solar (Germany)

The Bosch Group, a leading global supplier of technology and services in the areas of automotive and industrial technology, consumer goods, and building technology, took over the 1997 founded ErSol Solar Energy AG Erfurt in 2008 and renamed it Bosch Solar. Bosch Solar manufactures and distributes photovoltaic crystalline and thin-film silicon products. In 2010, the company had a production of 335 MW [Pvn 2011] and a production capacity of 520 MW

2010. The completion of the Arnstadt expansion project to 630 MW is planned for 2011.

In spring 2011, Bosch Solar announced that they would build a new 150 MW module manufacturing plant in Vénissieux, France and also a new manufacturing site for cells and modules with 630 MW in Malyasia, which should become operational in 2013.

Bosch Solar holds a 35% interest in 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 has been producing solar modules since 2006. In 2009, Bosch Solar also acquired 68.7% of the German module manufacturer Aleo Solar AG and took over the majority of the German CIS company Johanna Solar GmbH.

4.3.3 Conergy (Germany)

Conergy was founded in 1998 and started the production of solar cells in 2007 in Frankfurt/Oder. The company manufactures cells, modules, inverters and mounting systems and is active in the stem business as well. For 2010, a production capacity of 250 MW and a production 208 MW is given [Pvn 2011].

4.3.4 Inventux Technologies AG (Germany)

Inventux was founded in spring 2007 to manufacture amorphous/microcrystalline thin-film silicon solar modules and broke ground for its 40 MWp factory in Berlin, Germany, in September 2007. Commercial production started at the end of 2008. For 2010, a production of 40 MW is reported [Pho 2011].

4.3.5 Isofotón (Spain)

Isofotón, a private-owned company, was set up in Malaga to produce silicon solar cells by Professor 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 2010, Isofotón acquired a new investor and owner: the consortium Affirma-Toptec. The company announced that it would increase its production capacity from 140 MW to 230 MW in 2011 and build a new module factory with a capacity of 50 MW in Ohio, USA. About 80 MW of production were reported for 2010 [Pho 2011].

In 2006, Isofotón teamed up with the utility Endesa and GEA 21, and together with the Andalusian Department of Innovation, Science and Business, they announced the building of the first polysilcon plant in Spain. However, due to the difficult economic conditions, the project stalled. In spring 2011, Isofotón teamed up with the Korean material company Hankook Silicon to realise the project. The Silico Energía plant should have an initial capacity of 2,500 tons and in its final stage 10,000 tons.

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.

4.3.6 Masdar PV (Germany/UAE)

Masdar PV was founded in 2008 by the Masdar Initiative, which is driven by the Abu Dhabi Future Energy Company (ADFEC), a fully owned company of the Government of Abu Dhabi, through the Mubadala Development Company. The company broke ground on a 40 MW a-Si thin film plant, Ichtershausen (Thuringia), Germany, the same year and started commercial operation in 2009. At the end of 2010, the capacity of the plant was 65 MW and an expansion to 95 MW is ongoing. In 2010, 30 MW of actual production is reported [Pho 2011].

4.3.7 Photowatt (France)

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. In 2010, the company opened a 100 MW module plant in Ontario, Canada, and in February 2011, it announced that it would move the French production to Poland. In 2010, Photowatt had a production capacity of 70 MW and actual production of 58 MW [Pho 2011].

4.3.8 Photovoltech (Belgium)

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.
According to the company, production capacity at the end of 2010 was 150 MW, and the expansion to 500 MW is ongoing as planned.
In 2010, the company had a production of 89 MW of polycrystalline solar cells [Pvn 2011].

4.3.9 Schott Solar AG (Germany)

Schott Solar AG has been a fully owned subsidiary of Schott AG, Mainz, since 2005, when 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 2010, the company had a production capacity of 350 MW and an actual production of 320 MW [Pvn 2011].

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

Schott Solar Wafer GmbH was established as a joint venture of Wacker Chemie AG (Munich) and Schott Solar AG (Mainz) in 2007. In September 2009, Wacker announced its exit from the joint venture and Schott Solar took over the remaining shares. In April 2008, a second factory for the production of silicon wafers for the solar industry was opened in Jena. In May 2009, the company opened its new manufacturing building in Jena and full capacity of 275 MW was reached at the end of the year. Total solar-wafer production capacity is set to expand in stages, reaching about 1 GW per year by 2012.

4.3.10 Schüco Dünnfilm GmbH & Co. KG (Germany)
Schüco Thin Film GmbH & Co. KG is a subsidiary of Schüco International KG and was founded in 2008, under the name Malibu. In 2009, the company opened its a-Si thin-film plant with 40 MW production capacity. In 2010, it took over the 60 MW a-Si factory of the insolvent Sunfim AG in Gro≤röhrsdorf, Germany. For 2010, a production of 40 MW was reported [Pho 2011].

4.3.11 Solar Cells Hellas Group S.A. (Greece)
Solar Cells Hellas, was founded in 2006, and started their commercial production with a 30 MW capacity in 2008. The capacity for wafers and solar cells was gradually increased and reached 80 MW at the beginning of 2010. Module production capacity reached 110 MW in February 2011. In 2010, the company had a solar cell production of 48 MW [Pho 2011].

4.3.12 Soltecture Solartechnik GmbH (Germany)
Soltecture was founded as Sulfurcell Solartechnik GmbH, in June 2001, and is jointly owned by its founders and investing partners. In 2004, the company set up a pilot plant to scale up the copper indium sulphide (CIS) technology, developed at the Hahn-Meitner-Institut, Berlin. First prototypes were presented at the 20th PVSEC in Barcelona in 2005. Production of CIS modules started in December 2005 and in 2006 the company had sales of 0.2 MW. The first 35 MW expansion phase was completed in October 2009 and for 2010 a production of 18 MW is reported [Pho 2011]. A further expansion to 75 MW is under way.

4.3.13 Solland Solar Energy BV (The Netherlands/Germany)
Solland Solar is a Dutch-German company and was registered in 2003. At the end of 2004 the construction of the factory went underway and start-up of production was in September 2005. At the end of 2007, production capacity was 60 MW and increased to 170 MW in the first half year of 2008.Solland had a production of 120 MW in 2010 [Pvn 2011].

4.3.14 Sovello AG (Germany)
Sovello opened its first factory to produce 30 MW String-Ribbon™ wafers, solar cells and solar modules in Thalheim, Germany, in 2006. The second factory, with 60 MW capacity, was added in 2007 and in total capacity reached 180 MW in 2009. From 2012, the company plans to produce 600 MW. In 2010, Sovello had a production of 127 MW [Pvn 2011].

4.3.15 Sunways AG (Germany)
Sunways AG was incorporated in 1993 in Konstanz, Germany, and went public in 2001. Sunways produces polycrystalline solar cells, transparent solar cells and inverters for PV systems. In 2010, the company produced 98 MW [Pvn 2011].

Sunways opened its second production facility with an initial production capacity of 30 MW in Arnstadt, Germany, in 2005, which was expanded to 100 MW in 2008. Total production capacity in 2010 was 116 MW.

4.3.16 Additional Solar Cell Companies

- **Calyxo GmbH** was founded as a subsidiary of Q-Cells AG, located in Wolfen, Saxony-Anhalt, Germany. In 2008, the company started to manufacturer CdTe thin-film solar cells with a pilot 25 MW and started an 85 MW expansion project, which is ramped up in 2011. About 7 MW of CdTe modules were manufactured in 2010 [Pho 2011].

- **Concentrix Solar GmbH** was founded in 2005 as a spin-off company of Fraunhofer Institute for Solar Energy Systems and is located in Freiburg/Breisgau, Germany. Under the brand name FLATCON® , complete, turnkey concentrator photovoltaic power plants on the commercial level are offered. From 2006 until August 2008, the company manufactured its concentrator modules on a pilot production line, before a commercial production line with 25 MW capacity started operation in September 2008. In December 2009, the French Soitech Group acquired Concentrix.

- **G24 Innovations Limited (G24i)**, headquartered in Cardiff, Wales, manufactures and designs solar modules based on Dye Sensitised Thin-film (DSTF) technology. In 2007, production of dye sensitised solar cells, with a roll-to-roll process, started. First commercial sales took place in 2009.

- **Helios Technologies** located in Carmignano di Brenta (PD), Italy, was established in 1981 and became a part of the Kerself Group in 2006. It manufactures solar cells, modules and photovoltaic systems. Current production capacity is 60 MW for solar cells and 50 MW for modules.

- **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 cooperate, in August 2004. The first production line was inaugurated on 19 April 2007. On 26 March 2008, the company laid the cornerstone for its 30 MW expansion project. The first 20 MW phase of this expansion was inaugurated in June 2010. For 2010, 5 MW of production is reported [Pho 2011].

- **Pramac Ecopower** is a division of the Pramac SpA Group, located in Balerna (Chiasso), Switzerland. The company manufactures mono- and polycrystalline modules and started with the production of amorphous/ microcrystalline thin-film solar modules at their 30 MW factory in July 2009. For 2010, 25 MW of production is reported [Pho 2011].

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

- **Solsonica s.p.A.**, located in Cittaducale (RI), Italy, is a subsidiary of EEMS and was set up in 2007. In 2008, the company started commercial production of polycrystalline silicon cells and photovoltaic modules (initial installed capacity: 30 MW for cells, 40 MW for modules).

- **T-Solar Global, S.A.** (T-Solar) was founded in October 2006. In October 2009, a factory with an initial production capacity of 40 MW was inaugurated in Ourense, Spain. The production plant is based on technology from Applied Materials and the company plans to expand the capacity to 65 MW, without a date set. For 2010, a production capacity of 48 MW, and actual production of 15 MW, is reported [Pho 2011].

- **VHF Technologies SA (Flexcell)**, is located in Yverdon-les-Bains in Switzerland and produces amorphous silicon flexible modules on plastic film, under the brand name „Flexcell“. The first production line on an industrial scale of 25 MW became operational in 2008.

- **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). The Copper Indium Selenide (CIS) thin-layer technology was perfected in a former power station to facilitate industrial-scale manufacture. In August 2008, the company announced the successful ramp up of their production facilities to 30 MW. In 2010, the company announced a know-how licensing and cooperation agreement with Manz Automation AG for constructing manufacturing facilities for CIGS PV modules modelled after the CISfab plant in Schwäbisch Hall.

4.3.17 Meyer Burger Group (Switzerland)

Meyer Burger was founded in 1953 and entered the solar business in 1998 with the development of a dedicated band saw for solar wafer mass production. In 2010, the company merged with 3S Industries Ltd., a provider of manufacturing equipment and entire production lines for the manufacturing of solar modules. Core competencies include 3S Swiss Solar Systems Ltd. (laminating), Somont GmbH (electrical cell connection, soldering process) and Pasan SA (testing and measuring of solar cells and modules). In spring 2011, the company announced its plans for a takeover of the German equipment manufacturer Roth & Rau to strengthen its offerings in the solar cell process and combine the most important technology steps within the value chain of photovoltaics.

4.3.18 Leybold Optics Solar (Germany)

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

4.3.19 Elkem AS (Norway)

Elkem has been a subsidiary of the China National Bluestar Group Co., Ltd. since April 2011. Elkem Solar developed a metallurgical process to produce silicon metal for the solar cell industry. Elkem is industrialising its proprietary solar grade silicon production line at Fiskaa in Kristiansand, Norway. According to the company, the first plant at Fiskaa has a capacity of 6,000 tons of solar grade silicon and was opened in 2009.

4.3.20 PV Crystalox Solar plc (Germany/United Kingdom)

PV Crystalox Solar plc arose from the merger of Crystalox Ltd. in Wantage, near Oxford, UK, and PV Silicon AG in Erfurt, Germany. The product range includes: solar grade silicon; single crystal ingots, single crystal wafers and multicrystalline wafers. The company went public in June 2007 and is listed on the London Stock Exchange. In February 2009, the new production facility for solar-grade silicon in Bitterfeld, Germany, was opened. The annual production is expected to reach its full capacity of approximately 1,800 MT in 2011. In 2009, wafer shipment was 378 MW.

4.3.21 Manz Automation AG (Germany)

Manz is headquartered in Reutlingen, Germany, and was established in 1987. In 2002, they entered the solar business and delivered their first automation system for fully automated crystalline solar cell manufacturing lines. Next was the development of fully automated quality testing and sorting systems for crystalline solar cells. In the summer of 2010, Manz signed a cooperation agreement with Würth Solar, Schwäbisch Hall, Germany, that gives Manz access to exclusive know-how in CIGS thin-film technology. The company plans to open a new production facility in Suzhou, China, at the end of 2011.

4.3.22 Nitol Solar (Russia)

Nitol Solar was established in 2006 as part of the NITOL group, with a production facility based in the Irkutsk region in Russia. The production activity is based on two divisions – the Chemical Division and the Polysilicon Division, which produces trichlorosilane (TCS) and polysilicon (PCS). In January 2007, the company commissioned and commenced operation of a 10,000 MT per year solar-grade TCS production facility and began selling solar-grade TCS in March 2007. The company is currently constructing an additional solar-grade TCS capacity of 15,000 MT per year and the first 5,000 MT phase is expected to become fully operational in 2011.

4.3.23 NorSun AS (Norway)

NorSun AS is a subsidiary of the technology group SCATEC AS. The Norwegian start-up company was established in 2005. The construction of a monocrystalline ingots and wafer manufacturing facility in Årdal, Norway, started 2007 and reached a capacity of over 200 MW at the beginning of 2011. A second ingot plant is located in Vanta, Finland, and is operating with 30 MW. The company is in the development of a 500 MW plant in Singapore for 2013

4.3.24 OERLIKON Solar (Switzerland)

The cooperation 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 with the aim to develop the production technology for large-scale production of PV modules, based on the micromorph solar cell concept developed at IMT and UNAXIS's KAI production systems.

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

5. India

The Indian National Solar Mission or Jawaharlal Nehru National Solar Mission (JNNSM) was initiated by the Government as one of the eight programmes under the National Action Plan for Climate Change by the Prime Minister of India in 2008. In November 2009, the Mission outline was released and the Mission was formally launched by the Prime Minister of India on 11 January 2010. It aims to make India a global leader in solar energy and envisages an installed solar generation capacity of 20 GW by 2020, 100 GW by 2030 and 200 GW by 2050.

In May 2010, the Indian Semicondutor Association (ISA) published a report about the Solar PV Industry and the importance of the Jawaharlal Nehru National Solar Mission for the development of the Indian PV industry and the actual PV system implementation [Isa 2010].

At the end of 2008, most of photovoltaic applications in India were off-grid, mainly solar lanterns, solar home systems, solar street lights and water pumping systems. Grid-connected were 33 solar photovoltaic systems, with a total capacity of approximately 2 MWp. For its 11th Five Year Plan (2008 – 2012), India has set a target to install 50 MW grid-connected photovoltaic systems, supported by the Ministry of New and Renewable Energy, with an investment subsidy and power purchase programme.

5.1 Implementation of Solar Energy[26]

5.1.1 National Solar Mission

The objective of the National Solar Mission is to establish India as a global leader in solar energy, by creating the policy conditions for its diffusion across the country as quickly as possible [GoI 2010].

The Mission will adopt a 3-phase approach, spanning the remaining period of the 11th Plan and first year of the 12th Plan (up to 2012-13) as Phase 1, the remaining four years of the 12th Plan (2013-17) as Phase 2 and the 13th Plan (2017-22) as Phase 3. At the end of each Plan, and mid-term during the 12th and 13th Plans, there will be an evaluation of progress, review of capacity and targets for subsequent phases, based on emerging cost and technology trends, both domestic and global. The aim would be to protect the Government from subsidy exposure, in case expected cost reduction does not materialise, or is more rapid than expected.

The immediate aim of the Mission is to focus on setting up an enabling environment for solar technology penetration in

[26] Indian fiscal year runs from 1 April to 31 March

the country, both at a centralised and decentralised level. The first phase (up to 2013) will focus on the capturing of the low-hanging options in solar thermal; on promoting off-grid systems to serve populations without access to commercial energy and modest capacity addition in grid-based systems. In the second phase, after taking into account the experience of the initial years, capacity will be aggressively ramped up to create conditions for up-scaled and competitive solar energy penetration in the country.

To achieve this, the Mission targets are:

- To create an enabling policy framework for the deployment of 20,000 MW of solar power by 2022.
- To ramp up capacity of grid-connected solar power generation to 1,000 MW within three years – by 2013; an additional 3,000 MW by 2017 through the mandatory use of the renewable purchase obligation by utilities backed with a preferential tariff. This capacity can be more than doubled – reaching 10,000MW installed power by 2017 or more, based on the enhanced and enabled international finance and technology transfer. The ambitious target for 2022 of 20,000 MW or more, will be dependent on the 'learning' of the first two phases, which if successful, could lead to conditions of grid-competitive solar power. The transition could be appropriately up-scaled, based on availability of international finance and technology.
- To create favourable conditions for solar manufacturing capability, particularly solar thermal for indigenous production and market leadership.
- To promote programmes for off-grid applications, reaching 1,000 MW by 2017 and 2,000 MW by 2022.
- To achieve 15 million square metres solar thermal collector area by 2017 and 20 million by 2022.
- To deploy 20 million solar lighting systems for rural areas by 2022.

The Solar Mission requires that the Tariff Policy be modified to mandate that the Regulators fix a percentage for purchase of power generated using solar energy. The indicated start point percentage is 0.25% in Phase I, to be increased to 3% by 2022.

5.1.2 National Tariff Policy

The existing Tariff Policy from 2006 mandates the State Electricity Regulatory Commissions (SERCs) to fix a minimum percentage of energy purchase from renewable energy sources. Eleven State regulators have introduced Renewable Energy Purchase Obligations (RPOs) for the State power distribution companies. The RPOs vary considerably amongst States, from as low as 1% in some States to 10% in others. The mandate has been largely fixed on the basis of the relative renewable energy development potential of the State. However, no specific solar obligations were set.

In July 2010, the Central Electricity Regulatory Commission (CERC) announced the guidelines for the selection of new grid-connected projects, with a feed-in tariff for 25 years of 17.91 Rs/kWh (0.320 €/kWh) for PV projects commissioned in FY 2010 and 2011. Already in September 2010, the tariffs for FY 2011 (all PPAs signed after 31 March 2011) were revised and set at 15.39 Rs/kWh (0.275 €/kWh).

At the end of June 2010, 12.28 MW grid-connected systems were contracted on the CERC determined tariff.

In December 2010, India's first solar auction took place and resulted in 150 MW of photovoltaic projects. The maximum size of a single PV project was 5 MW. Under the auction rules, those projects offering to sell their electricity at the lowest rates were selected. As the lowest solar photovoltaic bid price came in at 10.95 Rs/kWh (0.196 €/kWh), and the average bidding price was 12.16 Rs/kWh (0.217 €/kWh), it is an open question how and when these projects will be realised.

A second solar auction is foreseen later this year. For this auction, the Ministry of New and Renewable Energy is considering to raise the maximum project size to 20 to 25 MW.

5.1.3 Gujarat Tariff Policies

Gujarat, located in western India, receives an average solar radiation between 5.6 – 6 kWh/m2 per day. Gujarat was one of the first States to establish an agency dedicated to the development of renewable energy in 1979, Gujarat Energy Development Agency (GEDA). In January 2009, the *Gujarat Solar Policy 2009* was passed and it sets a 10% Renewable Purchase Obligation to be achieved by the end of FY2013.

In September 2009, the Gujarat Government signed an MoU with the Clinton Foundation for setting up a 3,000 MW Solar Power Project in Gujart on Government waste-land.

Solar Policy 2009 defined a feed-in tariff for PV and CSP systems. The tariff for PV systems depends on when the systems are commissioned:

- before 31 December 2010:
  13.00 Rs/kWh (0.232 €/kWh) for first 12 years
  3.00 Rs/kWh (0.054 €/kWh) from the 13th to 25th year

- before 1 March 2014:
  12.00 Rs/kWh (0.214 €/kWh) for first 12 years
  3.00 Rs/kWh (0.054 €/kWh) from the 13th to 25th year

Under the Gujarat Solar Policy 2009, 365 MW of PV projects were assigned to 25 project developers, but in May 2011 only a fraction was actually connected to the grid.

5.1.4 Rajasthan Solar Energy Policy

In April 2011, the State Government of Rajasthan passed its Solar Energy Policy 2011 with the objective to develop Rajasthan into a global hub for solar power, and install a capacity of 10 to 12 GW over the next 10-12 years to meet energy requirements of Rajasthan and India.

The State will promote Solar Power Producers to set up Solar Power Plants along with Solar PV manufacturing plants in Rajasthan. The target under this category will be 200 MW up to 2013. This will result in the establishment of 500 MW per annum of SPV manufacturing capacity in the State.

Rajasthan plans to develop Solar Parks of more than 1000 MW capacity in identified areas of Jodhpur, Jaisalmer, Bikaner and Barmer districts, in various stages.

5.2 Solar Photovoltaic R&D Programme

R&D projects are supported by the Ministry of Non-Conventional Energy Sources at research organisations of the Central or State Governments, autonomous societies, Universities, recognised colleges, Indian Institutes of Technology (IITs) and industries, etc., which have suitable infrastructure for undertaking R&D in solar photovoltaic technology. R&D proposals are evaluated by experts and recommended to the Ministry for approval.

R&D is supported on various aspects of solar photovoltaic technology, including development of polysilicon and other materials, development of device fabrication processes and improvements in crystalline silicon solar cell/module technology, development of thin-film solar cell technology (based on amorphous silicon films, cadmium telluride (CdTe) films and copper indium diselenide (CIS) thin-films, organic, dye sensitised and carbon nano-tubes). MNRE is also supporting development of photovoltaic systems and components used in the manufacturing of such systems. For the 11th Plan, the Ministry has identified the so-called **Thrust Areas of R & D in Solar Photovoltaic Technology.**

In order to make solar cells and modules cost effective, the global R&D efforts are directed to reduce the consumption of silicon and other materials and improve the efficiency of solar cells/modules to achieve significant cost reduction. Further R&D is also undertaken on non-silicon based solar cell modules and other aspects of PV systems.

The Ministry of New and Renewable Energy Sources has been supporting R&D and technology development in solar photovoltaic technology for more than three decades. During the 11th Plan period, it is envisaged that the cost of solar photovoltaic modules can be brought down to about Rs. 120 (€ 2.14) per Wp.

In order to achieve this goal, the key areas of R&D and technology development have been identified. Research, design and development efforts during the 11th Plan are proposed to be focused on the development of (I) polysilicon and other materials, (II) efficient silicon solar cells, (III) thin-film materials and modules, (IV) concentrating PV systems, and (V) PV system design, with the objective of significantly reducing the ratio of capital cost to conversion efficiency. The following are the thrust areas for R&D support in solar photovoltaic technology:

1) Polysilicon Material:

- R&D for producing polysilicon with alternative methods (non triclorsilane) with a direct electricity consumption of less than 125 kWh/kg. The quality of the material should allow for cells with efficiency higher than 15%.

- Design, develop and demonstrate at a pilot plant (100 tons annual capacity).

2) Crystalline Silicon Solar Cells & Modules

- Reduction of silicon use to 3 g/Wp for monocrystalline cells by wafer thickness reduction and efficiency increase to ≥ 18%.

- Develop and produce multi-crystalline silicon ingots/wafers and produce solar cells with conversion efficiency of 17% and more in commercial production.

- R&D on alternative device structures to make crystalline silicon solar cells to demonstrate very high efficiency (22-24% on small size laboratory devices).

- Increase PV module life to 25 years and more, with total degradation within 10% of the initial rating under STC.
- Design and development of low-cost, low-weight, non-glass type PV modules with effective module life of 10 years or more, with total degradation within 10% of the initial rating under STC.
- Study and evaluate new materials for use in PV modules.
- Develop low resistance metal contact deposition materials and processes.

3) Thin-Film Modules

- R&D on different processes and device structures to make laboratory scale small area (2cm x 2cm) devices of efficiency >10% using CdTe, CIGS and silicon thin-films.
- Development of polycrystalline thin-film integrated modules (1 sq ft or more) at pilot plant scale, using different materials (CdTe, CIGS, silicon films) to achieve efficiency of>8% and life of integrated module >15 years).

4) New Materials for Solar Cells

- Investigation and characterisation of new materials to determine their suitability for fabrication of solar cells.
- Design and development of new thin-film device structures, based on dye sensitised (liquid and solid state) organic, carbon nano-tubes, quantum-dots, etc. materials. Target: laboratory scale efficiency of 5 – 10%.

5) Concentrating Solar Cells and Modules

- Design and development of concentrator solar cells (concentration ratio of 200 X and more) with module efficiency between 25 – 30% and testing of concentrating PV system in Indian conditions.
- Development of two axis tracking systems suitable for high concentration PV systems.
- Design and development of heat sinks for mounting solar cells under high concentration.
- Design and development of optical systems to achieve concentration ratio of 200 X and more, with minimum optical aberration.
- Development of silicon and GaAs-based solar cells suitable for use under high concentration (200 X or more).

6) Storage System

- Development of long-life (5,000 cycles or more) storage batteries suitable for use in PV systems/ applications.
- Development and testing of new storage systems up to MW scale. It should be possible to store electricity for about 8-10 hours, with storage losses limited to about 10%.

7) Balance of System and PV Systems

- Design and development of a small capacity inverter, including charge controller, with efficiency of 90% or more, suitable for use in solar lighting systems including LED-based lighting systems.
- Design and development of LED-based PV lighting systems for indoor and outdoor applications
- Design, development and field-testing of inverters and grid synchronising system components (peak efficiency >96% and part load of 30% efficiency >88%,) used in residential grid interactive rooftop PV systems.
- Field-testing and performance evaluation of grid interactive rooftop residential PV systems.

8) Testing and Characterisation Facilities

- Upgrade the testing and characterisation facilities for PV materials, devices, components, modules and systems.
- Set up of testing facilities for concentrating PV systems
- Study and evaluate new material, device structures and module designs, etc.

5.3 Solar Companies

In the following chapter, some of the solar companies in India 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.

5.3.1 Bharat Heavy Electricals

Bharat Heavy Electricals Limited (BHEL) is the largest engineering and manufacturing enterprise in the energy-related/infrastructure sector in India today. In 2009, the company increased its manufacturing capacity of silicon solar cells and modules from 3 MW to 8 MW. For 2010, a production of 2.5 MW solar cells is reported [Pho 2011].

5.3.2 Central Electronics

Central Electronics Limited (CEL) is a Public Sector Enterprise under the Department of Scientific and Industrial Research (DSIR), Ministry of Science and Technology, Government of India. It was established in 1974, with an objective to commercially exploit the indigenous technologies developed by National Laboratories and R&D Institutions in the country. At the end of 2010, CEL had a production capacity of 15 MW and is planning to increase it up to 25 MW by the year 2012. For 2010, a production of 4 MW is reported [Pho 2011].

5.3.3 Euro Multivision Ltd.

Euro Multivision Ltd. is a subsidiary of the Euro Group and started commercial solar cell production with a 40 MW capacity in 2010. According to the company, they plan to expand their capacity to 320 MW in the future. For 2010, a production of 7.5 MW was estimated [Pho 2011].

5.3.4 HHV Solar Technologies

HHV Solar Technologies is owned by the Hind High Vacuum Company Pvt. Ltd. (HHV), a manufacturer of vacuum hardware. In 2008, HHV developed a full production line for amorphous silicon solar modules and HHV Solar Technologies set up a thin-film manufacturing line of 10 MW, which started commercial production in 2010. The company has expansion plans for an additional 30 MW (Phase 2), without a specified date. In addition, the company produces crystalline silicon modules with a production capacity of 30 MW.

5.3.5 Indosolar

Indosolar was founded in 2008 and has its production site at Greater Noida (Uttar Pradesh). Within 18 months, the company has set up a production capacity of 160 MW for multicrystalline solar cells. The company plans to reach a capacity of 360 MW by the end of FY 2011 and 1 GW by 2015. For 2010, a production of 140 MW is reported [Pho 2011].

5.3.6 KL Solar Company

KL Solar was founded in 2004 and is located in Coimbatore, Tamil Nadu and manufactures mono and polysilicon solar cells and modules. According to the company, the total installed annual production capacity for solar cells was 27 MW and 12 MW for solar modules at the end of 2010. For 2010, a production of 20 MW is reported [Pho 2011].

5.3.7 Moser Baer

Moser Baer Photovoltaic Limited (MBPV) and PV Technologies India Limited (PVTIL) are subsidiaries of Moser Baer India Limited. They were launched between 2005 and 2007 with the primary objective of providing reliable solar power as a competitive non-subsidised source of energy.

At the end of 2010, the production capacity was given by the company with 90 MW crystalline cells, 100 MW crystalline modules, and 50 MW thin-films with expansion plans in place.

5.3.8 PLG Power

PLG Power is a subsidiary of the Indian PLG Group, manufacturing solar modules in Sinnar, Nasik, since 2008. Module manufacturing capacity in 2010 reached 100 MW and is being expanded to 150 MW in 2011. The company announced that it will start solar cell production with a manufacturing capacity of 60 MW in 2011 and that it is setting up a polysilicon plant with 1,500 tons of polysilicon in Gujarat in 2012, with expansion an option to 3,000 tons by 2013.

Besides the manufacturing activities of polysilicon, solar cells and modules, the company is active in developing and investing in its own PV Power plants in India and Europe (in total over 40 MW of projects are under development for 2011 and 2012).

5.3.9 Solar Semiconductor

Solar Semiconductor was incorporated in the Cayman Islands in April 2006 and has subsidiaries in the United States and India. Manufacturing plants are located in Hyderabad, India, and, according to the company, it had a module production capacity of 195 MW and solar cell capacity of 60 MW at the end of 2010.

5.3.10 Tata BP Solar India Ltd.

Established in 1989, Tata BP Solar is a joint venture between the Tata Power Company and BP Solar. According to the company, the manufacturing capacity at the end of 2010 was 84 MW for solar cells and 125 MW for modules. For 2010, actual production is reported as 50 MW [Pho 2011].

5.3.11 Websol Energy Systems Ltd.

Websol Energy Systems Ltd. (formerly Webel SL Energy Systems Ltd.) was established in 1990 and began production in 1994. Its monocrystalline solar cell and module manufacturing facilities are located at Falta Special Economic Zone, Sector II, Falta, West Bengal. According to the company, its manufacturing capacity was 60 MW at the end of 2010 and the equipment for the expansion to 90 MW is already ordered. A further expansion to 120 MW is planned in 2012. For 2010, the company reported about 18 MW of solar cell production.

5.3.12 Udhaya Energy Photovoltaics Pvt Ltd.

UPV Solar has been manufacturing solar cells and modules in its plant at Coimbatore since 1988. According to the company, cell and module capacity is 12 MW.

5.3.13 Bhaskar Silicon Ltd.

Bhaskar Silicon Ltd. was set up as an independent company by Environ Energy Group as a Solar Energy Solution Provider to build solar photovoltaic power plants and large industrial solar thermal plants. In 2007, the company took over the solar business units of Shell Overseas Investment in India and Sri Lanka. In 2008, the company announced that it would build and operate an integrated polysilicon, cell and wafer-processing facility in West Bengal's industrial township, Haldia, with a planned capacity of 2,500 tons of polysilicon.

The company announced that it will initially invest Rs 350 crores (€ 62.5 million) to manufacture solar cells, based on imported wafers, by October 2009. The facility is to add the capability to manufacture wafers in 2011, enabling it to produce 250 MW of cells annually. Within two years, the company aims to produce 5,000 metric tons of polysilicon annually and to also supply polysilicon for the semiconductor industry.

[32] Exchange rate: 1 € = 56 Rs

6. Japan

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

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

6.1 Renewable Energy Policy in Japan

After the dramatic events which took place at the Fukujima Daiichi nuclear power plant in March 2011, the current energy policy and with it the role of renewable energies and photovoltaics is under revision. Renewable energy will definitely play a larger role in Japan, according to Government officials.

On 10 May 2011, Prime Minister Naoto Kan said at a news conference: *"The current basic energy policy envisages that over 50% of total electricity supply will come from nuclear power, while 20% will come from renewable power in 2030. … But that basic plan needs to be reviewed now from scratch after this big incident."*

A description of the development of the Japanese legislation and activities can be found in the 2008 PV Status Report [Jäg 2008], and earlier Status Reports reported about the history and the main differences between the Japanese and European reasons for the introduction of renewable energies [Jäg 2004, 2010].

6.2 Implementation of Photovoltaics

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

The Residential PV System Dissemination Programme has been leading the expansion of Japan's PV market for 12 years. In 2006, 88.5%, or 254 MW of the new installations, were grid-connected residential systems, bringing the accumulated power of solar systems under the Japanese PV Residential Programme to 1,617 MW, out of 1,709 MW total installed PV capacity at the end of FY 2006 [Mat 2007]. After a decrease in FY 2007, and a slight recovery in FY 2008, the Japanese market started to grow again significantly in 2009 and 2010, thanks to a renewed investment subsidy programme and the introduction of a "feed-in tariff for excess" energy [Epi 2011, Ikk 2011].

In July 2009, the new Law on the *Promotion of the Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Source Materials by Energy Suppliers was enacted. With this Law, the purchase of "excess"* electricity from PV systems was no longer based on a voluntary agreement by the electricity utility companies, but it became a National Programme with cost-burden sharing of all electricity customers.

The outline of the new programme to purchase surplus electricity from PV systems is the following:

- Obligation of utility companies to purchase PV power at a fixed price;
- Eligible for the fixed price are PV systems on residential and non-residential buildings, which are grid-connected and have contracts with an electricity utility company (reverse flow). PV systems designed for power generation and systems larger than 500 kWp are not eligible;
- The fixed prices in FYs 2009 and 2010 were:
  · 48 ¥/kWh (0.37 €/kWh) for PV systems < 10 kW on residential houses
  · 39 ¥/kWh (0.30 €/kWh) for residential houses with double power generation,e.g. PV + fuel cells, etc.
  · 24 ¥/kWh (0.18 €/kWh) for PV systems on non-residential houses;
- The rates are fixed for 10 years;
- The purchase price will be reviewed and decreased by the Sub-Committee on *Surplus Power Purchase Programme annually.*
- All electricity users will equally bear the costs of the PV surcharge.

From April 2011 on, the following tariffs apply to the scheme:

The purchasing prices for customers, who newly sign up in FY 2011, is 42 ¥/kWh (0.323 €/kWh) for residential photovoltaic (PV) facilities (less than 10 kW) and 40 ¥/kWh (0.308 €/kWh) for non-residential PV facilities (in the case of double power generation)[27], it is 34 ¥/kWh (0.262 €/kWh) for residential PV facilities and 32 ¥/kWh (0.246 €/kWh) for non-residential PV facilities.

In 2004, NEDO, METI, PVTEC[28] and JPEA[29] drafted the "PV Roadmap towards 2030" (Fig.13) [Kur 2004]. The worldwide changes of circumstances, especially the rapidly growing photovoltaic production and markets, as well as the accelerated growth of energy demand in Asia, together with a changed attitude towards Climate Change and the necessary greenhouse gas reductions in Japan, have led to a revision of the Roadmap PV2030 to 2030+. The review aims at further expanding PV usage and maintaining the international competitiveness of Japan's PV industry.

The 2030 Roadmap has been reviewed and the goal has been changed from "making PV power generation one of the key technologies by 2030" to "making PV power generation one of the key technologies, which plays a significant role in reducing CO_2 emissions by 2050, so that it can contribute, not only to Japan, but also to the global society".

In PV2030+, the target year has been extended from 2030 to 2050 and a goal to cover between 5 and 10% of domestic primary energy demand with PV power generation in 2050 was set. PV2030+ assumes that Japan can supply approximately one-third of the required overseas market volumes (Table 2). To improve economic efficiency, the concept of "realising Grid Parity" remained unchanged and the generation cost targets remained unchanged from PV2030. In addition, PV2030+ aims to achieve a generation cost of below 7 ¥/kWh in 2050. Regarding the technological development, an acceleration to realise these goals is aimed to achieve the 2030 target already in 2025, five years ahead of the schedule set for PV2030. For 2050, ultra-high efficiency solar cells with 40%, and even higher conversion efficiency, will be developed.

[27] Double power generation means in the case that both PV facilities and in-house power generation facilities, excluding PV facilities, have been installed.

[28] Phtovoltaic Power Generation Technology Research Association
[29] Japan Photovoltaic Energy Association

Fig. 13: Japanese Roadmap for PV R&D and market implementation [Kur 2004]

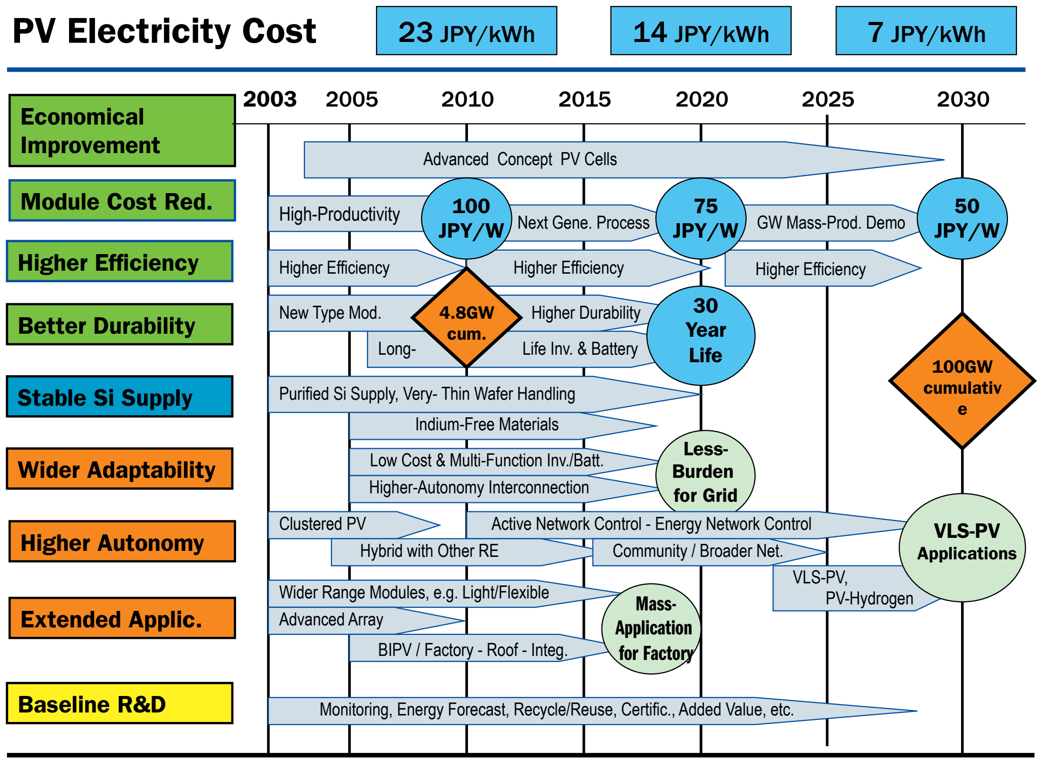


Table 2: Key points of PV2030+ scenario for future growth of PV power generation

Target (completion of development)	**2010 or later**	**2020 (2017)**	**2030 (2025)**	**2050**
Power generation cost	Equivalent to household retail price (23 ¥/kWh)	Equivalent to commercial retail price (14 ¥/kWh)	Equivalent to general power generation (7 ¥/kWh)	Equivalent to general power generation (7 ¥/kWh or below)
Commercial module conversation efficiency (Lab.efficiency)	16 % (20 %)	20 % (25 %)	25 % (30 %)	Ultra-high performance modules with 40 % added
Production for Japanese Market [GW/annum]	0.5 – 1	2 to 3	6 to 12	25 – 35
Production for Export [GW/annum]	ca. 1	ca. 3	30 – 35	ca. 300
Major applications	Single-family houses, public facilities	single/multi-family houses, public facilities, commercial buildings	single/multi-family houses, public facilities, consumer use, charging EVs, etc	consumer use, industries, transport, agriculture, etc., stand alone power source

6.3 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 for photovoltaics, in the frame of Energy and Environment Technologies Development Projects, has three main pillars [NED 2007]:

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

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

Within the **New Energy Technology Development Programme,** there are projects on photovoltaic technology specific issues, problems of grid-connected systems, as well as public solicitation. In addition to the projects listed below, a number of new initiatives were launched in FY 2010. These projects have relevance for PV and range from R&D of next generation high performance PV systems to a demonstration project on next generation smart power transmission and distribution and R&D on combined storage systems.

Field Test Projects on Photovoltaic Power Generation-

FY2007 – FY2014 (Installation work to be completed in FY2010)

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

Research and Development on Innovative Solar Cells

FY2008 - FY2014 (peer review after 3rd year)

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

- **Post-silicon Solar Cells for Ultra-high Efficiencies**
  (1) Super high-efficiency concentrator multi-junction solar cells;
  (2) High efficiency quantum structure tandem solar cells and their manufacturing technologies;
  (3) Ultra-high efficiency solar cells based on quantum dots and super lattice;
  (4) Ultra-high efficiency multiple junction solar cells with hybrid materials.

- **Thin-film Full Spectrum Solar Cells with low concentration ratios**
  (1) Band-gap control of nano dots/multi-exiton/band-gap engineering of strained Ge/ novel Si-based and amorphous alloy thin-films/thin-film materials design;
  (2) Si-based thin-film concentrators/wide band-gap Si based thin-films/multi-cell interface junction/Chalcopyrite based thin-film concentrators on metal substrates/ optical design/CdTe thin-film concentrators;
  (3) Surface plasmons/p-type TCO/full-spectrum TCO/ graphene transparent conductive film.

- **Exploring Novel Thin-film Multi-junction Solar Cells with Highly-ordered Structure**
  (1) Highly-ordered plane poly-silane/ordered nano-crystalline Si-materials/Ge-based narrow band-gap materials/heterojunction devices;
  (2) Wide band-gap chalcogenide-based materials/solar cells using novel wide band-gap material/Oxynitride-based wide band-gap materials/Oxide-based wide band-gap materials/CIGSSe-based tandem-type solar cells;
  (3) Novel concept solar cells using nano-Si, nano-

carbon and single-crystalline organic semiconductors/ novel concept solar cells using correlated materials/ novel concept solar cells using nano-materials with controlled structure;
(4) Mechanical stacking-techniques/highly efficient light-trapping techniques/ improved transparent conduction oxide films using preparation techniques for improved glass substrates.

Verification of Grid Stabilisation with Large-scale PV Power Generation Systems
FY2006 – FY2010

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

- Development and verification of the effectiveness of various technologies required when large-scale PV systems are connected to power grids, including voltage fluctuation suppression technology, frequency (output) fluctuation suppression technology, large-scale PV output control technology to enable scheduled operations, and harmonic suppression technology. Large PV power conditioners capable of stabilising grids will also be developed.

- Development of simulation methods to apply to the above research topics, which will also be useful for studying specific conditions in preparation for future large-scale PV system installations.

Project to Support Innovative New Energy Technology Ventures
FY2006 – FY2011

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

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

Project for Promoting the Local Introduction of New Energy
FY1998 – open

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

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

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

International Cooperative Demonstration Project Utilising Photovoltaic Power Generation Systems
FY1992 – open

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

Joint Call with the European Commission:
Ultra-high concentration photovoltaics (CPV), cells, modules and systems
FY 2011 – 2014

NEDO and the European Commission launched a project to develop concentrator photovoltaic cells1, aiming to achieve a cell conversion efficiency of more than 45%, which is the highest efficiency in the world. This is the first joint project under the EU-Japan Energy Technology Cooperation Agreement[30].

The Japanese research team is led by Professor Masafumi Yamaguchi of the Toyota Technological Institute and includes Sharp Corporation, Daido Steel Co., Ltd., the University of Tokyo, and the National Institute of Advanced Industrial Science and Technology. The EU research group, led by Professor Antonio Luque of the Technical University of Madrid, consists of Fraunhofer Institute for Solar Energy Systems (Germany), Imperial College London (United Kingdom), the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Italy), BSQ Solar, SL. (Spain), PSE AG (Germany) and the French National Institute for Solar Energy (France).

6.4 Solar Companies

In the following chapter those market players in Japan, not yet mentioned in Chapter 3, are described briefly. 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.

6.4.1 Kaneka Solartech

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

[30] The EU-Japan Energy Technology Cooperation Agreement is designed to strengthen cooperation in the energy field between NEDO, which promotes the development of energy-related technologies, and the EU, which is conducting research and development programmes under the EU 7th Framework Programme for Research. The agreement was reached at ministerial level (the Minister of Economy, Trade and Industry of Japan and the EU Commissioner for Science and Research) to promote EU-Japan cooperation in the field of energy-related technologies

Currently Kaneka produces a-Si and amorphous/microcrystalline silicon modules for rooftop application and built-in roofing types for the Japanese, as well as export markets. The built-in roofing types were developed for the Japanese housing market in cooperation with Quarter-House and Kubota and are either shingle type modules or larger roofing elements. In 2006, the company opened a module factory in Olomouc, Czech Republic, where the capacity was increased to 30 MW in 2008. In FY2010, the total production capacity was expanded to 150 MWp/year. A further expansion to 350 MW in 2011 and to 1 GW in 2015 was announced by the company. In FY 2010, production was 58 MW [Pvn 2011].

6.4.2 Mitsubishi Electric

In 1974, research and development of photovoltaic modules started. 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. Current production capacity is 270 MW and production in 2010 was 210 MW [Pvn 2011].

6.4.3 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 2010, MHI produced 50 MW of amorphous silicon solar cells [Pho 2011] and had a production capacity of 118 MW.

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.

6.4.4 Solar Frontier

Solar Frontier is a 100% subsidiary of Showa Shell Sekiyu K.K. In 1986, Showa Shell Sekiyuki started to import small modules for traffic signals, and started module production in Japan, cooperatively with Siemens (now Solar World). The company developed CIS solar cells and completed the construction of the first factory with 20 MW capacity in October 2006. Commercial production started in FY 2007. In August 2007, the company announced the construction of a second factory with a production capacity of 60 MW to be fully operational in 2009. In July 2008, the company announced they would open a research centre "to strengthen research on CIS solar powered cell technology, and to start collaborative research on mass production technology of the solar modules with Ulvac, Inc.". The aim of this project is to start a new plant in 2011 with a capacity of 900 MW. The ramp up started in February 2011. In 2010, the company changed its name to Solar Frontier and production is reported with 74 MW [Pvn 2011].

6.4.5 Additional Solar Cell Companies

- **Clean Venture 21:** Clean Venture 21 Corporation was founded in 2001 as a privately held solar company and develops spherical Silicon solar cells. In 2006, CV21 opened its first production facility in Kyoto. The company claims that the cells have 12% efficiency and that the costs should be only one fifth of a conventional silicon cell thanks to the significantly reduced silicon use. CV21 entered into an exclusive sale agreement with the FujiPream Corporation in December 2005. According to the RTS Corporation, the company had a production capacity of 15 MW for spherical silicon solar cells at the end of 2010 and plans to expand this to 36 MW in 2011 and 100 MW in 2012 [Ikk 2011].

- **Fuji Electric Systems Co. Ltd.:** In 1993, Fuji Electric started its activities in amorphous thin-film technology. The company developed amorphous-silicon thin-film solar cells in the framework of a NEDO contract. The cells, which use a plastic film substrate less than 0.1mm thick, are light, inexpensive to manufacture and easily processed into large surface areas. The capacity in 2010 is given with 24 MW and should be expanded to 40 MW in 2011 [Ikk 2011].

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

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

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

6.4.6 Kobelco (Kobe Steel)

In April 1999, Kobe Steel's Engineering Company formed an agreement with Germany's Angewandte Solarenergie - ASE GmbH that enables Kobe Steel to market ASE's (now Schott-Solar) photovoltaic systems in Japan. Kobe Steel is focusing on selling mid- to large-size systems for industrial and public facilities.

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

6.4.7 MSK Corporation

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

In August 2006, Suntech Power (PRC) announced the first step of its acquisition of MSK. Suntech acquired a two-third equity interest in MSK and completed the 100% takeover in June 2008. Current module manufacturing capacity is reported as 100 MW [Ikk 2011].

6.4.8 YOKASOL

After the takeover of MSK by Suntech Power, employees of MSK's Fukuoka Plant bought the plant and set it up as a new company named YOKASOL. The company manufactures mono- and polycrystalline silicon modules. Current module manufacturing capacity is reported as 65 MW [Ikk 2011].

6.4.9 Daiwa House

Since August 1998, Daiwa House has been selling the "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.

6.4.10 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 rooftop system in the suburbs of Tokyo. In 2003/4 Misawa Homes built "Hills Garden Kiyota", a 503-home residential community in Kiyota, Hokkaido. The homes are all equipped with solar photovoltaic systems, with a total electrical generation capacity of 1,500 kW, the world's largest in terms of electricity generated by a residential development at that time.

6.4.11 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. In 1971, Sekisui Chemical created the Heim Division to build modular houses. Sekisui Heim, currently the fourth largest house builder in Japan, builds about 15,000 houses per year, of which about 50% are equipped with a solar photovoltaic system.

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

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

In its 2011 Annual Report, Sekisui stated that in FY 2010 about 80% of their houses were equipped with photovoltaic electricity systems and they plan to increase the share to 90% in 2011.

6.4.12 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 cooperative framework for the Matsushita Group for the 21st century. As a part of this new Group framework, PanaHome was turned into a consolidated subsidiary of Matsushita Electric Industrial on 1 April 2004.

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

6.4.13 Additional Silicon Producers

- **JFE Steel Corporation:** JFE Steel began to produce silicon ingots in 2001. To stabilise their supplies of feedstock, it began to investigate techniques for producing SOG silicon in-house from metallic silicon as an alternative to polysilicon. Prototypes created with 100% metallic silicon have achieved the same high conversion efficiency as conventional polysilicon units. According to RTS, the production capacity in 2010 was about 400 tons [Ikk 2011].

- **Japan Solar Silicon:** JSS was established in June 2008 as a joint venture between Chisso Corporation, Nippon Mining Holdings (since 1 April 2009 – Nippon Mining & Metals) and Toho Titanium. According to RTS, the production capacity in 2010 was about 100 tons and the capacity should be ramped up to 660 tons in 2011 and 1,500 in 2012 [Ikk 2011].

- **M.Setek:** This is a manufacturer of semiconductor equipment and monocrystalline silicon wafers. The company has two plants in Japan (Sendai, Kouchi) and two in the PRC, Hebei Lang Fang Songgong Semiconductor Co. Ltd. (Beijing) and Hebei Ningjin Songgong Semiconductor Co. Ltd. (Ningjin). In April 2007, polysilicon production started at the Soma Factory in Fukushima Prefecture. According to the company, the current production capacity is 3,000 tons.

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

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

7. South Korea

2008, the South Korean Government announced the "Low Carbon, Green Growth" Plan and in 2010, it announced the intention to invest KRW 40 trillion (€ 26.3 billion[31]) by 2015 in renewable energy in order to increase its competitiveness in the sector and join the world's top five countries in the sector. This "green growth" strategy is aimed at turning environmental technologies into the main drivers of economic growth and new sources of jobs. Under the Plan, the Government will work together with the private sector to invest about half of the amount KRW 20 trillion (€ 13.2 billion) in solar power. The PV industries are seen as the 'next semiconductor' industries and the Government policy is aimed to make them the back-bones of the future national economy. This makes clear that the Korean Government's support towards the PV industry is an industry policy and is aimed to increase Korean exports!

7.1 Implementation of PV

In January 2009, the Korean Government announced the Third National Renewable Energy Plan, under which renewable energy sources should steadily increase their share of the energy mix between 2009 and 2030. The Plan covered areas like investment, infrastructure, technology development and programmes to promote renewable energy. The Plan called for a Renewable Energies share of 4.3% in 2015, 6.1% in 2020 and 11% in 2030.

To reach this target, South Korea introduced an attractive feed-in tariff for 15 years, along with investment grants up to 60%. From October 2008 to 2011, the following feed-in tariffs were set (Table 3).

In this tariff scheme it was possible to choose between a 15 year guarantee and a higher kWh price and a 20 year guarantee and a somewhat lower kWh price. The previous 100 MW cap was increased to 500 MW. The cumulative installed capacity at the end of 2007 was 78 MW. In January 2008, 46 MW of installed capacity was under the cap scheme and more than 560 MW was already under planning or construction. Due to the fact that the 500 MW cap was reached already in 2009, only a moderate growth was possible in 2009 and 2010.

In order to help create an investment-favourable environment in the residential area, the Korean Government has been expanding the existing 100,000 solar roof programme to diversify and optimise RE use in residential areas in 2009. This aims to disseminate 1 million green homes by 2020.

[31] Exchange rate: 1 € = 1 520 KRW

From 2012 on, it is planned to substitute the tariffs by a Renewable Portfolio Standard. The share of New & Renewable Energy will expand from 2% in 2012 to 4% in 2016, 7% in 2019 and 10% in 2022.

The Government budgets in 2010, for renewable energy R&D, were KRW 253 billion (€ 166 million), which was a small increase over the KRW 241 billion (€ 159 million) in the previous year. The total Korean solar cell production capacity reached 1.3 GW/year in 2010.

7.2 Solar Companies

In the following chapter those market players in Korea, not yet mentioned in Chapter 3, are described briefly. 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.

7.2.1 GETWATT

GETWATT is the Energy Division of KISCO and launched its PV business in 2008. The company runs an a-Si manufacturing line with 20 MW capacity. Production for 2010 is reported with 20 MW [Pho 2011].

7.2.2 Hankook Silicon Co. Ltd.

Hankook Silicon was established in 2008 and its polysilicon plant is located in Yeosu, Jeollanam-do. According to the company, commercial production started in 2010 and the nameplate capacity of 3,200 tons was reached in April 2011. The company plans to increase its production capacity to 14,500 tons by 2013.

In spring 2011, the company announced the intention to invest and supply the technology for a joint venture with Isofóton in Spain. Silico Energía should become a 10,000 ton polysilicon factory with an initial stage of 2,500 tons.

7.2.3 Hyundai Heavy Industries

In 2005, Hyundai Heavy Industries established their Renewable Energy Department, dealing with solar and wind power. The solar cell factory is located in Eumesong, Chungcheongbuk-do, and reached a production capacity of 370 MW at the end of 2010. Further expansion to 600 MW in 2011 and 1 GW in 2012 are planned. For 2010 a production of 299 MW is reported [Pvn 2011].

7.2.4 JUSUNG Engineering

JUSUNG Engineering is a semiconductor and solar cell equipment manufacturer founded in 1995. The company developed and produces manufacturing equipment for thin-film solar cells, as well as crystalline silicon solar cells.

7.2.5 Kyungdong Photovoltaic Energy (KPE) Co. Ltd.

KPE Solar was established as Photon Semiconductor & Energy (PSE) in 2000 and started solar cell production in 2003 with a 6 MW line. In 2006, PSE merged with the pant division of Kyungdong Construction Co. Ltd. and changed the name to Kyungdong Photovoltaic Energy. At the end of 2010, the company had a production capacity of 100 MW and 75 MW of production was reported for 2010 [Pho 2011].

7.2.6 LG Solar

GoldStar was founded in 1958 and in 1995 became LG. Already in 1985, GoldStar Electronics conducted research on polycrystalline solar cells. In 2004, the LG business group consolidated several solar research laboratories under

Table 3: Korean Feed-in Tariffs [Kim 2009] Fixed Price in Korean Won/k Wh (€[32]/kWh)

Until 30 Sept. 2008	Period		< 30 kW		> 30 kW	
	15 years		711.25 (€ 0.44)		677.38 (€ 0.42)	
1 Oct. 2008 – 2009	Period	< 30 kW	30 – 200 kW	200 kW – 1MW	1 MW – 3 MW	> 3 MW
	15 years	646.96 (0.40)	620.41 (0.39)	590.87 (0.37)	561.33 (0.35)	472.70 (0.30)
	20 years	589.64 (0.37)	562.84 (0.35)	536.04 (0.34)	509.24 (0.32)	428.83 (0.27)

[32] Exchange rate: 1 € = 1 600 KRW

the LG Electronics umbrella, using decades of R&D experiences. In 2009, LG Electronics built a PV cell and module factory in Gumi, with a capacity of 120 MW. The company announced that it would increase its production capacity to 330 MW in 2011 and 1 GW in 2013. Production in 2010 was reported as 100 MW [Pho 2011].

7.2.7 Millinet Solar Co. Ltd.

Millinet Solar was established in 2005 and started multicrystalline solar production in 2007. Since then, the production capacity has increased to 300 MW at the end of 2010 and the company is aiming to reach 1 GW by 2013. Production for 2010 is reported with 100 MW [Pho 2011].

7.2.8 Samsung Solar Energy

In 1987, Samsung started its R&D Programme on Buried Contacts, PERL, SP technologies, and thin-film technologies. In 2009, the company set up a 35 MW silicon pilot line in Giheung-gu, Yongin-si, Gyeonggi-do, and in May 2010, the company announced the intention to invest KRW 6 trillion (€ 3.85 billion in its photovoltaics business) to reach a production capacity in the GW range by 2020. Production in 2010 was estimated at 30 MW [Pho 2011].

7.2.9 Shinsung Solar Energy Co.

Shinsung Solar Energy started as Shinsung ENG in 1977 and moved into the solar cell business in 2007. Since then the production capacity was increased to 250 MW in 2010. According to the company, the production capacity should be increased to 600 MW by 2015. Production for 2010 was reported with 250 MW [Pho 2011].

7.2.10 STX Solar

STX Solar was established in 2007 as a subsidiary of the STX Corporation, formerly from Ssangyong Heavy Industries. The company started its commercial solar cell production with a 50 MW plant in 2009 and is planning to increase the capacity to 180 MW in 2011.

8. People's Republic of China

The production of solar cells, and the announcements of planned new production capacities in the People's Republic of China, have sky-rocketed since 2001. Production rose from just 3 MW in 2001 to 1070 MW in 2007, and for 2010 the estimates varied between 10.6 and 13 GW. In 2010, production capacity was increased to close to 20 GW and the announcements for 2012 would more than double that to 41 GW. In parallel, China is ramping up its own polysilicon production capacity and tightening the regulations on new entrants for the polysilicon production.

In January 2011, the Chinese Ministry of Industry and Information Technology announced new rules for polysilicon factories. New factories must be able to produce more than 3,000 metric tons of polysilicon a year and meet certain efficiency, environmental and financing standards. The maximum electricity use is 80 kWh/kg of polysilicon produced a year, and that number will drop to 60 kWh at the end of 2011. Existing plants that consume more than 200 kWh/kg of polysilicon produced at the end of 2011 will be shut down.

China produced about 45,000 metric tons, or 32%, capable of supplying about 75% of the domestic demand [Sem 2011]. According to the Semi PV Group Roadmap, the Chinese production capacity rose to 85,000 metric tons of polysilicon in 2010.

This development has to be seen in the light of the PRC's strategy to diversify its energy supply system, due to the huge demand for energy necessary to fuel the economic growth needed and the limited traditional resources, as well as the pressure to reduce environmentally-harmful emissions.

8.1 PV Implementation

The PRC's continental solar power potential is estimated at 70,338 EJ (equivalent to 19,538,400 TWh) per year [CDF 2003]. One percent of China's continental area, with 15% conversion efficiency, could supply 29,304 TWh of solar energy. That is 145% of the world-wide electricity consumption in 2008.

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 grid-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.

According to the 12th Five-Year Plan, which was adopted on 14 March 2011, China intends to cut its carbon footprint and be more energy efficient. The targets are 17% less carbon dioxide emissions and 16% less energy consumption unit of GDP. Total investment in the power sector, under the 12th Five-Year Plan, is expected to reach $ 803 billion (€ 618 billion), divided into $ 416 billion (€ 320 billion), or 52%, for power generation, and $ 386 billion (€ 298 billion) to construct new transmission lines and other improvements to China's electrical grid. Renewable, clean, and nuclear energy are expected to contribute 52 % of the increase and it is planned to raise power generation capacity from non-fossil fuels to 474 GW by 2015.

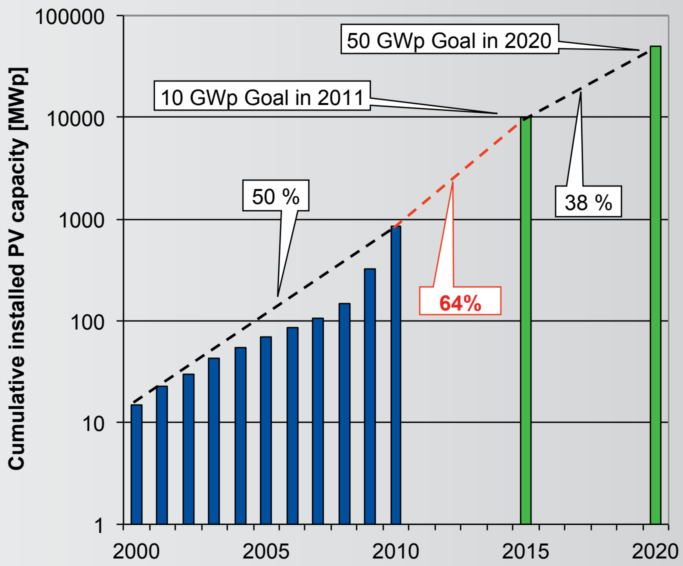
The necessary investment figures are in line with a World Bank report stating that China needs an additional investment of $ 64 billion (€ 49.2 billion) annually, over the next two decades, to implement an "energy-smart" growth strategy [WoB 2010]. However, the reductions in fuel costs, through energy savings, could largely pay for the additional investment costs, according to the report. At a discount rate of 10%, the annual net present value (NPV) of the fuel cost savings, from 2010 to 2030, would amount to $ 145 billion (€ 111.5 billion), which is about $ 70 billion (€ 53.8 billion) more than the annual NPV of the additional investment costs required.

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

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

Also the National Medium- and Long-Term Renewable Energy

Fig. 14: Cumulative installed photovoltaic capacities in PRC, targets for 2015 and 2020 and annual growth rates.



33 Exchange rate 2003: 1 € = 9.09 RMB
34 Exchange rate 2010: 1 € = 8.33 RMB

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

With the support from national ministries and commissions, the top efficiency of China's current lab PV cell is 21%. Commercialised PV components, and normal commercialised cells respectively, have an efficiency of 14 – 15% and 10 – 13%. China has reduced the production cost of solar PV cells and the price of solar cells has gradually decreased from the 40 RMB/Wp (4.40 €/Wp)[33] in 2000 to 10 to 13 RMB/Wp (1.20 to 1.60)[34] in 2010.

In 2009, the Ministry of Finance (MoF), Ministry of Science and Technology (MoS&T) and the National Energy Administration (NEA) announced the "Golden Sun" Programme. The Government announced that it would subsidise 50% of total investment in PV power generation systems and power transmission facilities in on-grid projects, and 70% for independent projects, according to the notice. The available budget should allow at least 500 MW of PV installations. In November 2009, the MoF declared that it had selected 294 projects, with a total capacity of 642 MW. The Ministry estimated that the projects would require construction costs of roughly RMB 20 billion (€ 2.4 billion).

Some Chinese Provinces have announced their own solar programmes, with support schemes ranging from investment subsidies or tax incentives for new manufacturing industries, as well as solar photovoltaic electricity plants to feed-in tariffs. In July 2010, Shandong Province has set an electricity purchase price of 1.7 RMB/kWh (0.204 €/kWh) for photovoltaic power plants for 2010, which will decrease for new ground-mounted photovoltaic plants to 1.4 RMB/kWh (0.168 €/kWh) in 2011 and 1.2 RMB/kWh (0.144 €/kWh) in 2012.

In spring 2011, China updated its target to install 10 GW of PV solar power by 2015 and 50 GW by 2020, according to the National Development and Reform Commission's Energy Research Institute.

With all these measures, the development of a GW size market in China seems possible from 2011 on. Figure 14 shows the necessary growth rates of the domestic market to realise the new targets.

8.2 Solar Companies

In the following chapter, some of the major market players in the PRC, not yet mentioned in Chapter 3, are described briefly. This listing is far from being complete, due to the fact that more than 100 solar-cell and more than 300 solar-module-companies exist in China. In addition, availability of information or data for some companies is very fragmentary.

8.2.1 Aiko Solar Energy Technology Co., Ltd.

Aiko Solar was founded in 2009 and is located in Foshan City, Guangdong Province. Commercial solar cell production started in June 2010, with a 120 MW capacity and the expansion to 240 MW was completed in March 2011. According to the company, a further expansion to 1 GW is ongoing. For 2010, a production of 60 MW is reported [Pho 2011].

8.2.2 Astronergy Solar

Astronergy Solar was established as a member of the Chint Group in October 2006. The first production line of 25 MW, for crystalline silicon cells and modules, was installed in May 2007 and an increase of the production capacity to 100 MW was finished in July 2008. Commercial production of micromorph® solar modules started in July 2009. The thin-film capacity was 30 MW in 2010 and the company planned to increase it to 75 MW early 2011 as part of an expansion to 400 MW in the future. Total production capacity for 2010 is reported with 400 MW and 160 MW of production [Pho 2011].

8.2.3 CETC Solar Energy Holdings Co., Ltd.

CETC Solar Energy Holdings Co., Ltd. is a technology company providing solar energy manufacturing equipment, solar cells and modules, together with solar power solutions, all based upon a common technology platform. It consists of a group of institutes and companies, namely, the 48th Institute of China Electronics Technology Group Corporation (CETC), Beijing Zhongkexin Electronics Equipment Co., Ltd., Hunan Red Solar New Energy Science and Technology Co., Ltd., and Hunan Red Solar Photoelectricity Science and Technology Co., Ltd. According to the company, it is operating 60 solar cell lines with a combined capacity of 1.5 GW.

8.2.4 Changzhou EGing Photovoltaic Technology Co. Ltd.

The company was founded in 2003 and works along the complete photovoltaic industry value chain, from the production of monocrystalline furnaces, quartz crucibles, 5-8 inch mono-crystalline silicon ingots, supporting equipment of squaring and wire sawing, mono-crystalline silicon wafers, solar cells, and solar modules. According to the company, it has a production capacity of 500 MW across the complete value chain of ingot, wafer, cell and modules and according to PV News there are plans to increase it to 1 GW in 2011. For 2010, a production of 312 MW was reported [Pvn 2011].

8.2.5 CSG PVTech Co. Ltd.

CSG Solar is a part of the CSG Holding Co. Ltd., which was founded in Shenzhen Economic Special Zone in 1984. CSG has become a leading manufacturer of architectural energy-saving glass. CSG Solar was set up in 2006 and commercial silicon solar cell and module production began in 2008. CSG works along the PV value chain covering poly-silicon, ingot, wafer, solar cell, solar glass and solar modules. In 2010, production capacity in Dongguang was 200 MW of solar cells and modules.Wafer, solar cell and module capacity expansions are planned, and according to the company, the manufacturing capacity should reach 1 GW each by 2013. Production in 2010 was reported with 80 MW [Pho 2011].

8.2.6 DMEGC Solar Energy

DMEGC Solar Energy is a Division of the Hengdian Group DMEGC Magnetics Co., Ltd. (DMEGC). DEMEGC Solar started in 2009 and has now seven production sites manufacturing ingots/rods, wafers, solar cells and solar modules. It is headquartered in Hengdian, Dongyang, with over 3000 employees. According to the company, in 2011 they have a capacity of 300 MW for solar wafers (Henan), 1 GW of solar cells (Hengdian) and 350 MW modules. DMEGC has also launched a project to manufacture poly-silicon. The first phase of the project, with an annual capacity of 6,000 tons, is planned to become operational at the beginning of 2012.

8.2.7 Hareon Solar Technology Co., Ltd.

Haeron Solar was established as the Jiangyin Hareon Technology Co., Ltd. in 2004 and changed its name to the Hareon Solar Technology Co., Ltd. in 2008. Hareon Solar has three wholly-owned subsidiaries, including Jiangyin Hareon Power Co., Ltd, Altusvia Energy (Taicang) Co., Ltd, and Hefei Hareon Solar Technology Co., Ltd, as well as a holding subsidiary named Jiangyin Xinhui Solar Energy Co., Ltd., which are specialised in producing solar cells and modules. Solar cell production started in 2009, with an initial capacity of 70 MW. For 2010, a production capacity of 580 MW and a production of 155 MW is reported [Pho 2011].

8.2.8 Jetion Holdings Ltd.

The group was founded in December 2004, went public in 2007, and manufactures solar cells and modules. For 2010, a production capacity of 200 MW and actual production of 200 MW is reported [Pho 2011].

8.2.9 Jiangxi Risun Solar Energy Co., Ltd.

Risun Solar Technologies was established in 2008. The company manufactures mono- and multicrystalline solar cells and modules. According to the company, the production capacity is 600 MW and it is planning an expansion to 3 GW with a specified date.

8.2.10 JinkoSolar Holding Co., Ltd.

Jinko Solar was founded by HK Paker Technology Ltd in 2006. Starting from up-stream business, the company expanded operations across the solar value chain, including recoverable silicon materials, silicon ingots and wafers, solar cells and modules in 2009. In May 2010, the company went public and is now listed at the New York Stock Exchange. According to the company, manufacturing capacities reached 600 MW each for wafers, solar cells and solar modules in October 2010, and 900 MW in March 2011, and it is planned to reach 1.5 GW by the end of 2011. For 2010, the company reported about 320 MW of production.

8.2.11 LDK Solar Co. Ltd. (PRC)

LDK was set up by the Liouxin Group, and is mainly known as a producer of polysilicon material. In 2010, the company set up a production line for solar cells, with a capacity of 120 MW, and is planning to increase it to 1.26 GW in 2011. For 2010, an initial production of 25 MW of solar cells is reported [Pho 2011].

8.2.12 Magi Solar Energy Technology

In June 2010, Dongfang Electric Corporation (DEC), a maker of heavy electrical equipment, signed an agreement to restructure Magi Solar Energy Technology. At that time, Magi Solar had an annual capacity of 180 MW and DEC planned to increase it to 500 MW at the end of 2010, and to 1 GW by 2013. For 2010, a production of 120 MW is reported [Pho 2011].

8.2.13 Shanghai Topsolar Green Energy Ltd.

Topsolar is a joint-stock company established by Shanghai Electric Group Holding Co., Ltd., Shanghai Jiao Da NanYang Co., Ltd., and Shanghai Zhenglong Technology Investment Co., Ltd. The company manufactures mono- and multicrystalline solar cells and modules. For 2010, a production capacity of 70 MW and a production of 60 MW is reported [Pho 2011].

8.2.14 Shenzhen Topray Solar Co.,Ltd.

The company was founded in 1992 and manufactures solar cells, solar chargers, solar lights, solar garden products and solar power systems, as well as solar charge controllers, solar fountain pumps and solar fan caps. From the beginning, the company manufactured thin-film solar cells and added mono- and multicrystalline cell production in 2004. The company went public in 2011 and reported a combined production capacity of 800 MW. For 2010, a production of 180 MW is reported [Pho 2011].

8.2.15 Sungen International Ltd.
Sungen is a division of the Hong Kong based Anwell Group and was founded in 2008. The company manufactures amorphous silicon solar cells and modules in Hennan and mono- and multicrystalline modules in Suzhou. According to the company, the current capacity for amorphous silicon modules of 50 MW in 2010 is expanding to 100 MW in 2011.

8.2.16 TIANWEI New Energy Holdings Co., Ltd.
Tianwei is an affiliate of China South Industries Group Corporation (CSGC). According to the company, its current manufacturing capacity is 500 MW for silicon wafers, 500 MW for PV cells and 500 MW for PV modules. The company plans to increase the capacity of all three products to 1 GW each, by 2011, and 1.5GW, by 2012. For 2010, a production of 180 MW is reported [Pho 2011].

8.2.17 Trony Solar Holdings Company, Ltd.
Trony Solar is located in Shenzhen, Guangdong Province, and manufactures thin-film silicon solar cells and modules for BIPV and consumer applications. According to the company, the capacity was 205 MW at the end of 2010. In May 2010, Trony Technology's "1,000 MW Thin-Film Solar Cell Industrial Base" was recognised as one of the "Top 500 Modern Industrial Projects" of Guangdong Province. For 2010, a production of 145 MW is reported [Pho 2011].

8.2.18 Wuxi Shangpin Solar Energy Science & Technology Co., Ltd.
This is a UK-invested company which specialises in R&D, manufacturing and sales of crystalline silicon solar cells, modules and PV powered products. According to the company, the first 25 MW production line was put into operation in April 2007, and the second followed in August 2008. According to the company, the capacity was 500 MW for solar modules and 125 MW for solar cells in 2010. For 2010, a production of 55 MW is reported [Pho 2011].

8.2.19 Zhejiang Sopray Solar Co., Ltd.
Sopray Solar was established in 2005 as a joint venture between Taizhou Luqiao Huanneng Lights Factory and Mr. Michael Ming. According to the company, the annual output capacity of mono- and polycrystalline solar cells is 300 MW and for solar modules is 300 MW. For 2010, a production of 160 MW is reported [Pho 2011].

8.2.20 Zhejiang Sunflower Light Energy Science & Technology Co., Ltd.
Sunflower was funded by Hong Kong YauChong International Investment Group Co., Ltd., founded in 2004 in Shaoxing, Zhejiang and went public in 2010. According to the company, current capacity is 400 MW. For 2010, a production of 170 MW is reported [Pho 2011].

8.2.21 Additional Solar Cell Companies

- **Aide Solar** is based in the Economic Development Zone of Xuzhou and was founded in 2003. In 2007, it became a subsidiary of the Taiwanese Panjit Group. According to the company, it has a solar module capacity of 350 MW and a solar cell capacity which is estimated at 360 MW. In January 2011, the company announced that it started to increase its production capacity to 2 GW without a date set.

- **Amplesun Solar**, located in the Xiasha Export Processing Zone, is a private company, founded in early 2008. According to the company, it currently has an annual capacity of over 25 MW, with its first amorphous silicon thin-film production line which was supplied by ULVAC, Japan. The company plans to reach 120 MW production capacity with tandem junction technology in 2011.

- **Baoding TianWei Solar Films Co., Ltd.** was set up in 2008. It is a subsidiary of the Baoding TianWei Group Co., Ltd., a leading company in the China power transformer industry. Phase I of the production was set-up with a capacity of 50 MW and the start of commercial operation was in the second half of 2009. The company plans to reach a capacity of 500 MW in 2015.

- **Best Solar Hi-Tech Co., Ltd.** was set up by LDK Solar's founder and CEO Xiaofeng Peng and started operations in February 2008. The company aims to produce amorphous/microcrystalline silicon thin-film modules and has contracted AMAT for the equipment. The ground-breaking for their "Site 1" in JinagSu SuZhou took place in February 2008 and for "Site 2" in JiangXi NanChang in June 2008. In November 2009, phase one with 130 MW production capacity started the ramp up. Production capacity and production is reported with 120 MW and 15 MW respectively [Pho 2011].

- **ENN Solar Energy** (part of XinAo Group) was set up in the Langfang Economic and Technological Development Zone in 2007. In November 2007, ENN Solar

Energy signed a contract with AMAT for a SunFab thin-film production line to produce ultra-large 5.7 m^2 (GEN 8.5) solar modules. The 50 MW line is planned to be the first phase of an expected 500 MW capacity plant. Commercial production started in 2009. Production capacity and production is reported with 65 MW and 4 MW respectively [Pho 2011].

- **Jiangxi Solar PV Corp.** is a manufacturer of crystalline solar cells, located in the Economic Development Zone of Xinyu City, Jiangxi Province. Production started in 2009 with an initial capacity of 200 MW.

- **Nantong Qiangsheng Photovoltaic Technology Co., Ltd.** (QS Solar, Shanghai, China) started the production of amorphous silicon thin-film solar with their new 25 MW production line in January 2008. The company announced that it would add two more production lines in 2008, bringing the total production capacity to 75 MW. The company plans to increase production capacity within the next three years to 500 MW.

- **Ningbo Best Solar Energy Technology Co., Ltd.** is located in Zhejiang and manufactures mono- and multicrystalline solar cells and modules. According to the company, the production capacity reached 150 MW in 2010.

- **Solargiga Energy Holdings Ltd.** was incorporated in March 2007 and listed on the Hong Kong Stock Exchange on 31 March 2008. The Group operates polysilicon reclaiming and upgrading facilities in Shanghai and Jinzhou. In 2010, the company reported a production capacity of approximately 800 MW and 600 MW of monocrystalline silicon solar ingots and wafers, respectively, and plans to expand this to 1.2 GW and 900 MW in 2011.

  On 21 September 2010, the Group entered into a cooperation framework agreement with Liaoning Oxiranchem, Inc. for the establishment of the joint venture company to manufacture multicrystalline silicon solar ingots and wafers with a production capacity of 500MW, which is expected to be completed and commence operation by the end of 2011.
  In January 2011, the Group acquired the Jinzhou Huachang Photovoltaic Technology Co., Ltd (HPT), which had expanded its solar cell production capacity from 100 MW to 300 MW in 2010

- **Sunlan Solar Co., Ltd.**, is located in the Shanghe Economic Development Zone. The company has ambitious plans to build up a capacity of 2,000 MW solar polysilicon ingots, 1,000 MW solar cells and 1,000 MW modules by 2015. The first phase to realise a 100 MW module line has been completed and went into commercial operation early 2010. Construction of an ingot plant, with a capacity of 250 MW and a solar cell line with 100 MW, is in progress.

- **Yunnan Tianda Photovoltaic Co. Ltd.** is one of the oldest companies which make, design, sell and install solar modules and PV systems in China and was founded in 1977 as the Yunnan Semi-Conductor Device Factory. In 2005, the production capacity of solar cells was extended to 35 MW and the production of 5-inch solar cells started. In 2006, the capacity was increased to 60 MW and in 2007 the production capacity of solar cells was extended to 100 MW. In April 2009, the company reported the signature of agreements with the Jiaxing Xiuzhou Industrial Park Management Committee to build a production facility with an aim of 100 MW/year in the first stage and 200 MW in the final stage.

8.3 Polysilicon, Ingot and Wafer Manufacturers

In the following chapter, some of the major market players in the PRC are briefly described. This listing is far from being complete, due to the fact that at the moment there are a large number of start-up activities. In addition, availability of information or data for some companies is very fragmentary.

8.3.1 EMEI Semiconductor Material Factory

EMEI is a subsidiary of the Dongfang Electric Corp., located in Chengdu, and produces and markets semiconductor material silicon. According to the company, the manufacturing capacity has reached 2,200 tons for polysilicon and 600 tons for monocrystalline silicon.

8.3.2 ReneSola Ltd.

ReneSola, previously known as the Zhejiang Yuhui Solar Energy Source Co. Ltd., was listed on London's AIM Stock Market on 8 August 2006. ReneSola's factories are based in China, but the company is registered in the British Virgin Islands. ReneSola changed from recycling silicon for making wafers, to an integrated solar company, producing along the value chain from polysilicon to wafers, cells and modules with the acquisition of JC Solar in May 2009.
The company increased its wafer manufacturing capacity to 1,300 MW (400 MW monocrystalline, 900 MW polycrystalline) in 2010 and plans to increase this to 1,900 MW (400 MW monocrystalline, 1,500 MW polycrystalline) in

2011.
The annual polysilicon manufacturing capacity, at the wholly-owned facility in Meishan, Sichuan Province, China, was increased to 3,000 tons in 2010 and a further expansion to 8,500 tons in 2011 is underway.

At the end of 2010, the company had a solar-cell production capacity of 240 MW and a 375 MW capacity of solar modules. For 2011, an increase to 600 MW for solar modules is foreseen. In 2010, 883 MW of wafers and 291 MW of modules were shipped. A cell production of 120 to 150 MW can be estimated.

8.3.3 Additional Solar Silicon Companies

- **Chongqing Daqo New Energy Co., Ltd.** Daqo New Energy is a subsidiary company of the Daqo Group and was founded by Mega Stand International Limited in January 2008. The company started to build a high-purity polysilicon factory, with an annual output of 3,300 tons in the first phase in Wanzhou. The first polysilicon production line, with an annual output of 1,500 tons, started operation in July 2008. Production capacity in 2009 was 3,300 tons and a further expansion to 9,300 tons by March 2012 is planned. In May 2010, the company opened its 200 MW module manufacturing plant.

- **China Silicon Corporation Ltd. (SINOSICO)** was established in 2003 and started a 300 ton polysilicon project, based on the technology of the China Enfi Engineering Corporation, an engineering company established by the China Nonferrous Engineering and Research Institute. The plant was put into operation in October 2005. A Phase II expansion project had an annual yield of 1,000 tons polysilicon and became operational in February 2007. Phase III, with a 2,000 ton capacity, became operational at the end of 2008. The company started its new silicon wafer processing plant with a capacity of 75 MW in April 2011.

- **DALU New Energy Company** is a subsidiary of the DALU Industrial Investment Group, established in 1993. The company plans a polysilicon production plant with a total capacity of 18,000 tons. The construction of the plant will be executed in three phases, i.e., Phase I: 2,500 t/a P; Phase II: 5,000 t/a and Phase III: 10,000 t/a.

- **Jiaozuo Coal Group Hejing Technique Co., Ltd.** was established as a subsidiary of the Jiaozuo Coal Group of Henan Coal and the Chemical Industrial Group in 2008. The company has a 1,800 ton polysilicon manufacturing plant.

- **Leshan Ledian Tianwei Silicon Science and Technology Co., Ltd.** is a joint venture formally set up in January 2008 by the Baoding Tianwei Baobian Electric Co., Ltd. and the Leshan Electric Power Co., Ltd. The company built a polycrystalline facility at Leshan in the Sichuan Province, with a capacity of 3,000 t/a. commercial production, started in April 2010.

- **Luoyang Zhonggui Material Co., Ltd.** The company is a joint venture of the American MEMC Company and the Chinese Sijia Semiconductor Company. The main products are multi-crystal silicon, single-crystal silicon and organic silicon. The production capacity is 500 tons and it is planned to increase it to 2,000 tons.

- **Niking Technology Co., Ltd.** was founded in 1998 and engaged in scientific research and purified polysilicon. The company manufactures polysilicon, ingots and wafers, as well as mono- and multicrystalline solar cells. In 2008, a production of 300 tons of polysilicon was reported and the company planned to increase its capacity to 500 tons in 2009.

- **Nan'an Sanjing Silicon Refining Co., Ltd.** was established in 1996. The corporative company includes Taining Sanjing Silicon Smelting Co., Ltd., Dehua Longtengfei Smelting Co. Ltd. and Xiamen Sunhope Silicon Products Co., Ltd. The company is engaged mainly in crude metal silicon mining, primary smelting, purification, refinement, exporting and its R&D.
It presently possesses an annual processing capacity of approximately 40,000 tons of metal silicon.

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

- **Sichuang Yongxiang Co., Ltd.** was jointly established by the Tongwei Group and Giant Star Group in 2002. In July 2006, the Leshan Yongxiang Silicon Co., Ltd. was established as a subsidiary. The company operates a 20,000 tons/year production of trichlorosilane and plans to expand this to 100,000 tons. According to the company, the annual production capacity of polysilicon is 4,000 tons and an expansion to 10,000 tons was started in 2010.

- **Wuxi Zhongcai Technology Co., Ltd.** is a subsidiary of the Wuxi Zhongcai Group and was founded in 2006. According to the company, polysilicon production capacity is 2,800 tons/year and 8 million wafers.

- **Yaan Yongwang Silicon Industry Co., Ltd.** is a subsidiary of the Hong Kong based Yongwang Silicon Industry Investment Co. The company is located in the Yaan Industry Park, an area with rich hydropower resources. According to the company, it started with the trial production of its second 300 ton silicon line at the end of March 2009. The company also started the construction of a 3,000 ton polysilicon factory and is aiming for 10,000 tons capacity in the long run.

- **Yichang CSG Polysilicon Co. Ltd.** is a subsidiary of CSG Holding Co., Ltd., a glass producer, and was established in the Xiaoting Distict, Yichang City, Hubei Province in 2006. This polysilicon project is divided into three stages with unified planning of 4,500 to 5,000 tons per year of high-pure polysilicon. The first stage, with 1,500 tons/year, was started in October 2006 and reached full capacity in 2010.

8.3.4 Ingot and WaferCompanies

- **JiangSu Shunda Group Corporation** is based in Yangzhou. As a high-technology company, it focuses on the photovoltaic market and produces monocrystalline ingots, wafers and solar modules.

- **Jinglong Industry and Commerce Group Co., Ltd.** mainly produces monocrystalline silicon ingots and wafers, but also produces graphite products, quartz crucibles and chemical products. Jinglong produce mono-crystalline silicon, mainly for the semiconductor industry, but also for solar cells. According to the company, it produced about 6,000 tons of ingots, and 500 million wafers, sufficient for 2.5 GW of solar cells.

In addition, there are a considerable number of smaller and start-up companies along the whole value chain. However, information is still very fragmented and due to the rapid development quickly goes out of date. In the meantime, an increasing number of consultancies are providing market analysis and study tours. The PRC's Long-Term Energy Plan calls for a considerable strengthening of the solar industry and all aspects from silicon production, wafering, cell and module manufacturing and distribution, are covered. Chinese manufacturers are expected to export their products as Chinese PV production will grow much faster than the market. In China, photovoltaics is discussed at the level of a strategic industry policy for the future.

9. Taiwan

Within the last five years, Taiwan's solar cell production has increased 20-fold and is now the second largest producer after the People's Republic of China. Like there, the main focus is on export, and compared to the speed of the ramp up of production capacities, the home market is only developing slowly.

As an emerging industrial nation, Taiwan has focused in its recent past towards an industrial structure, with emphasis towards the manufacturing industry, which resulted in a relatively high energy consumption and greenhouse gas emissions. Over the last 15 years, Taiwan's energy consumption has almost doubled from 2.55 EJ in 1993 to 4.99 EJ in 2007, and then slightly decreased to 4.69 EJ in 2009 and back to 4.93 EJ in 2010. This, and the fact that Taiwan's current energy supply is still dominated by imported traditional fossil energy sources with almost 90% (2010: crude oil & petrol products 40.3%, coal & coal products 37.9%, natural gas 10%), makes the country highly vulnerable to price volatility and supply disruptions. In order to enhance security of supply, there is a need to diversify the energy supply, as well as the need to move to less carbon-rich energy sources to reduce greenhouse gas emissions.

9.1 Policies to promote Solar Energy

In 2002, the *Renewable Energy Development Plan* was approved by the Executive Yuan and aimed for 10% or more of Taiwan's total electricity generation capacity by 2010. Depending how Renewable Energy is accounted for (with or without municipal waste), the share of the renewable electricity generation capacity at the end of 2010 was around 5.8 to 8.3% and delivered about 2% of the total electricity consumption.

In 2004, Taiwan enacted *"Measures for Subsidising Photovoltaic Demonstration Systems"*, as part of its National Development Plan by 2008. The Solar Energy Development Project has a number of long-term goals. It is planned that a total of 7.5 million residents should utilise solar energy by 2030. Industrial and commercial use should be about half that of residential use. Public utilities are expected to have the same solar power generating capacity as the industrial and commercial sectors, and independent solar power generating systems will be set up in mountain areas and on off-shore islands. The aim is that in 2020, the island's renewable power capacity should reach 6.5 GW (1.2 GW PV).

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

It is estimated that the two above industries may generate production value exceeding NT$1 trillion (€ 24.4 billion)[35] by 2015. To promote the solar energy industry, the Government subsidises manufacturers engaging in R&D and offers incentives to consumers that use solar energy. With the help of official programmes, material suppliers are expanding operations and increasing their investments in the field. In addition, about a dozen manufacturers expressed the intention to invest in fabricating thin-films for solar cells and eight of them will set up their own plants to process the products. The solar energy industry may see its output reach NT$ 450 billion (€ 10.98 billion) by 2015.

The Industrial Technology Research Institute (ITRI), a Government-backed research organisation, has drawn up an R&D Strategy for Taiwan, with the aim to lower module costs to around 1 $/Wp between 2015 and 2020. The research topics identified range from efficiency increase in the various wafer-based and thin-film solar cells to concentrator concepts and novel devices. Despite the fact that the national R&D budget should be doubled within the next four years, it is visible that the main focus is on the industry support to increase production capacities and improved manufacturing technologies.

In 2008, the Ministry of Economic Affairs (MoEA) published the guidelines of Taiwan's Sustainable Energy Policy [GoT 2008]. The declared policy objective is to create a Win-Win-Win Solution for Energy, the Environment and the Economy. To achieve this, sustainable energy policies should support the efficient use of the limited energy resources, the development of clean energy, and the security of energy supply. The following targets were defined:

1. Improvement of energy efficiency: The goal is to improve energy efficiency by more than 2 % per annum, so that when compared with the level in 2005, energy intensity will decrease 20% by 2015. Supplemented by further technological breakthroughs and proper administrative measures, energy intensity will decrease 50% by 2025.

2. Development of clean energy:
(1) Reduce nationwide CO_2 emission, so that total emission could return to its 2008 level between 2016 ~ 2020, and be further reduced to the 2000 level in 2025.
(2) Increase the share of low carbon energy in electricity generation systems from the current 40% to 55% in 2025.

3. Securing stable energy supply:
Build a secure energy supply system to meet economic development-goals, such as 6% annual economic growth rate from 2008 to 2012, and 30,000 $ per capita income by 2015.

The Executive Yuan (the Cabinet) passed the "Programme for Coping with Economic Slowdown and Bolstering the Economy" on 11 September 2008. The package covers a total of 41 measures and includes the promotion of solar energy. For 2008 and 2009, the Government set aside NT$ 1 billion (€ 24.4 million) for subsidies to consumers who buy solar-power systems. The Government plans to subsidise half of the installation cost for solar devices, and households which install solar photovoltaic electricity systems would be offered a favourable electricity rate of 2.1 NT$/kWh (0.051 €/kWh). For 2010, a National Target to double the cumulative capacity installations to 31 MW was set.

On 12 June 2009, the Legislative Yuan gave its final approval to the Renewable Energy Development Act, a move that is expected to bolster the development of Taiwan's green energy industry. The new law authorises the Government to enhance incentives for the development of renewable energy via a variety of methods, including the acquisition mechanism, incentives for demonstration projects and the loosening of regulatory restrictions. The goal is to increase Taiwan's renewable energy generation capacity by 6.5 GW to a total of 10 GW within 20 years.

According to Tsai Chin-Yao, Chairman of the Photovoltaic Committee, the law will attract investment of at least NT$ 30 billion (€ 732 million) per year, create at least 10,000 jobs and generate output value of NT$100 billion (€ 2.44 billion) within two years. In December 2009, the Ministry of Economic Affairs (MoEA) has set the feed-in tariffs, which will be paid for 20 years. For systems between 1 and 10 Kw, customers can opt for a higher tariff, or a lower tariff, with an investment subsidy of 50,000 NT$/kW (1,220 €/kW).

- System size 1 to 10 kW:
  Without investment subsidy: 14.60 NT$/kWh (0.356 €/kWh)
  With investment subsidy: 11.19 NT$/kWh (0.273 €/kWh)

- System size 10 to 500 kW: 12.97 NT$/kWh (0.3163 €/kWh)

[35] Exchange Rate: 1 € = 41 NTD

- System size > 500 kW: 11.12 NT$/kWh (0.2712 €/kWh)

  Following the general price reductions of PV electricity generation stems, the feed-in tariffs were lowered at the beginning of 2011 by approximately 30%.

- Rooftop: 10.32 NT$/kWh (0.252 €/kWh)
- Ground mounted systems: 7.33 NT$/kWh (0.179 €/kWh)

9.2 Solar Companies

In the following chapter, some of the Taiwanese market players, not yet mentioned in Chapter 3, 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.

9.2.1 Auria Solar Co.

Auria was founded in October 2007 as a joint venture between E-Ton Solar, Lite-On Technology Corp, Hermes-Epitek Corp. and the MiTAC-SYNNEX Group to manufacture thin-film solar cells. The company has chosen Oerlikon as equipment supplier and plans to produce amorphous/micromorph silicon thin-films. The first factory, with a capacity of 60 MW, began pilot production at the end of 2008 and ramped up to full capacity in 2019. In March 2011, the company announced a cooperation agreement with Mitsubishi Heavy Industries (Japan) for their next expansion to 200 MW in 2012. For 2010, a production of 40 MW is reported [Pho 2011].

9.2.2 Big Sun Energy Technology Incorporation

Big Sun was founded in 2006, and started its solar cell production in the third quarter of 2007 with a capacity of 30 MW. According to the company, the production capacity in 2011 will be increased from the current 90 MW to 150 MW and further expansion to 270 MW is foreseen. Production in 2010 is reported with 75 MW [Pho 2011].

9.2.3 DelSolar Co. Ltd.

DelSolar was established as a subsidiary of Delta Electronics in 2004 and went public in November 2007. DelSolar has a strategic cooperation with the Industrial Technology Research Institute (ITRI), and had a production capacity of 360 MW (240 MW PRC, 120 MW Taiwan) at the end of 2010 and produced 280 MW in 2010 [Pho 2011]. The company has plans to expand the production capacity to 1.4 GW by 2012.

Together with IBM, Tokyo Ohka Kogyo Co. Ltd. (TOK) and Solar Frontier DelSolar, developed its CZTS thin-film solar cell technology with lab efficiency of 10%.

9.2.4 Mosel Vitelic Inc.

The Group's principal activities are the design, research, development, manufacturing and sale of integrated circuits and related spare parts. As part of a five-year transformation project, the company moved into the solar cell business in 2006. According to the company, current production capacity is 100 MW and the expansion to 200 MW should be operational at the end of 200 MW. Mosel also plans to develop thin-film solar cell production from its own technology and to expand production capacity to 1.5 GW by 2014. For 2010, a production of 60 MW is reported [Pho 2011].

9.2.5 Solartech Energy Corp.

Solartech was founded in June 2005. Solartech expanded its production capacity from 60 MW to 500 MW in 2010. An expansion to 1 GW per year should be realised in 2011. For 2010 a production of 260 MW is reported [Pho 2011].

9.2.6 Sunrise Global Solar Energy

Sunrise is located in Yilan and started commercial production for silicon solar cells, with an initial manufacturing capacity of 40 MW in 2009. According to the company, the production capacity of 210 MW at the end of 2010 will be increased to 320 MW in 2011. For 2010, a production of 120 MW is reported [Pho 2011].

9.2.7 Tainergy Tech Company Ltd.

Tainergy was founded in 2007 and went public in March 2010. According to the company, production capacity was 60 MW in 2008 and increased it to 240 MW in 2010. The company announced plans to build a factory in Eastern China with a total capacity of 800 MW. The first phase is foreseen to be completed in 2011. For 2010, a production of 180 MW is reported.

9.2.8 Additional Taiwanese Companies

- **AUO Solar** was established as a Business Unit of AU Optronics Corporation (AUO), a global player of thin-film transistor liquid crystal display panels (TFT-LCD), in 2009. The company acquired the Japanese polysilicon manufacturer, M. Setec, in 2009. AUO established a solar module plant in Brno, Czech Republic, which should reach the nameplate capacity of 100 MW during 2011. In July 2010, AUO entered into a joint venture agreement with SunPower to invest in a solar-cell manufacturing facility in Malaysia. Following this collaboration in technology and intellectual property, AUO achieved the mass production of solar cells with a record-breaking conversion efficiency rate of 22.5%. The aim for 2013 is a 1.4 GW annual supply. In February 2011, the company announced that their subsidiary, AUO Crystal Corp. (“ACC”), will establish a solar wafer plant in Taiwan's Chungkang Export Processing Zone.

- **AxunTech Solar Energy** was established in 2007 to fabricate CIGS solar modules. In 2010, the company started commercial production of CIGS solar modules, with a production capacity of 30 MW. According to the company, the capacity will be increased to 200 MW in 2012.

- **BeyondPV Co., Ltd,'s** main shareholder is optical film maker Efun Technology and produces amorphous/microcrystalline silicon thin-film modules. The company had an annual capacity of 40 MWp in 2010, to be ramped up to 80 MWp by 2011, and 350 MWp by 2014, according to the parent company.

- **Ever Energy Co., Ltd.** was established in October 2005 by a group of investors. In early 2007, Ever Energy signed a contract with Centrotherm AG, Germany, to purchase equipment with 90 MW capacity for the initial phase of a 210 MW facility. According to the company, the current capacity is 90 MW.

- **Green Energy Technology (GET)** was founded as a subsidiary of the Tatung Group of companies in Taiwan and went public in 2008. GET's initial capacity in May 2005 was 25 – 30 MW wafers with 13 furnaces, band saws, and wire saws. At the end of 2010, the company reported an ingot growing capacity and a wafer capacity of 1 GW. According to the company, it is planned to increase, with the expansion of their subsidiaries in China, the wafer and cell capacity to 1.5 GW each at the end of 2011. The company purchased a fully-integrated thin-film solar cell production line with a nominal rated capacity of 50 MW from Applied Materials and started mass production in December 2008. Capacity for 2010 is given with 45 MW and a production of 20 MW is reported [Pho2011].

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

- **Jenn Feng Co., Ltd.** was incorporated in 1975. The company plans and installs solar systems. According to the company, commercial production on their first CIGS 30 MW line started in December 2009.

- **Kenmos Photovoltaic** was founded as a joint venture of Kenmos Technology Co., Ltd., NanoPV Corporation and a Taiwanese equipment manufacturer in September 2007. Kenmos PV set up a 10 MW amorphous silicon thin-film production capacity and started mass production in February 2009. According to the company, they plan to expand their production capacity to 500 MW before 2015.

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

- **Nexpower Technology Corporation** was formed by United Microelectronics Corporation (UMC) in 2005. UMC is one of the world-wide IC foundry providers. In addition to crystalline silicon solar cells, Nexpower is dedicated to silicon thin-film photovoltaics technology and commercial applications, by building up a new manufacturing facility in Hsin Chu, Taiwan, with an annual production capacity of 25 MW in 2008. According to the company, they have a production capacity of 100 MW.

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

- **Sunner Solar Corporation** was founded in Taoyuan, Taiwan, in June 2007. The company started their pilot production in March 2009 and plan to start mass production of thin-film amorphous silicon modules in the second half of 2009 with 25 MW capacity. The next expansion is planned in 2012, with an emerging technology of amorphous and microcrystalline silicon (?c-Si), and the capacity is expected to exceed 150 MW in 2013. A further expansion to more than 600 MW is planned for 2014. For 2010, a production of 10 MW is reported [Pho 2011].

- **Sunwell Solar Corporation**, a subsidiary of CMC Magnetics Corporation, Taiwan's top compact disc maker, contracted a 45 MW thin-film PV production plant with Oerlikon Solar. The plant started production at the beginning of September 2008. For 2010, a production of 45 MW is reported [Pho 2011].

- **Taiwan Semiconductor Manufacturing Company, Ltd.** (TSMC) signed a technology licensing, supply, and joint development agreement with the Stion Corporation (USA). Under the agreements, Stion licenses and transfers its thin-film CIGSS technology to TSMC, while TSMC will provide a certain quantity of solar modules to Stion, using the technology. TSMC Solar will manufacture CIGS thin-film modules and plans to reach a production capacity of 1 GW in the next 3-5 years. Construction began on the first production facility in September 2010 in Taichung, Taiwan. The facility is scheduled to enter commercial production in Q1 2012 and reach volume production of 200 MW per year in thin-film photovoltaic modules by the end of 2012. A second phase is planned, which will expand production to over 700 MW.

- **Top Green Energy Technologies Inc.** was established in January 2006 by Powercom. The company produces silicon solar cells and invested in the upstream polycrystalline silicon production with a modified Siemens manufacturing process. They broke ground for the factory at "Chang Pin Industrial Park" in May 2009.

- **United Printed Circuit Board (UPCB)** started the construction of its first solar cell factory at the high-tech industrial park in Yilan County of Eastern Taiwan in August 2007. The first stage was a 30 MW multicrystalline silicon line from Centrotherm, Germany. According to the company, production increased from the 80 MW in 2009 to 130 MW in 2010 and a further expansion to 280 MW is planned in 2011. For 2010, a production of 36 MW is reported [Pho 2011].

10. United States

In 2010, the USA installed close to 900 MW of new PV electricity generation capacity and increased its cumulative capacity to 2.5 GW. Utility PV installations more than tripled, compared to 2009, and reached 242 MW in 2010. The top ten states, California, New Jersey, Nevada, Arizona, Colorado, Pennsylvania, New Mexico, Florida, North Carolina and Texas, accounted for 85% of the US grid-connected PV market [Sei 2011].

PV projects with Power Purchase Agreements (PPAs), with a total capacity of 6.1 GW, are already under contract and are to be completed by 2014 [Enf 2011]. An additional 10.5 GW of projects have been publicly announced and are yet to sign PPAs. Adding these, the total “pipeline” is more than 16.6 GW.

10.1 Policies supporting PV

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 (such as tax credits). 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. All different support schemes are described there and it is highly recommended to visit the DSIRE website www.dsireusa.org/ and the corresponding interactive tables and maps for details.

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 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 (€ 2.23 billion)[36] "California Solar Initiative" to offer rebates on solar photovoltaic systems. However, because the CPUC only has authority over investor-owned utilities, the rebates were funded by the customers of those utilities, and only available to those customers. SB 1 expanded the programme to municipal utilities, such as the Sacramento Municipal Utility District and the Los Angeles Department of Power and Water, and allows the total cost of the programme to increase to as much as $ 3.35 billion (€ 2.58 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.

On 17 February 2009, President Obama signed the *American Recovery and Reinvestment Act (ARRA)* into law. The main solar provisions that are included in this bill are:

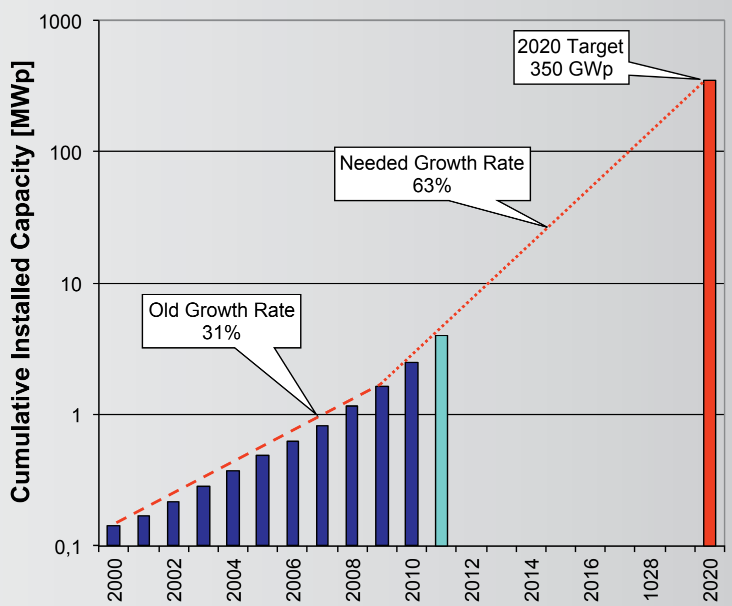
- The creation of a Department of Treasury Grant Programme (TGP).
- Improvement to the investment tax credit by eliminating ITC penalties for subsidised energy financing.
- A new DoE Loan Guarantee Programme.
- Create tax incentives for manufacturing, by offering accelerated depreciation and a 30% refundable tax credit for the purchase of manufacturing equipment used to produce solar material and components for all solar technologies (MITC).

In the run up to the COP 15 meeting in Copenhagen in December 2009, the Solar Energy Industry Association (SEIA) published their new vision to supply 10% of the US electricity demand with photovoltaic electricity systems [Sta 2009]. Such a scenario would require a cumulative installed capacity of 350 GW in 2020 and is similar to the European vision. This vision is significantly higher than the base-line scenario, which adds up to roughly 150 MW, or 4.3% in 2020, or the 84 GW of photovoltaics and concentrated solar power plants, as outlined in the "A Solar Grand Plan" for the US, published in 2007 [Zwe 2007]. However, for all scenarios it would be necessary to start with laying the foundation of the necessary High Voltage Direct Current (HVDC) transmission system now.

In May 2010 SEIA published a study evaluating the effects of a prolongation of the TGP and MITC on additional job creation and solar installations between 2010 and 2016 compared to the base-line scenario [Eup 2010]. The results are an additional 6.2 GW of PV installations between 2010 and 2016 and more than 160,000 additional new PV related jobs.

[36] Exchange rate 1€ = 1.30 $

Fig. 15: SEIA vision for 10% solar electricity in 2020 (2011 figures are estimates).



PV electricity system prices have decreased considerably over the last years, but the world market prices are not wholly reflected in local support schemes. Taking the electricity prices for consumers and the available solar radiation as a base, the residential US market for grid-connected systems can be classified into four categories without incentives if an investment pay-back of 20 years is assumed. It should be noted that this is a simplified categorisation and conditions in a State might vary due to solar radiation, weather conditions or individual system performance. Nevertheless, it indicates at what unsubsidized turn-key prices for a PV system PV electricity production is already now (without considering further electricity price increases) competitive with residential electricity prices.

According to the Solar Energy Industry Association, the PV system prices for residential systems have decreased from 6.98 $/W (5.37 €/W) in the first quarter of 2010 to 6.42 $/W (4.94 €/W) in the fourth quarter of 2010 and stayed flat at 6.41 $/W (4.93 €/W) in the first quarter of 2011 [Sei 2011a]. These price reductions are far less than in the non-residential (1Q 2010: 6.36 $/W (4.89 €/W), 1Q 2011 5.35 $/W (4.12 €/W)) or utility sector (1Q 2010: 4.80 $/W (3.69 €/W), 1Q 2011 3.85 $/W (2.96 €/W)) and is attributed to a higher proportion of *soft costs*, which decline far slower than hardware component costs.

A significant proportion of the soft costs for small residential systems are due to the high permitting costs, as reported by a study published in January 2011 by SunRun [Sun 2011]. According to the study, additional installation costs of 0.5 $/W are due to excessive fees, an unnecessarily slow process and wide permitting variations not connected to safety. The report cites that Germany has a 40% installation price advantage over the USA.

These high permitting costs are two thirds of the targeted BOS *soft costs* reduction of 0.76 $/W under DoE's SunShot Initiative. As first State in the USA, Vermont has enacted a first-in-the-US registration process for small solar systems, providing a national model for mitigating costly local solar permitting. Bill H.56, signed into law on 25 May 2011, and takes effect in January 2012, establishes a simple registration process for solar systems with a maximum power of 5 kW. The process, which replaces the existing permitting, allows solar customers to install the system ten days after completing a registration form and certificate of compliance with interconnection requirements. The utility has ten days to raise any interconnection issues; otherwise, a Certificate of Public Good is granted and the project may be installed.

10.2 Incentives supporting PV

Due to the political situation in the US, there are no uniform implementation incentives for photovoltaics. 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[37] (such as tax credits). Financial incentives typically involve appropriations or other

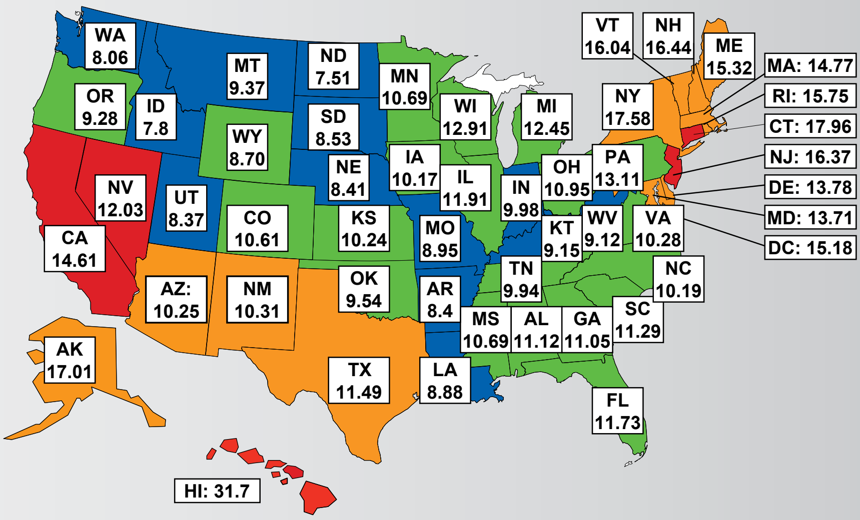
Fig. 16: Average residential electricity prices (¢/kWh) for 2010/11 [Eia 2011].
The $/Wp is the necessary system prices to compete with electricity prices.

Already cost competitive with net metering and guaranteed grid access: above 4 $/Wp; 5 States: California, Conneticut, Hawai, New Jersey, Nevada

Cost effective markets with a small premium on top of net metering: between 3.25 $/Wp and 4 $/Wp; 11 States + Washington DC, Arizona, Delaware, Main, Maryland, Massachusetts, New Hampshire, New Mexico, New York, Rhode Island, Texas, Vermont

Emerging markets with moderate premium on top of net metering: between 2.5 $/Wp and 3.25 $/Wp; 21 States:
Alabama, Alaska, Colorado, Florida, Georgia, Illinois, Indiana, Kansas, Michigan, Minnesota, Mississippi, Montana, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Virginia, Wyoming

Significant incentives needed: below 2.5 $/Wp; 13 States



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

Table 4: Financial Incentives for Renewable Energy [DSIRE]

State/Territory	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Support	Bonds	Performance Based Incentives
Federal Gov.	3	4				4	5	1		1
Alabama	1-S				2-U	1-S	2-S, 2-U			2-U
Alaska				1-S		1-S	2-S			1-U
Arizona	4-S	2-S	1-S	2-S	8-U, 1-L		1-U	1-S		
Arkansas					1-S		1-S, 1-U	1-S		
California				1-S	7-S, 44-U, 3-L		1-U, 1-S, 3-L	1-S		1-S, 2-U
Colorado			2-S, 1-L	3-S	2-S, 18-U, 3-L	1-S, 1-L	2-S, 1-U, 1-L			
Connecticut			2-S	1-S	3-S, 2-U, 1-L	3-S	2-S, 1-U, 1-P	3-S		
Delaware					3-S, 3-U	2-S	2-S			1-S
Florida			1-S		1-S, 15-U, 3-L		1-S, 6-U, 1-L	1-L		2-U
Georgia	1-S	1-S	1-S		11-U, 1-L	1-P	1-S, 1-L, 1-P			3-U
Hawaii	1-S	1-S		1-L	1-S, 1-U		2-S, 2-U, 1-L			1-S
Idaho	1-S		1-S	1-S	3-U	1-P	1-S		1-S	
Illinois			1-S	2-S	1-S, 7-U	2-S, 1-L, 1-P	2-S		1-S	1-P
Indiana	1-S			1-S	29-U		1-U			1-U
Iowa	1-S	2-S	1-S	3-S	21-U		2-S, 2-U			1-U
Kansas	1-S	1-S		1-S	2-U		1-S	1-S		
Kentucky	1-S	2-S	1-S		1-S, 10-U	1-S	1-S, 1-P, 1-L, 1-U			2-U
Louisiana	1-S	1-S		1-S	1-S, 1-U		2-S			
Maine			1-S		2-S	1-S	3-S, 1P			1-S
Maryland	3-S	3-S	4-S	4-S, 10-L	4-S		3-S			1-S
Massachusetts	1-S	2-S	1-S	1-S	3-S, 9-U	4-S	2-S, 1-U, 1-P	2-S		1-S
Michigan				2-S	7-U	2-S	4-S, 2-P	5-S		
Minnesota			2-S	1-S	4-S, 50-U	1-S, 2-U	7-S, 2-U			1-S, 1-U
Mississippi					6-U		1-S, 3-U	1-S		2-U
Missouri		1-S			1-S, 11-U		2-S, 2-U, 1-L			
Montana	3-S	1-S		3-S	4-U	1-U	1-S	2-S		
Nebraska	1-S	1-S	1-S		2-U		1-S			
Nevada			1-S	3-S	2-S, 1-U		1-S, 1-U			1-S
New Hampshire				1-S	3-S, 6-U	1-S	4-S, 1-P			
New Jersey			1-S	2-S	6-S		1-S	3-S		2-S
New Mexico	6-S	5-S	4-S	1-S	1-U		1-S	1-S	1-S	3-U
New York	2-S	1-S	3-S, 1-L	2-S, 1-L	8-S, 6-U	1-S	3-S, 1-U			2-S
North Carolina	1-S	1-S	1-S	2-S	8-U, 1-L	1-S	3-S, 1-U, 1-L	1-S		5-U, 1-P
North Dakota	1-S	1-S		2-S	3-U		2-U			
Ohio			1-S	2-S, 2-L	4-U, 1-P		3-S, 1-U, 1-L	1-S		1-S
Oklahoma		1-S			6-U		4-S, 3-U	1-S		
Oregon	1-S	1-S		1-S	6-S, 21-U	2-S, 1-P	3-S, 9-U	1-S		1-S, 1-U
Pennsylvania				1-S	1-S, 5-U	6-S, 1-U, 2-L	6-S, 1-U,5-L	2-S		1-S
Rhode Island	1-S	1-S	1-S	2-S		1-S	1-S, 1-P			
South Carolina	1-S	2-S	1-S		6-U		1-S, 5-U			1-S, 3-U, 1-P
South Dakota			1-S	2-S	6-U		2-U			
Tennessee				1-S	1-U	1-S	2-S, 1-U	2-S		2-U
Texas		1-S		1-S, 2-L	27-U, 2-L	1-S, 1-L	2-S, 1-U	1-S		2-U
Utah	1-S	1-S	1-S		5-U			1-S		
Vermont		2-S	1-S	1-S	1-S	1-U	2-S, 1-P			1-S, 2-U
Virginia				1-S	1-S		2-S	3-S		2-U
Washington			1-S		16-U	1-L, 1-P	10-U	1-S		1-S, 3-U
West Virginia	1-S	1-S		1-S	1-U					
Wisconsin	1-S	1-S	1-S	1-S	7-S, 5-U	1-S	2-S, 1-L			4-U
Wyoming			1-S		6-U		2-U			
D.C.					1-S		1-S			1-S
Palau										
Guam										
Puerto Rico	1-S		2-S	1-S	4-S			1-S		
Virgin Islands					1-S	1-S	1-S			
N. Mariana Isl.										
Amer. Samoa										
Totals	**41**	**41**	**43**	**72**	**495**	**55**	**192**	**38**	**3**	**66**

Legend for table 4 and 5:

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) (2010). 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: www.eere.energy.gov/greenpower/markets/certificates.shtml?page=2

Table 5: Rules, Regulations & Policies for Renewable Energy [DSIRE]

State/Territory	PBF	RPS	Net Meter-ing	Inter-connection	Contractor License	Equipment Certification	Access Laws	Construction & Design Standards	Green Power Purchase	Required Green Power
Federal Gov.				1				1		
Alabama										
Alaska			1-S	1-S			1-S			
Arizona		1-S, 1-L	1-S, 1-U	1-S	1-S	1-S	1-S	3-S, 4-L		
Arkansas			1-S	1-S	1-S			1-S		
California	1-S	1-S	1-S, 1-U	1-S	1-S		2-S, 7-L	4-S, 12-L		
Colorado	1-L	1-S	1-S	1-S			1-S, 1-L	3-S, 4-L		1-S
Connecticut	1-S	1-S	1-S	1-S	1-S			2-S		
Delaware	1-S, 2-U	1-S	1-S	1-S			1-S	2-S		
Florida		1-U	1-S	1-S	1-S	1-S	1-S, 1-L	1-S		
Georgia			1-S	1-S			1-S	2-L		
Hawaii	1-S	1-S	1-S	1-S	1-S		1-S	2-S		
Idaho			3-U				1-S			
Illinois	1-S	1-S	1-S	1-S			1-S	2-S, 1-L		
Indiana		1-S	1-S	1-S			1-S	1-S, 1-L		
Iowa		1-S	1-S	1-S			1-S	1-S		1-S
Kansas		1-S	1-S	1-S			1-S	1-L		
Kentucky			1-S	1-S			1-S			
Louisiana			1-S, 1-L	1-S	1-S		1-S			
Maine	1-S	1-S	1-S	1-S	1-S		2-S	2-S		1-S
Maryland		1-S	1-S	1-S			1-S	1-S		
Massachusetts	2-S	1-S	1-S	1-S			1-S	3-S		
Michigan	1-S	1-S	1-S	1-S	1-S			2-S, 1-L		
Minnesota	1-S	2-S	1-S	1-S		1-S	1-S	1-S		
Mississippi										
Missouri		1-S, 1-L	1-S	1-S			1-S	1-S		
Montana	1-S	1-S	1-S, 1-U	1-S			1-S			1-S
Nebraska			1-S	1-S			1-S			
Nevada		1-S	1-S, 1-U	1-S	1-S		1-S	1-S		
New Hampshire		1-S	1-S	1-S			1-S	1-S		
New Jersey	1-S	1-S	1-S	1-S			2-S	4-S		
New Mexico		1-S	1-S, 1-U	1-S			1-S			1-S
New York	1-S	1-S, 1-U	1-S, 1-U	1-S			1-S	2-S, 1-L		
N. Carolina		1-S	1-S	1-S			1-S, 1-L	1-S, 12-L		
North Dakota		1-S	1-S				2-S			
Ohio		1-S	1-S	1-S			1-S	1-S		
Oklahoma		1-S	1-S					1-S		
Oregon	1-S	1-S	1-S, 1-U	1-S	1-S		1-S, 2-L	4-S, 2-L		1-S
Pennsylvania	1-S	1-S	1-S	1-S				1-S		
Rhode Island	1-S	1-S	1-S				1-S	1-S		
S. Carolina			3-U	1-S				1-S		
South Dakota		1-S		1-S			1-S	2-S		
Tennessee							1-S			
Texas		1-S,1-L 1-U	3-U	1-S			1-S, 1-L	2-S, 5-L		
Utah		1-S	1-S, 3-U	1-S	1-S		1-S	1-L		
Vermont	1-S	1-S	1-S	1-S			1-S			
Virginia	1-S	1-S	1-S	1-S			2-S	2-S, 1-L		1-S
Washington		1-S	1-S, 1-U	1-S			1-S	1-S, 1-L		1-S
West Virginia		1-S	1-S	1-S						
Wisconsin	1-S	1-S	1-S	1-S	1-L		1-S, 1-L	2-S		
Wyoming			1-S	1-S				1-S		
D.C	1-S	1-S	1-S	1-S				1-S		
Palau										
Guam		1-S	1-S					1-S		
Puerto Rico		1-S	1-S	1-S	1-S	1-S		1-S		
Virgin Islands		1-S	1-S				1-S	1-S		
N. Mariana Isl.		1-S								
Amer. Samoa			1-S							
Totals	**23**	**49**	**70**	**46**	**14**	**5**	**60**	**116**	**0**	**8**

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

- personal tax exemptions
(Federal Government, 24 States + Puerto Rico)
- corporate tax exemptions
(Federal Government and 25 States)
- sales tax exemptions for renewable investments
(28 States + Puerto Rico)
- property tax exemptions
(34 States + Puerto Rico, 15 local)
- buy-down programmes
(23 States + District of Columbia, Puerto Rico, Virgin Islands, 398 utilities, 17 local)
- loan programmes and grants
(Federal Gov., 42 States + District of Columbia, Virgin Islands; 72 utilities, 22 local, 13 private)
- industry support
(Federal Government, 21 States + Puerto Rico, 1 local)

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 2011]. All different support schemes are described there and it is highly recommended to visit the DSIRE website[38] and the corresponding interactive tables and maps for more details.

A study by B.J. Rabe for the Pew Centre on Global Climate Change, investigated 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.*

The Union of Concerned Scientists predicted that State RPS and Renewable Energy Funds could lead to the development of 76,750 MW of new renewable production capacity by 2025. This would be an increase of more than 570% compared to the total US RE capacity in 1997 (excluding hydro) [Uni 2009]. The commitment to increase renewable energy use at State level will have a significant impact on reducing CO_2 emissions. By 2025, these State RPSs will reduce total annual CO_2 emissions by more than 183 million tons of CO_2, which is the equivalent of taking 30 million cars off the road.

The benefits at State level do not only include the significant reduction of greenhouse gas emissions, but they are also an effective means to diversify energy supply sources, increase energy security and create local jobs and economic benefits. The latter reasons are probably behind the fact that a number of States have recently revisited and significantly increased or accelerated their annual requirements.

In June 2011, 29 States, the District of Columbia and Guam had Renewable Portfolio Standards, eight additional States have State Goals and in Florida one utility has agreed on an RPS (Fig. 17).

In 21 States and the District of Columbia, the RPS include minimum solar or distributed generation (DG) provisions (Fig. 18). It is interesting that 15 other States and DC have followed the Colorado RPS with a specific target for solar electricity. In addition, a number of States have provisions in their RPS which counts electricity from PV systems with a higher multiplier. The RPS laws in California and New York create the two largest markets for new renewable energy growth in the short-term.

Another very important measure for photovoltaics is the grid access. In June 2011, 43 US States, Washington DC, Guam, Puerto Rico the Virgin Islands and American Samoa had implemented a net metering policy (Fig. 19). In Idaho, South Carolina and Texas some utilities have agreed on voluntary net metering.

[38] www.dsireusa.org

Fig. 17: States with Renewable Portfolio Standards in the US (June 2011); Figure © DSIRE [Dsi 2011].

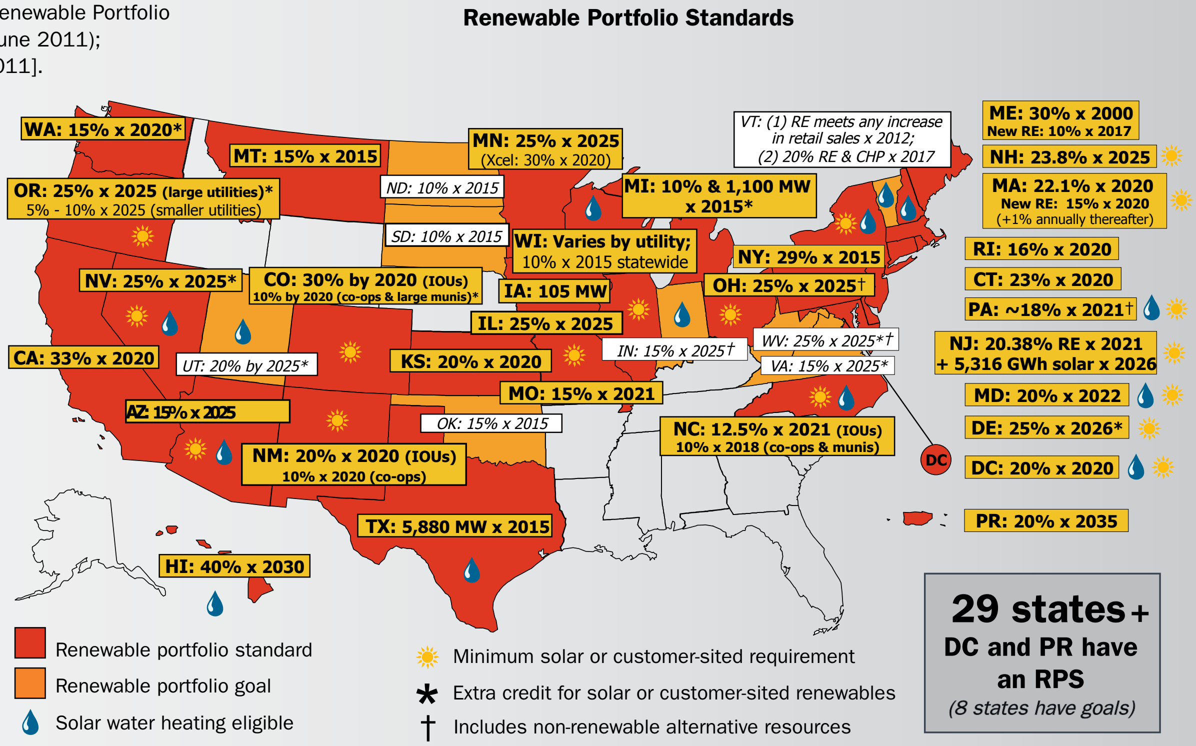


Fig. 18: US States with RPS Policies with Solar/DG Provisions (June 2011); Figure © DSIRE [Dsi 2011].

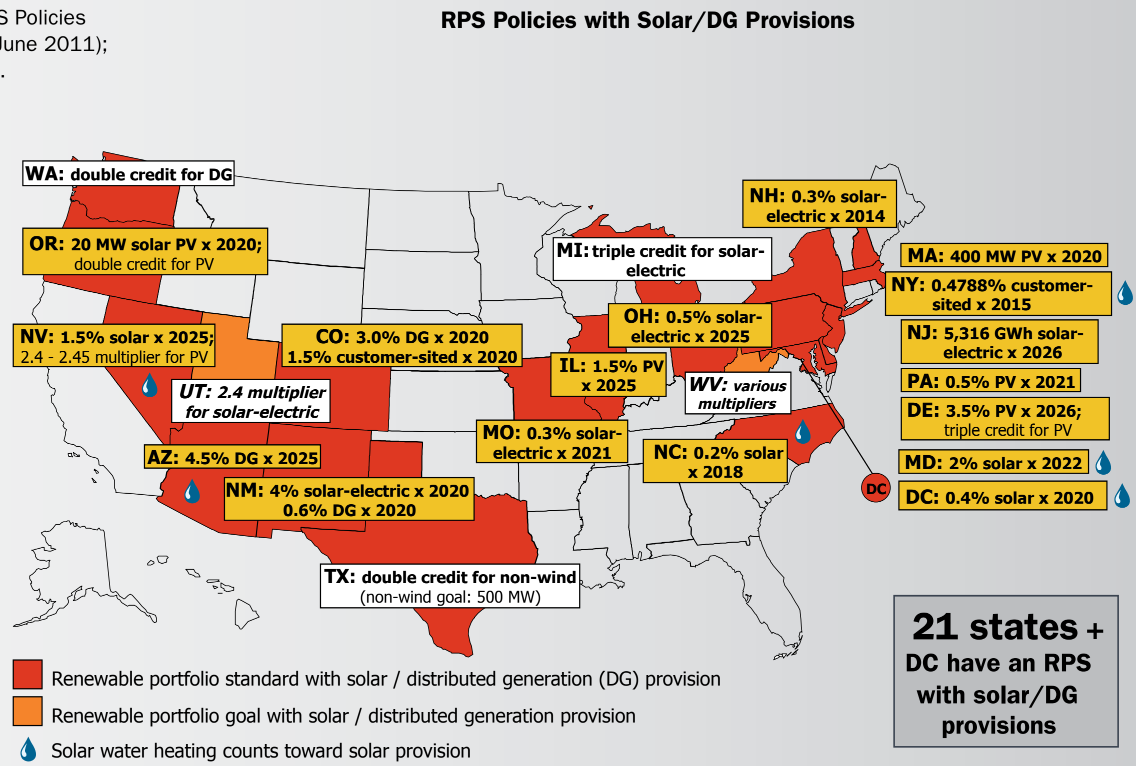
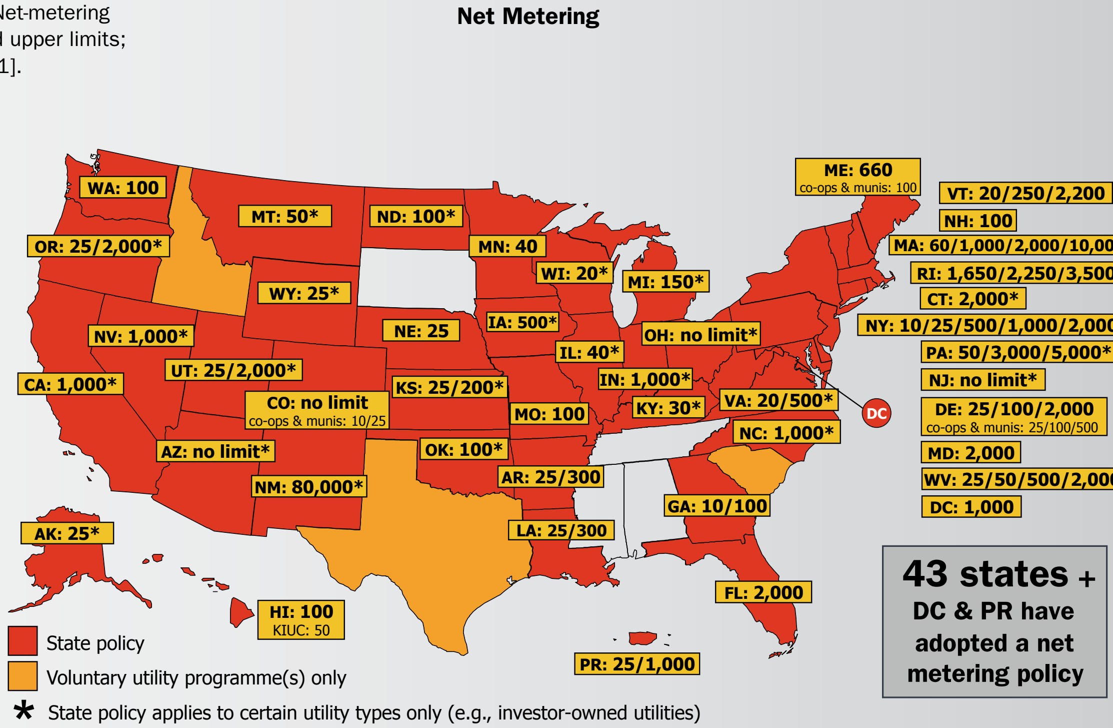


Fig. 19: US States with Net-metering in the US (July 2011) and upper limits; Figure © DSIRE [Dsi 2011].



Note: Numbers indicate individual system capacity limit in kW. Some limits vary by customer type, technology and/or application. Other limits might also apply.

10.3 Solar Programmes

10.3.1 Solar Energy Technologies Programme

The aim of the US Solar Energy Technologies Programme (SETP or Solar Programme) is to develop cost-competitive solar energy systems for America. The current Multiannual Work-Programme runs from 2008 to 2012 [DoE 2008]. More than $ 170 million (€ 130.8 million) are spent each year for research and development on the two solar electric technologies which are considered to have the greatest potential to reach cost competitiveness by 2015: photovoltaics and concentrating solar power. The programme names as the greatest R&D challenges the reduction of costs, improvement of system performance, and the search for new ways to generate and store energy captured from the sun.

The Solar Programme also aims to ensure that the new technologies are accepted in the market-place. Work is done to remove many non-technical market barriers, such as updating codes and standards that aren't applicable to new technologies, improving interconnection agreements among utilities and consumers, and analysing utility value capacity credits for utilities. Such activities should help consumers, businesses, and utilities to make more informed decisions when considering renewable energy, and they also facilitate the purchase of solar energy.

The Solar Programme conducts its key activities through four sub-programmes:

- Photovoltaics
- Concentrated Solar Power
- Systems Integration
- Market Transformation.

The 2008-2012 time-frame emphasises the following areas:

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

5. Improving the ability of DoE and its laboratories and partners to quickly and effectively transfer R&D concepts from basic to applied science and then to the market-place.

6. Exploring and developing the next generation of PV technologies that will reach consumers beyond the SAI time-frame (post-2015).

7. Assisting US industry in regaining its leadership role in the global solar market-place.

8. Promoting increased understanding of environmental and organisational safety across all Solar Programme activities by all participants.

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

The Solar Programme lists economic targets for PV (Table 6), which were determined by an analysis of key markets. They were set based on assessments of the Levelised Costs of Energy (LCOE) for solar technologies to be competitive in these markets.

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

Ten photovoltaic technology roadmaps were developed in 2007 by staff at NREL, Sandia National Laboratories, DoE, and experts from universities and private industry [DoE 2008a]. This work was done, in part, to support activities within the Solar America Initiative. These technology roadmaps summarise the current status and future goals for the specific technologies.

10.3.2 Solar Technology Research Plan

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

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

The PV sub-programme's R&D activities were already described in the 2010 Report [Jäg 2010].

Table 6: Solar Programme Cost Targets

Market Sector	Current U.S. Market Price Range for Conventional Electricity(¢/kWh)	Levelised Cost of Energy (¢/kWh)		
		Benchmark	Target	
		2005	2010	2015
Utility	4.0 - 7.6 2.6 - 24.5 [b]	13–22	13–18	5–7
Commercial [a]	5.4 - 15.0 [c] 6.09 - 20.89 [d]	16–22	9–12	6–8
Residential	5.8 - 16.7 [c] 7.5 - 23.3 [d]	23–32	13–18	8–10

a) In many commercial applications, utility costs are tax deductible. In these cases, the cost of solar energy should be compared to the effective market price, considering tax effects.
b) 2011 (January – June 2011) Wholesale Day Ahead Prices at Selected Hubs, Peak on ICE platform [Eia 2011].
c) Average retail electricity price for the 12 months March 2010 – February 2011 [Eia 2011].

10.3.3 Advanced Research Projects Agency – Energy (ARPA-E)

In 2006 the National Academies released a report *"Rising Above the Gathering Storm"*, where it recognised the need to re-evaluate the way the United States spurs innovation. The report included the recommendation to establish an Advanced Research Projects Agency – Energy (ARPA-E) within the Department of Energy (DoE), which was realised in 2007.

ARPA-E is modelled after the successful Defense Advanced Research Projects Agency (DARPA), the Agency responsible for technological innovations such as the Internet and the stealth technology. Specifically, ARPA-E was established and given the following objectives:

1. To bring a freshness, excitement, and sense of mission to energy research that will attract many of the US's best and brightest minds — those of experienced scientists and engineers, and, especially, those of students and young researchers, including persons in the entrepreneurial world;

2. To focus on creative "out-of-the-box" transformational energy research that industry by itself cannot or will not support, due to its high risk, but where success would provide dramatic benefits for the nation;

3. To utilise an ARPA-like organisation that is flat, nimble, and sparse, capable of sustaining for long periods of time those projects whose promise remains real, while phasing out programmes that do not prove to be as promising as anticipated; and

4. To create a new tool to bridge the gap between basic energy research and development/industrial innovation.

In April 2011 ARPA-E launched a call for funding (Funding Opportunity Announcement) "Solar Agile Delivery of Electrical Power Technology (Solar ADEPT)". The motivation for the call is described as follows:

SunShot leverages the unique strengths across DOE to reduce the total cost of utility-scale solar systems by 75 percent by 2017. If successful, this collaboration would deliver solar electricity at roughly 6 cents a kilowatt hour – a cost competitive with electricity from fossil fuels. This would enable solar electricity to scale without subsidies and make the U.S. globally competitive in solar technology. ARPA-E's portion of the collaboration is the Solar ADEPT program, which focuses on integrating advanced power electronics into solar panels and solar farms to extract and deliver energy more efficiently. Specifically, ARPA-E aims to invest in key advances in magnetics, semiconductor switches, and charge storage, which could reduce power conversion costs by up to 50 percent for utilities and 80 percent for homeowners.

The objectives of the call, which has a funding volume of about $ 10 million (€ 7.7 million) are the following:

This FOA is primarily focused on the development of advanced component technologies, converter architectures, and packaging and manufacturing processes with the potential to improve the performance and lower the cost of photovoltaic systems. Specifically, four categories of performance and integration level will be considered.

Category 1 seeks to broaden the application space for *fully-integrated, chip-scale power converters* for sub-module integrated applications. The performance of integrated converters must scale from today's 1W class chips to 10-80W class converters. Technologies for chip-scale DC/DC converter with Maximum Power Point Tracking (MPPT) that can be integrated during module assembly are of particular interest.

Category 2 seeks to broaden the application space for *package integrated microconverters* by reducing the size and improving component and package performance. The existing state-of-the-art for microinverters requires large (as high as 500) numbers of discrete components to achieve high efficiency over the full-operating range as defined by California Energy Commission (CEC). Highly integrated DC/AC converters with total part-counts less than 10 are required.

Category 3 addresses *lightweight inverter* for commercial roof-top and wall-mount application. State-of-the-art inverters weigh in excess of 250 lbs for 100kW. Reducing the inverter weight simplifies siting of inverters for small to medium sized commercial buildings – allowing the inverters to be rooftop mounted or wall-mounted within an instrument room. High performance component and circuit architectures will be required to realize dramatic (> 6x) improvements in power densities.

Category 4 addresses *lightweight, solid-state, medium voltage* energy conversion for high power applications such as utility-scale inverters with direct grid connection. To address these applications, new solid-state switch technology at voltages exceeding 13kV and advanced magnetics technology supporting MW scale power converters with multi-kilohertz frequencies are of particular interest.

10.4 Sun Shot Initiative

February 2011, Energy Secretary Steve Chu, formally unveiled the Sun Shot Initiative, which is labelled after President Kennedy's famous *moon shot* speech in 1962. According to the DoE, it is *a collaborative national initiative to make solar energy technologies cost-competitive with other forms of energy by reducing the cost of solar energy systems by about 75% before 2020.*

The aim of the initiative is *to accelerate and advance existing DoE research efforts by refocusing its solar energy programs – valued at approximately $ 200 million (€ 154 million) per year – to make large-scale solar energy systems cost competitive without subsidies by the end of the decade.*

Figure 20 shows the price reduction targets of the SunShot Initiative.

In the first half of 2011three calls for funding opportunities were launched:

Funding Number: DE-FOA-0000520

- Reducing Market Barriers and Non-Hardware Balance of System Costs:

  The objective of this Funding Opportunity Announcement (FOA) is to significantly reduce market barriers and the balance of system non-hardware cost components of photovoltaic (PV) systems.

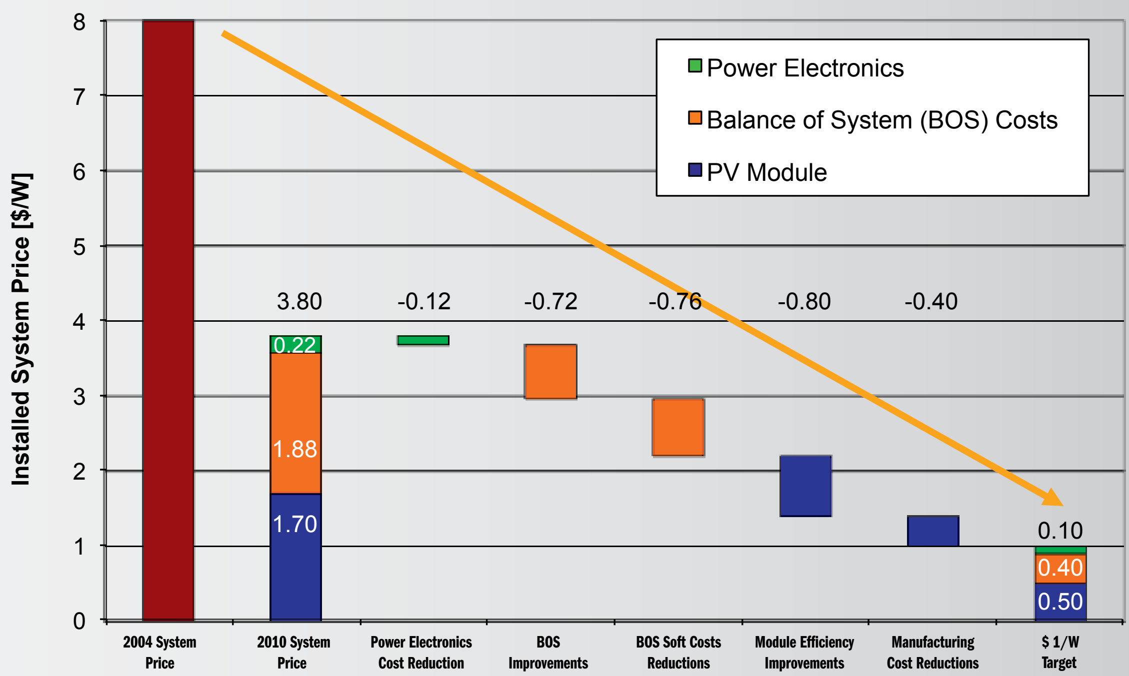
  Under this FOA, the U.S. Department of Energy (DOE) aims to reduce costs by improving information technology systems and streamlining building codes, zoning laws, permitting rules, and business processes for installing solar systems.

  There are three main topics to which an application may be submitted under this FOA:
  Topic 1: Codes, Standards, and Processes
  Topic 2: Software Design Tools and Databases
  Sub-Topic 2A: Utility-Scale Project Siting Tool
  Sub-Topic 2B: Plug-and-Play Tools to Facilitate Preparation and Review Review of Permit Applications
  Sub-Topic 2C: Database of PV Permitting Processes in Authorities Having Jurisdiction (AHJ)
  Sub-Topic 2D: PV System Verification Tool
  Sub-Topic 2E: Utility Rates Database
  Topic 3: Regulatory, Financial and Utility Solutions
  Funding Organization: Solar Energy Technologies Program

Funding Number: REU-1-11979

- **SunShot Incubator**
  The SunShot Incubator program represents a significant component of the U.S. Department of Energy (DOE) business strategy of partnering with U.S.

Fig. 20: Price reduction targets of the SunShot Initiative



industry to accelerate commercialization of photovoltaic (PV), concentrating solar thermal power (CSP), and balance of systems (BOS) research and development (R&D) and validation. The goal is to meet the aggressive DOE SunShot Initiative targets for significantly lower installed costs and greater market penetration.

The SunShot Incubator has two tiers of funding.

Tier 1 projects will receive up to $1 million each through 12-month subcontracts and will focus on accelerating the development of innovative technologies to commercially relevant, albeit lab-scale, processes at a commercially relevant size. DOE anticipates selecting 3-7 Tier 1 projects for awards.

Tier 2 projects will receive up to $4 million each through 18-month phased subcontracts and will focus on shortening the timeline for companies to transition an innovative lab-scale and pre-commercial prototype material, device, module, or system into pilot and eventually full-scale manufacture. DOE anticipates selecting 2-3 Tier 2 projects for awards.

Funding Organization: Solar Energy Technologies Program/National Renewable Energy Laboratory

Funding Number: DE-FOA-0000549

- **SunShot Initiative:** Rooftop Solar Challenge to Induce Market Transformation

The goal of the Rooftop Solar Challenge is to achieve measurable improvements in market conditions for rooftop photovoltaic across the United States, with an emphasis on streamlined and standardized permitting and interconnection processes. This opportunity directly supports the goals of the U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy, Solar Energy Technologies Program, and the SunShot Initiative.

This FOA will take a phased approach, addressing four main action areas (listed below), designed so awardees that succeed in all action areas will have the necessary policy and process framework in place to support a robust solar market in their region:

- Permitting and Interconnection Processes
- Net Metering and Interconnection Standards
- Financing Options
- Planning and Zoning.

10.5 Solar Companies

In the following chapter those solar companies not yet mentioned in Chapter 3, are described briefly. This listing does not claim to be complete, especially due to the fact that for some companies, information or data were very fragmented. Data were collected from the companies' websites. A lot of start-up companies are missing, due to sparse and sometimes contradictory information.

10.5.1 Abound Solar, Inc.

Abound Solar (formerly AVA Solar) was founded in 2007 to commercialise the manufacturing of cadmium telluride (CdTe) thin-film photovoltaic modules. In November 2009 the company started mass production at their factory in Longmount (CO). According to the company, the current manufacturing capacity is 65 MW and an expansion to 840 MW is ongoing. For 2010 the company reported a production of 30 MW.

10.5.2 Calisolar

Calisolar was founded in 2006 and started commercial shipments of solar cells in January 2010. In February 2010, the company acquired 6N Silicon Inc., an Ontario-based polysilicon manufacturer with a 2,000 ton/year capacity. According to the company it is expanding its production capacity from 60 MW in 2010 to over 200 MW in 2011. For 2010 a production 40 MW is reported [Pho 2011].

10.5.3 Evergreen Solar

Evergreen Solar, founded in 1994, develops, manufactures and sells solar power products, primarily solar panels. The company serves three markets: wireless power, rural electrification and grid-connected applications. The company uses its own String Ribbon wafers. Production in 2010 was 158 MW [Pvn 2011]. The Devens factory was closed at the end of 1Q 2011.

In 2009 Evergreen announced the signing of a manufacturing agreement with Jiawei Solar, PRC. Under the agreement, Evergreen manufactures String Ribbon wafers at Jiawei's facility in China and Jiawei uses the wafers to manufacture Evergreen Solar-branded modules. The current capacity of the factory is75 MW. A further expansion to 500 MW was intended to be realised by 2012.

10.5.4 Global Solar Energy Inc.

GSE is located in Tucson and was established in 1996. In 2006, German module manufacturer, SOLON AG, acquired a 19% stake in Global Solar Energy Inc. The remaining 81% are owned by a European venture capital investor. The company is producing thin-film photovoltaic CIGS solar cells for use in solar products, as well as installing and managing large solar photovoltaic systems. According to the company, the new 40 MW plant was opened in March 2008 and a 35 MW plant in Germany opened in the autumn of 2008. In 2010, a production of 30 MW is reported [Pho 2011].

10.5.5 Miasolé

Miasolé was formed in 2001 and produces flexible CIGS solar cells on a continuous, roll-to-roll production line. According to the company the current manufacturing capacity of 50 MW will be increased to 150 MW at the end of 2011. For 2010, a production of 20 MW is reported [Pho 2011].

10.5.6 PrimeStar Inc.

PrimeStar Solar was founded in 2006 to manufacture CdTe solar cells. In September 2007, GE Energy, took a minority equity position in PrimeStar Solar and became a majority shareholder in June 2008. The company has a 30 MW manufacturing line in Arvada, CO. In April 2011, GE Energy announced not only the completion of the acquisition of PrimeStar but its plans to build a 400 MW manufacturing facility.

10.5.7 Solyndra

Solyndra was founded in 2005 and produces PV modules using their proprietary cylindrical CIGS modules and thin-film technology. The company operates a state-of-the-art 300,000 square foot factory, which would allow production of up to 100 MW. In 2010, the company announced to increase their total production capacity to 300 MW by 2011. For 2010, a production of 67 MW was reported [Pvn 2011].

10.5.8 Suniva Inc.

Suniva was founded in 2007 by Dr. Ajeet Rohatgi, Director of Georgia Tech's University Center of Excellence for Photovoltaic Research and Education. On 4 November 2008, the company announced the start of production at their 32 MW factory in Norcross (GA). In 2009, the capacity was increased to 96 MW and to 170 MW in 2010. For 2010, a production of 170MW is reported.

10.5.9 United Solar Systems

United Solar Systems Corp. is a subsidiary of Energy Conversion Devices, Inc. (ECD). The first 25 MW manufacturing facility of the flexible a-Si triple junction solar cell is located in Auburn Hills (MI) and was inaugurated in 2002.

According to the company, production capacity was foreseen to expand to 320 MW by 2010 and 720 MW in 2011. In 2008, financing deals were closed which would allow an expansion to 1 GW in 2012 [Ecd 2008]. The current nameplate capacity in Auburn Hills is quoted with 58 MW and in Greenville, Michigan, 120 MW. A joint venture United Solar Ovonic Jinneng Limited was set up with Tianjin Jinneng Investment Company (TJIC) to operate a 30 MW module plant in Tianjin. In April 2011, the company announce to build another module manufacturing plant with an initial capacity of 15 MW in Ontario. Production in 2010 is reported with 120 MW [Pvn 2011].

10.5.10 Additional Solar Cell Companies

- **AQT Solar Inc.** was founded in 2007 to manufacture CIGS thin-film solar modules and opened its first manufacturing plant with 15 MW capacity in Sunnyvale, California, in August 2010. Early 2010 the company announced to build a second factory in Carolina Pines, North Carolina with about 30 to 40 MW. Production should start 2012 and it is planned to increase the capacity to approximately 1GW by the end of 2014. First product shipments were reported in December 2010.

- **Ascent Solar Technologies Incorporated** was established in 2005 to manufacture CIGS thin-film solar modules with a roll-to-roll process. According to the company, it is on track to commence full-scale production on their 1.5 MW pilot line by the end of 2008. A 30 MW production line was completed in 2009 and was planned to ramp-up to full capacity during 2010. Early 2011, the company announced that its FAB3 project aimed to build a 150 MW factory has advanced to the U.S. Department of Energy (DOE) Loan Guarantee Programs Office (LGPO) due diligence phase of review.

- **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.

- **HelioVolt** was founded 2001 with the aim to develop and commercialize its FASST® process for applying CIGS thin-film photovoltaics directly onto conventional construction materials. The company operates a pilot line in Austin, TX and plans to start commercial production in 2011.

- **Nanosolar** was founded in 2001 and is based in Palo Alto. It is a privately held company with financialbacking 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. In September 2009 the company announced the completion of its European 640 MW panel-assembly factory. Production for 2010 is reported with 2.5 MW [Pho 2011].

- **New Millennium Solar Equipment Corporation** (NMSEC), a solar equipment manufacturing company took over EPV SOLAR Inc. in 2010. On 1 December 2008, EPV announced that EPV SOLAR Germany GmbH started production at their 30 MW Senftenberg factory, increasing total capacity to 55 MW.

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

- **Solo Power Inc.**, founded in 2006, is a California-based manufacturer of thin-film solar photovoltaic cells and modules based on CIGS. In June 2009, the company received certification under ANSI/UL 1703 standard. In February 2011, the company announced that it had received a conditional commitment from the U.S. Department of Energy (DOE) Loan Programs Office for a $197 million (€ 152 million) loan guarantee. The company plans to construct a ne manufacturing plant which, when completed and at full capacity, is expected to produce approximately 400 MW of thin-film modules annually.

- **SpecraWatt** was formed from assets spun out of Intel Corporation in June 2008. In 2009, the company built its first solar cell factory in Hopewell Junction, NY, which is capable of housing over 200 MWp of capacity. Production stared on the first 60 MW manufacturing line. For 2010, a production of 10 MW is reported [Pho 2011].

- **Stion** was founded in 2006 to manufacture CIGS solar cells and is headquartered in San Jose, CA. According to the company its manufacturing capacity in San Jose should be expaned to 140 MW at the end of 2011. In January 2011, the company announced to build another 100 MW manufacturing plant in Hattiesburg, MS, which should become operational in 2012.

- **Xunlight Corporation** is a technology spin-off from the University of Toledo (OH) to develop and manufacture flexible and lightweight thin-film silicon solar modules. In 2009, the company completed the installation of its first 25 MW roll-to-roll photovoltaic manufacturing equipment.

10.5.11 AE Polysilicon Corporation

AE Polysilicon (AEP) was founded in 2006 to manufacture polysilicon for the solar industry. The main investors are Motech (33.3%) and since 2010 Total Gas & Power USA (25.4%). On 19 February 2008, the company broke ground on its production facility at its site at the Keystone Industrial Port Complex (KIPC) in Fairless Hills (PA). In May 2010, AEP announced that it expects to complete fluidised bed reactor (FBR) testing and begin commercial production in the coming months. When operating at full capacity, the initial facility will support the production of approximately 250 MW per year of installed solar energy. The company expects to ramp up the initial facility to full capacity (1,800 tons) by late 2011.

10.5.12 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. The company partnered with Tianwei New Energy Holdings Co., Ltd. which became a majority shareholder in 2009.

In September 2008, Hoku Materials announced that they hade adjusted their planning for the polysilicon manufacturing plant, located in Pocatello (ID), to 3,500 tons, in order to meet customer demand. Due to the difficult economic conditions, pilot production was delayed almost a year and started in April 2010. According to the company the current manufacturing capacity is 2,500 tons and the expansion to 4,000 tons is on track.

11. Outlook

New investment in clean energy technologies, companies, and projects increased to a new record of $ 243 billion (€ 187 billion), up 30% from 2009 and for the third year in a row solar power attracted, behind wind, the second largest amount of new investments into renewable energies [Wor 2011]. Europe was still the leading region in terms of renewable energy investments, but the growth rates of renewable energy investments in the Asia/Oceania region are already higher than in Europe and it is very likely that Asia is becomming the world's leading destination for renewable energy finance investments [Pew 2011]. The main driver there are the private investments in China's renewable energy sector, which increased by 39% to $ 54.4 billion (€ 41.8 billion). With this amount China was again the No 1 in the clean energy investment ranking followed by Germany $ 41.2 billion (€ 31.7 billion), which surpassed the USA, the USA $ 34.0 billion (€ 26.2 billion) and Italy $ 13.9 billion (€ 10.7 billion), which moved up from No 8.

At the end of 2010 about 48% or $ 94.8 billion (€ 72.9 billion) of the $ 194.3 billion (€ 149.5 billion) global “green stimulus” money from Governments, aimed to help relieve the effect of the recession, had reached the markets [Wor 2011]. For 2011 another $ 68 billion (€ 52.3 billion) are expected.

The Photovoltaic Industry has changed dramatically over the last few years. China has become the major manufacturing place for solar cells and modules followed by Taiwan, Germany and Japan. Amongst the 20 biggest photovoltaic manufacturers in 2010, only four had production facilities in Europe, namely First Solar (USA, Germany, Malaysia, Vietnam), Q-Cells (Germany and Malaysia), REC (Norway and Singapore) and Solarworld (Germany and USA).

The focus of this report is on solar cells and modules with some additional info about the polysilicon supply. Therefore, it is important to remember, that the PV industry is more than that and looking only at the cell production does not grasp the whole picture of the whole PV value chain. Besides the information in this report about the manufacturing of solar cells, the whole upstream industry (e.g. materials, polysilicon production, equipment manufacturing), as well as the downstream industry (e.g. inverters, BOS components, system development, installations) has to be looked at as well.

The implementation of the 100,000 roofs programme in Germany in 1990, and the Japanese long-term strategy set in 1994, with a 2010 horizon, were the start of an extraordinary PV market growth. 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. Since 1990 PV, production has increased more than 500-fold from 46 MW to about 23.5 GW in 2010. This corresponds to a CAGR of a little more than 36.5% over the last twenty years. Statistically documented cumulative installations world-wide accounted for 39 GW in 2010. The interesting fact is, however, that cumulative production amounts to 55 GW over the same time period. Even if we do not account for the roughly 6 GW difference between the reported production and installations in 2010, there is a considerable 9 to 10 GW capacity of solar modules which are statistically not accounted for. Parts of it might be in consumer applications, which do not contribute significantly to power generation, but the overwhelming part is probably used in stand-alone applications for communication purposes, cathodic protection, water pumping, street, traffic and garden lights, etc.

The temporary shortage in silicon feedstock, triggered by the high growth-rates of the photovoltaics industry over the last years, resulted in the market entrance of new companies and technologies. New production plants for polysilicon, advanced silicon wafer production technologies, thin-film solar modules and technologies, like concentrator concepts, were introduced into the market much faster than expected a few years ago. However, the faster than expected price decline for solar modules of more than 50%over the last three years triggered by the overcapacity for solar modules and polysilicon has caught a significant number of market players unprepared.

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

Even with the current economic difficulties, the number of market implementation programmes world-wide is still increasing. This as well as the overall rising energy prices and the pressure to stabilise the climate, will continue to keep the demand for solar systems high. In the long-term, growth rates for photovoltaics will continue to be high, even if economic frame conditions vary and can lead to a short-term slow-down.

This view is shared by an increasing number of financial institutions, which are turning towards renewables as a sustainable and lucrative long-term investment. Increasing demand for energy is pushing the prices for fossil energy resources higher and higher. Already in 2007, a number of analysts predicted that oil prices could well hit 100 $/bbl by the end of that year or early 2008 [IHT 2007]. After the spike of oil prices in July 2008, with close to 150$/bbl, prices have decreased due to the world-wide financial crisis and hit a low around 37 $/bbl in December 2008. However, oil demand has increased from about 84 million bbl/day in 1Q 2009 to around 90 million bbl/day in 1Q 2011, whereas the supply just increased from about 87 million bbl/day to a little over 88 million bbl/day.

It is obvious that the fundamental trend of increasing demand for oil will drive the oil price higher again. Already in March 2009, the IEA Executive Director, Nobuo Tanaka, warned in an interview that the next oil crisis with oil prices at around 200 $/bbl due to a supply crunch, could be as close as 2013 because of lack of investments in new oil production. The oil price has rebounced and a significant number of investment analysts expect oil prices in the 110 to 120 $/bbl range towards the end of 2011.

The Energy Watch Group estimated that world-wide spending on combustibles, fuels and electricity was between $ 5,500 billion (€ 4,231 billion) to 7,500 billion (€ 5,769 billion) in 2008 [Ewg 2010]. Between 8.5 and 11.8% or $ 650 billion (€ 500 billion) of this amount is spent on subsidies for fossil fuels ($ 550 billion) and fossil fuel producers ($ 100 billion) each year, according to a joint report of the IEA, OPEC, OECD, and World Bank which was discussed at the G20 meeting in Toronto in June 2010 [IEA 2010]. This annual subsidy would be sufficient to install about 200 GW of PV systems annually world-wide.

The FT cited Fatih Birol, chief economist at the IEA in Paris, saying that removing subsidies was a policy that could change the energy game "quickly and substantially". *"I see fossil fuel subsidies as the appendicitis of the global energy system which needs to be removed for a healthy, sustainable development future"* he told the FT [FiT 2010].

This is in line with the findings of a 2008 UNEP report Reforming Energy Subsidies [UNEP 2008], which concluded: *Energy subsidies have important implications for climate change and sustainable development more generally* *through their effects on the level and composition of energy produced and used. For example, a subsidy that ultimately lowers the price of a given fuel to end-users would normally boost demand for that fuel and the overall use of energy. This can bring social benefits where access to affordable energy or employment in a domestic industry is an issue, but may also carry economic and environmental costs. Subsidies that encourage the use of fossil fuels often harm the environment through higher emissions of noxious and greenhouse gases. Subsidies that promote the use of renewable energy and energy-efficient technologies may, on the other hand, help to reduce emissions.*

The IEA study estimates that energy consumption could be reduced by 850 million tons equivalent of oil – or the combined current consumption of Japan, South Korea, Australia, and New Zealand – if the subsidies are phased out between now and 2020. The consumption cut would save the equivalent of the current carbon dioxide emissions of Germany, France, the UK, Italy, and Spain.

Over the last 20 years, numerous studies about the potential growth of the photovoltaic industry and the implementation of photovoltaic electricity generation systems were produced. In 1996 the Directorate General for Energy of the European Commission published a study "Photovoltaics in 2010" [EC 1996]. The medium scenario of this study was used to formulate the White Paper target of 1997 to have a cumulative installed capacity of 3 GW in the European Union by 2010 [EC 1997]. The most aggressive scenario in this report predicted a cumulative installed PV capacity of 27.3 GW world-wide and 8.7 GW in the European Union for 2010. This scenario was called "Extreme scenario" and it was assumed that in order to realise it a number of breakthroughs in technology and costs as well as continuous market stimulation and elimination of market barriers would be required to achieve it. The reality check reveals that even the most aggressive scenario is lower than what we expect from the current developments. At the end of 2010 PV systems with a cumulative capacity of over 39 GW world-wide and over 29 GW in Europe were generating electricity.

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 Greenpeace, the European Renewable Energy Council (EREC) and the International Energy Agency, have developed new scenarios for the future growth of PV. Table 7 shows the different scenarios of the Greenpeace/EREC study, as well as the different 2008 IEA *Energy Technology Perspectives scenarios.*

These projections show that there are huge opportunities for photovoltaics in the future, if the right policy measures are taken, but we have to bear in mind that such a development will not happen by itself. It will require the constant effort and support of all stakeholders to implement the envisaged change to a sustainable energy supply with photovoltaics delivering a major part. The main barriers to such developments are perception, regulatory frameworks and the limitations of the existing electricity transmission and distribution structures.

The International Energy Agency's Energy Technology Perspectives 2010 stated that for their current Baseline Scenario, the total investments in energy supply and use for the period between 2007 and 2050 totals $ 270 trillion[39] (€ 208 trillion) [IEA 2010b]. The BLUE-Map scenario, which would limit the concentration of Green-House Gases at 450 ppm has an additional financing need of $ 46 trillion (€ 35.4 trillion) but at the same time the cumulative fuel savings of this scenario compared to the Baseline would be $ 112 trillion (€ 86.2 trillion) or more than twice the investment cost. This clearly indicates the huge societal benefit of a more aggressive climate change approach.

In the electricity sector, the investments over the next 40 years would amount to $ 23.5 trillion (€ 18.1 trillion) and about $ 15 trillion (€ 11.5 trillion) would be needed for new power-generation plants. The average BLUE-Map scenario, has an additional financing need of $ 9.3 trillion (€ 7.2 trillion), mostly in power generation capacity.

It is worthwhile to mention, that the high renewable BLUE Map scenario with 75% electricity from renewables has the highest additional investment cost of $ 12.9 trillion (€ 10 trillion), but this is less than 20 years of the annual subsidies paid to fossil energy as mentioned earlier.

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, a 2003 IEA study pointed out that fuel costs will be in the same order of magnitude as investment in infrastructure. The price development over the last eight years has exacerbated this trend and increased the scale of the challenge, especially for developing countries.

The above-mentioned solar photovoltaic scenarios will only be possible if new solar cell and module design concepts can be realised, as with current technology the demand for some materials like silver would dramatically increase the economic costs for this resources within the next 30 years. Research to avoid such kind of problems is underway and

[39] In 2008 U.S.$

it can be expected that such bottle-necks will be avoided.

The photovoltaic industry is changing from a MW size industry into a mass-producing industry aiming for multi GW production. 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 very competitive commodity mass market, and to compensate the advantage 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.

Despite the fact that Europe – especially Germany – is still the biggest world market, the overall world market is gradually changing into a more balanced one. The internationalisation of the production industry is mainly due to the rapidly growing PV manufacturers from China and Taiwan as well as new market entrants from companies located in India, Malaysia, Philippines, Singapore, South Korea, UAE, etc. Should the current trend in the field of world-wide production capacity increase continue, the European share will further decrease, even with a continuation of the growth rates of the last years. At the moment, it is hard to predict how the market entrance of the new players all over the world will influence future developments of the markets.

A lot of the future market developments, as well as production increases, will depend on the realisation of the currently announced world-wide PV programmes and production capacity increases. During 2010 and the first half of 2011, the announcements from new companies wanting to start a PV production, as well as established companies to increase their production capacities, continued to increase the expected overall production capacity. If all these plans are realised, thin-film production companies will increase their total production capacities even faster than the silicon wafer-based companies and increase their market share from the 2007 market share of 10% to about 25% in 2015. However, the number of thin-film expansion projects which are caught between the fact that margins are falling, due to decreasing module prices and the need to raise additional capital to expand production in order to lower costs, is increasing.

Already for a few years, we have now observed 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, subsidies in conventional energies and price volatility risks are generally not yet taken into consideration, renewable energies and photovoltaics are still perceived as being more expensive in the market than conventional energy sources. Nevertheless, electricity production from photovoltaic solar systems has already proved now that it can be cheaper than peak prices in the electricity exchange

Table 7: Evolution of the cumulative solar electrical capacities until 2050

Year	2010 [GW]	2020 [GW]	2030 [GW]	2050 [GW]
ACTUAL INSTALLATIONS	**39**			
Greenpeace* (reference scenario)	14	80	184	420
Greenpeace* ([r]evolution scenario)	18	355	1,036	2,968
Greenpeace* (advanced scenario)	21	439	1,330	4,318
IEA Reference Scenario	10	30	< 60	non competitive
IEA ACT Map	22	80	130	600
IEA Blue Map	27	130	230	1,150
IEA PV Technology Roadmap	27	210	870	3,155

* 2010 values are extrapolated as only 2007 and 2015 values are given

in a wide range of countries and are closing in on residential consumer prices. If the ambitious EPIA and SEIA visions can be realised, electricity generation cost with photovoltaic systems will have reached grid parity in most of Europe and the USA by 2020. In addition, renewable energies are, contrary to conventional energy sources, the only ones to offer a reduction of prices rather than an increase in the future.

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Abstract

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

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

Growth in the solar Photovoltaic sector has been robust. Yearly growth rates over the last decade were on average more than 40%, thus making photovoltaics one of the fastest growing industries at present. The PV Status Report provides comprehensive and relevant information on this dynamic sector for the public interested, as well as decision- makers in policy and industry.

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