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PV Status Report 2003

Research, Solar Cell Production and Market Implementation in Japan, USA and the European Union

Arnulf Jäger-Waldau

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September 2003

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Front cover: Polycrystalline modules as sun-shades at the "Casa-Solare", a Solar House with active and passive solar at the JRC Ispra, Italy
Picture by: Jennifer Rundle

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PREFACE

Photovoltaics is one of the fastest growing industries at present. In the last five years, the production of photovoltaic cells has increased steadily by an average of 40% per year, driven not only by the progress in materials and processing technology, but by market introduction programmes in many countries around the world. This leads to the search for new developments with respect to material use and consumption, device design and production technologies, as well as new concepts to increase the overall efficiency.

At present solar cell manufacturing based on the technology of crystalline, single junction devices is growing by approx. 40% per year and this growth rate is increasing. Consistent with the time needed for any major change in the energy infrastructure, another 20 to 30 years of sustained and aggressive growth will be required for photovoltaics to substitute a significant share of the conventional energy sources. This growth will be possible if a continuous introduction of new technologies takes place, made possible by sound fundamental research.

The rising number of market implementation programmes in Japan and Europe, as well as the different regional incentive programmes in the U.S., contribute to increase the demand for solar systems. In the long-term the growth rates for photovoltaics will continue to be high, even if the economic frame conditions could lead to a short-term slow down of the growth rates. This report tries to give an overview about the current activities in Japan, the U.S. and Europe regarding Research, Manufacturing and Market Implementation. 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.

This second edition of the "PV Status Report" is based on visits to Japan (2002, 2003) and the U.S. (2002), where government entities, research centres and the leading industry companies were visited, as well as on many fruitful discussions with a lot of the people working in this field. I would like to thank all my hosts for their kindness and the time they took to receive me, to share their knowledge and to discuss about the status and prospects of photovoltaics. In addition I have carried out an extensive web and literature search to collect the latest data available.

Ispra, September 2003

Arnulf Jäger-Waldau
European Commission
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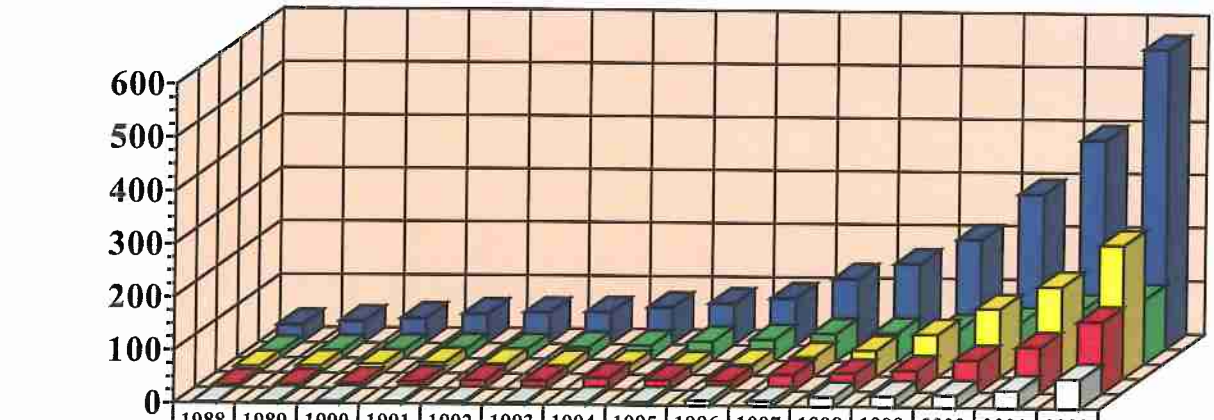
1. INTRODUCTION

In 2002, the photovoltaic industry delivered world-wide some 560 MWp [1] of photovoltaic generators (Fig. 1) and has become a 3.5 bill. $ business. In the past 5 years, the world-wide yearly growth rate was an average of more than 30%, making further increase of production facilities an attractive investment for industry. As about 85% of the current production involves crystalline silicon technology, scale-up of production capacity for this technology will be required in the same proportion. This is a well-established market, which achieves sufficient efficiency for at least 20 years of lifetime and constitutes a low-risk investment with high expectations for return on investments.

Should growth in this technology continue as in the past years, the supply of cost-effective silicon feedstock might limit the achievable cost reduction, especially if feedstock costs cannot be kept below about 0.50 €/Wp. In the last years this problem was often mentioned as the bottleneck for the further growth of the silicon wafer based PV industry. In March 2003 Solar Grade Silicon LLC announced the full production of polycrystalline silicone for PV at the Moses Lake facility with an initial capacity of 2000 metric tons [2]. This indicates that the silicon producers have recognised PV as a full fledged industry, which provides a stable business for the silicon industry, which traditionally depended strongly on the demand cycles of the microelectronic industry. Therefore, it can be expected that silicon feedstock will be available for the further growth of the PV industry.



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Rest of World	3	4	4,7	5	4,6	4,4	5,6	6,35	9,75	9,4	18,7	20,5	23,42	32,6	55,5
Europe	6,7	7,9	10,2	13,4	16,4	16,55	21,7	20,1	18,8	30,4	33,5	40	60,66	86,38	135,1
Japan	12,8	14,2	16,8	19,9	18,8	16,7	16,5	16,4	21,2	35	49	80	128,6	171,2	251,1
United States	11,1	14,1	14,8	17,1	18,1	22,44	25,64	34,75	38,85	51	53,7	60,8	74,97	100	120,6
Total	33,6	40,2	46,5	55,4	57,9	60,09	69,44	77,6	88,6	125,8	154,9	201,3	287,7	390,2	561,8

Fig. 1: World PV Cell/Module Production from 1988 to 2002 (data from PV News [1])

Similar to learning curves in other technology areas, a second generation of devices will steadily increase its market share, until the previous, first technology will be replaced. This 2nd generation technology, after years of research and technology - and also lawsuits - is readily available and just in the transition from pilot to industrial production. Equally competitive technologies are amorphous Silicon, CdTe and CI(G)Se. This growth of these second generation technologies will be accelerated by the positive development of the PV market as a whole and there are many indications that the required scale-up to manufacturing units of 50 MWp yearly capacity will soon join 1st generation silicon devices in satisfying demand. However, the growth of thin film production capacity within this decade must be at least 40% to achieve a market share of 50% in the photovoltaic production of 2010, assuming that total PV growth continues at a constant 27% per year. By then, Silicon technology would deliver about 1.500 MWp per year, requiring probably 12,000 metric tons of Si-feedstock, about half of today's entire Silicon world production, and one can speculate that thin-film technology will continue to grow even faster. Further cost reduction will depend not only on the scale-up benefits, but also on the cost of the encapsulation system, as efficiency will remain limited below 15%, stimulating strong demand for very low area-proportional costs.

2. THE WORLD MARKET

Figure 1 shows the development of the sale figures from 1988 to 2002. Besides the exponential increase of the world market, which led to a rising interest of institutional investors [3], there is the rapid increase of the Japanese production capacities of particular interest. Within 8 years from 1994 to 2002, Japan has propelled itself to the position of a world market leader, both in supply and demand of solar cells (Fig. 2). The situation is even more impressive if one takes into account the increase of production capacities announced (Fig. 3). Compared to their U.S. and European competitors, the Japanese photovoltaic companies have fulfilled what they announced with remarkable reliability concerning the time frame. One remarkable example is the Sharp Corporation.

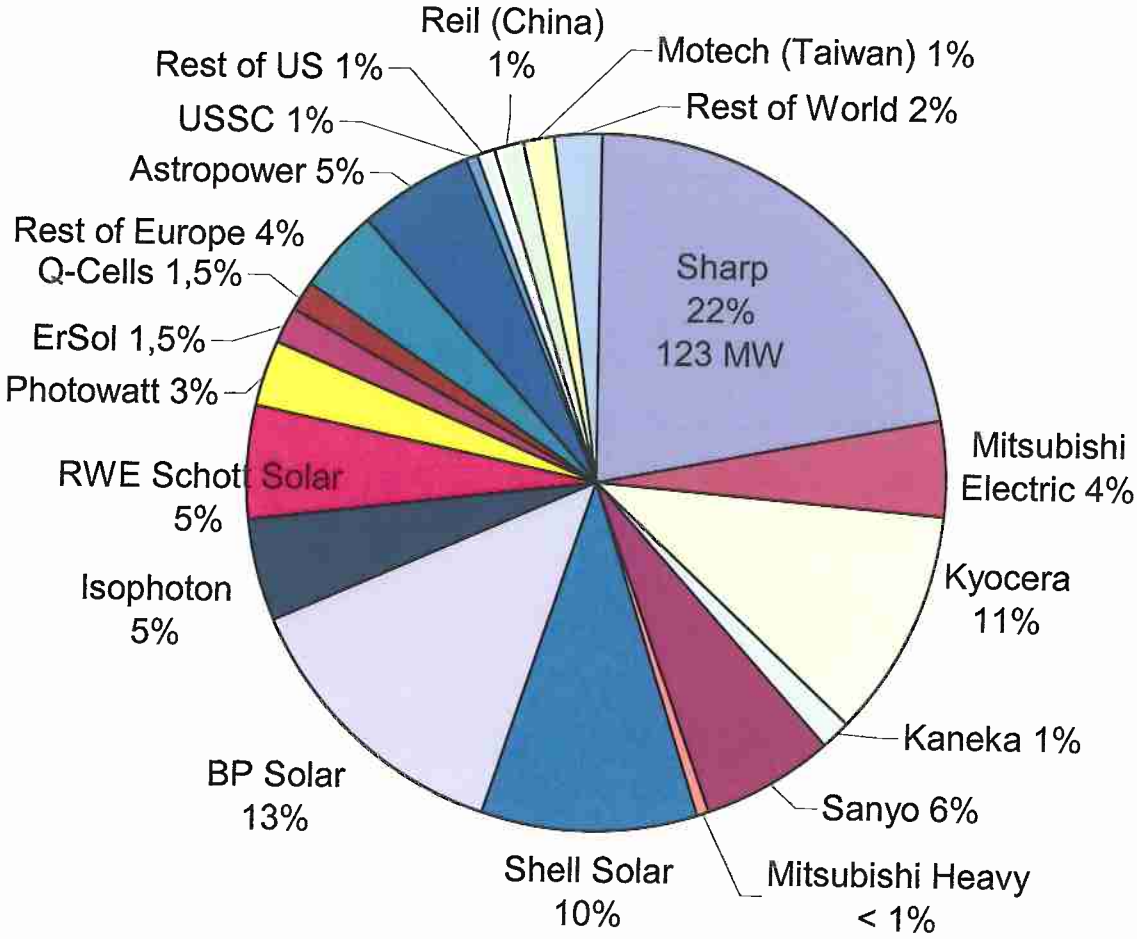


Fig. 2: World-wide sales of solar cells 2002 (562 MW) [1]

On 20 June 1997, Sharp released the following press release [4]: "In response to a rapidly increasing demand for solar cells at home and abroad, Sharp Corporation will build Plant No. 3 of Electronic Components Group, a solar cell plant of world-class scale and capacity, in Shinjo-cho, Kita-Katsuragi-gun, Nara prefecture. The initial production capacity will be 20

MW in fiscal 1998[1] (FY1998), and can be expanded to a maximum of 150 MW, depending on demand trends." When the Business Plan for 2002 [5] was presented on 1 February 2002 an expansion to 200 MW was announced for the end of FY2002. In order to promote further business expansion, the Solar Systems Division was separated from the Electronic Components Group and the new Solar Systems Group was created in January 2002.

The press release of 1997 was received with caution due to the fact that at that point Sharp had only a production capacity of 5 to 10 MW/year and held only approx. 6% of the world market share. However, the production capacity had reached 148 MW in July 2002 and with that accomplished the target set in 1997 [6]. In 2002 Sharp reported sales of over 123 MW and is the world market leader with 22% market share. According to a Sharp press release of 29 July 2003 [7] Sharp plans to increase the production capacity from currently 200 MW to 248 MW by the beginning of 2004. Further growth can be expected in accordance with the world market. In addition, the other four Japanese solar cell producers plan significant increases of production capacities as well: Mitsubishi Electric Corporation: 50 MW by September 2003 [8]; Sanyo Electric Co., Ltd: 120 MW by 2005 and 180 MW from FY 2006 onward [8,9]; Kyocera Corp.: 100 MW by 2004 [10].

The planned expansion of production capacity in Europe and the U.S. is rather moderate. The time frame for the increase announced by RWE-Schott Solar [11] and BP-Solar [12] to 60 MW annual production, each in Europe, stretches to 2004/5. Promising developments can be seen at the Spanish solar cell producer Isofoton who has outperformed the other European manufacturers so far and the German newcomers Q-Cells AG and Deutsche Cell GmbH. With growth rates above average, Isofoton, has become the largest manufacturer of solar cells in Europe (27.4 MW in 2002) [1] and plans to increase the production capacities to 70 MW by 2004 [13]. Q-Cells AG has finished the installation of their second 24 MW line in July 2003 and according to the Q-Cells AG web page, their strategy is to increase it to 72 MW in 2004 [14]. Deutsche Cell GmbH has reported the opening of its new 30 WM plant in Freiberg, Germany in September 2002 and plans to increase the capacity to 60 MW by 2004/5 [15].

Figure 3 shows the announced and estimated increase of production capacities by 2004/5. The figures are taken from additional press releases [16-19], a public report [20] or extrapolated from the production increases of the companies during the last years. It has to be noted that the assessment of all the capacity increases is rather difficult and is affected by the following uncertainties:

- The announcement about the increase in production capacity in Europe and the U.S. often lack the information about completion time compared to Japan. Due to the Japanese attitude that a public announcement reflects a commitment, the pressure to meet a given time target is higher in Japan than in the U.S. or Europe where delays are more acceptable.

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[1] Japanese financial year (FY): 1 April to 30 March

- The announcement of completion of the capacity increase very often only refers to the installation of the equipment. It does not mean that the production line is really fully operational. This means, especially with new technologies, that there can be some time delay between the installation of the production line and real sales of solar cells.
- Available production capacities are not equal to sales, therefore there is always a noticeable difference between the two figures, which cannot be avoided.

Therefore, only limited comparisons between the U.S., Japan and Europe are possible. Despite the fact that in actual sales, Europe surpassed the U.S. in 2002, the overall difference between Europe and Japan has become even larger. This development is of particular interest in view of the strategic importance of solar cell production as a key technology of the 21st century, as well as for the electrification of developing countries and the fulfilment of the Kyoto Targets.

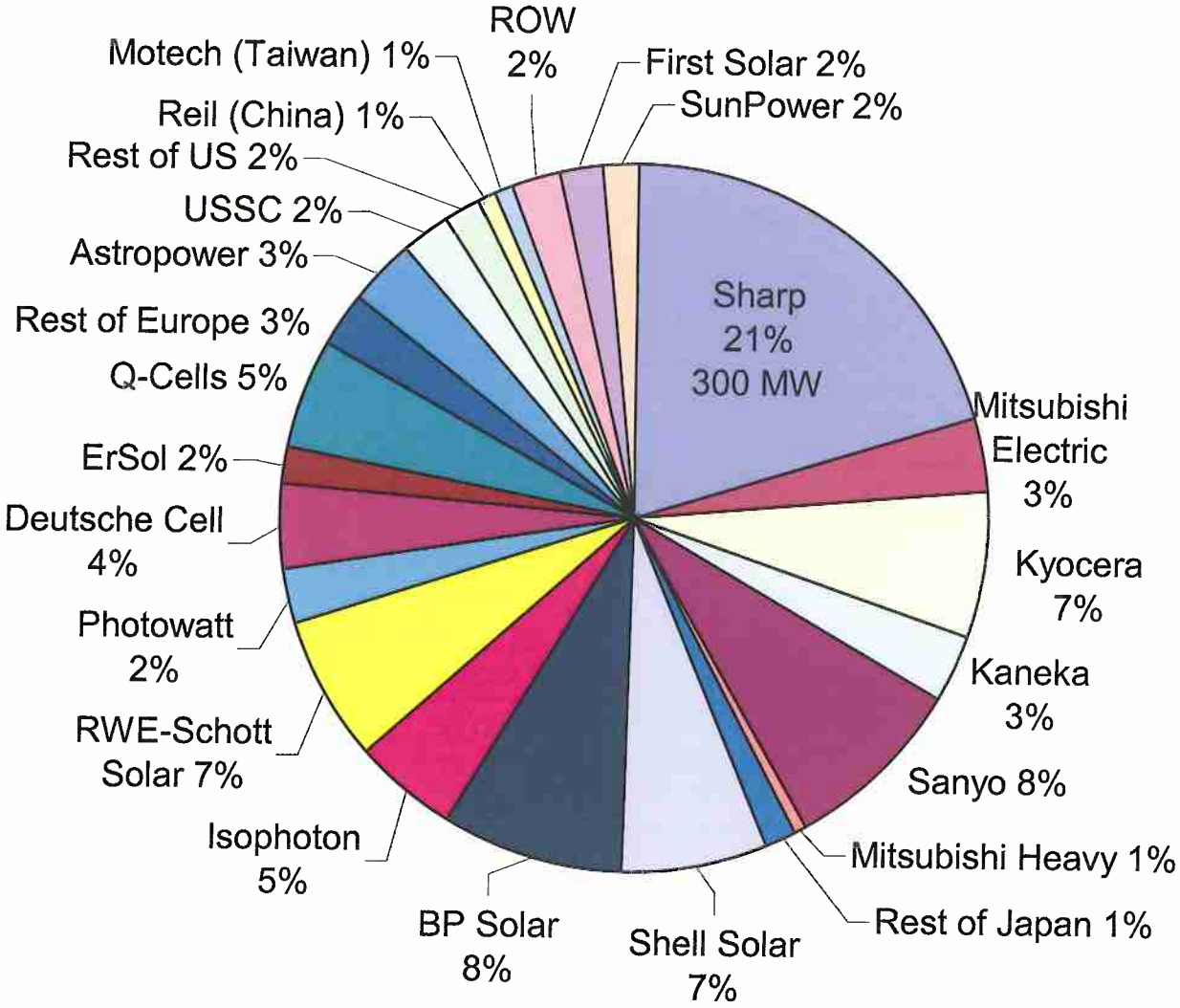

Fig. 3: Announced and estimated increase of production capacities world-wide by 2004/5 (1425 MWp)

3. PV IN JAPAN

The Japanese PV research and development programmes, as well the measures for market implementation, have ensured within the last 10 years that Japan has become the leading PV nation world-wide both on the supply as well as on the demand side. The main reasons for the METI to support renewable energies are:

- Security of Japanese energy supply
- Support of strategic key technology
- Fulfilment of the pledged Kyoto Targets.

3.1 Introducing New Energies

The reasons and necessities for introducing new energy resources in Japan differ from those in Europe deserves a closer look.

The basic goals of the Japanese activities for the introduction of 'New Energy' as a national energy supply were laid down in the 1993 New Sunshine Project, a follow up of the Sunshine Project started 1974, under the impression of the first oil crisis. The 'Basic Guidelines for New Energy Introduction' were set by the 'Council of Ministers for the Promotion of Comprehensive Energy Measures' in December 1994 and were based on a Cabinet Decision in September 1994. In the framework of the 'New Sunshine Project – 1st Stage', which ended in March 2001, photovoltaics was one of the 'New Energies' under investigation. In Japan, the term 'New Energy' includes besides renewable energies such as biomass, solar thermal, photovoltaics and wind energy also the innovative use of fossil fuels, e.g. co-generation, fuel cells, etc. and recycled fuel energy like waste power generation, etc.

This highly successful programme underwent a basic review in 2000, which led to the outline of the New PV Technology Programme called "Advanced PV Generation" (APVG). Due to the administrative reform of the Japanese governmental structure, the New Energy Development Organisation (NEDO) now has a new structure (independent governmental entity) and a new role in the execution of the photovoltaic programme. The New Sunshine Project Headquarters was abandoned at the end of FY 2000, and taking effect in FY 2001, NEDO replaced the New Sunshine Project by the "Advanced PV Generation" programme. As a result of the New Sunshine Project (NSP or NSS) evaluation, several important priorities were selected.

The first topic mentioned in the 'Basic Guidelines' is to decrease the almost 100% dependence on petroleum imports, which account for approx. 53% of the primary energy consumption in Japan. After the first oil crisis, this was a primary issue in Europe as well, but now with the exploitation of the North Sea oil and gas fields it does not have the same importance.

Second, the commitment of Japan under the Kyoto Protocol to reduce its heat-trapping gas emissions by 6% from 2008 to 2012, compared to the 1990 level, is another argument for the

accelerated introduction of new energies. It was intended to reach this aim with the introduction of new energies, energy savings and the increase of nuclear power generation. So far this mixture seemed to be in agreement with the national energy consensus. However, after the last few problems with nuclear facilities, it looks like that this consensus is fading, due to increasing opposition to nuclear power and the linked safety and storage problems.

On 14 March 2002, Kyodo News reported about the new draft guidelines to achieve the greenhouse-gas emissions reduction by a "policy mix" approach, which combines voluntary efforts by industry, with mandatory restrictions and market-based approaches. These new guidelines suggest for the first time, that Japan should study introducing an environment tax and market-based methods. The revision of the guidelines originally set in June 1998 became necessary because the total amount of greenhouse-gas emissions in Japan rose 6.8% from the 1990 levels in fiscal 1999, and in 2010 the amount is expected to stay at 7.4% above the 1990 figures. In such an event, Japan would be obliged to cut greenhouse-gas emissions by 13.4%. The new formula presents 45 fresh approaches to achieve the goal, including further promotion of renewable energy, such as solar and wind power and energy-saving measures like the introduction of daylight-saving time. The document shows that Japan will aim to achieve 2 percentage points of the 6% reduction through "development of innovative technology and citizens' efforts."

Japan's Renewable Power Portfolio Standard (RPS) became effective as of 1 April 2003, requiring that 'New Energy' be provided at a constant percentage of the electric power supply. This obligation can be accomplished through the holding, buying and selling of bonds from electric power suppliers of renewable energy.

Another reason for the introduction of new energies is stipulated in the "Basic Guidelines" chapter about photovoltaics: *'The international market'*. This is a fundamental difference in the attitude of implementing renewables between Japan and Europe. The Japanese policy has not only the advantage to be much more market oriented, but also has a major aim in the policy guidelines: *'The establishment of a prospering market'*. These expectations are also expressed by the long-term goals, which already in 1994 made a commitment for the next fifteen years until the year 2010. This long-term policy and commitments are a huge advantage as can already be seen, as industry can rely on such a long-term programme and plan their individual industry policy as well. Hitherto, in Europe the national as well as the European Community programmes are clearly lacking these long-term policy commitments!

At the beginning of the programme, the critics said that the set goals are just mere visions and will not be fulfilled due to the very high targets set in the plans. However, the target for 2000 to install 400 MWp in Japan was met with only one year's delay and the present developments of production capacities and market growth indicate that the target of 4.8 GWp in 2010 can be met as well. This shows that the attempt to promote new technologies with

visions of future developments is creative, competitive and successful. Figure 4 and Table 1 show the increase of PV roof-top installation since 1997 [21, 22].

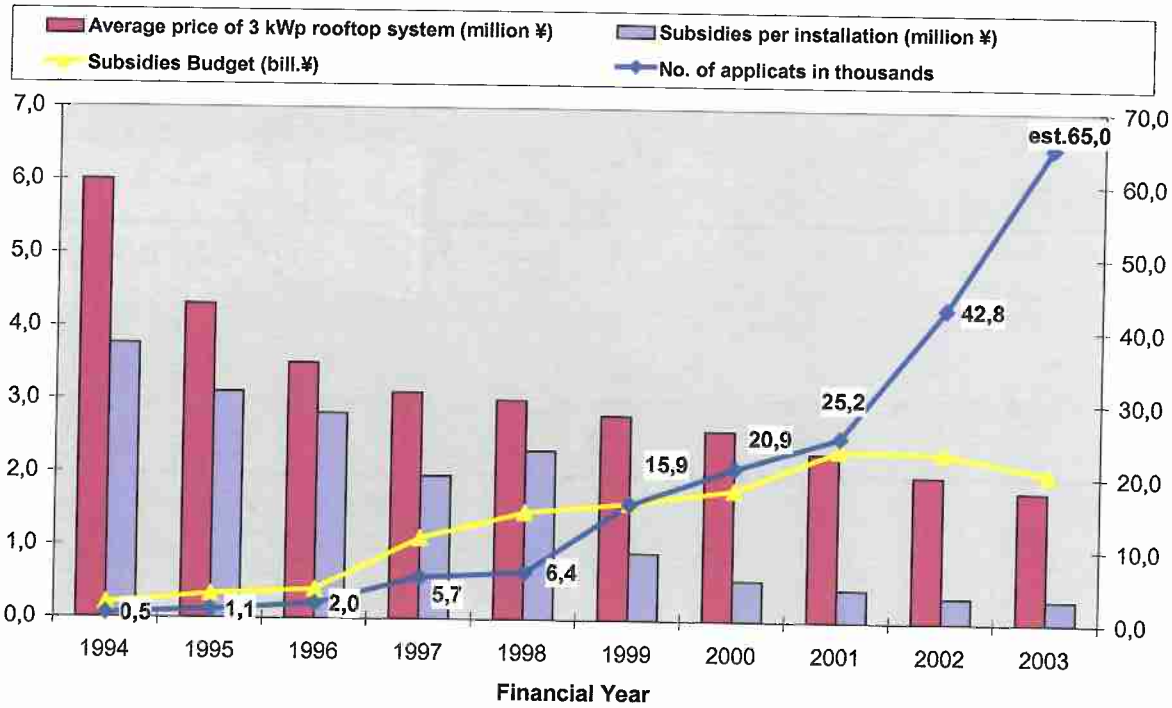

Fig. 4: Increase of PV roof-top installation

Tab. 1: **Development of PV roof top systems**

Year	Average price for 3 kWp system [mill. ¥]	Budget [bill. ¥]	Systems [in 1000]	Subsidy per system[2] [mill. ¥]
1994	6,0	2,0	0,539	3,76
1995	4,3	3,3	1,065	3,10
1996	3,5	4,0	1,986	2,81
1997	3,1	11,1	5,654	1,96
1998	3,0	14,7	6,352	2,31
1999	2,8	16,0	15,879	0,92
2000	2,6	17,9	20,877	0,56
2001	2,3	23,5	25,151	0,44
2002	2,0	23,2	42,837	0,35
2003	est. 1,5 to 1.8	20,5[3]	est. 65[4]	0,32

[2] The average system size varies around 3.5 kWp

[3] approx. 10 bill. ¥ are carried over from 2002

[4] On 5 September 2003, 24,122 applications were already registered for FY2003 [23]

When looking at these PV installation figures one has to bear in mind that they do not include PV installations by public organisations or industry. It can be observed that despite the relatively low level of METI subsidies, there is a high potential for PV in Japan. An additional incentive is the "net-metering" of the electricity produced. The average electricity prices in Japan are 24 ¥/kWh for residential use and 10 – 12 ¥/kWh for industrial use.

3.2 History of Renewable Energy Introduction

The first programme to stimulate the implementation of PV in Japan was called "Monitoring Programme for Residential PV systems" from 94 to 96 and managed by the New Energy Foundation (NEF). Within this programme, 50% of the installation costs were subsidised. This led to a cost reduction from 2 million ¥/kWp in 1994 to 1.2 million ¥/kWp in 1996. The annual budget was relatively modest, increasing from 2 billion ¥ in 1994 to 4.06 billion ¥ in 1996. The number of installations per year increased from 539 to 1986 during this time. In 1997 the "Programme for the Development of the Infrastructure for the Introduction of Residual PV Systems" was launched with a massive increase in funds. From 1997 to 2001, the funds increased from 11.11 billion ¥ to 23.5 billion ¥. Then they decreased slightly for 2002 and 2003. However, it has to be noted that the funds in 2001 and 2002 were not fully used and carried over into the next FY. The national subsidy decreased from 340,000 ¥/kWp (1997) to 90,000 ¥/kWp (2003) and the average system price decreased from approx. 1 million ¥/kWp to 5-700,000 ¥/kWp. The price target set for the future ranges between 300,000 and 500,000 ¥/kWp and should be realised with the help of increased production (learning curve) and PV integration into the buildings.

In addition to this national subsidy, handled by NEF, some local governments (more than 260 additional local subsidising bodies) add additional funds of up to a maximum of 40% of the total installation costs of the systems. The number of 260 local governments seems high, but one should remember that Japan has approx. 3 700 local governments (Prefectures, Cities, Townships etc.). It can be observed that those Prefectures which give additional subsidies have significantly more PV installations than the others (FY 2001: Aichi 12,812 MWp, Hyogo 11,319 MWp, Nagano 10,866 MWp; vs. Akita 703 kWp, Shimane 697 kWp, Fukui 447 kWp). The average residential PV system has 3.5 to 3.7 kWp. This size correlates with the upper limit of 4 kWp per system to receive subsidies from central and local governments. The METI original subsidy programme was scheduled to finish at the end of FY 2002, but it was prolonged for three more years until FY 2005. From FY 2006 it is expected, that the promotion of solar systems will be managed by prefecture/local governments. New corresponding subsidy schemes are currently under development.

Driving forces for the residents to install PV systems are a growing environmental awareness in the light of the Kyoto protocol, the subsidies offered as well as the net-metering of the generated electricity. The electricity production averages 950 kWh/kWp year in Japan and

even the snow-rich west coast along the Japanese Sea, the so-called Snow-Land, averages 850 kWh/kWp year. This means that the average annual electricity savings are approximately 23,400 ¥/kWp and 21,000 ¥/kWp respectively. Due to these programmes, the PV power accumulated in Japan has reached 620 MWp by the end of FY 2002 with approx. 440 MWp installed as residential PV systems.

The average residential PV system in Japan had 3.6 kWp (2002) and was priced at an average of 720.000¥ per kWp. The subsidy for residential PV systems in FY 2002 was 100,000 ¥, but was lowered in FY 2003 to 90,000 ¥. The allocated budget in FY 2002 was 23.20 billion ¥ (198.29 million €)[5]. This budget would have been sufficient for the installation of 232 MWp (approx. 65,000 systems) for FY 2002. However, the actual number of installed systems was 42,837. This and the lower than expected number of installed systems in 2001 led to an unused budget of approx. 10 billion ¥ in FY2002, which was carried over to FY 2003. Together with new allocations of 10.5 billion ¥ the total budget available in FY 2003 is around 20.5 billion ¥ (175.21 million €). This sum would be again sufficient to support the installation of 65,000 PV systems.

One of the main distribution channels in Japan for PV systems are prefabricated new houses with integrated PV systems. After a decline in new house sales in 2001 due to the economic slowdown, the numbers picked up again in 2002 and the industry is confident for 2003 as well. Housing companies like "Sekisui Heim" started to offer homes equipped with "zero-cost-electricity system" [24]. Such systems combine PV installation, energy efficient water supply and an airtight housing structure that maintains a constant temperature inside the home. According to Sekisui, the cost of a PV system sold with a new house has fallen to 480,000 ¥/kWp in 2002 [24].

The new Renewable Portfolio Standard (RPS) drafted by METI was passed by the Diet in spring 2002 and went into effect on 1 April 2003. The bill obliges power retailers, from FY 2003 on, to sell certain amounts of renewable energies. The legislation is aimed at tripling the FY 1999 ratio of new energy in the total power supply to 3.2% in FY 2010 (currently: 0.2% is RE excluding hydro and geothermal; target here 1%) as part of Japan's efforts to attain the greenhouse gas reduction target under the Kyoto protocol. The bill requires each power retailer to set an annual sales target for six types of renewable energies: sunlight, wind, terrestrial heat, water and "sources other than oil that the government specifies", which may include biomass and waste. METI will set the aggregate targets (with special treatment of PV) for the use of the different new energies in the coming eight years, and this will serve as the basis of the annual target calculations by each energy retailer. Each retailer will be required to report to the Ministry its specific targets for the coming year and results from the preceding year. The companies could achieve their targets either by generation of new energy with own

[5] exchange rate used: 1€ = 117¥

facilities, buying electricity from authorised new energy generators or buying surplus from other retailers. The exchange of surplus will be handled by certificates issued by METI. These certificates will be valid for two years and issued for every 1000 kWh of renewable energies generated. A company which fails to meet its target in the initial year will be allowed to pay METI in the following year an amount of certificates equivalent to its annual target, plus the first year shortage. RPS will replace the pay-back system, but METI will set frame conditions to ensure future growth of PV installations.

3.3 NEDO PV Programme

The current programme is called "Projects for New Energies". Due to the administrative reform of the Japanese governmental structure, NEDO has now a new structure (independent governmental entity) and a new role in the execution of the photovoltaic programme. The New Sunshine Project Headquarters was abandoned at the end of FY 2000. Taking effect in FY 2001, NEDO replaced the New Sunshine Project by a programme named "Advanced PV Generation" (APVG). As a result of the New Sunshine Project (NSP or NSS) evaluation, several important priorities were selected [25].

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

One of the dominant priorities, besides the future increase in PV production, is obviously the cost reduction of solar cells and PV systems. The two main funding tools for R&D issues are:

First:

Seed identification with respect to production technologies, industrialisation and commercialisation. These measures receive funding up to 50% by NEDO with matching funds by the participating companies.

Second:

APVG, this is a 100% NEDO sponsored R&D activity carried out by selected research institutions and companies. **This activity includes the 100% NEDO sponsoring of pilot plant developments for new PV technologies (an action which is completely missing in Europe!).**

In addition to these activities, there are programmes on future technologies (in and outside NEDO) where participation is for Japanese institutes or companies on invitation only. For the participation of non Japanese partners there are "future development projects" and the NEDO Joint Research Programme, mainly dealing with non applied research topics.

The R&D programme is divided into short-mid-term targets and long-term targets. The short to mid-term targets are cost reduction, mass production, reliability and infrastructure. Long-term targets are dealing with prospective research and the transformation of research results concerning innovative PV technologies into the production process.

SHORT TO MID-TERM TARGETS (until 2010):

The short-mid term research is aimed at establishing a technical infrastructure in order to realise mass deployment of PV systems in the future. In addition it is targeted to apply the results of the Sunshine- and New-Sunshine Projects towards mass production in order to decrease the system costs to 250 ¥/Wp by 2010 (see Roadmap Fig. 5). To realise these goals an urgent technical demand for mass production was diagnosed. The following projects are running under this heading.

- **Demonstrative Research on Clustered PV Systems**

  This project runs from FY 2002 to 2006 and the plan is to build 400 houses with PV systems in the City of Ota, Gunmma Prefecture (200 houses in FY 2003 and 100 houses in FY 2004 and 2005). The aims of the project are:
  - Development of a technology to avoid restriction of PV system output
  - Analysis and evaluation of higher harmonics
  - Analyses of mis-actuation of function to prevent islanding operation
  - Development of applied simulations

  Consignment: Kandenko Co. Ltd.

- **Infrastructure (Technology Development for Future Mass Deployment):**
  - Technology Development on Measurement of Performance and Reliability of Solar Cells and Modules (AIST[6], JET[7]).
  - Technology Development on Performance and Durability of Photovoltaic Power Generation Systems (AIST, JET).
  - Research and Development on Recycling Technologies of Photovoltaic Power Generation Systems (Sharp Corp., Showa Shell Sekiyu K.K., Asahi Glass Co. Ltd., PVTEC, AIST).
  - Research and Development on Electromagnetic Compatibility of Photovoltaic Power Generation Systems (JET).

- **Mass Production:**

  Development of Advanced Manufacturing Technology
  - Development of Mass Production Process of Low-cost Silicon for Solar Cells (Chisso Corporation).

    Targets for 2005:

    Cost: 2,000 ¥/kg or lower (Production at 1000 t/year scale)

    Quality: Solar Cell Grade (Resistivity 50 Ωcm or over)

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[6] National Institute of Advanced Industrial Science and Technologies (former ETL)

[7] Japan Electrical Safety & Environment Technology Laboratories

- Development of Mass Production Technology of Amorphous-Silicon Solar Cells on Plastic Films (Fuji Electric Corporate Research and Development, Ltd.)
  Targets for 2005:
  Active Area: 93%
  Deposition Rate of a-Si: > 30 nm/sec
  Continous Fabrication: 1,000 cells/roll
  Yield: > 90%

Development of Advanced Solar Cells and Modules

- Development of High Quality Crystalline Silicon Thin Films (Mitsubishi Heavy Industries, AIST)
  Targets for 2005:
  Cost: < 100 ¥/Wp (calculated for 100 MWp/year production)
  Module Efficiency: $\eta > 12\%$ (3600 cm^2)
- Development of Hybrid Solar Cells Comprising Amorphous Silicon and Polycrystalline Silicon (Kaneka Corporation)
  Targets for 2005:
  Cost: < 100 ¥/Wp (calculated for 100 MWp/year production)
  Module Efficiency: $\eta > 12\%$ (3600 cm^2)
- Development of High Quality Thin-Film CIS Solar Cell Modules (Matsushita Electric Industrial Co., Ltd.)
  roll to roll process
  Targets for 2005:
  Cost: < 100 ¥/Wp (calculated for 100 MWp/year production)
  Module Efficiency: $\eta > 13\%$ (3600 cm^2)
- Development of High-Speed Production Process for Thin-Film CIS Solar Cell Modules (Showa Shell Sekiyu K.K.)
  Targets for 2005:
  Cost: < 100 ¥/Wp (calculated for 100 MWp/year production)
  Module Efficiency: $\eta > 13\%$ (3600 cm^2)
- Development of Practical Technology for High-Efficiency Solar Cells (Kawasaki Steel Corp., Sharp Corp.)
  Targets for 2005:
  Substrate size: 15×15 cm^2
  Substrate thickness: 150 μm
  Kerf loss: 150 μm
  Cell Efficiency: $\eta > 20\%$
  Cost (module): < 147 ¥/Wp (calculated for 100 MWp/year production)
- Development of Super-Efficient Solar Cell Modules with Crystalline III-V Solar Cells (Sharp Corp., Daido Steel Co., Ltd., Daido Metal Co., Ltd.)
  Sharp (cell), Daido Steel (module; concentrator) and Daido Metal (system; tracking); Sharp took over the equipment and results from Japan Energy, which was no longer continuing PV research.
  Targets for 2005:
  Cell Efficiency: $\eta > 40\%$ (concentrator cells)
  Cost: < 100 ¥/Wp (calculated for 100 MWp/year production)

LONG-TERM TARGETS (beyond 2010):

The goal of the Japanese long-term research programme is to realise a dramatic cost reduction in order to become cost competitive to commercial and conventional power sources (below 15 ¥/kWh) by 2020. To achieve this, investigations of novel materials, novel structures and novel manufacturing processes are considered essential to plant the seeds for these developments. The following projects are running under this heading.

- **New Materials**
  - Investigation of New Si/SiGe Heterostructural Solar Cells having an Epitaxial Si Layer on a Polycrystalline SiGe Substrate (Institute for Matereials Research, Tohoku University)
    Target (end of 2003):
    Cell Efficiency: 50% higher than multicrystalline Si solar cells
  - Investigation of New Solar Cells with β-$FeSi_2$ (System Engineers Co., Ltd; AIST)
    Target (end of 2003):
    Cell Efficiency: $\eta = 8\%$
  - Investigation of Organic Thin Solid Film Solar Cell (AIST, Kanazawa University, Nippon Shokubai Co., Ltd.)
    Target (end of 2004):
    Cell Efficiency: $\eta = 5\%$
  - Investigation of Carbon-based Thin-Film Solar Cell (Chubu University, Nagoya Institute of Technology)
    Target (end of 2004):
    Cell Efficiency: $\eta = 8\%$
  - Investigation of High-Efficiency Chalcogenide Solar Cells (AIST, Kagoshima University, Aoyama Gakuin University)
    Target (end of 2004):
    Cell Efficiency: $\eta = 18\%$
- **New Structures**
  - Investigation of Controlled Nanostructure Silicon (a-Si and multi-Si) Solar Cells (AIST; Kyushu University; Toppan Printing Co.; Stanley Electric Co.; Nippon Sheet Glass Co. Ltd)
    Content:
    Development of a novel a-Si (controlled nanostructure silicon) that is possibly immune to light-soaking and investigation of high efficiency solar cells with this material.
    Target (end of 2003):
    Cell Efficiency: $\eta = 12\%$ (after stabilisation)
  - Investigation of Spherical Micro Silicon Solar Cells (Clean Venture 21 Corporation)
    Target (end of 2003):
    Production rate: 300 spheres/s
    Quality: equal to that of monocrystalline silicon
  - Investigation of Advanced Light-trapping Silicon Thin-Film Solar Cells (Asahi Glass Co., Ltd)

Target (end of 2003):
Cell Efficiency: 20% higher than cells with conventional TCO

- Investigation of Dye-sensitised Solar Cells (University of Tokyo, Graduate School of Engineering)
  Target (end of 2003):
  Cell Efficiency: $\eta > 7\%$ (100cm^2 cell, after 500 h of continuous generation)
- Investigation of Thin-Film Solar Cells with Wide Bandgap Microcrystalline SiC (Tokyo Institute of technology)
  Target (end of 2004):
  Cell Efficiency: $\eta = 9\%$ (single cell)
- Investigation of High Performance Dye-sensitised Solar Cells Using Ion Gel (Osaka University, Yokohama National University, Fujikura Ltd.)
  Target (end of 2004):
  Cell Efficiency: $\eta = 10\%$
  Heat stability: 85°C × 1000h

♦ **New Processes :**

- Investigation of Solar Cell Manufacturing Technology with Cat-CVD Method. (Japan Advanced Institute of Science and Technology; Graduate School of Engineering Science, Osaka University; Institute of Scientific and Industrial Research, Osaka University; Graduate School of Engineering, Gifu University)
  Content:
  Catalytical Chemical Vapour Deposition of a-Si (Cat-CVD) allows an effective decomposition of the source material by a heated catalyser and a high speed deposition. Solar cell manufacturing technologies using the Cat-CVD process and the stabilisation of the films deposited by vapour and/or liquid CN treatment are investigated.
  Target (end of 2003):
  Cell Efficiency: $\eta = 13\%$
- Investigation of Plating Technology for $CuInS_2$ Thin Film Solar Cells (Shinko Electric Industries Co., Ltd.)
  Target (end of 2003):
  Cell Efficiency: $\eta = 13\%$
- Investigation of Thin-Film Si Solar Cells Prepared by Lateral-crystallisation (Hitachi Cable, Ltd.)
  Target (end of 2004):
  Cell Efficiency: $\eta = 11\%$

3.4 Japanese Market Situation and Roadmap

The Japanese photovoltaic production has rapidly increased following the development of roof-type technologies and the introduction of the subsidy system "Programme for the Development of Infrastructure for the Introduction of Residential PV Systems" in 1997. Despite the current recession, the sales of PV systems has increased steadily even when the growth rates were somewhat lower than anticipated in 2001. The assurance that the subsidy

system for residential PV systems would be in place at least from 1997 to 2002, has encouraged housing manufacturers to promote the integration of PV systems in new houses. In the meantime, PV systems are an additional added value for existing or new houses as an increasing number of Japanese consumers are considering their lower environmental impact by using a PV system more important than the higher price.

After 30 years of PV development under the different NEDO programmes, there are at present 9 Japanese PV manufacturing companies on the market [22]. In addition there are a few module manufacturers as well as inverter and glass producers. Due to massive increase in production capacities in FY 2002 approx. two thirds of the world-wide PV manufacturing capacity (approx. 500 MW) were in Japan. However, in order to reach the target for PV installations set for 2010 at 4.8 GWp, the increase of the production capacity has to be further accelerated. A special conditionn of the Japanese PV industry is the fact that a few large companies bundle the whole or at least large portions of the PV value chain inside their own company, i.e. the solar cell, BOS components and sometimes even the installation and maintenance of the PV systems are offered from the same company. This development is fostered by the special situation of the Japanese construction market. The average lifetime of a residential home is about 25 years and corresponds well with the lifetime of solar modules. A lot of houses are either prefabricated or the construction companies use standardised building components, which is favourable for the integration of solar modules. This advantage was recognised by the solar cell manufacturers and they have either bought housing or construction companies, or concluded strategic alliances with such companies. In 2002 approx. 45% of the solar cells sold world-wide were produced in Japan (251 MW). The current expansion of production capacities in Japan makes it likely that this market share will even rise in the future.

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

In addition, the integration of the PV system at an early stage in the planning of prefabricated and mass manufactured houses offers the chance for a significant price reduction of the PV systems compared to individually built houses or add-on PV systems. For example, to offer stainless steel roofs and aluminium shadings, the advantage of low maintenance costs

while being able to be used as PV substrates at the same time. This combination of different functions adds to the cost reduction for the PV system. In addition, an average 3,6 kWp system leads to a saving in energy costs of approx. 82.000¥ (3420 kWh). In the case of the "Sekisui Heim" house this leads, together with a subsidy between 90.000¥/kWp (NEF, 2003) and up to 40% of the investment costs (NEF + prefectural subsidy) for the investment costs, to an approximate monetary pay-back time of 13 to 17 years. With a lifetime expectation of the PV system of 20 to 25 years, this is an additional incentive for the customers. The pre-installation and mass fabrication of the unit homes, enable the manufacturer to limit the actual installation work of the PV system on the building site to the optimisation of the PV power performance and therefore, lead to considerable savings for the installation. In order to attract a large variety of customers, housing companies offer a large variety of PV systems with different sizes and technologies. The choice of technology, depends on the customers' option for system size and design.

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

In the framework of the last evaluation of the "New Sunshine Project" NEDO, METI, PVTEC[8] and JPEA[9] drafted a roadmap for PV research and development as well market implementation activities for the next 30 years. This roadmap reflects the research activities described in the previous chapter and their impact on the industrial progress (Fig. 5).

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[8] Phtovoltaic Power Generation Technology Research Association

[9] Japan Photovoltaic Energy Association

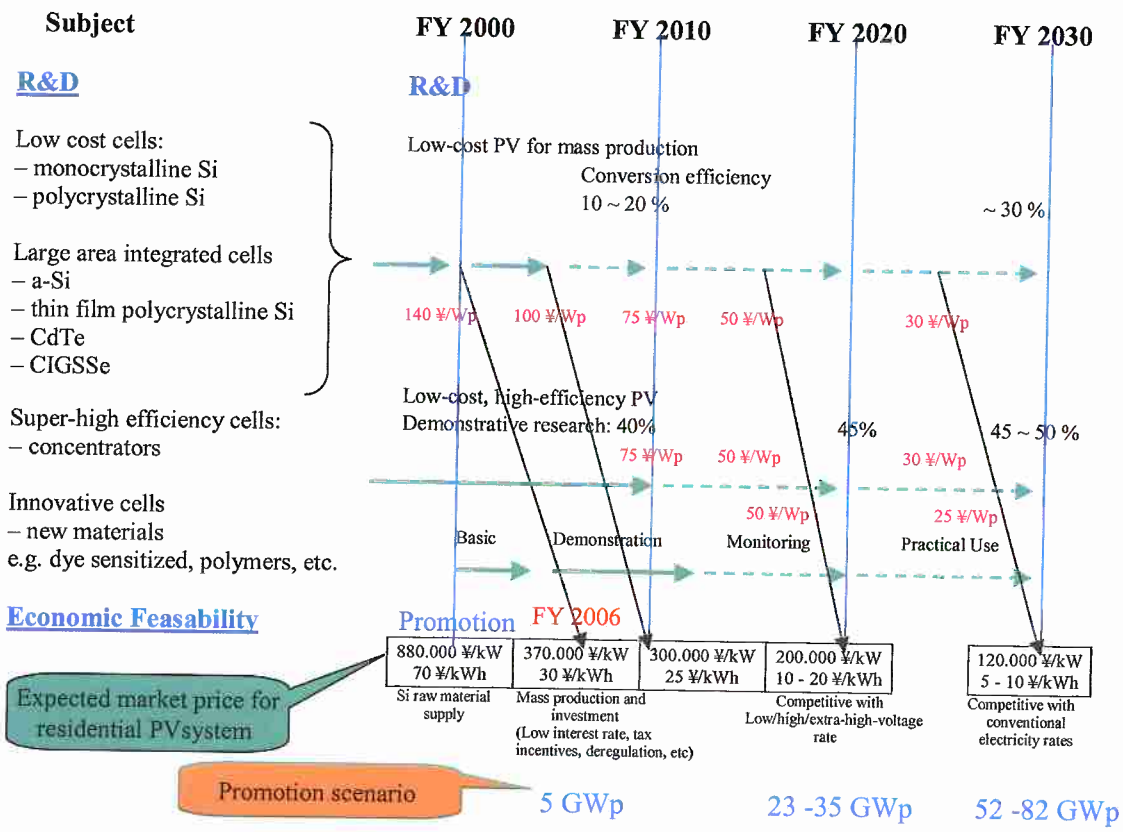

Fig. 5: Japanese roadmap for PV R&D and market implementation

During this evaluation, the following connections were identified between research and development on the one side and market implementation of photovoltaics on the other side, which are of strategic importance for the shaping of future R&D programmes [27].

- To realise the scenario of mass production of solar cells and low costs for PV systems it is indispensable to stimulate technical R&D, as well as market implementation at the same time.

- It is essential to define price/cost targets for R&D processes. Such targets are always the best motivation for private companies to undertake their own R&D endeavours, as soon as markets emerge.

- Roof integrated PV systems have developed in Japan into a promising market and ensure penetration in large numbers. This behaviour might also be explained by the rather high electricity price in Japan of approx. 25 ¥/kWh for private customers.

- Despite the rapid advances of PV technology in industry, it is indispensable to promote R&D projects dealing with new types of solar cells aimed at realising PV systems for lower costs. In parallel, it is important to use the current PV technology to be put into practical operation and generate a PV market. To realise this goal, it is necessary to get PV systems recognised by the market players and to meet the customer demand for price,

design and quality. To do so, leading companies are required to make great efforts as pioneers and create a market.

- Education and training for architects, designers and installers of PV systems are essential to establish and maintain a market and its infrastructure. It is important to understand that a market is never created just because a new technology has been developed.

- Deregulation for PV system business, safety and environmental requirements can eventually promote the penetration of PV systems to the same extent or even more than promotion measures may do.

- To realise the scenario of mass production and low costs for PV systems, it is further important that big companies or consortia, which have the ability to place and receive large orders for PV systems in bulk with good sales logistics, e.g. trading companies, appear on the stage. In Japan, housing companies have played a significant role to increase orders for PV systems. Approximately 500 000 new houses are built in Japan every year and the activities of the housing companies in marketing PV systems have led to a significant increase of orders for the PV manufacturers. Normally 50% of the PV systems sold in Japan each year are sold with a new house. The advantage for the customer is the lower price of the system, completely integrated into the new house and the low financing costs, as the additional costs are included in the house loan.

3.5 Market players

In the following, most of the market players in Japan are described briefly. In comparison to last years version I have tried to include module manufacturers as well as housing companies. This listing does not claim to be complete, especially due to the fact that the availability of information or data for some companies were only very fragmentary.

3.5.1 Sharp Corporation

Sharp started to develop solar cells in 1959 and succeeded in mass-producing them in 1963. Since its products were mounted on "Ume", Japan's first commercial-use artificial satellite, in 1974, Sharp has been the only Japanese maker to produce silicon solar cells for use in space. Another milestone was in 1980, with the releases of electronic calculators equipped with single-crystal solar cells. In addition, Sharp has been successfully installing solar modules in up to 1,223 locations of lighthouses in Japan.

Sharp is currently the world largest PV cell and module manufacturer with a production capacity of 200 MWp/year (July 2002). In 2002, 123 MWp were shipped. According to the press release from 29 July 2003 [7], Sharp is currently under way to increase the production capacity to 248 MWp/year and is planning to reach this by the beginning of 2004. Due to this development and to promote further business expansion, Sharp's Photovoltaics Department was upgraded to become the Solar Systems Group in January 2002.

Within the last 6 years, Sharp has managed to become the leading company with about 60% market share in the Japanese residential market. The company has close collaboration with Japanese major housing companies. Sharp offers complete PV systems with all components made within the company (Fig. 7). At the moment the residential PV market is the driving force for the capacity expansion, but Sharp considers future growth in the industrial sector as well. Therefore, Sharp plans to offer the installation and service of large PV systems (in the range of a few hundred kWp) for industrial clients. A step in this direction is the development of a 100 kW inverter for PV systems together with Daihen Corporation [28].

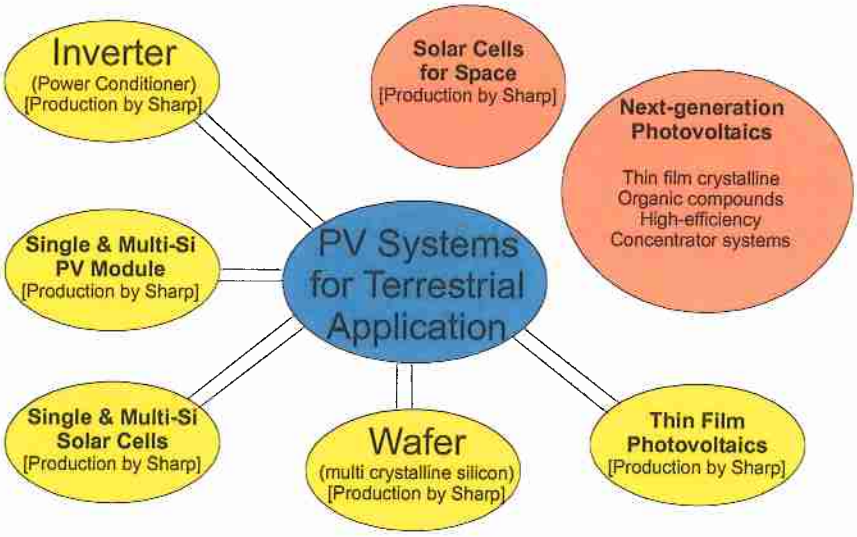

Fig. 6 Development concept of Sharp

In order to support future growth Sharp announced in March 2003 to start production of PV modules, either in the UK or France by the end of the year [29]. The factory is expected to have a capacity of 15 to 20 MW. This would then be the second module plant outside Japan. The first one was opened in Memphis, Tennessee in the spring of 2003 [30, 31] with 12 MW capacity.

Concentrator Systems: Sharp is involved in developing super high-efficiency Compound Solar Cells and low cost solar concentrator modules and systems, together with Daido Steel and Daido Metal within a NEDO research project. At the moment Sharp is not in a position to prospect its production yet.

3.5.2 Kyocera Corporation

In 2002, Kyocera Corp. had sales of 60 MW and is marketing systems that both generate electricity through solar cells and exploit heat from the sun for other purposes, such as heating water. The new products will take advantage of a new government subsidy made available in April 2001 for systems using solar heat. The Sakura Factory in the Chiba Prefecture is

involved in everything from R&D and system planning to construction and servicing and the Shiga factory, in the Shiga Prefecture, is active in R&D, as well as the manufacturing of solar cells, modules, equipment parts, and devices, which exploit heat. Like the other Japanese manufacturers, Kyocera is planning to increase its capacity. According to Kyodo News in April 2003 [32] the Shiga factory has a current capacity of 72 MW and is planing to increase this to 100 MW by the end of 2004.

The growing markets in developing countries are of major interest to the company. Therefore, Kyocera announced to set up a joint venture in Tianjin, China, to produce PV modules for the local market [32]. The factory aims for 10 MW production in 2004 and should start operation in October 2003.

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

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

3.5.3 SANYO Electric Company

Sanyo started 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 (now the president of SANYO) installed the first residential PV system at his private home. Amorphous Silicon modules for power use became available by SANYO in 1993 and in 1997 the mass production of HIT solar cells started. Current production capacities are 30 MWp HIT and 5 MWp a-Si. According to the Nihon Keizai Shinbun (August 2002) Sanyo plans to increase its production capacity by 40% by the end of FY2002 and up to 120 MW by 2005 [33].

At the end of last year, Sanyo also announced the start of module production outside Japan. The company announced the start of HIT PV module production (10 MW/a) at SANYO Energy S.A. de C.V.'s Monterrey, Mexico in the summer of 2003 [34].

Sanyo has set a world record for the efficiency of the HIT solar cell with 21%. This technology offers Sanyo the possibility to produce PV systems, which need less space per kWp. This is a sales argument especially for small area installations on small Japanese houses. In addition, the HIT technology has a lower thermal budget for producing the cell and the

wafer can be thinner than with conventional cells. This leads to savings in the material used as well as production energy. The HIT structure offers the possibility to produce double-sided solar cells, which offer the advantage to collect scattered light on the rear side of the solar cell and can therefore increase the performance by up to 30% compared to one-sided HIT modules in the case of vertical installation. This application is interesting for sound barriers, rooftop fences or horizontal installation as carports, etc. For October 2002 Sanyo announced the release of their latest version of the HIT module with 18.5 % cell efficiency and 16.1 % module efficiency.

Sanyo is working together with Daiwa House to promote the HIT power roofing tile. The advantages are a lower weight (50%) compared to a conventional roof tile. Like other big Japanese solar companies Sanyo offers the complete PV systems manufactured by its own factories. As part of its solar product strategy, Sanyo Electric acquired home builder Kubota House Co. (since renamed Sanyo Homes Corp.) in 2001 to market houses with roofs incorporating solar cells, according to Shigeru Nomoto, general manager of Sanyo's Clean Energy Division [35].

Solar Ark Project: The "Solar Ark", a large scale Solar power generation system (630 kWp) at SANYO's Gifu facility was completed in December 2001. The Solar Ark was built in the image of an Ark embarking into the 21st century powered by solar energy. The Ark's total length measures 315 metres, its highest point measuring 37.1 metres (31.6 metres at its centre point) making it the largest single structure solar installation in the world. Power generation began in April 2002. Placed underneath the Arch is the "Solar Lab", a Solar Energy Museum opened on 3 April 2002. The main activities are:

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

3.5.4 Mitsubishi Electric

In 1974 research and development of photovoltaic modules was 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 (2003). The current production capacity is 35 MW and it is planned to increase this to 50 MW in 2004 [8].

3.5.5 Kaneka Solartech

Kaneka has been involved in the development of amorphous solar cells for 24 years. At the beginning this was aimed at the consumer electronics market, but the overall R&D as well as business strategy was changed in 1993. At this time Kaneka decided to move into the power module market for residential and industrial applications. The goal set was to mass-produce a-Si Modules for rooftop applications by 1999. Besides economical consideration, one of the main reasons for this decision was the fact that Dr. Kenji Yamamoto found a possibility to deposit microcristalline silicon at a low enough temperature (200°C) to combine it with an a-Si solar cell and was able to patent this method. The patents on the previous important findings (Hydrogenated a-Si solar cell, Carlson, RCA 1976; pin a-Si solar cell, Hamakawa, Osaka Univ. 1978; integrated a-Si solar cell, Kuwano, Sanyo 1979 and a-SiC/a-Si heterojunction solar cell, Tawada, Kaneka 1981) expired by 2002, so that this decision looked fairly economically backed. The planned cost target was to reach half of the c-Si with an annual capacity of 40 MWp.

Currently Kaneka produces a-Si modules for rooftop application and built in roofing types for the Japanese, as well as export markets. The built in roofing types were developed for the Japanese housing market in co-operation with Quarter-House and Kubota and are either shingle type modules or larger roofing elements. The total production capacity is currently 25 MWp/year with annual sales in FY 2002 of 7.5 MW. The locations are Shiga (5 MWp) and Toyooka (20 MWp). The increase of the production capacity of the Toyooka plant to 40 MWp, which was planned for 2003 was postponed. A new date has not been announced yet. An important market with future potential is at present Germany, with 2 MWp a-Si modules in 2001 (due to the high demand following the introduction of the feed-in tariff) and in the future Europe.

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

Kaneka's Plans for the thin film PV business can be summarised as follows:

- The system price with 7.5% a-Si modules and 10% hybride modules in 2002 is 1.5 million ¥ for 3 kWp.
- In 2005, 12% hybrid modules are planned with a system price of 1.2 million ¥ for 3 kWp.
- In 2006, increase to 13% hybrid modules with a system price of 1.0 million ¥ for 3 kWp.
- In 2010, 16% hybrid modules should be realised with a system price of 0.6 million ¥ for 3 kWp.

This technological development depends on the realisation of an increase in the deposition rate for the polycristalline silicon, due to the necessary larger thickness of this layer. The production yield of 97.1% already reached is remarkable. The main losses are "Low Performance" (1.4%), these are modules which deviate more than 10% from the set target of 10.5% and "Cosmetic Defects" (1.1%).

So far the "Hybrid PV Modules" (a-Si/polycristalline silicon thin film) are only sold to Japanese customers, as the certification for Europe is still missing. Therefore, Kaneka Solartech is very much interested in field-testing their hybrid modules in order to learn about the outdoor performance at different locations world-wide. Another urgent issue is the development of testing standards for the hybrid multi-junction cells and modules, as the performance differs very much according to the solar spectrum, air mass and relation of direct/diffuse solar radiation. Under the standard test conditions using a solar simulator the standard hybrid module (3738 cm^2) shows an efficiency of 11.57% with a power output of 43.24 W, whereas the outdoor measurement in Otsu, Shiga, (T = 31.8°) led to an initial efficiency of 12.3% and a power output of 46.0 W.

3.5.6 Mitsubishi Heavy Industries

Mitsubishi Heavy Industries (MHI) is a new player in the PV manufacturing business. Solar energy has attracted increasing attention as an environment-friendly form of energy. According to MHI's business plan 2002 [36], a facility for the mass production of solar cells was completed on the grounds of the Isahaya plant of its Nagasaki shipbuilding facility in February 2001. The mechanical construction of the production line was finished in December 2001. The new plant has high-speed production equipment and is scheduled to begin producing solar cells with an annual production capacity of 10 MW from autumn 2002.

Compared with crystalline solar cells, MHI's amorphous solar cells can supply energy more inexpensively and are therefore expected to make a considerable contribution to environmental protection. The used plasma CVD deposition 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 expectance can be rated at 20 to 25 years. Mitsubishi is currently working on improving the efficiency to 12% by using a microcristalline/a-Si structure in the future. Another feature of the Mitsubishi modules is their high voltage. The modules are produced with either 50V or 100V and power ratings between 24 and 100Wp.

One of the main reasons given for the solar cell activities at Mitsubishi Heavy is the increasing market for photovoltaic systems, as well as the promising outlook of the future growth of this field. Why did Mitsubishi Heavy invest in the amorphous silicon technology?

The answer to this question lies in the portfolio of the company. The core technologies for the a-Si manufacturing, were already well established business sectors: deposition technologies for large scale thin film deposition and the manufacturing of the respective machinery. Especially the fact that Mitsubishi has the equipment development in-house enables a fast feedback and improvement of the production technology.

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

3.5.7 Additional Solar Cell Companies

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

- **Fuji Electric**: In 1993 Fuji started its activities in amorphous thin film technology. Currently they are developing amorphous-silicon thin film solar cells in the framework of a NEDO contract. The cells, which use a plastic film substrate less than 0.1mm thick, are light, inexpensive to manufacture and easily processed into large surface areas. They are now pushing forward with field tests, with a view to meeting demand for applications in a wide range of fields.

- **Hitachi:** Tokyo-based Hitachi Ltd. has announced plans to start commercial production of a new bi-facial crystalline solar cell in September 2003. By the end of the year, Hitachi plans to produce 1 MW of its new cell. That total will increase to 5 MW in 2004, and 8 MW in 2005, when production will be operating at full capacity in a three-shift mode [37].

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

- **Showa Shell Sekiyu**: In 1986 Showa started to import small modules for traffic signals, and started module production in Japan, co-operatively with Siemens (now Shell Solar). In 2002 Showa Shell produced about 1.2 MW of modules [38]. In addition they are involved in the NEDO sponsored research project "Development of

High-Speed Production Process for Thin-Film CIS Solar Cell Modules". During the 3rd World Conference on Photovoltaic Energy Conversion in Osaka, May 2003, they reported about a 30 × 30 cm^2 module with 14.2% efficiency from a pilot plant.

3.5.8 Kobelco (Kobe Steel)

In April 1999, Kobe Steel's Engineering Company formed an agreement with Germany's Angewandte Solarenergie - ASE GmbH that enables Kobe Steel to market ASE's (now RWE-Schott-Solar) photovoltaic systems in Japan. Kobe Steel is focusing on selling mid- to large-size systems for industrial and public facilities. By 2010, it aims to acquire a 10% share of the domestic market.

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

3.5.9 MSK Corporation

MSK Corporation is a 100% solar energy company and was founded in 1967 as an import/export company for electrical parts. Already in 1981 MSK began with sales of solar cells and in 1984 opened a photovoltaic module factory in Nagano Prefecture. 1992 they concluded a distribution agreement with Solarex (now BP Solar) and with the beginning of the Japanese residential dissemination programme in 1994 MSK developed the roof material "**Just Roof**" together with Misawa Homes and started sales of residential PV systems.

MSK develops and produces photovoltaic modules and accessories. In addition, the company designs and installs solar panel systems and related electrical equipment. 1998 MSK released **Photovol Roof**, a roof material integrated photovoltaic system and **Photovol Dry**, an under-floor solar ventilation system. **Just Roof** obtained the Japan Building Code, Article 38 certification and others in 1999. In August 2003 MSK opened the world largest PV module production plant with 100 MW annual production capacity in Saku, Nagano Prefecture [39].

3.5.10 Daiwa House

Despite the fact that FY 2002 was another sluggish year for the housing market, Daiwa house could sell more than 40,000 units and maintain to be the No. 2 in the market for newly constructed houses and apartment buildings [40].

Since August 1998 they sell "Whole-Roof Solar Energy System" attached to single-family houses. This system, which is a unique type that comes already fixed to the steel roofing material, uses thin-film solar cells made from amorphous materials. In February 1999, Daiwa House began testing a pilot "all-electric house" in Niigata Prefecture. This model of house

utilizes surplus night-time electricity to supply hot water for central heating, and was a new approach to "ecological coexistence" in housing. [41]

3.5.11 Misawa Homes

Misawa Homes Co., Ltd. one of the biggest housing companies in Japan, in 1990 started research activities to utilise PV as roofing material. In October 1992 they built the first model of the "Eco Energy House" with a PV roof top system in the suburbs of Tokyo. This Eco House uses polycrystalline PV modules from BP Solar (1992 Solarex), which have been especially developed by BP Solar's exclusive Japanese distributor MSK Corporation. In 1999 the "Hybrid Z" energy efficient home was introduced with either a six or 12.5 kilowatt PV system [42]. However, Misawa Homes also co-operates with Kobe Steel and others as a module supplier [43]. The New York Times reported on 29 July 2003 that Misawa homes is building a 500 home solar town in Sapporo, on the northern Island of Hokkaido.

3.5.12 Sekisui Heim

Sekisui Heim is a housing division of the Sekisui Chemical Company, which was founded in 1947. Sekisui Chemical was the first to develop plastic moulds in Japan. Its current annual revenue base is $1.35 billion, 50 percent of which comes from Sekisui Heim. In 1971, Sekisui Chemical created the Heim division to build modular houses. Sekisui Heim, currently the fourth largest house builder in Japan, builds about 20,000 houses per year.

In January 2003 Sekisui introduced the "utility charges zero dwelling house" [24]. It is said that they will be able to take the cost standing the introduction of specification off the market in about 14 years. They plan to sell 2,000 buildings in the 2003 fiscal year.

The basic specification of the "utility charges zero dwelling house" are: (1) the "creative energy" = the solar energy generation system of 5.5 kWp, (2) the "energy saving" = heat pump and the building frame responsive to the next-generation energy saving standard and (3) the "effective operation" = the total electrification by using the electricity in the middle of night. The introduction of this concept became possible due to the price-reduction of the PV systems (the cost in 2003 is only 55% of the FY 1999 value) and the development of the sloping roof responsive to the large volume. Sekisui says it costs about 2.5 mill. ¥ in addition, but they are anticipating that the utility charges will be reduced by about 170,000 ¥ per year and that "the additional cost will be recovered in an average of 14 or 15 years".

4. PV IN THE UNITED STATES

In special market segments and local markets PV is becoming more and more competitive. Within the last decades, the U.S. spent approximately 1.7 bill. $ of public funds for the development of photovoltaic technologies. Despite the fact that the envisaged price reductions have not been reached yet these investments have already paid off. The continuous improvement of the technologies and the development of markets indicate the potential of a higher return on investment. In 2002 the total U.S. shipments of cells and modules were 121 MW with only 44 MWp installations in the U.S. itself.

The Solar Electricity Power Association (SEPA) has made a study about the current status of PV in the U.S. with the title "The Solar Power Solution", which was presented in April 2002 [44]. This study concentrates on the factors critical to the success of a constructive and focused path forward for PV in the years ahead. The support for renewable energies from U.S. States and local initiatives (utilities, municipalities, etc.) have surpassed federal support (2001: 66 mill. $ federal funds out of 470 mill. $ total). The opinion of SEPA is that federal funding and policies should be better leveraged to support and link together the manifold state and local activities. In November 2002, 36 U.S. States already had measures for net-metering electricity produced by PV (Fig. 7).

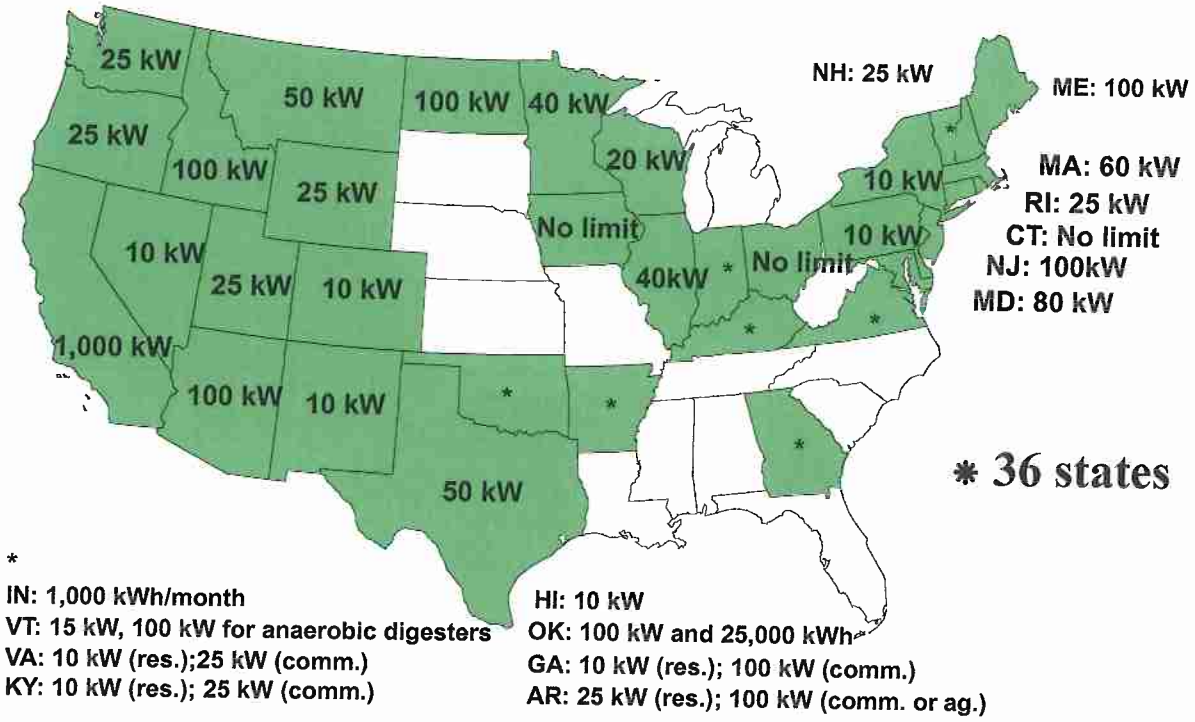

Fig. 7: States with Net-metering in the U.S. (November 2002) and upper limits; Figure © Union of Concerned Scientists [45]

However, one of the main problems of PV is still the lack of infrastructure in the areas of sales, marketing, as well as installation and maintenance of PV systems. In addition, a

standardisation of PV systems according to IEEE standards is missing. This is not only a technical problem but prevents further cost reduction by the use of cheap standard installation components. According to SEPA there is an urgent need for more highly visible demonstration and education projects to show the public the advantages and possibilities of PV systems. In general the federal government should make more information available to the public.

There is no single market for PV in the U.S., but a conglomeration of regional markets and special applications for which PV offers the most cost-effective solution (Fig. 8). Until recently the PV market has been dominated by off-grid applications, such as remote residential power, industrial applications, telecommunications and infrastructure, such as highway and pipeline lighting or buoys. For these applications PV is not only cost effective but the market shows a continuing growth potential.

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

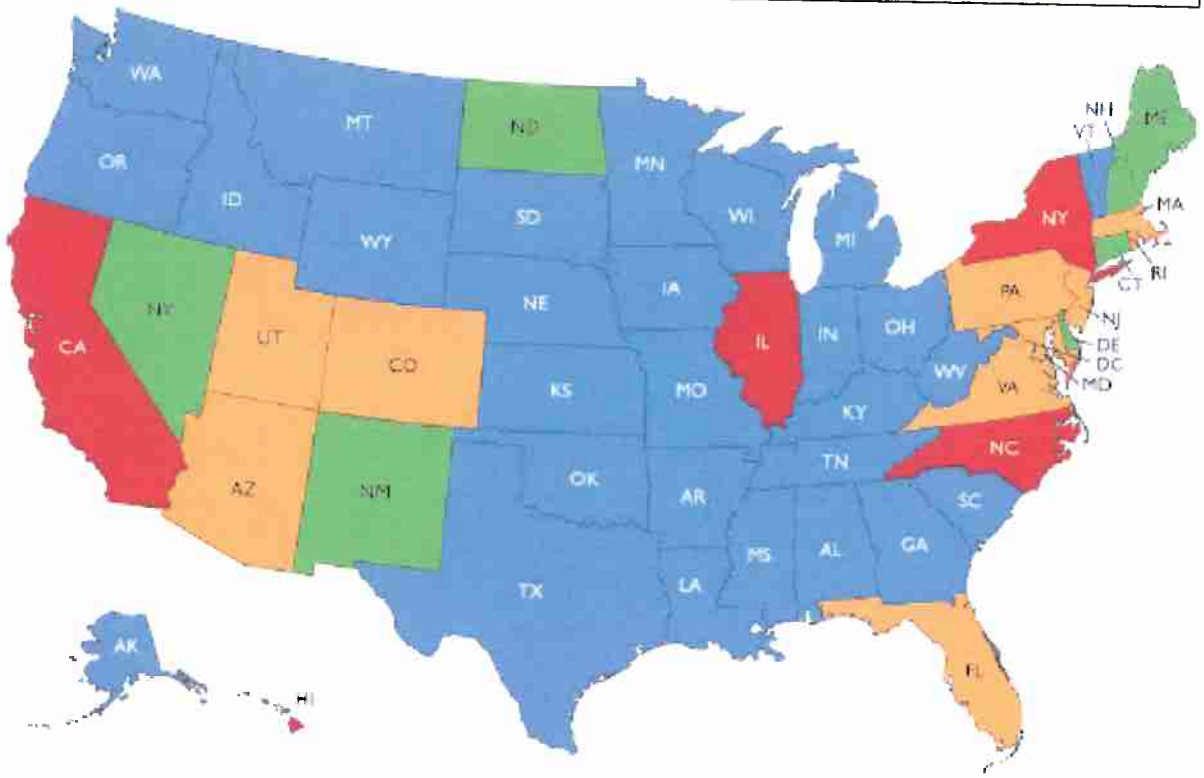

Fig. 8: U.S.-PV-markets [Figure: SEPA]

According to the SEPA study, the markets for grid-connected PV are less mature but due to market implementation programmes have increased tremendously in recent years and provide the largest potential for growth. These applications include PV for residential and commercial buildings as well as government facilities. To develop and expand these markets targeted approaches are required.

Currently the U.S. market can be classified in four categories, where according to the local electricity costs, net-metering and market incentives the listed turn key price for a PV system allows competitive PV electricity production (Fig. 8).

Although the majority of U.S. States are in the category where significant incentives are needed, one has to note that a quarter of the U.S. population lives in the top five States for PV. In those States, PV is cost-effective at an installed cost of $7/W (assuming long-term financing as in a mortgage). These five States belong also to those with the highest economic potentials. In addition it has to be noted that half of the population lives in States in the top two tiers, where PV is cost-effective at a cost of $4.50/W[10].

One of the most promising programmes for the promotion of photovoltaics, which is under discussion, is to use renewable energies and especially PV for electricity generations on Federal Land and in National Parks. The Ministry of the Interior is in charge of implementing this programme, as they are responsible for these lands. PV systems would have a double advantage. First, PV systems are the most reliable and cost effective solution for electricity generation in remote and environmentally sensitive areas. Second, due to the fact that a lot of people are visiting these Parks, they could serve as demonstration systems, which provide first hand information about the benefits and prospects of PV systems. A similar programme, albeit for different reasons, is being discussed at the Ministry of Defence. However, SEPA could not give any information about details or the status of the discussion.

On 31 July the "Energy Policy Act of 2003" was passed in the U.S. Senate in its 2002 version, which died last year when the Conference Committee of House and Senate members failed to agree on a final bill before the 107th Congress adjourned [46]. The Bill includes, similar to Japan, the introduction of a RPS to promote the use of renewable energies and photovoltaics. The National Renewable Electricity Standard requires major electric companies to obtain a minimum of 10 percent of their electricity from wind, solar, geothermal, and other renewable sources by 2020; this provision, along with an extension and expansion of tax credits for renewable electricity, should lead to a doubling of the amount of renewable electricity that would otherwise have been generated in 2020. However, there are two setbacks:

1) The "Energy Policy Act of 2003" does not significantly change the current Tax Code, which contains more than $13 billion in tax breaks for energy production and conservation

[10] Based on data from U.S. Census 2000

over the next five years. The Code is heavily skewed toward polluting industries, giving away approximately 96 percent or $12.5 billion to polluting industries, with the remaining $ 0.5 billion benefiting renewable energy and energy conservation.

2) Since the beginning of September 2003, the U.S. Senate and House of Representative are again negotiating about the completion of the "Energy Policy Act of 2003". The outcome of these negotiations is still unclear. An additional threat to the RPS is the fact, that the Secretary of Energy, Spencer Abraham, in a letter to the Chairman of the House, Senate Conference, dated 10 September 2003, expressed the opposition of the Bush Administration to a national RPS.

4.1 Incentives supporting PV

Due to the political situation in the U.S., there are besides the suggested RPS and some federal tax breaks, no uniform incentives for market implementation of photovoltaics. The 1 000 000 solar roof initiative signed by President Clinton in 1997 lacks a dedicated budget and the Department of Energy (DoE) can only support measures for the removal of market barriers or the development of local promotion programmes. In the framework of State and local initiatives and partnerships, approximately 150 000 systems have been installed since 1997.

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[11] (such as tax credits). Financial incentives typically involve appropriations or other public funding, whereas direct mandates typically do not. In both cases, these programmes provide important market development support for PV. The types of incentives are described below. Amongst them, investment rebates are the most commonly used – at least 37 States, in all regions of the country, have such programmes in place. The most common mechanisms are:

- personal tax exemptions (15 States)
- corporate tax exemptions (17 States)
- sales tax exemptions for renewable investments (14 States)
- property tax exemptions (23 States)
- buy down programmes (10 States; 23 utilities)
- loan programmes and grants (24 States; 7 utilities)
- industrial recruitment incentives (9 States)

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[11] DOE has defined a financial incentive as one that: (1) transfers economic resources by the Government to the buyer or seller of a good or service that has the effect of reducing the price paid or increasing the price received; (2) reduces the cost of producing the good or service; and/or (3) creates or expands a market for producers. EIA, "Renewable Energy 2000: Issues and Trends," section on "Incentives, Mandates, and Government Programs for Promoting Renewable Energy," Mark Gielecki, Fred Mayes, and Lawrence Prete.

4.1.1 Federal Incentives

Production Tax Credit: The Energy Policy Act of 1992 (EPAct) provides an incentive of 1.5 cents/kWh (1993 $) for generation from solar and other renewable sources during their first 10 years of operation. The incentive – Renewable Energy Productive Incentive (REPI) – is only available to tax-exempt publicly owned utilities, local and county governments and rural cooperatives[12].

President George W. Bush proposed to extend and expand this Production Tax Credit as a measure to promote renewable energies and opposes the RPS passed by the U.S. Senate on 31 July 2003 and wants to leave the RPS regulation to the individual States. The argument against the national RPS is that it would rise consumer costs, "especially in areas where the resources are less abundant and harder to cultivate or distribute".

Qualifying facilities must use solar, wind, geothermal (with certain restrictions as contained in the rule making), or biomass (except for municipal solid waste combustion) generation technologies.

Taking into account inflation, the current incentive is equivalent to 1.7 cents/kWh. This is not a very significant incentive given the current cost of PV electricity, but it might be as high as 10% of the system cost in some cases. SMUD, among others, has benefited from this.

There are two tiers or technology classifications in REPI: Tier 1 is solar, wind, geothermal, and closed-loop biomass. Tier 2 includes open-loop biomass technologies, such as landfill methane gas, biomass digester gas, and plant waste material that is co-fired in a generation facility to generate electricity. REPI funds are first distributed to qualifying Tier 1 facilities; then, remaining funds are allocated to Tier 2 facilities. Historically, Tier 2 facilities have been the major recipient of the funds, but this is changing as wind installations increase. Table 2 shows REPI payments to PV systems.

Federal Business Investment Tax Credit for Qualifying Energy Property: EPAct also provides a tax credit for business investment in solar and geothermal generating equipment. Up to 10% of the investment or purchase and installation amount of qualifying energy property can be claimed by a business when filing annual tax returns. Qualifying energy property includes equipment that:

- Uses solar energy to generate electricity, to heat or cool (or provide hot water for use in) a structure, or to provide process heat; or
- Produces, distributes, or uses energy derived from a geothermal deposit.

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[12] For FY 02, the House Energy and Water Appropriation Committee recommended $4M for REPI.

Table 2: REPI Payments for PV Systems

Year of production	Year of payment	PV Facilities	PV Payments (thousand $)	Tier 1 Payments (thousand $)	Total REPI
1994	1995	2	8	101	693
1995	1996	4	15	219	2397
1996	1997	9	28	196	2490
1997	1998	2	31	155	2854
1998	1999	3	91	122	4000
1999	2000	5	46	603	1500
2000	2001	6	53	1339	3991

Source: Office of Power Technologies, http://www.eren.doe.gov/power/repi.html

For electricity produced from geothermal power, equipment qualifies only up to, but not including the electrical transmission stage. There are exclusions for public utility property and reductions on the amount of credit claimed if the qualifying property is/was financed by subsidised energy financing or by tax-exempt private activity bonds.

Federal Modified Accelerated Cost Recovery System: Section 168 of the Internal Revenue Code contains a Modified Accelerated Cost Recovery System (MACRS) by which businesses can recover investments in solar, wind, and geothermal property through depreciation deductions. The MACRS establishes a set of class lives for various types of property, ranging from three to 50 years, over which the property may be depreciated. For solar, wind, and geothermal property placed in service after 1986, the current MACRS property class is five years. The property (equipment) allowable by MACRS must meet the same standards for eligibility required by the Federal Investment Credit (see above), with the inclusion of wind energy systems[13].

Federal Tax Exemption for Nontaxable Energy Grants or Subsidised Energy Financing: Energy grants and subsidised energy financing received by a business from Federal, State, or local government entities may be exempt from Federal taxation. Such grants and financing must be for the principal purpose of conserving or producing energy. The administrator of the grant or financing must report disbursements of such funds to individual businesses using IRS Form 6497. The business/recipient of the grant or financing should ensure that the administrator of the grant or financing files Form 6497 with the IRS. It is the

[13] For more information on and to claim MARCS see IRS Form 4562: Depreciation and amortisation and Instructions for Form 4562, and Internal Revenue Code Sec. 168 (e)(3)(B)(vi).

administrator's responsibility to notify the recipient of the grant or financing that the grant or financing is nontaxable[14].

Federal Support for Renewable Energy Project Development: The Federal Government has various programmes and mechanisms that may provide funds or financing to support renewable energy projects. In general, these funds are available under specific programmes of specific agencies and are dependent on annual appropriations from the U.S. Congress. The U.S. Department of Energy (DOE) has funding programmes focused on developing new technologies, and from time-to-time may have funds available for project feasibility studies and even technology demonstrations. Most focus on specific technologies or applications, and are often cost-shared.

4.1.2 State Incentives

Many State and local governments offer one or more of a broad range of financial incentives for investment in PV and other renewable energy technologies. These incentives include:

- ***Income Tax Credits,*** which allow personal income tax deductions for PV and other renewable investments. Hawaii, for example, allows individuals to deduct 35% of the cost of equipment and installation of residential PV and solar heating systems, up to a maximum deduction of $1,750 for houses and $350/unit in multi-unit complexes.
- ***Property Tax Exemptions,*** which exempt the value of PV and other renewable systems from the property values on which taxes are assessed. For example, Texas exempts taxpayers from any value added by a qualified solar and wind energy equipment for property tax purposes.
- ***State Sales Tax Exemptions,*** which exempts sales of qualifying renewable energy generating or heating equipment from State retail taxes. Arizona, for example, exempts PV and solar heating equipment from State retail taxes, up to equipment values of $5,000.
- ***Loan Programmes,*** which provide low-interest loans to residential and commercial investments in PV and other renewable equipment. Whatcom County, Washington, for example, offers a revolving loan fund for low-interest loans for grid-tied PV and solar thermal systems in residential and commercial applications. Loans are available for up to $5,000 with up to 25 years for repayment.
- ***Investment Rebates,*** in which a portion of the cost of solar projects is rebated by the government. Delaware, for example, rebates 35% of the cost of qualified PV and solar hot

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[14] Generally, reporting on Form 6497 is required only for nontaxable energy grants and subsidised energy financing made for Section 38 property, as defined in Section 48 and the regulations under Section 48, of the Internal Revenue Code.

water systems to residential and commercial investors. It provided a $1 million budget for the rebate programme in 2000.

- ***Industry Recruitment Incentives***, which essentially exempt qualifying renewable-industry businesses from corporate and/or other taxes. Texas, for example, exempts solar equipment manufacturers, sellers or installers from its franchise tax (essentially equivalent to a corporate tax). There is limit to the value of this exemption in Texas.
- ***Project Development Grants***, which provide funding for a portion of the cost of new qualifying PV and other renewable projects. These grants are typically funded by "public benefit funds" or "system benefits charges" on electricity sales. These funds are most common at the State level, having been created through State electricity restructuring or reliability legislation. Delaware's 1999 restructuring law, for example, provides $1.5 million annually for efficiency and renewable programmes, funded by an average 0.178 mill./kWh charge on power sales in the State.

Table 3: State Financial Incentives for Renewable Energy [44]

State	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit	Leasing Programmes	Equip. Sales	Production Incentive
Alabama	1-S					1-S	1-U				
Alaska							1-S				
Arizona	2-S		1-S		1-U				1-U	1-U	
Arkansas		1-S			1-S			1-S			
California	2-S	1-S		1-S	3-S, 8-U	5-S	1-U	1-S	2-U	1-U	
Colorado	1-S	1-S									
Connecticut		2-S	1-S	1-S			1-S				
Delaware											
DC											
Florida			1-S		1-S, 2-U				1-U		
Georgia											
Hawaii	2-S	2-S	1-S		3-U		1-L				
Idaho	1-S						1-S				
Illinois				1-S	1-S	2-S		1-L			
Indiana				1-S		3-S					
Iowa			2-S	3-S		1-S	3-S				
Kansas				1-S		1-S					
Kentucky											
Louisiana											
Maine											
Maryland	2-S	2-S	3-S	1-S			2-S				
Massachusetts	2-S	3-S	1-S	1-S			1-L				
Michigan						1-S					
Minnesota			2-S	1-S	1-S	1-S	2-S				
Mississippi							1-S				
Missouri		1-S					1-S				
Montana							1-S	1-S			

State	Personal Tax	Corporate Tax	Sales Tax	Property Tax	Rebates	Grants	Loans	Industry Recruit	Leasing Programmes	Equip. Sales	Production Incentive
Nebraska	4-S	2-S		1-S			1-S				
Nevada				2-S	1-U						
New Hampshire				1-S		1-S					
New Jersey			1-S		1-S						
New Mexico											
New York	1-S	1-S			1-S, 1-U	1-S	1-S				
North Carolina	1-S	1-S		1-S				1-S			
North Dakota	1-S	1-S	1-S	2-S							
Ohio		1-S	1-S	1-S							
Oklahoma											
Oregon	1-S	1-S		1-S	2-S, 4-U		1-S, 4-U				
Pennsylvania						1-S					
Rhode Island	1-S		1-S	1-S	2-S	2-U					
South Carolina					1-U						
South Dakota				1-S							
Tennessee							1-S				
Texas		1-S		1-S	1-U		1-U	1-S		1-U	
Utah	1-S	1-S									
Vermont			1-S	1-S							
Virginia				1-S			1-S	2-S			
Washington			1-S		1-S		1-L	1-S			
West Virginia		1-S		1-S							
Wisconsin				1-S	1-U	1-S					
Wyoming									1-U	1-U	
Totals	23	18	18	27	37	21	28	9	5	4	1

Source: North Carolina Solar Center, North Carolina State University research based on information in the Database of State Incentives for Renewable Energy (DSIRE) (2001).

In February 2003, 13 States (Fig. 9) had implemented minimum renewable energy standards. The largest RPS in the U.S. was enacted in California in September 2002. The CA RPS requires the State's 3 biggest investor-owned utilities to increase their use of renewable energy for electricity to 20% by 2017 [47]. Arizona, Connecticut, Maine, Massachusetts, Nevada, New Jersey, New Mexico, and Texas enacted renewable portfolio standards as well as a part of their efforts to restructure their electricity industry.

Pennsylvania included renewable standards in restructuring settlements with distribution companies. Wisconsin enacted a renewable standard as part of electricity reliability legislation, without restructuring to allow retail competition. Iowa and Minnesota have enacted minimum renewable energy requirements for regulated utilities. Most recently, New Mexico joined Nevada in becoming the second State to revisit and significantly increase its RPS.

Compared with 2000, these State RPS laws will provide for over 13,200 MW of new renewable production capacity by 2012 (Fig. 10) – an increase of more than 90% over total 1997 U.S. levels (excluding hydro). The RPS laws in California and Texas create the two

largest markets for new renewable energy growth. Wisconsin, Iowa, Minnesota and Texas have already seen significant developments, e.g. Wisconsin utilities have already acquired enough renewable electricity to meet their target through 2005.

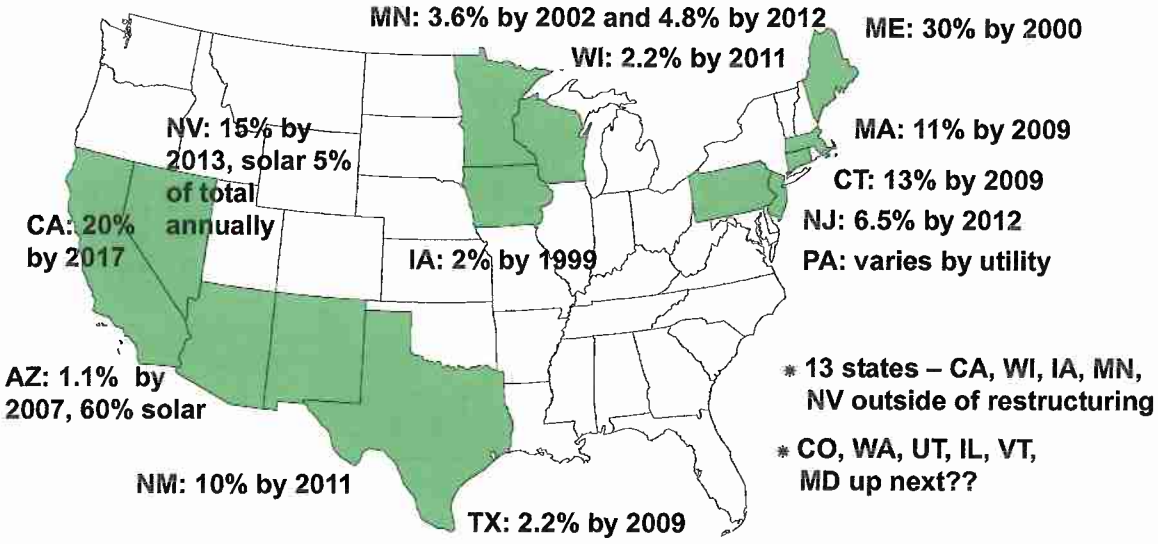

Fig. 9: Renewable Energy Portfolio Standards in 13 States (February 2003)
Figure © Union of Concerned Scientists [45]

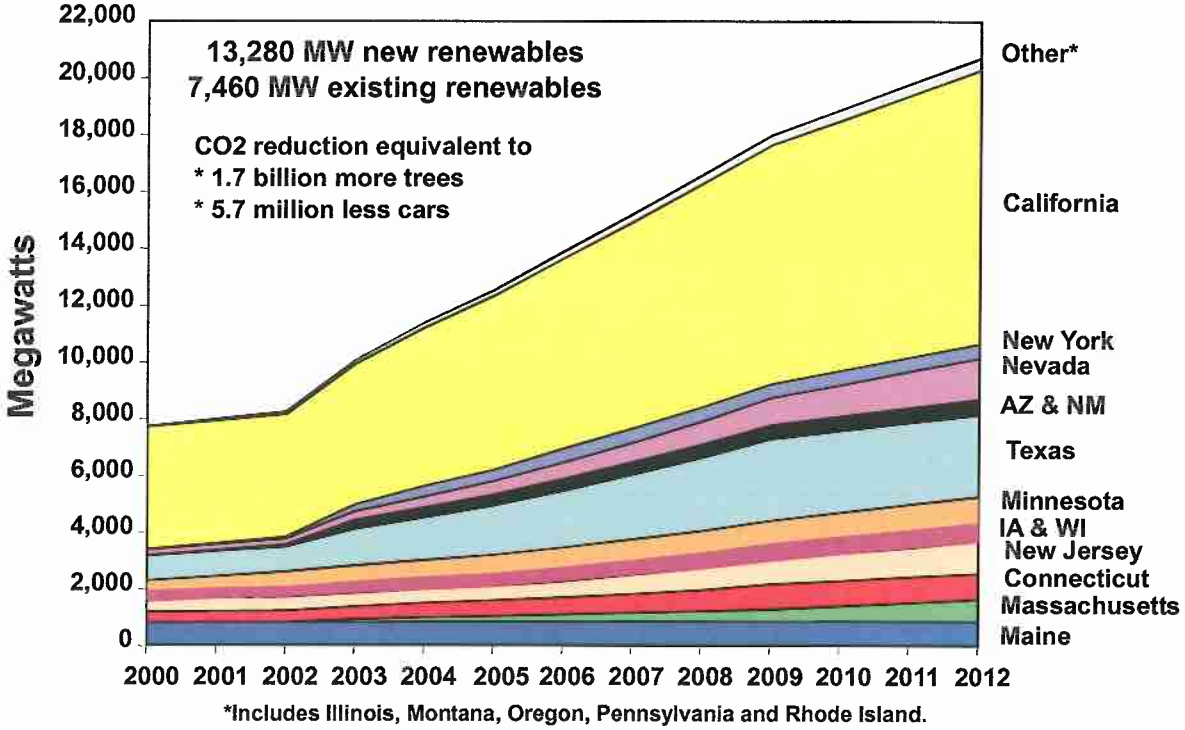

Fig. 10: Prediction of new Renewables from State Standards and Renewable Energy Funds
Figure © Union of Concerned Scientists [45]

So far, Texas has the most successful State RPS initiative. In 1999 a renewable energy standard was adopted that requires 2,000 MW of new renewable generating capacity to be installed by 2009. Then-Governor George W. Bush signed the RPS into law and Federal Energy Regulatory Commission Chairman Pat Wood, a former Texas utility regulator, implemented it. Instead of 400 MW renewable energy generation capacity, as required by the end of 2002, more than 900 MW have been installed. This happened mainly because of the cost-effectiveness of numerous wind power projects and the expiration of the federal production tax credit for wind in 2001 (which was extended again by Congress through 2003). The success of the Texas standard is a combination of the availability of good renewable energy resources in the State and the inclusion of the following key provisions in the RPS legislation:

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

4.1.3 Local incentives

In addition to the already mentioned incentives, local governments use many of these same financial incentives to encourage investment in photovoltaics and other renewable power. The main difference is however, that local programmes tend to be more tailored to local circumstances and interests than State Programmes. It is interesting to note that there is a coincidence between State support for renewables and local government support. Nearly all of them exist in States that offer support for renewables, such as California (at least 6 local incentive programmes), Oregon, Florida, North Carolina, Ohio, Virginia and Washington (at least 2 local incentive programmes each). A December 2000 study[15] identified 33 local programmes offering financial incentives for renewable energy, most of which relied on grants, loans or rebates to support photovoltaics and other renewables. Some of these measures are PV-specific incentives, while others applied to broader categories of renewables that included photovoltaics. It is highly probable that many more local programmes have been established since the December 2000 study was undertaken. The actions can be divided into two main types of measures. First, Investment and Awareness with measures like Green Pricing, Education & Assistance, Green Power Purchasing or other Local Projects. The second ones are financial incentives like Grants, Rebates, Loans, Tax incentives, Green Buildings or Industrial Recruitment activities.

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[15] Gouchoe, S., "Local Government and Community Programs and Incentives for Renewable Energy – National Report," North Carolina Solar Center, North Carolina State University (December 2000).

4.2 The U.S. PV-Industry Roadmap

To meet the challenge of the expanding PV markets the U.S.-based PV industry has developed a PV roadmap as a guide for building their industry [48]. Their main issues were, ensuring U.S. technology ownership and implementing a sound commercialisation strategy that should yield significant benefits at minimal cost. To do so they call for "reasonable and consistent co-investment by our industry and government in research and technology development". Despite the high investments needed, the environmental and direct economic benefits, together with the additional energy security, will by far exceed the investments.

The goal of the industry is to meet 10% of U.S. peak electricity generation capacity by 2030. Within the next 25 years the PV industry expect to employ more than 150.000 people in the U.S. and grow to a $15 billion industry in 2020. To reach these goals the following scenario has been developed.

In the near term

During the next 3 years, the *solar-electric industry* will deliver quality products and services into the marketplace at fair prices. The industry will emerge during this period and continue to build manufacturing capacities to meet growing demands both in the United States and in the rest of the world.

To support these efforts, the *government* at state and federal level need to ensure fair market entrance conditions for the solar-electric power industry to compete with other power players, as well as lower the barriers that hinder photovoltaics from being developed and deployed. Government oversight and implementation is required to bring about national net metering (equity in selling PV electricity to the grid at the utility retail rate), moderate residential tax credits at both the state and federal level, and manufacturing incentives (equity with other energy-product producers). In addition, standards, codes and certification, which are essential for consumer protection and acceptance have to be established.

In the mid term

Within the next 4 to 10 years, PV industry will develop the technical products necessary – whether for residential and commercial distributed generation or for architectural and building-integrated PV applications. Shares of the profits have to be reinvested to ensure vitality and growth of manufacturing capacities as well as expanding the range of products to meet consumer needs. The impact on the supply of new electrical power in the United States will increase significantly and help to firmly establish PV technologies and the solar-electric industry.

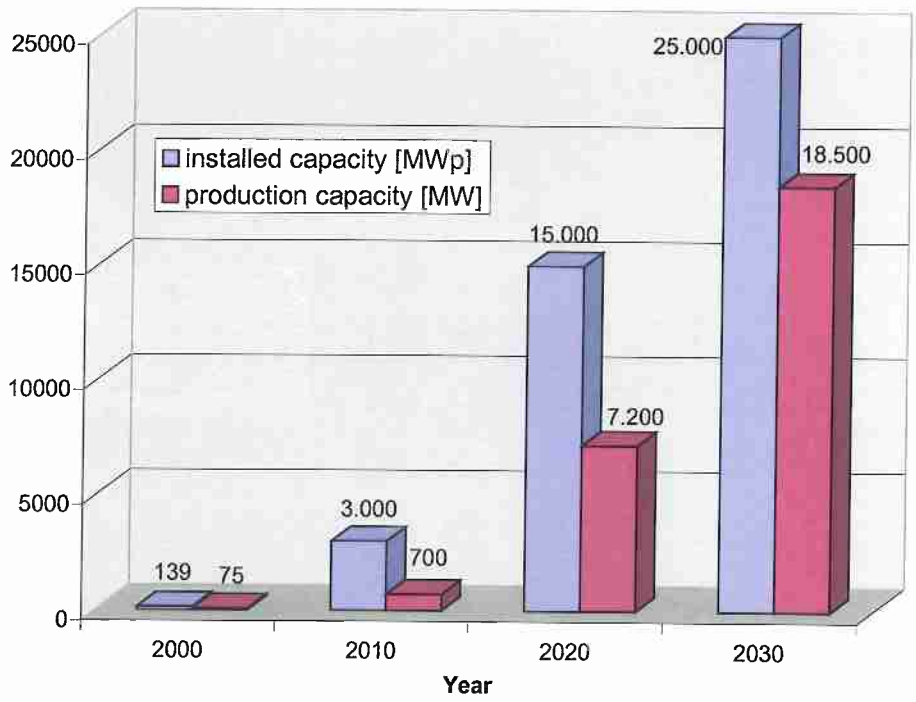

Fig. 11: U.S. PV-Industry Roadmap [48]

In the long-term

During the next 20 years the PV industry will invest in R&D to make manufacturing lines more effective, improve production throughput and bring manufacturing to a position of world leadership. The government is asked to continue a reasonable investment in the nation's intellectual and research resource at national laboratories, universities and other research organisations. This investment is needed to improve existing technologies and develop new and better technologies. These next-generation photovoltaic devices and products are vital for meeting future energy needs and maintaining U.S. leadership.

A close look onto the production targets of the U.S. PV-Industry Roadmap (Fig. 11) reveals that 70% of the production capacities are aimed for export. A strong home market like in Japan, where it accelerated the expansion of production capacities is missing in the U.S.. This might be one of the reasons why the U.S. lost its market leader position held for many years and is now at third place behind Japan and Europe. In addition it should be noted that four out of the five biggest U.S. PV manufactures are owned by European companies.

4.3 PV Companies

In the following chapter most of the cell manufacturers in the U.S. are described briefly. This listing does not claim to be complete, especially due to the fact that for some companies information or data were very fragmented. A lot of the data were collected from the companies' web-sites.

4.3.1 BP-Solar

BP Solar has its headquarters in Linthicum, MD, and after the acquisition of SOLAREX is one of the biggest PV companies with different factories world-wide. In number of sales it was number 2 in 2002 with 73.8 MW. BP Solar has 5 solar cell plants located in Madrid, Spain (Alcobendas: 16 MW, c-Si Saturn solar cells; Tes Cantos: 30 MW, c-Si Saturn solar cells), Sydney-Homebush Bay, Australia (25 MW, mc-Si and c-Si Saturn solar cells) [16], Bangalore, India (15 MW, mc-Si), and Frederick, Maryland (35 MW mc-Si). The thin film factories in Tonano, Virginia (8 MW, a-Si) and Fairfield, California (2 MW CdTe-pilot Apollo line) were closed at the end of 2002. In addition, there are module manufacturing plants in Saudi Arabia and Thailand. At present the Frederick plant is BP Solar's biggest policrystalline wafer production site with an annual capacity of approx. 50 MW/a, with a solar cell line of 35 MW/a. The rest of the wafers is shipped to Australia and India for cell manufacturing. The expansion of the wafer production to 60 MW/a capacity is under way and cell production will be expanded as well. As announced in 2001, BP-Solar will increase the production capacity of the Madrid (Tres Cantos) plant to 60 MW/a [49] by 2004 and in Homebush Bay to 35 MW [50] with no date set.

4.3.2 Shell Solar

Shell Solar was established to develop commercial opportunities in solar energy. In 2001, subject to economic review, Shell committed to invest 0.5 to 1 billion $ in solar photovoltaics (PV) and wind energy in the period from 2001 to 2006. Shell Solar recently joined the top tier players in the solar PV industry when it integrated its business with the acquisition of Siemens Solar, a long time market leader in solar cell production. The key objective for Shell Solar is to sell solar solutions at a profit and thus meeting the criteria of sustainable development in a commercial way. To achieve this, the solar business of Shell should grow in line with the market, currently growing at around 20% - 25% a year.

Shell Solar is now active across the whole field of solar photovoltaics, from wafer production to sales to end consumer. Shell has access to both mono- and multi-crystalline cell technologies and to CIS or thin film technology, the next generation of PV technology. Well-established in the manufacturing of two types of solar cells and modules, single-crystal silicon and copper indium diselinide (CIS), Shell Solar was the first company in the world to start series production of CIS solar modules. These thin-film modules boast an efficiency of over 11 percent, which is clearly higher than with competing thin-film technologies.

In 2002 Shell Solar had total sales of 57.5 MW (46.5 MW U.S. and 11 MW Europe). 2002 was also a year of restructuring the PV activities after the complete take-over of Siemens Solar. In October 2002 Shell Solar announced that the PV manufacturing operations will be consolidated in Camarillo (CA), Vancouver (WA) (both U.S.), Gelsenkirschen (Germany) and

Evora Portugal [51]. The Gelsenkirchen plant is scheduled to increase production capacity to 25 MW in 2003 [52]. The Shell Solar Headquarters are located in Amsterdam and Shell Solar has PV manufacturing facilities with a total yearly capacity of some 85 MW. The factory sites are in 3 countries namely:

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

4.3.3 AstroPower

AstroPower began as a division of Astrosystems Inc., founded in 1983 as an outgrowth of semiconductor work initiated at the University of Delaware. In 1989, the company was incorporated in Delaware. The company now employs over 700 people and is currently the biggest PV-only company worldwide. Sales in 2002 were 29.7 MW [1].

In spring 2002 AstroPower had just completed the new office and manufacturing building with the first fully building-integrated overhead PV system in the U.S. The new manufacturing lines will be APex™ solar cells featuring AstroPower's SiliconFilm™ technology and when fully operational should add another 60 MW production capacity to the existing 26 MW. The equipment necessary is already ordered and according to AstroPower the factory should be fully operational by the end of 2003.

AstroPower offers not only modules, but complete PV systems. One of their strategic partners is "Home Depot", the major retail chain for building products with 1300 stores all over the U.S.. Following a successful pilot programme in San Diego in September 2001, AstroPower and Home Depot plan to expand the programme to more than 70 stores in California, Long Island (NY), New Jersey and Delaware in 2002 [53]. In addition to this retail channel, AstroPower is working together with home building companies in order to realise future cost reduction of PV systems by integration of the system already in the planning phase. In some developments, all houses are already equipped with solar systems. Because the added costs are rather small and the costs are financed by a long-term interest moderate mortgage, customers prefer such developments due to the added value.

In order to secure the supply of feedstock silicon for their SiliconFilm™ technology Astropower has signed a Technical Co-operation Agreement with Elkem, the world's largest producer of silicon metal in December 2001. Together they have developed cost-effective

processes that convert quartz into feedstock for the SiliconFilm™ technology. Using this material they have reported first commercial-quality solar cells in June 2002 [54].

4.3.4 RWE-Schott Solar

RWE-Schott Solar (was ASE Americas) is a subsidiary of RWE-Schott Solar GmbH (formerly Angewandte Solarenergie - ASE GmbH). RWE-Schott Solar covers three product segments of solar power technology: Wafers, solar cells and modules for the terrestrial market, thin-film solar modules based on amorphous silicon as well as high-performance solar cells for aerospace applications. In 2001, the company generated net sales of € 96 million with over 550 employees.

ASE's origins date back to 1974 when Tyco Laboratories and Mobil Corporation joined forces to begin developing advanced silicon solar cells. Although Mobil Solar Energy Corporation began selling around the world in 1981, by 1986 a strategic decision was made to focus exclusively on the U.S. utility market. In 1994, Mobil Oil Corporation decided to leave the photovoltaic industry and in July of that same year, ASE GmbH of Germany acquired 100% of Mobil's technology and assets.

ASE Americas' technology is based on a patented method called Edge-Defined, Film-Fed Growth (EFG), a process used to pull crystalline silicon octogons with a diameter of 38,5 cm and 5 m in length from growth furnaces. So far ASE Americas is mainly a material producer with a newly increased capacity of 20 MWp ribbon wafers/year [55]. In 2002 it manufactured. 5 MWp. All the other material is shipped to Alzenau, Germany, for cell production. However, with the installation of ribbon pullers in Germany, the cell production capacities in Billerica will be expanded [56]. The equipment to process additional 10 MW was expected to be installed at the end of 2002.

4.3.5 United Solar Systems

United Solar Systems Corp. is a subsidiary of Energy Conversion Devices, Inc. (ECD). A new manufacturing facility located in Auburn Hills, MI with an annual capacity of 30MW was inaugurated on 24 June 2002 [57]. This plant is fully automated and allows simultaneous processing of six rolls of stainless steel, each 1 ½ miles long, during deposition of the a-Si layers. Sales in 2002 were 4 MW of the felxible a-Si triple junction solar cells.

4.3.6 Evergreen Solar

Evergreen Solar, founded in 1994, develops, manufactures and sells solar power products, primarily solar panels. The company serves three markets: wireless power, rural electrification and grid-connected applications. The company expects to exploit its proprietary and patented technology known as String Ribbon wafer production to produce distinctive products, to

reduce manufacturing costs through lower materials use and streamlined processes, and to manufacture internationally for global market penetration.

In June 2001, the Company received certification and shipped its new Cedar Line (TM) series of photovoltaic modules, which incorporate 3.2-inch-wide solar cells and have a 12% conversion efficiency. The production ramp-up at the Marlboro site continues. All major equipment for the first production line (5 MWp) has been received. The Company has implemented substantial automation in the new factory. The sales for 2002 were 1.9 MW.

The major technological change in 2003 is the introduction of double ribbon furnaces in the second fabrication line. According to Mark A. Farber, President and Chief Executive Officer of Evergreen Solar, Line 2 is producing solar cells with an average conversion efficiency of approximately 13% [58]. In the second quarter of 2003, Evergreen Solar ordered 100 double-ribbon String Ribbon furnaces, the first of which is expected to arrive during the fourth quarter, in order to accelerate the Line 2 expansion [59]. This expansion should then approximately quadruple the manufacturing capacity.

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

4.3.7 First Solar LLC.

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

In June 2003 First Solar announced they have broken ground on an expansion of their manufacturing facility in Perrysburg, Ohio [60]. The expansion will increase annual plant capacity of First Solar's thin film solar module production to 25 MW in 2005.

4.3.8 Sunpower Corporation.

SunPower Corporation was founded in 1988 by Richard Swanson (President) and Robert Lorenzini to commercialise proprietary high-efficiency silicon solar cell technology. The initial application was a high-efficiency photovoltaic cell for use in solar concentrators.

SunPower designs and manufactures high-performance silicon solar cells based on an interdigitated rear-contact design for commercial use. The initial products, introduced in 1992, were high-concentration solar cells with an efficiency of 26%. SunPower also manufactures a 22% efficient solar cell called Pegasus that is designed for non-concentrating applications. Pegasus is based on an adaptation of the concentrating cell technology for flat-plate applications, and is the highest-efficiency non-concentrating silicon solar cell commercially available.

In May 2002 Cypress Semiconductor Corporation announced that it has signed an agreement to invest in SunPower Corporation [61]. SunPower conducts its main R&D activity in Sunnyvale, California and maintains a pilot line for solar cells in Round Rock, Texas adjacent to Cypress's manufacturing facility. This line has a capacity of 2 MW per year and is an interim step to large-scale production. The factory with a production capacity of 25 MW is planned to be built in the Philippines, scheduled to start operation in 2004 [62]. Further expansion plans are already there: 150 MW in 2006. To complement the SunPower factory in the Philippines, Asahi Glass is building a state-of-the-art glass production facility for solar panels in the Philippines as well [63].

4.3.9 EPV

Energy Photovoltaics, Inc. (EPV) is a privately owned US company based in Princeton, New Jersey (one of the main shareholders is the utility company MVV Energie AG, Germany). EPV's core product is an integrated manufacturing system for the production of amorphous silicon (a-Si) thin-film photovoltaic modules (PV-IMS; 5 MW/year). The PV-IMS incorporates a license to utilise EPV's proprietary technology and know-how with all of the manufacturing equipment required to manufacture a-Si PV modules. EPV strategy is to provide the installation, commissioning, training, and warranty for the system as well. The customer provides the facility and supporting infrastructure to house and operate the PV-IMS, and a programme suitable for the local markets to sell the manufactured PV modules. Currently EPV's technology is commercially used by operating systems in Budapest, Hungary, and in the United States in Sacramento, California and Princeton, New Jersey.

The broad goals are to reduce module manufacturing cost and to increase module efficiency and output power. Three research topics are currently under investigation:

- Improvement of the existing tandem junction amorphous silicon (a-Si) modules from 38 Wp (5% efficiency) to 73 Wp in 2007 (10% stableised efficiency). The main problem is the degradation of the modules and like their Japanese competitors, EPV is working to improve the stabelised efficiency by introducing an a-Si/μ-Si tandem solar cell structure.
- Development of new photovoltaic materials such as microcrystalline silicon (μ-Si)
- Development of processing techniques to produce copper indium gallium diselenide (CIGS) modules that are potentially capable and have twice the efficiency of a-Si modules.

5. PV IN EUROPE

Due to the political structure in Europe with the different Member States and the European Union, there is no unified approach towards renewable energies yet. Despite this, the European Union has set targets within the White Paper *"Energy for the Future: Renewable sources of energy"* [64] and the Green Paper *"Towards a European strategy for the security of energy supply"* [65]. These targets are 12% of the total and 22% of the electrical energy in the European Union has to be generated from renewable energies (Fig. 12 and 13) in order to meet the obligations towards the CO_2-reduction pledged in the Kyoto Protocol and to lower the dependence on energy imports.

For this purpose, targets were set in the European Renewable Grid Directive [66] for the Member States, but the European Commission left it to the Member States how to reach these targets by 2006. The main aspects of this Directive are: Indicative targets were set for the Member States (Figures 12 and 13), but the Member states have the freedom until 2005 to choose the kind of measures and incentives they want to use to reach the targets.

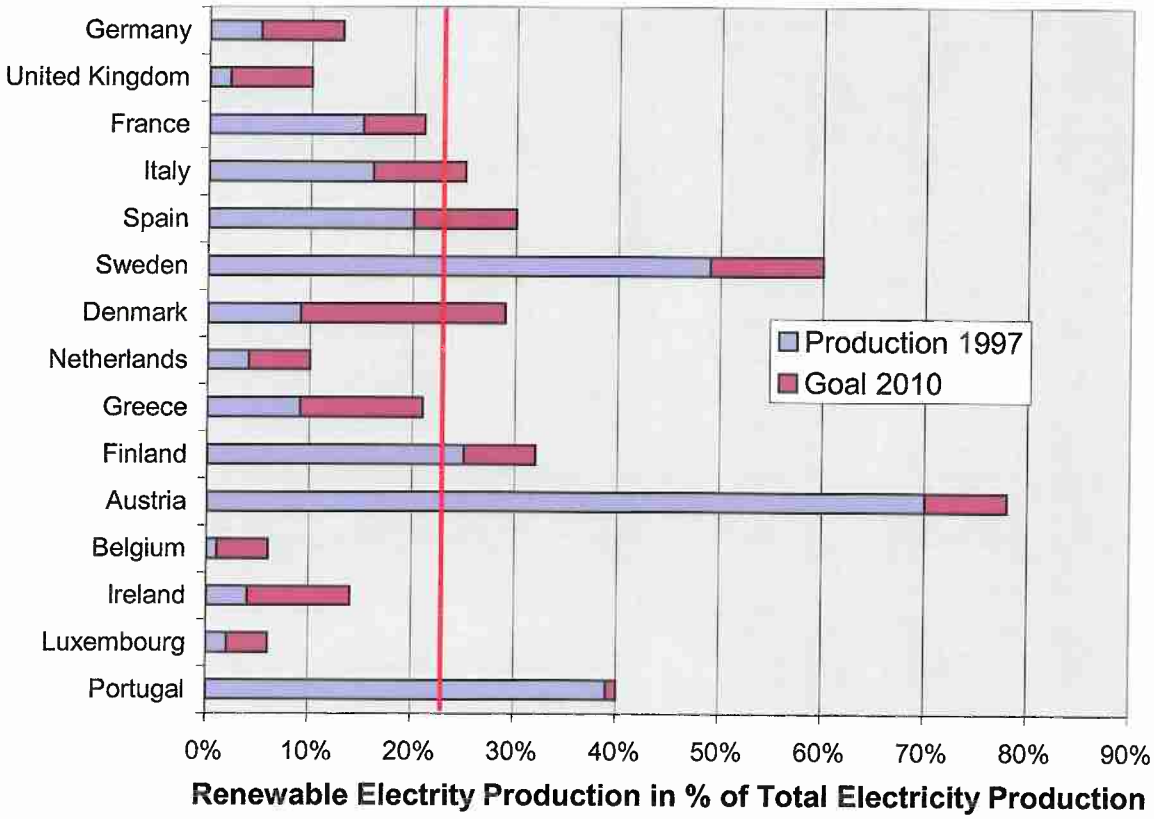

Fig. 12: Share of renewable energies of total European Union electricity production.

The Member States are obliged to report about the progress of implementation and the success of the methods chosen every two years. On 27 October 2005, the Commission has to

present a report on the experience gained with the application and coexistence of the different mechanisms. If necessary, the report should be accompanied by a proposal for a Community framework with regard to support schemes for electricity produced from renewable energy sources to ensure that the targets for 2010 are met. The Directive also regulates the grid access and obliges the Member States to ensure a non discriminating treatment of electricity generated by renewable energies.

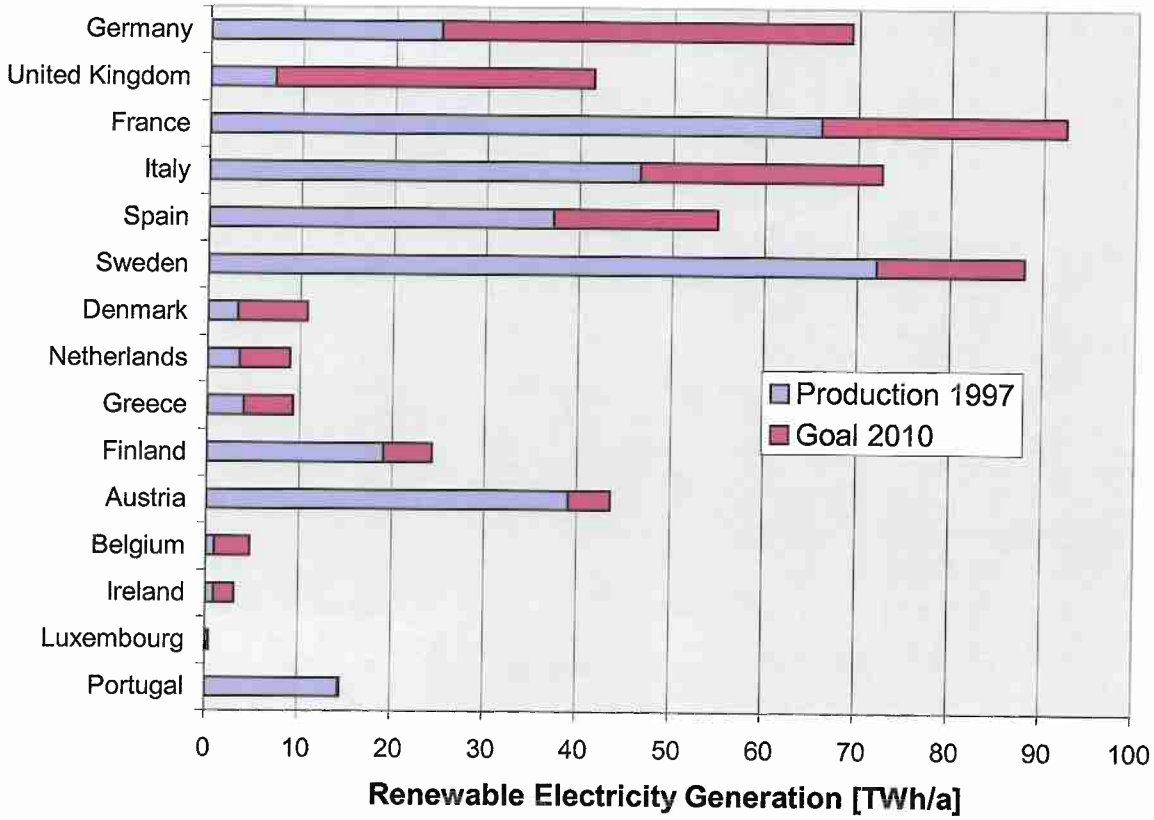

Fig. 13: Electricity generation from renewable energies in the European Union

If necessary, a common directive for the promotion of renewable energies will then be introduced after 2006. The target for the cumulative photovoltaic systems capacity installed in the European Union by 2010, is 3 000 MW or a 100-fold increase of the 1995 capacity. The electricity generation from these PV systems could then be in the order of 2.4 to 3.5 TWh depending under which climatic conditions the systems are installed.

5.1 Situation of Incentives for Photovoltaics in Europe

Similar to the U.S., the market conditions for photovoltaics differ quite a lot from country to country. This is due to the different public support programmes for renewable energies and especially photovoltaics, as well as the different grade of liberalisation of the electricity markets. After the end of the "1,000-roof programme" in Germany at the end of the 90s, one could observe a shift in the investment activities of the big European PV-companies from Europe towards the U.S. The reasons for this were on the one hand the more favourable economic frame conditions, like lower labour costs, but as well the competitive technological edge in the U.S. New production capacities in Europe were created only on a small scale by innovative start-up companies. One reason for this development was the missing market for PV systems in Europe. After the start of the large scale market implementation programmes in Japan in 1997 and the dramatic increase of production capacities, there the European market picked up momentum and the big companies started to increase their production capacities as well. Due to the "100,000 roof programme" and the new Feed-In-Law in Germany, which started 1999, Germany has become the second biggest single market for photovoltaics.

The different Member States of the European Union use different market incentives to support the introduction of renewable energies and in particular photovoltaics. The following list names some of these incentives. However, this list is far from complete due to the large number of programmes and some problems to retrieve the information, especially on local levels.

- **Austria:**
  – investment subsidies (different in the different Federal States)
  –feed-in tariff (but only for 2003 and 2004)
  – RES target quotas

Austria has no national programme to promote the implementation of renewable energies, but several regulations, which define the framework of RES promotion. In 2001 the Energy Law, ElWOG 2, went into force and was implemented via decrees in each of the nine Federal States. The regional governments had to determine the different types of promotion strategies and incentives that are used. These circumstances led to a very diverse situation with very ambitious incentives in some regions, and made it difficult for investors and planners to keep an overview of all the regulations. The feed-in tariffs, for example, varied between 0.10 and 0.74 €/kWh, depending on the region, on the system size as well as on seasonal and day/night aspects. At the end of 2002 9 MWp of PV were installed in Austria.

In order to harmonise this situation the "Ökostromgesetz" (a special new law, for Green Electricity) was adopted in 2002 by the Federal Government regulating issues concerning the electricity supply from RES on the national level. The new regulation, which became effective at the beginning of 2003, shifted the competencies from the regional governments to the

Federal Government and defined preferential feed-in tariffs for RES that have to be paid by the distribution network operators.

PV has a nation-wide tariff of 0,60 €/kWh for installations up to 20 kWp and 0,41 €/kWh for larger systems. The extra costs for the network operators will be compensated by an additional supplement on the customer invoices.

However, a limit of 15 MWp total installed capacity is stated in the law, up to which the high tariffs will be paid. This ceiling was already reached already in the first months of 2000 and makes the feed-in tariff system almost ineffective and threatens the further deployment of PV by generating uncertainty among investors and installers of PV systems.

- **Denmark:**
  – Renewable Energy Portfolio
  – Solar roof Projects
  – net metering

The SOL-1000 projects (launched 2001) intend to demonstrate highly visible and architectural acceptable integration of PV technology on existing single-family houses. The owner of a PV system installed under this programme receives a subsidy of about 35% of the turn-key costs. Net metering for privately owned PV-systems was introduced mid 1998 and at that time for a pilot-period of four years. Work is ongoing to make this system more permanent.

- **Finland:**
  – investment subsidies for demonstration projects
  – "Green electricity"

Until the end of 2001, investment subsidies (up to 30%) were available only to communities, organisations and enterprises. In 2002 the subsidy level rose up to 40% and subsidies for PV systems were made available to private persons.

In autumn 2002 a new project called Solar ESCO started. In the first phase, an ESCO concept will be worked out, suitable for the Finnish market conditions. Later, the project will seek possible investors and companies to start ESCO activities in the solar markets. The aim is to realise at least 30 kW PV capacity, based on the ESCO concept.

- **France:**
  – Tax Exemption Law in the Overseas Departments
  – investment subsidies for isolated sites
  – feed-in tariff

The main sources of public financing for the installation of photovoltaic systems, are primarily the FACÉ fund and the Tax Exemption Law in the Overseas Departments. In addition, there are complementary supports provided by the regional authorities, the Agence de l'Environnement et de la Maîtrise de l'Énergie (ADEME), the European Commission and

Electricité de France (EdF). The subsidies are for isolated sites in "urban scheme" which includes a subsidy lower or equal to 40 % of the cost of the system installed. The subsidy granted by the FACÉ fund is equal to 70 % of the cost of the PV system installed.

ADEME prepared an aid system aiming at the dissemination of grid-connected photovoltaic systems. This system began to operate in 2002 and photovoltaic systems are subject to two types of support granted by ADEME:

- Support of selected projects within the framework of European tenders up to 4.6 €/Wp (basic grid-connected PV system) and 6.1 €/Wp (grid-connected with safety storage).
- Subsidy, in the absence of European Commission funding on tenders, equal to 4.6 €/Wp, which could be increased to 6.1 €/Wp in the case of a grid-connected PV system with safety storage.

The figures given include all public subsidies. In mainland France, these aid rates will decrease as of 1 January 2005, at 3.8 €/Wp (basic grid-connected) and 4.9 €/Wp in the case of grid-connected PV systems with safety storage. A power ceiling will be applied of 5 kW for individuals and 30 kW in the community/tertiary sector.

The Ministre de l'Industrie et du Commerce finally published a 0.15 €/kWh PV feed-in tariff on 13 March 2002. The scheme will cover residential systems up to 5 kW, non-building systems (such as noise barriers) up to 150 kW, and commercial and public buildings up to 1 MW and is guaranteed for 20 years. The tariff has a double value of 0.30 € for installations in Corsica and in the Overseas Departments. However ADEME has only budgeted 1 MW for each of the programme's three years. In addition to the mainland target, rebates for Overseas Departments are available for 1 MW in the first year, 2 MW in the second and 3 MW in the third.

- **Germany:**
  – 100 000 – Roof Programme (interest reduced loan; ended 30. June 2003)
  – Renewable Energy Sources Act (feed-in tariff)
  – New Renewable Energy Sources under negotiation (September 2003)
  – investment subsidy of various Federal States

A decisive change came with the introduction of the German Renewable Energy Sources Act "Erneuerbare Energien Gesetzes (EEG)" in 2000 [67]. This Act guarantees a cost-covering feed in tariff for 20 years of currently 45.6 ct./kWh (2003) for PV generated electricity. Every year this guaranteed feed-in tariff is reduced by 5% for new PV systems in order to put pressure on the reduction of the price for PV systems. In addition, the Kreditanstalt für Wiederaufbau (KfW), a public bank, gave loans with reduced interest rates to buyers of PV systems under the so-called 100 000-roof programme, which ended on 30 June 2003. With these mechanisms a market for PV systems was generated. Thanks to the EEG Act, PV systems with a total of 199 MWp were installed in Germany between 1999 and 2002.

This is equivalent to approximately 20% of the world market and makes Germany the biggest net importer of solar cells and modules, due to its not yet existing own production capacities. The new production facilities of RWE-Schott Solar, Q-Cells AG and Deutsche Cell GmbH will ease this situation. Between January and 31 August 2003 the KfW has granted loans for 115 MWp under this programme [68].

The Renewable Energy Sources Act is currently under revision and the Federal Ministry for Environment (BMU) has already circulated the draft of the new Act to the other Ministries for comments. The current draft guarantees a basic feed-in tariff of 43.4 ct./kWh for PV systems (this is the 2003 value minus 5%). In addition, PV systems installed on buildings (roofs, facades) will receive an additional payment of 15.6 ct./kWh for PV systems up to 30 kWp and 11.6 ct./kWh for PV systems above. These additional payments are designed to compensate for the discontinuation of the 100,000 roof programmes.

- **Italy:**
  – feed-in tariff
  – 10 000 – Roof Programme (different investment subsidies in the different Regions)

The 10 000 rooftop programme is devoted to the realisation of grid-connected photovoltaic systems, ranging from 1 kWp to 20 kWp and preferably integrated in building structures. The purpose is to promote a wide diffusion of building integrated photovoltaic applications all over Italy and to create a sure and lasting market, in order to allow companies long-term investment planning. In addition, some long-term benefits are expected concerning a decrease of photovoltaic costs, the creation of job opportunities and the local development in unfavoured regions. There are two Sub-programmes:

- The National Programme, funded by about 10.3 mill. €, is managed by the Ministry for Environment (MATT), and was addressed only to Public Bodies, such as Local Authorities, Universities and Research Institutions. In the period July – October 2001, 587 applications submitted to the MATT have been evaluated and 460 out of them were admitted for funding. However, the requests summed up to about 5.5 MW, more than three times the offer in terms of both power and public contribution requested. As a consequence, only 146 installations have been financed with the resources available (10.3 mill. €) with a capacity of 1.8 MW. During the year 2002, 135 systems have been already installed, corresponding to an installed power of 1.7 MW. Additional funds amounting to about 20 mill. € were made available in March 2003 by the MATT and Regions to finance (50:50) the other 314 applications already positively evaluated (for total power of about 3.6 MW).

- The Regional Programmes, addressed also to citizens and private companies, are composed of 21 local Programmes. In 2001 the nineteen Italian Regions and the two Autonomous Provinces of Trento and Bolzano have agreed to jointly fund the initiative.

  At the end of March 2002, the Italian Regions (Sicily Region December 2002) issued their own announcements. The response was overwhelming and about 6,680 applications were received. This was well beyond the objective to realise a total capacity around 5.5 MW, corresponding to about 2,000 projects.

In general, contributions of up to 75% of the eligible investment cost can be provided by both Sub-programmes. The maximum investment cost has been fixed at about 8 €/Wp, for photovoltaic plants ranging from 1 to 5 kWp. In the range from 5 to 20 kWp, the maximum investment cost is decreasing to 7 €/Wp.

In total, MATT and the Regions incentives should activate with both Programmes an investment amount of approximately 175 mill. € and lead to an installation of a total capacity around 23 MWp. 2 MWp of them have actually been installed in 2002.

- **The Netherlands:**
  – Renewable Energy Portfolio
  – investment subsidies
  – green tariffs
  – tax incentives for companies

Since 1 January 2001, PV together with Solar Domestic Hot Water (SDHW)-systems and heat-pump boilers, are on the Energy Premium Regulation (EPR) products list. This EPR is meant for house-owners (including housing corporations) who invest in improving their houses energy-wise. The amount of subsidy for PV in 2002 is 3,50 €/Wp, which can be obtained by filling in a simple form with a copy of the receipt. The subsidy can even be increased by 25% when an EPA, an Energy Performance Assessment, of the house is done.

Utilities like NUON and Eneco Energie have published subsidies of around 1 €/Wp in their service area, due to the importance of the positive image of solar energy in the liberalised green energy market.

- **Portugal**
  – feed-in tariff (Decree-Law 2001)
  – grants for investments

A new (revised) legislation promoting renewable electricity was introduced in the framework of the 2001 E4 Programme. The tariff rates are now differentiated by technology, allowing not only for increasing penetration of consolidated technologies (wind, mini-hydro), but also for developing projects relying on emerging technologies with high potential in the medium run (e.g. biomass, wave and photovoltaics). In particular, the new buy-back rates for

PV are 0.29 €/kWh (> 5 kWp) and 0.51 €/kWp (< 5 kWp), which are considerably higher than the former tariff (0.06 €/kWh).

In addition, a new legal figure has been created for the interconnection of PV micro-generators to the low voltage public grid: producer-consumer, allowing single persons to qualify as independent power producers, but obliging self-consumption up to 50 % of the total produced energy. The tariff rate was maintained at about 0,29 €/kWh.

Financial incentives for renewables and energy efficiency applications are available under the POE programme (2000-2006) – III EC Framework Programme. The last amendments were made on 10 April 2002 making this measure consistent with the objectives of the E4 Programme. Besides grid-connection projects, grants are now also provided to autonomous photovoltaic applications: up to 40% of the total eligible costs (maximum eligible limit: 3,000 €/kW), with a maximum of 1 500 k€ per application. The non-reimbursable part accounts for 50 % of the total subsidy, reaching 100 % when the promoter is a public entity. The total indicative budget for renewable energies and co-generation projects is 350 mill. € for the whole period.

- **Spain:**
  – investment subsidies (several Spanish Autonomous Regions)
  – feed-in tariff (Royal Decree 2818/1998)

Several Spanish Autonomous Regions have developed programmes to support renewable energies. PV installations, both off-grid and grid connected, are subsidised with about 30-35% of the total installation cost.

The Royal Decree 2818/1998 provides an advantageous feed-in tariff for every kWh produced by photovoltaic systems connected to grid. Producers have the right to opt either for a fixed price or "market price" + "premium". According to Article 32 of the Royal Decree 2818/1998, "every four years the premiums set in this Royal Decree shall be revised by taking into account the evolution of the price of electric power on the market, the participation of these facilities in the coverage of demand and their impact on the technical management of the system". The setback of this regulation is, that compared to the German system the revision is not only valid for new systems, but for existing systems as well. This sort of measures, together with a major knowledge and acceptance of photovoltaic energy on the part of the public, have contributed to the constant growth of photovoltaic sector in recent years.

Table 4:RES-E Tariffs for 2003 (in €ct/kWh) [69]

	Fixed Price	Premium
PV < 5 kWp	39.6	36
PV > 5 kWp	21.6	18

- **Switzerland:**
  – feed-in tariff (different from Canton to Canton)
  – green tariffs (different from utility to utility)
  – investment subsidies (different from Canton to Canton)

The market implementation of PV systems is driven by the campaign for "Solar electricity from the utility." At the end of 2001, more than 130 utilities (1996: 7) offered solar electricity to their customers. Different financial models are being used according to the preferences of the utilities. Meanwhile, more than 50% of the Swiss population have access to solar electricity and more than 30 000 customers annually use about 4 GWh of renewable energy.

The introduction of the labels "naturemade basic®" and "naturemade star®" for green power products (www.naturemade.ch), promotes green power produced by different technologies. The "nature made star®" label, promises that 2.5% of the total energy delivered is from new renewable energies (photovoltaics, wind, biomass). Using these labels, green electricity is now also promoted as part of the Swiss Energy programme.

- **United Kingdom:**
  – investment subsidies (so far only demonstration projects)
  – investment grants
  – reduced VAT for professional installations of PV systems (5%)

The Major PV Demonstration Programme was launched in the first quarter of 2002. This is the first phase of a potential 10 year programme. GBP 20 million funding has been allocated for the first phase (3 years). The programme provides capital grants for the installation of domestic and non-domestic PV systems in the public and private sectors.

A number of electricity utilities now offer to pay for exported electricity from a PV system. These include:

- **TXU-Europe** (Eastern Energy) under an agreement with Greenpeace is continuing to offer net-metering of residential PV systems under the 'Solarnet' scheme.
- **London Electricity (LE)/Seeboard** offer to pay 0,075 GBP/kWh for feed-in electricity for installations up to3 kWp. Payment for feed-in will be made once a year. However the customer must install an extra metre and must sign up to LE's green tariff.
- **npower/Innogy** are paying customers in the South West, South East, London and the South 120 GBP/year and 0.01 GBP/kWh to take part in a trial. Extra metres will be fitted free, and customers must take metre readings every month. In addition npower, has agreed to provide net-metering for the 102 kW PV roof installation on the new English Institute of Sport in Birmingham.
- **Powergen** (who now own TXU Energi), **Scottish & Southern and Southern Electric** all also offer some form of net-metering.

5.2 PV Research in Europe

In addition to the national programmes for market implementation, research and development, the European Union has been funding research (DG RTD) and demonstration projects (DG TREN) with the Research Framework Programmes since 1980. Compared to the combined national budgets the EU budget is rather small, but it plays an important role in creating a European Photovoltaic Research Area. This is of particular interest and importance, as the European PV industry is much more fragmented than their competitors in the U.S. and Japan (Fig. 14).

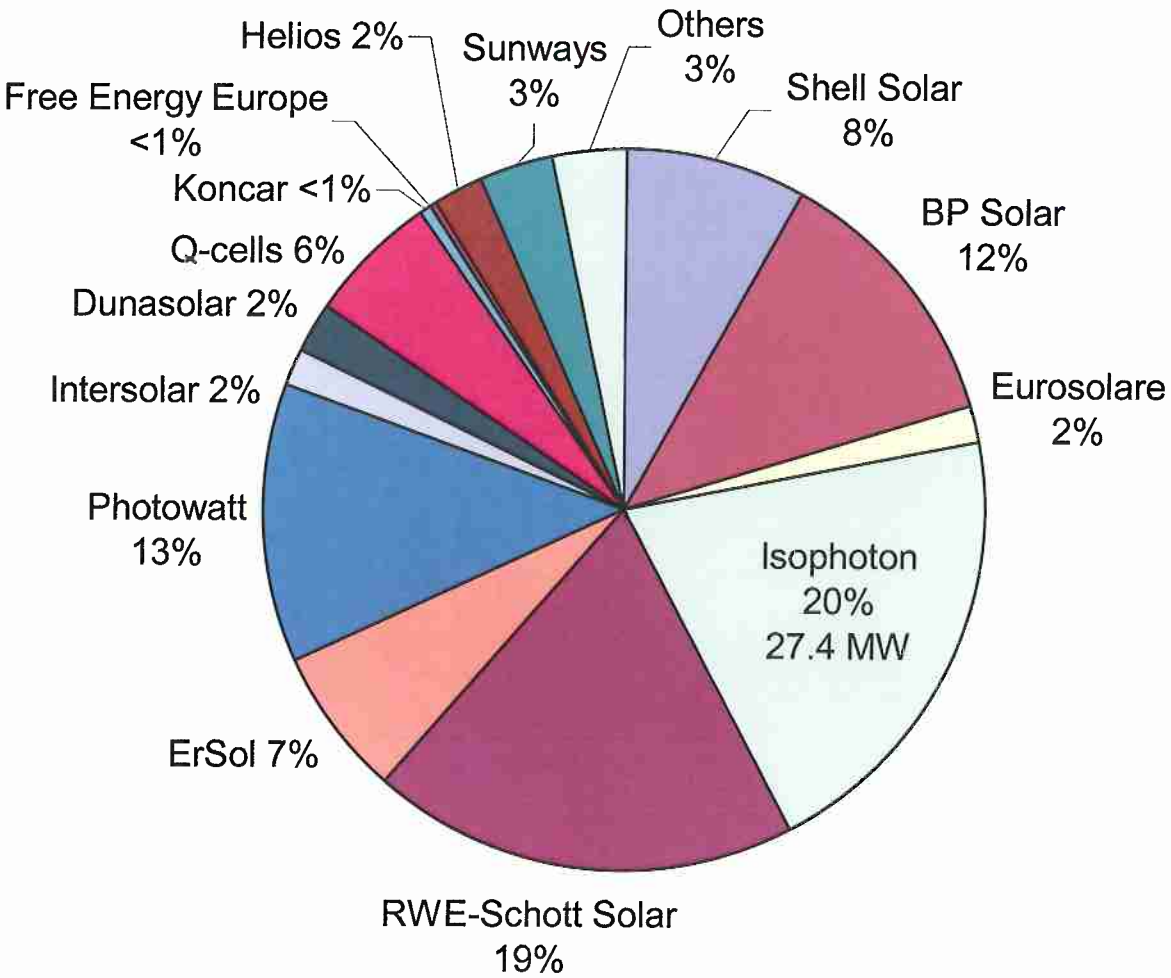

Fig. 14: Market shares of the European PV companies (2002: 135 MW, this corresponds to 24% of the world-wide sales) [1]

The European Commission's R&D activities are organised in Framework Programmes (FP), with a duration of 4 years. In FP5 (1998 to 2002) around 120 mill. € were spent for research (66 mill. €) and demonstration (54 mill. €). The project description of the EC funded projects can be found at the CORDIS web site (http://www.cordis.lu/guidance/services.htm).

For the current Framework Programme (2002 to 2006) 810 mill. € are foreseen for the topic "Sustainable energy systems" split into two equal parts for "short to medium" and "medium to long" term research, which includes PV. However, no specific budget was earmarked, especially for PV. The first call was launched in December 2002 and the successful projects are currently in the contract negotiation phase.

Besides the conventional silicon solar cell technology, a number of activities towards the commercialisation of thin film solar cells are under way in Europe. After Japanese companies having taken the lead in the field of amorphous solar cells, European researchers are trying to narrow the gap through new innovative developments. A field of particular interest is the combination of amorphous and nano/microcrystalline silicon to form a a-Si/ μ-Si tandem solar cell. This concept promises higher and more stable conversion efficiency. During a European workshop on "Cross-Fertilisation between the Photovoltaic Industry & other Technologies" at the Joint Research Centre in Ispra, an interesting and promising new production technology for this type of solar cell was presented by UNAXIS. The technology is based on the classical production technology for flat panel displays and was adopted for solar cell production [70]. There is hope that such new production technologies will contribute to a big increase in production capacities in Europe in the near future. An important step in this direction was the fact that UNAXIS established UNAXIS-Solar on 1 July 2003 [71].

Similar evolutions can be observed in the area of compound semiconductor solar cells (CdTe, $Cu(In,Ga)(S,Se)_2$). Despite the fact that two of them have their production in the U.S., all four companies, which are, even with small quantities, in the market are European companies. These companies are followed by about 15 additional start-up activities world-wide with the majority in Europe. Quite a number of these activities was or is supported by the European Commission, albeit it is not yet possible to support the development and installation of pilot plants on a European level.

The continuous expansion of the production capacities for solar cells is of particular importance in light of the export markets for solar systems to the rural areas in Asia, Africa and South America, where more than 2 billion people are still without electricity. The Europeans should not lose this future market, also with respect to the possibility it offers for the labour market. In October 2001 the European Photovoltaic Industry Association (EPIA) and Greenpeace presented a joint study, which estimates that the solar electricity industry in the European Union will create approximately 290 000 new jobs by the year 2020 [72]. To reach this goal it is estimated that solar electricity capacities of 54 GW will have to be installed in the European Union by 2020, which is very ambiguous. Under the more conservative estimate that the European Union will reach the White Paper goal of 3 GW in 2010 and that the installation of PV systems growth will be 17% the years after, 15 GW installed capacity would be reached in 2020. Even this would mean 20 000 new jobs by 2010 and 50 000 by 2020.

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

5.3 Solar cell manufacturers

In the following, most of the solar cell manufacturers in Europe are described briefly. This listing does not claim to be complete, especially due to the fact that information or data for some companies is very fragmented. A lot of the data were collected from the companies' web-sites. Despite the fact that BP Solar and Shell Solar are European companies, they were already listed in Chapter 4.3 because their biggest operations are still in the U.S..

5.3.1 Isofotón

Isofotón, a private owned company, was set up in Malaga to produce silicon solar cells by Professor D. Antonio Luque from the Universidad Politécnica de Madrid. In 1985, Isofotón expanded their activities in the solar sector and started to fabricate solar collectors as well. With growth rates above average, Isofoton has become the largest manufacturer of solar cells in Europe (27.4 MW in 2002). About 80% of the production is exported, with Germany as the biggest market. The production capacity in 2002 was 36 MW and it is planned to expand it to 70 MW by 2004.

To be present in a developing market in South Africa, Isofotón Southern Africa, an 80% subsidiary, started its operation in December 2002. To strengthen its market position in Germany a 20 MW module factory is also planned.

Besides silicon solar cells and modules, Isofotón is very active to develop 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.

5.3.2 RWE-Schott Solar

RWE-Schott Solar GmbH, Alzenau (Germany), is a subsidiary of RWE Solutions AG, Frankfurt am Main. It has four divisions: RWE headquarters in Alzenau. The Space Solar Cells Division in Heilbronn, the Phototronics Division in Putzbrunn and Billerica (see Chapter 4.3). In 2002, RWE Solar had sales of 29.5 MW with ASE Americas accounting for 5 MW.

Solar cell development started at the Space Solar Cells Division as long ago as 1964, initially for space and then also for terrestrial applications. In 1994 the company was

integrated into ASE via Daimler-Benz Aerospace. This merged many years of experience in the development for high power and space solar cells by the previous companies, Telefunken and AEG.

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.

The photovoltaic activities in Alzenau started in 1979 with NUKEM initially developing thin-film technologies. In 1986 they developed crystalline silicon solar cells and cast-resin large-format modules and started a pilot production. 2002 RWE-Schott Solar GmbH opened the fully automated production lines for solar cells with a capacity of 20 MW using their world-wide patented EFG silicon. In addition to the fabrication of solar cells, the plant will also produce EFG wafers. When running at full capacity in the year 2004, the fabrication plant is planned to produce 60 MW solar cells annually.

5.3.3 Photowatt

Photowatt was set up in 1979 and relocated to Bourgoin-Jallieu in 1991, where the company converts silicon waste into the raw material used for the manufacturing of solar energy cells. At the beginning of 1997, Matrix Solar Technologies, a subsidiary of the Canadian company ATS (Automation Tooling Systems), acquired Photowatt International and started to expand the production capacities. Matrix Solar Technologies used its marketing and management expertise, with the twin objectives of assisting the growth and reinforcing the position of Photowatt International in the world market, by facilitating its presence in new countries. This is particularly true in the Cape, in South Africa, where Photowatt is involved in a joint-venture technology transfer, installing and starting up an assembly unit. Other countries are presently being studied for such operations. In 2002 Photowatt had sales of 17 MW.

5.3.4 ErSol

ErSol Solar Energy AG was founded in 1997 and is a producer of polycrystalline solar cells and modules. The total production capacity in Erfurt, Germany are 10 MW with sales of 9 MW in 2002. In 2001 ErSol started its module production, where a part of the own solar cell production is processed. ErSol plans to expand its production capacity to 25 MW by the end of 2003 [73].

5.3.5 Eurosolare

Eurosolare S.p.A. is a subsidiary of Eni SpA. The company has been in the photovoltaic business since the early '80s and is the only Italian industry to operate with a vertically

integrated cycle, from raw material to systems. Eurosolare produces standard mono and multi-crystalline PV modules with sales of 2.2 MW in 2002.

5.3.6 Q-Cells AG

Q-Cells AG was founded at the end of 1999 and is based in Thalheim, Sachsen-Anhalt, Germany. Solar cell production started mid 2001 with a 12 MWp production line and the production capacity was increased to 24 MWp in mid 2002. The second line started operation in summer 2003, giving a total capacity of 48 MWp. Thereafter a further 24 MWp investment is planned for 2004, taking the overall capacity to 72 MWp. Sales in 2002 were 9 MW.

5.3.7 Sunways AG

Sunways AG was incorporated in 1993 in Konstanz, Germany and transformed into a stock corporation under German law (Aktiengesellschaft) in 1999. Sunways produces polycrystalline solar cells, transparent solar cells and inverters for PV systems. Sales in 2002 were 5 MW.

5.3.8 Würth Solar GmbH

Würth Solar GmbH & Co. KG is located at Marbach a. N., Germany. The company is a joint venture between Würth Electronic GmbH & Co KG, Energy Baden-Württemberg (EnBw) and the Centre for Solar and Hydrogen Research (ZSW). Würth Solar develops CIS modules with a standard size of 60 × 120 cm^2 and produced about 150 kW in 2002 on a pilot line.

5.4 Wafer producers and new companies

5.4.1 PV Silicon AG

PV Silicon is a privately held company specialised exclusively in the production of silicon for solar cells. PV Silicon is located in Erfurt, Germany and is one of the leading manufacturers of silicon wafers. Since 2000 PV Silicon co-operates with Crystalox in the production of polycrystalline silicon [74]. The product range includes: solar grade silicon; single crystal ingots, single crystal wafers and multicrystalline wafers. In 2002 PV Silicon produced 90 MWp of silicon wafers [73].

5.4.2 Solarworld AG

Since its founding in 1998 Solarworld, Germany has changed from a solar system and components dealer to a company covering the whole PV value chain from wafer production to system installations. Solarworld's corporate group consists of: Solar World AG, Bonn (marketing, development and plant engineering and construction), Joint Solar Silicon GmbH

& Co. KG, Freiberg in co-operation with DEGUSSA AG (development of raw silicon), Deutsche Solar AG, Freiberg (silicon wafer production and recycling of used PV products), Deutsche Cell GmbH, Freiberg (solar cell production), Gällivare PhotoVoltaic, Sweden (solar module production) and Solar Factotry GmbH, Freiberg (solar module production). The production in 2002 was 67 MWp wafer (production capacity at the end of 2002 100 MWp) and 1 MWp solar cells (production capacity at the end of 2002 25 MWp) [73].

5.4.3 Photovoltech

Photovoltech is a new company 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.

5.4.4 UNAXIS Solar

The co-operation of the Institute of Microtechnology (IMT), University of Neuchâtel (Switzerland) and UNIAXIS led to the establishment of UNAXIS Solar. The new company started operation on 1 July 2003 and the aim is to develop the production technology for large scale production of PV modules, based on the micromorph solar cell concept developed at IMT and Unaxis's KAI production systems. The milestones planned are quite ambitious:

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

6. OUTLOOK

Four of the 10 biggest solar cell manufacturers are from Japan, with the No 1 and 3 for 2002 (Sharp and Kyocera). Mitsubishi Electric has advanced to the top 10 companies with 14 MW sales in 2001 and its sister company, Mitsubishi Heavy, started its production line of amorphous silicon solar cells in autumn 2002 with an initial capacity of 10 MW. After the impressive increase of 60% in 2000 and 46% in 2001, the Japanese companies could increase their sales in 2002 by further a 40%. Despite the fact that the European companies similarly increased their output, one has to bear in mind that they started from a lower level. The U.S. companies, however, lost market shares due to lower growth rates in production capacities. 2002 Europe advanced to the 2nd place.

The continuous and consistent support for photovoltaics in Japan has made it possible that the ambitious goal of 1994 to install 200 MWp of PV systems in 2000 was reached with only one year delay in 2001. The long-term strategy until 2010 is another reason why the Japanese photovoltaic industry has advanced within only 10 years, to take the market lead. Despite the difficult economic situation, a further increase in production capacities for solar cells can be expected in Japan. The reason for this is the fact that METI and the Japanese industry sees PV manufacturing as a "key industry" at the beginning of the 21st century. This shift in the evaluation of future perspectives of the PV industry has resulted in the fact that traditional heavy industry companies like Mitsubishi Heavy have started a solar cell business. There are reports about solar cell research activities of other companies as well, e.g. Honda [75] or Sumitomo Electric Industries [76], but so far, no concrete business models have been released.

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. In the last five years the PV market has now grown by 30% annually and reached a volume of 560 MW or 3.5 bill $ in 2002. Despite the current economic slow down, the future for PV in Japan, Europe and the U.S. seems still to be bright. According to information given by METI in May 2003 the Japanese home construction market recovered quite substantial compared with 2001, which is an important distribution channel for new PV systems. This assessment of the market seems to be backed by the latest figures for new PV installations in Japan. From April to 22 August 2003, more than 24,122 new applications for PV systems were received by NEF [23]. The prediction for FY 2003 is that the number of applications can reach 60,000 (approx. 210 MW) in 2003, if the trend continues.

Also in Germany, it seems that the PV market recovered from its weakness at the beginning of last year. At the end of August the KfW approved interest-reduced loans for new PV systems with a total volume of 114.5 MWp [78]. This is already 146% of last year's new installed solar electrical capacity in Germany. This development, as well as the fact that a new

feed-in Act is already under negotiation in the Parliament indicates a good chance for continuous future demand for PV systems [78].

The rising number of market implementation programmes in other European Countries, e.g. Italy (10 000 roof programme), United Kingdom (Major Photovoltaic Demonstration Project), as well as the different regional incentive programmes in the U.S., contribute to keeping the demand for solar systems high. In the long-term, the growth rates for photovoltaics will continue to be high, even if the economic frame conditions can lead to a short-term slow down of the growth rates. In the run up to the UN Johannesburg Summit for Sustainable Development in August 2002, the then-president of BP Solar, Mr. Harry Shimp, declared in an interview with Reuters: "Ultimately the world has to move toward renewable power. In 20-25 years the reserves of liquid hydrocarbons are beginning to go down so we have this window of time to convert over to renewables." [79]. These remarks are in line with the energy scenario of the oil company Royal Dutch/Shell, which predicts high growth rates for renewable energies in the coming decades [80].

Figure 15 shows the world-wide potential of renewable energies, mainly geothermal and solar, which is sufficient to supply a world population of 10 billion people with approx. 300 GJ of energy per capita. Solely Europe and Asia, whose potential is only 100 GJ/capita, would be required to import energy.

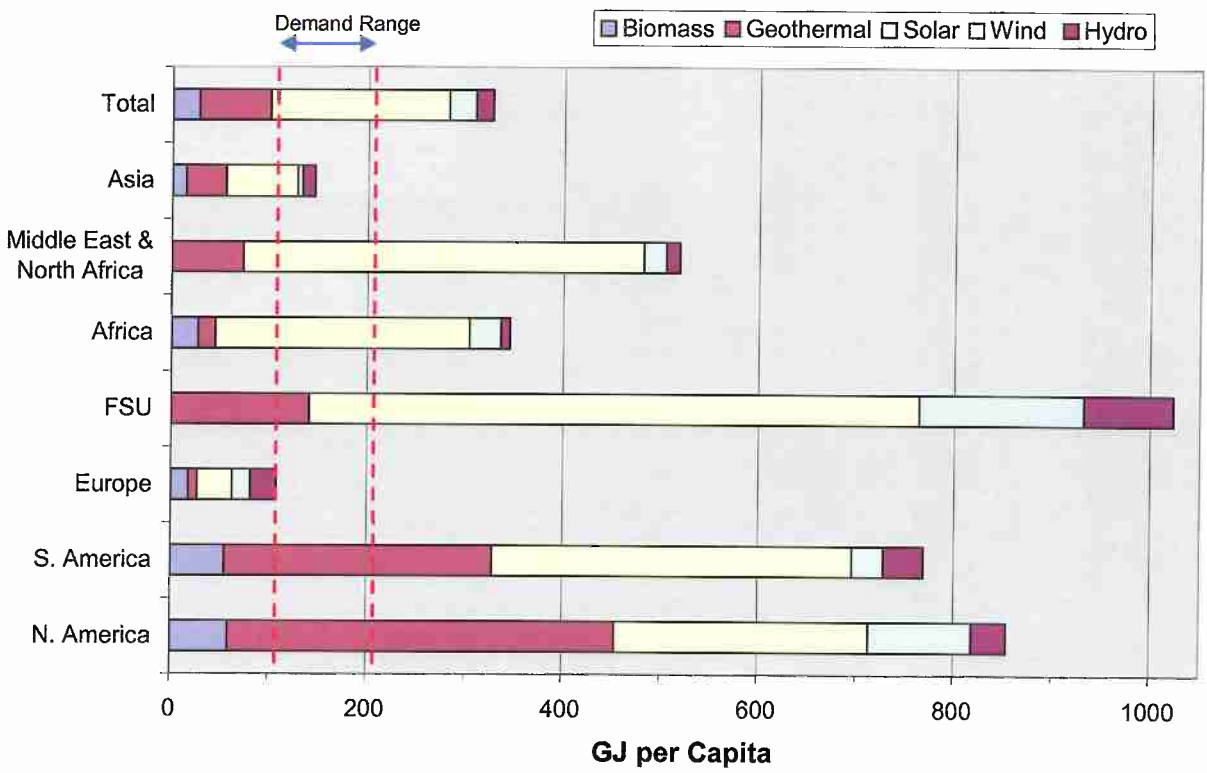

Fig 15: Potential of usable renewable energies calculated for a world population of 10 billion people [80]

Despite the fact that at the Johannesburg Summit no agreement could be made on the binding target of 15% renewable energies by 2010, the resolution passed is an important step forward. The Summit made a commitment to: "Increase access to modern energy services, increase energy efficiency and to increase the use of renewable energy." and "To phase out, where appropriate, energy subsidies" [81]. At the same time, the European Union announced a $700 million partnership initiative on (renewable) energy and the United States announced that it would invest up to $43 million in 2003.

According to bank analysts and prognoses by industry, solar energy will continue to grow at high growth rates in the coming years. Figure 16 and Table 4 show the different projections of the Japanese, U.S. and EPIA roadmaps.

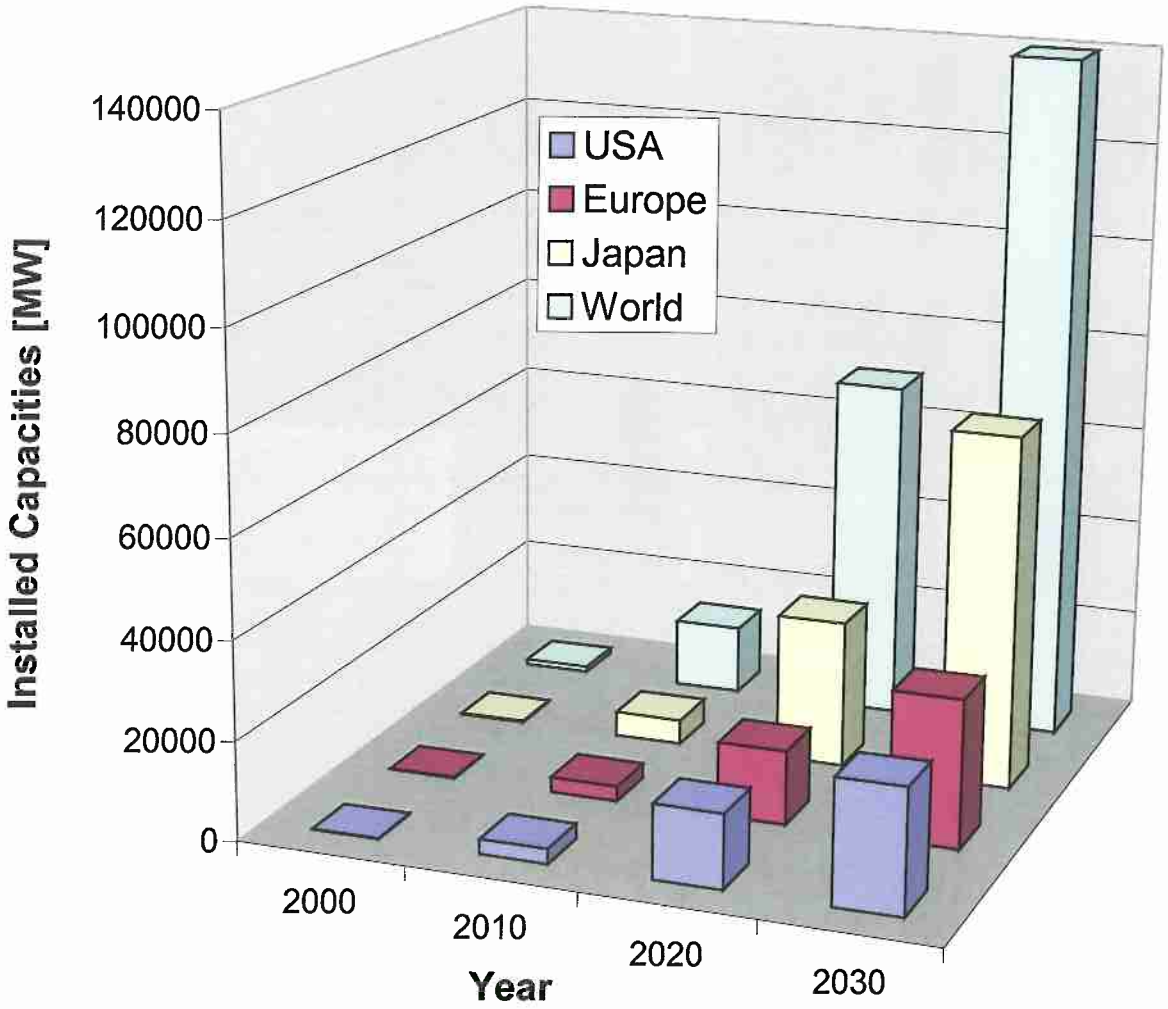

Fig. 16: Evolution of the solar electrical capacities till 2030
(Sources: Japanese, U.S. and EPIA Roadmap)

Tab. 4: **Evolution of the solar electrical capacities up until 2030 (Sources: Japanese, U.S. and EPIA Roadmap)**

Year	2000	2010	2020	2030
USA [MW]	140	3.000	15.000	25.000
Europe [MW]	150	3.000	15.000	30.000
Japan [MW]	250	5.000	30.000	72.000
World-wide[MW]	1.000	14.000	70.000	140.000

At present the photovoltaic industry is in the process of leaving its infancy and become a fully-fledged mass-producing industry. This development is connected with the current process of concentration and acquisition of competitors. This development is a risk and a chance at the same time. If the new large solar cell companies use their cost advantages to offer lower priced products customers will buy more solar systems and it is expected that the PV market will show an accelerated growth rate. However, this development will influence the competitiveness of small and medium companies as well. To survive the price pressure of the big companies made possible by the economics of scale of large production volumes, they have to specialise in niche markets with a high value added to their products. The other possibility is to offer technologically more advanced and cheaper solar cell concepts.

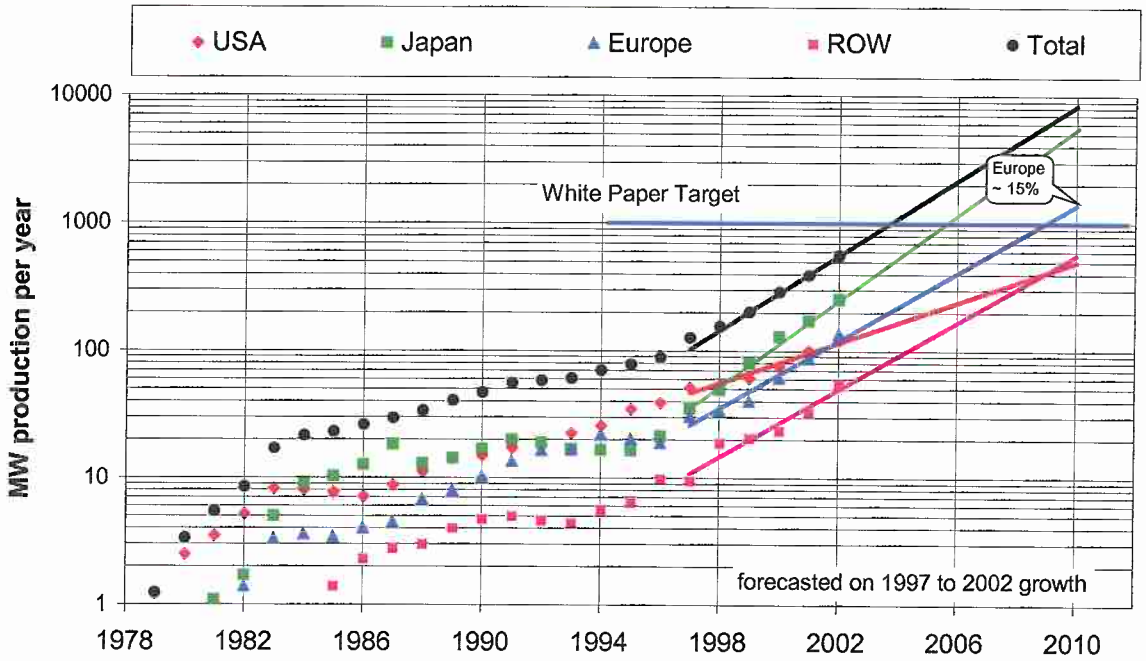

Fig. 17: Extrapolated increase of production capacities up until 2010 using the growth rates from 1997 to 2002 (Data source: PV News [1])

Europe is on track to fulfil its own – though not very ambitious – targets for 2010. Compared to last year the situation has improved quite substantially. 2002 saw a 56% growth

of production volume in Europe and some additional production capacities will become available this year and next year. However, should the current trend in the field of production capacity increase continue in Japan, Europe will not be able to increase its market share even with the impressive growth rates of the last three years. In addition, if the development in the U.S. continues like in the last few years, Japan will dominate the PV world-market in 2010 with about 70% of the market share (Fig. 17).

7. ACKNOWLEDGEMENT

This report is based on visits to Japan (2002 and 2003) and the U.S. (2002), where government entities, research centres and the leading industry companies were visited. I would like to thank all my hosts for their kindness and the time they took to receive me, to share their knowledge and to discuss about the status and prospects of photovoltaics.
In order of visit:

Japan: Delegation of the European Commission in Japan; METI: Ministry of Economics Trade and Industry (New and Renewable Energy Division, Energy Conservation and Renewable Energy Department, Agency of Natural Resources and Energy (ANRE)); NEDO: New Energy and Industrial Technology Development Organisation; CRIEPI (Central Research Institute of Electrical Power Industry); Sekisui Chemical Co., Ltd.; PVTEC: Photovoltaic Power Generation Technology Research Association; Mitsubishi Heavy Industries, Ltd. Tokyo and Isahaya; Tokyo Institute of Technology; NEF: New Energy Foundation; Shinshu Daigaku, Nagano; Kaneka Solartech Corporation; SANYO Electric Company; Sharp Corporation; Toyota Technology Institute, Semiconductor Lab; Nagoya; Yazaki Corporation, Kyocera Corporation, Sharp Corporation, Solar Systems Group, Resources Total System Co. Ltd, Tokyo.

USA: Evergreen Solar; ASE Americas; Energy Photovoltaics Inc.; BP Solar, Frederick; Solar Electric Power Association; Department of Energy; Delegation of the European Commission in the U.S.; ASTROPOWER

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