TRENDS IN PHOTOVOLTAIC APPLICATIONS

Survey report of selected IEA countries between 1992 and 2007

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T1-17:2008

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Foreword

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organization for Economic Cooperation and Development (OECD). The IEA carries out a comprehensive programme of energy cooperation among its 26 member countries and with the participation of the European Commission.

The IEA Photovoltaic Power Systems Programme (IEA PVPS) is one of the collaborative research and development agreements within the IEA and was established in 1993. The mission of the programme is to "enhance the international collaboration efforts, which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option".

In order to achieve this, the participants in the Programme have undertaken a variety of joint research projects in applications of PV power systems. The overall programme is headed by an Executive Committee, comprising one representative from each country, which designates distinct 'Tasks', which may be research projects or activity areas.

This report has been prepared under Task 1, which facilitates the exchange and dissemination of information arising from the overall IEA PVPS Programme.

[1] *The long-term participating countries are Australia, Austria, Canada, Denmark, France, Germany, Israel, Italy, Japan, Korea, Mexico, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom and the United States of America. The European Commission and the European Photovoltaic Industry Association are also members. Malaysia and Turkey are recent participants.*

The IEA PVPS Programme is pleased to present the 13th edition of the international survey report on Trends in Photovoltaic Applications. As in the previous years, there has been a substantial market growth in 2007, with an increasing number of countries contributing to the market. The trend towards a more balanced world market is thus confirmed. The total installed capacity in IEA PVPS member countries reached 7,8 GW by the end of 2007. While grid-connected applications continue to dominate the market, the range of applications evolves to a broader range of substantial sub-markets. Industrial production capacity continues to expand rapidly with further developments in countries that are not members of IEA PVPS, in particular China. Photovoltaics continue to enjoy public support and the support mechanisms are becoming more sophisticated with costs and benefits being addressed more systematically. The business character of photovoltaics is seen to progressively mature with emphasis on new business models, increasing finance industry involvement and large scale industry deployment plans reaching the GW level production capacity. Keeping track of all the developments in and around the PV sector on the global level is a challenge which IEA PVPS is taking forward and is pleased to provide a global network of analysis and information. I trust that this new edition of Trends in Photovoltaic Applications will find many interested readers and I would like to thank all experts who have contributed to this report.

Stefan Nowak
Chairman, IEA PVPS Programme

This report has been prepared by IEA PVPS Task 1 largely on the basis of National Survey Reports provided by Task 1 participating countries. The development of the Trends report has been funded by the IEA PVPS Common Fund and has been approved by the IEA PVPS Executive Committee.

To obtain additional copies of this report or information on other IEA PVPS publications contact the IEA PVPS website at www.iea-pvps.org.

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Introduction

Trends report scope and objective

As part of the work of the IEA PVPS programme, annual surveys of photovoltaic (PV) power applications and markets are carried out in the reporting countries. The objective of the series of annual Trends reports is to present and interpret developments in both the PV systems and components being used in the PV power systems market and the changing applications for these products within that market. These trends are analyzed in the context of the business, policy and non-technical environment in the reporting countries.

This report is not intended to serve as an introduction to PV technology. It is prepared to assist those responsible for developing the strategies of businesses and public authorities, and to aid the development of medium term plans for electricity utilities and other providers of energy services. It also provides guidance to government officials responsible for setting energy policy and preparing national energy plans.

The scope of the report is limited to PV applications with a rated power of 40 W or more. Most national data supplied were accurate to ±10 %. Accuracy of data on production levels and system prices varies depending on the willingness of the relevant national PV industry to provide data for the survey.

This report presents the results of the 13th international survey. It provides an overview of PV power systems applications, markets and production in the reporting countries and elsewhere at the end of 2007 and analyzes trends in the implementation of PV power systems between 1992 and 2007.

BIPV installation in Switzerland

Survey method

Key data for this publication were drawn mostly from national survey reports and information summaries, which were supplied by representatives from each of the reporting countries. These national survey reports can be found on the website www.iea-pvps.org. Information from the countries outside IEA PVPS are drawn from a variety of sources and, while every attempt is made to ensure their accuracy, confidence in some of these data is somewhat lower than applies to IEA PVPS member countries.

Following technical review by the national representatives the report was approved by the IEA PVPS Executive Committee. A list of the national authors is given at the end of this publication.

Definitions, symbols and abbreviations

Standard ISO symbols and abbreviations are used throughout this report. The electrical generation capacity of PV modules is given in watts (W). This represents the rated power of a PV device under standard test conditions of 1 000 W·m-2 irradiance, 25°C cell junction temperature and solar reference spectrum AM 1,5.

The term PV system includes the photovoltaic modules, inverters, storage batteries and all associated mounting and control components as appropriate. Supply chain refers to the procurement of all required inputs, conversion into finished PV products, distribution and installation of these products for final customers. The value chain looks at how increased customer value can be created across a company's business activities, which can include design, production, marketing, delivery and support functions.

Currencies are either presented as the current national currency (where it is considered that the reader will receive most benefit from this information) or as euros (EUR) and / or US dollars (USD) (where direct comparisons between countries' information is of interest). Care should be taken when comparing USD figures in this report with those in previous reports because of exchange rate movements. The exchange rates used for the conversions in this report are given at the end of this report.

1 Implementation of photovoltaic systems

1.1 Applications for photovoltaics

There are four primary applications for PV power systems:

PV Water Pumping Training day in Ghana (Courtesy Geoff Stapleton, Australia)

Off-grid domestic systems provide electricity to households and villages that are not connected to the utility electricity network (also referred to as the grid). They provide electricity for lighting, refrigeration and other low power loads, have been installed worldwide and are often the most appropriate technology to meet the energy demands of off-grid communities. Off-grid domestic systems in the reporting countries are typically around 1 kW in size and generally offer an economic alternative to extending the electricity distribution network at distances of more than 1 or 2 km from existing power lines. Defining such systems is becoming more difficult where, for example, mini-grids in rural areas are developed by electricity utilities.

Aerial mast, Bernina, Switzerland

Off-grid non-domestic installations were the first commercial application for terrestrial PV systems. They provide power for a wide range of applications, such as telecommunication, water pumping, vaccine refrigeration and navigational aids. These are applications where small amounts of electricity have a high value, thus making PV commercially cost competitive with other small generating sources.

Grid-connected distributed PV systems are installed to provide power to a grid-connected customer or directly to the electricity network (specifically where that part of the electricity network is configured to supply power to a number of customers rather than to provide a bulk

Grid connected PV systems in Malaysia (Courtesy of Ptm)

transport function). Such systems may be on or integrated into the customer's premises often on the demand side of the electricity meter, on public and commercial buildings, or simply in the built environment on motorway sound barriers, etc. Size is not a determining feature – while a 1 MW PV system on a roof-top may be large by PV standards, this is not the case for other forms of distributed generation.

Grid-connected centralized systems perform the functions of centralized power stations. The power supplied by such a system is not associated with a particular electricity customer, and the system is not located to specifically perform functions on the electricity network other than the supply of bulk power. These systems are typically ground-mounted and functioning independently of any nearby development.

1.1 MW PV Plant in Spain (Courtesy of Edisun Power)

1.2 Total photovoltaic power installed

About 2,26 GW of PV capacity were installed during 2007 (an increase of more than 50 % over the previous year) which brought the total installed capacity to 7,8 GW. By far the greatest proportion (73 %) was installed in Germany and Spain alone. If Japan and the US are also included, then over 90 % of PV installations in 2007 occurred in four countries.

This report continues to be updated to reflect the best information available at the time of writing which means that totals in some tables have been amended from previous years. This enables IEA PVPS to carry out a more realistic and rigorous evaluation of trends in PV markets and policies over the last decade or so.

Figure 1 illustrates the cumulative growth in PV capacity since 1992 within the two primary applications for PV. Particularly with the recent levels of growth seen in IEA PVPS member countries, this

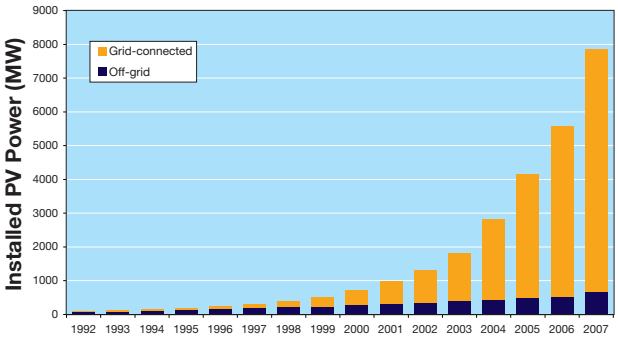

Figure 1 – Cumulative installed grid-connected and off-grid PV power in the reporting countries

reported installed capacity represents a significant and increasing proportion of worldwide PV capacity.

The annual rate of growth of cumulative installed capacity in the IEA PVPS countries was 40 %, up from the 34 % recorded in 2006. Germany's cumulative installed

Table 1 – PV power capacity in participating IEA PVPS countries as of the end of 2007

Country	Cumulative off-grid PV capacity (kW)		Cumulative grid-connected PV capacity (kW)		Cumulative installed PV power (kW)	Cumulative installed per capita (W/Capita)	PV power installed in 2007 (kW)	Grid-connected PV power installed in 2007 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	27 713	38 733	15 035	1 010	82 491	4,1	12 190	6 280
AUT	3 224		22 721	1 756	27 701	3,4	2 116	2 061
CAN	8 088	14 776	2 846	65	25 775	0,8	5 291	1 403
CHE	3 200	400	30 040	2 560	36 200	4,9	6 500	6 300
DEU	35 000		3 827 000		3 862 000	46,8	1 135 000	1 131 000
DNK	100	285	2 690	0	3 075	0,6	175	125
ESP	29 800		625 200		655 000	15,1	512 000	490 000
FRA	15 881	6 666	52 685	0	75 232	1,2	31 299	30 306
GBR	420	1 050	16 620	0	18 090	0,3	3 810	3 650
ISR	1 584	210	11	14	1 819	0,3	500	0
ITA	5 400	7 700	83 900	23 200	120 200	2,1	70 200	69 900
JPN	1 884	88 266	1 823 244	5 500	1 918 894	15,0	210 395	208 833
KOR	983	4 960	32 559	39 099	77 601	1,6	42 868	42 868
MEX	15 487	4 963	300	0	20 750	0,2	1 019	150
NLD	5 300		44 500	3 500	53 300	3,3	1 605	1 023
NOR	7 450	410	132	0	7 992	1,7	324	4
PRT	2 841		676	14 353	17 870	1,7	14 454	14 254
SWE	3 878	688	1 676	0	6 242	0,7	1 392	1 121
USA	134 000	191 000	465 000	40 500	830 500	2,8	206 500	151 500
Estimated total	**265 368**	**396 972**	**6 019 835**	**1 158 557**	**7 840 732**		**2 257 638**	**2 160 778**

Notes: ISO country codes are outlined in Table 13. Some countries are experiencing difficulties in estimating and / or apportioning off-grid domestic and non-domestic; in some markets the distinction between grid-connected distributed and centralized is no longer clear (eg MW scale plant in the urban environment), and mini-grids using PV are also emerging, with other problems of definition. Where definition has not been made in a national report this is shown in this table, however the totals have been estimated using the most recently available ratio from the national reports applied to the current national data. Australian off-grid domestic total includes 1 820 kW of PV on diesel grids.

Table 2 – Cumulative installed PV power (MW) in IEA PVPS countries: historical perspective

Country	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
AUS	7,3	8,9	10,7	12,7	15,7	18,7	22,5	25,3	29,2	33,6	39,1	45,6	52,3	60,6	70,3	82,5
AUT	0,6	0,8	1,1	1,4	1,7	2,2	2,9	3,7	4,9	6,1	10,3	16,8	21,1	24,0	25,6	27,7
CAN	1,0	1,2	1,5	1,9	2,6	3,4	4,5	5,8	7,2	8,8	10,0	11,8	13,9	16,7	20,5	25,8
CHE	4,7	5,8	6,7	7,5	8,4	9,7	11,5	13,4	15,3	17,6	19,5	21,0	23,1	27,1	29,7	36,2
DEU	5,6	8,9	12,4	17,7	27,8	41,8	53,8	69,4	113,7	194,6	278,0	431,0	1 034,0	1 897,0	2 727,0	3 862,0
DNK	*	0,1	0,1	0,1	0,2	0,4	0,5	1,1	1,5	1,5	1,6	1,9	2,3	2,7	2,9	3,1
ESP	~	~	~	~	~	~	~	~	1,0	3,0	7,0	11,0	22,0	45,0	143,0	655,0
FRA	1,8	2,1	2,4	2,9	4,4	6,1	7,6	9,1	11,3	13,9	17,2	21,1	26,0	33,0	43,9	75,2
GBR	0,2	0,3	0,3	0,4	0,4	0,6	0,7	1,1	1,9	2,7	4,1	5,9	8,2	10,9	14,3	18,1
ISR	0,1	0,1	0,2	0,2	0,2	0,3	0,3	0,4	0,4	0,5	0,5	0,5	0,9	1,0	1,3	1,8
ITA	8,5	12,1	14,1	15,8	16,0	16,7	17,7	18,5	19,0	20,0	22,0	26,0	30,7	37,5	50,0	120,2
JPN	19,0	24,3	31,2	43,4	59,6	91,3	133,4	208,6	330,2	452,8	636,8	859,6	1 132,0	1 421,9	1 708,5	1 918,9
KOR	1,5	1,6	1,7	1,8	2,1	2,5	3,0	3,5	4,0	4,8	5,4	6,0	8,5	13,5	34,7	77,6
MEX	5,4	7,1	8,8	9,2	10,0	11,0	12,0	12,9	13,9	15,0	16,2	17,1	18,2	18,7	19,7	20,8
NLD	1,3	1,6	2,0	2,4	3,3	4,0	6,5	9,2	12,8	20,5	26,3	45,9	49,5	51,2	52,7	53,3
NOR	3,8	4,1	4,4	4,7	4,9	5,2	5,4	5,7	6,0	6,2	6,4	6,6	6,9	7,3	7,7	8,0
PRT	0,2	0,2	0,3	0,3	0,4	0,5	0,6	0,9	1,1	1,3	1,7	2,1	2,7	3,0	3,4	17,9
SWE	0,8	1,0	1,3	1,6	1,8	2,1	2,4	2,6	2,8	3,0	3,3	3,6	3,9	4,2	4,8	6,2
USA	43,5	50,3	57,8	66,8	76,5	88,2	100,1	117,3	138,8	167,8	212,2	275,2	376,0	479,0	624,0	830,5
Total	**105**	**131**	**157**	**191**	**236**	**305**	**385**	**509**	**715**	**974**	**1 318**	**1 809**	**2 832**	**4 154**	**5 584**	**7 841**

Notes: Totals reflect conservative 'best estimates' based on the latest information made available to the IEA PVPS Programme from the individual countries for previous years, and are updated as required.

capacity grew at 42 % (close to the growth rate experienced the previous year) whereas Japan's growth rate dropped to 12 %. Spain's cumulative installed capacity increased more than four-fold. Cumulative installed capacity in the US continued to increase at around the 30 % level.

Growth of the annual market was evident in a number of countries as support programmes began to take effect. The Spanish annual PV market increased five-fold, the French annual market tripled, Italy's market increased more than five-fold, Korea's annual market doubled and Portugal went from a negligible amount of installations to 14,5 MW during 2007. The Dutch and Austrian annual PV markets remained relatively stagnant compared to the highs of previous years. During the year Japan's annual PV market decreased by about 26 % compared to 2006. In 2007 the size of Spain's annual PV market was second (the position previously held by Japan) to Germany's and the US annual market approximately matched Japan's, to share the third position.

Germany clearly has the highest level of installed capacity both in terms of total capacity (3 862 MW) and installed capacity per capita (46,8 W/capita).

Of the total capacity installed in the IEA PVPS countries during 2007 about 6 % (128 MW) were installed in off-grid projects. Figure 3 illustrates the proportion of various PV applications in the reporting countries. Whereas the number of

Table 3 – Annual installed photovoltaic power (MW) in selected countries – historical perspective (1995–2007)

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
AUS	2,0	3,0	3,0	3,8	2,8	3,9	4,4	5,5	6,5	6,7	8,3	9,7	12,2
AUT	0,3	0,3	0,5	0,7	0,8	1,2	1,2	4,2	6,5	4,2	3,0	1,6	2,1
CAN	0,4	0,7	0,8	1,1	1,3	1,4	1,6	1,2	1,8	2,1	2,8	3,8	5,3
CHE	0,8	0,9	1,3	1,8	1,9	1,9	2,3	1,9	1,5	2,1	4,0	2,6	6,5
DEU	5,3	10,1	14,0	12,0	15,6	44,3	80,9	83,4	153,0	603,0	863,0	830,0	1 135,0
ESP	~	~	~	~	~	~	2,0	4,0	4,0	11,0	24,0	98,0	512,0
FRA	0,5	1,5	1,7	1,5	1,5	2,2	2,6	3,3	3,9	5,2	7,0	10,9	31,3
ITA	1,7	0,2	0,7	1,0	0,8	0,5	1,0	2,0	4,0	4,7	6,8	12,5	70,2
JPN	12,2	16,2	31,7	42,1	75,2	121,6	122,6	184,0	222,8	272,4	289,9	286,6	210,4
KOR	0,1	0,3	0,4	0,5	0,5	0,5	0,8	0,7	0,6	2,5	5,0	21,2	42,9
NLD	0,4	0,9	0,7	2,5	2,7	3,6	7,7	5,8	19,6	3,6	1,7	1,5	1,6
PRT	~	0,1	0,1	0,1	0,3	0,2	0,2	0,4	0,4	0,5	0,4	~	14,5
USA	9,0	9,7	11,7	11,9	17,2	21,5	29,0	44,4	63,0	100,8	103,0	145,0	206,5

Notes: Countries that are experiencing (or have recorded in a past year) annual installed PV power of >5 MW

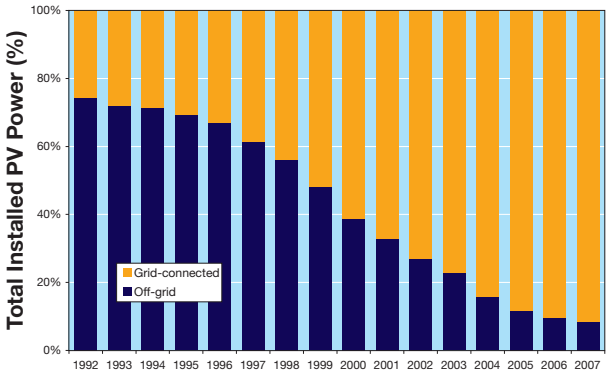

Figure 2 – Percentages of grid-connected and off-grid PV power in the reporting countries

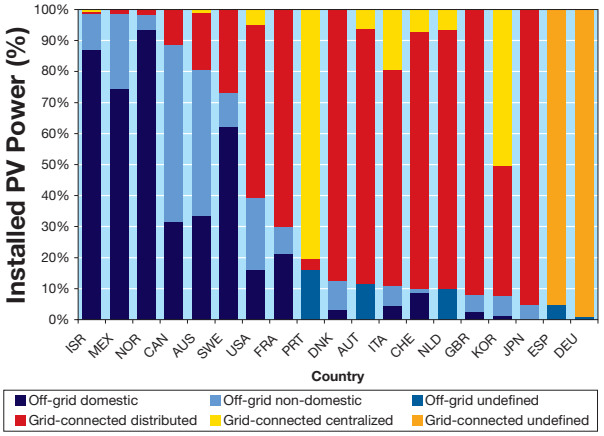

Figure 3 – Installed PV power in the reporting countries by application (%) in 2007

countries reporting off-grid applications as their dominant market is decreasing over time, the largely unsubsidized markets for vacation cottages, cost effective rural electrification, telecommunication and infrastructure applications continue to grow worldwide, albeit less vigorously than the publicly funded grid-connected PV markets.

An interesting feature of the 2007 cumulative installed capacity compared to 2006 is the three-fold increase in capacity defined as grid-connected centralized. This reflects the growth in investor-owned large-scale PV power systems being developed in response to the feed-in tariff frameworks in place in a number of countries, as outlined in the next section of this report.

1.3 PV implementation highlights from selected countries

The information presented in this section reflects the diversity of PV activity in the reporting countries and the various stages of maturity of PV implementation throughout these countries. Small landmark projects or programmes are as significant in some countries as policy debates and PV market expansion are in others. This section is based on the information provided in the national survey reports submitted each year by participating countries. For some countries, considerable detail is presented in their national survey report and the reader is directed to these reports on the IEA PVPS website for further details about specific markets, projects and programmes.

Australia (AUS)

In 2007 PV entered the mainstream Australian market, with a large increase in grid system sales and a significant growth and diversification of industry participants. A total of 12,2 MW of PV was installed in Australia in 2007, 2 MW more than last year. This was largely the result of higher grants for residential systems. Grid-connected systems accounted for 50 % of installations during 2007 and now account for 18 % of installed capacity. In November 2007 a new Labor Government was elected in Australia. It has ratified the Kyoto protocol, has pledged to increase the Renewable Energy Target from its current level of 9 500 GWh by 2010 to 45 000 GWh by 2020, to substantially increase the Solar Schools programme and to add two new Solar Cities.

The largest installed capacity of PV in Australia is for off-grid industrial and agricultural applications. Significant markets also exist for off-grid residential and commercial power supplies and increasingly for fuel saving and peak load reduction on community diesel grid systems. Some of this market is supported by government grants through the Renewable Remote Power Generation Program (RRPGP) which provides 50 % of system costs with the aim of reducing diesel fuel use. The market for PV installations connected to central grids continues to increase, with the majority of installations taking advantage of a government grant program (the PV Rebate Program, now called the Solar Homes and Communities Plan). The main applications are rooftop systems for private residences, schools and community buildings. Commercial and light industry sector interest is also growing, with support available to selected projects through the Solar Cities Program. All PV systems can benefit from the Renewable Energy Target. In 2007 a total of 57,25 million AUD was spent on demonstration projects and market incentives for PV.

In 2007 the residential grant from the PV Rebate Program was doubled from 4 000 AUD to 8 000 AUD for the first kW installed. This was introduced in May and resulted in significant market growth for the second half of the year, the establishment of many new businesses and a marked increase in PV installer accreditation. 150 million AUD were allocated to the program over five years, including funding for school and community PV systems, which were eligible to apply for 50 % of system costs up to 2 kW. System installations increased from an average of 300 per month to over 1 000, with the higher grant and other incentives resulting in payback times of around 20 years or less, and hence attracting a much broader customer base. The increased PV rebate stimulated competition in the market, as well as new marketing ideas. The latter included bulk purchase options offering 1 kW systems for 1 000 AUD or less, if 50 or more homes were involved. A total of 4,6 MW of PV was installed under the PV Rebate Program in 2007, up from 1,8 MW last year.

There has been a greatly increased interest in PV feed-in tariffs. The Northern Territory Power and Water Authority, as part of the Alice Springs Solar City, is offering an 0,45 AUD/kWh tariff for all electricity generated from the 225 homes being supported through the programme. This is about twice the daytime electricity tariff and the buyback is capped at 5 AUD per day (effectively limiting the tariff to 2 kW systems). With the grants and tariffs, system costs are expected to be repaid within 10 years. The South Australian and Queensland governments announced new net export feed-in tariffs of 0,44 AUD/kWh and the Victorian government has offered 0,66 AUD/kWh. The Australian Capital Territory is considering a total export model set at 3,88 X standard tariffs, with the aim of paying back system costs within 10 years. The national government has indicated an interest in a uniform PV feed-in tariff across Australia and is undertaking a review of State, utility and international programmes.

A range of promotional activities, including energy fairs, mail-outs and internet based special offers, have been rolled out by the various Solar Cities. This has greatly increased awareness of PV in the target communities. This interest will be reinforced over coming years as an increasing number of high profile community PV systems, as well as more residential systems, are installed in the Solar Cities. There has been a noticeable increase in the number of PV systems installed on commercial and public buildings as part of corporate or government green building or greenhouse gas reduction programs. This trend is expected to continue as Solar City installations begin, building energy standards improve and energy prices increase due to international resource prices, infrastructure upgrades and emissions trading. The increased Renewable Energy Target is providing stimulus to larger scale renewable systems, as well as to solar water heating, but has not been a large driver of PV to date.

With the high rebates, PV began to enter the mainstream retail market, with large hardware stores, builders, as well as solar shops and local governments selling or promoting PV. Several companies offer combined solar water heating and PV packages. A number of electricity utilities offered feed-in tariffs, mostly net export, but one offers a gross generation feed-in tariff for a selected customer base. In line with government mandates, electricity utilities are beginning to change over to electronic ‘interval’ meters, which in turn allow for the introduction of time of use tariffs. The relevance of this for PV depends on the tariff structure.

The Australian PV market is now heavily dependent on grant based support. This leaves it vulnerable to government election and budget cycles which have resulted in constant changes over the past decade. The Solar Cities Program, with its investment in community information, demonstration and new approaches to energy service provision, may see longer term benefits.

Whether the current momentum can be maintained, with changes to the grant program and resistance to feed-in tariff support from various sectors of industry and the community, remains to be seen. Nevertheless, retail electricity prices are set to rise consistently over the coming decade across the country and increasing diesel prices continue to improve the cost-effectiveness of PV in rural and remote areas.

Austria (AUT)

In 2007, after a three year decline, the size of the Austrian domestic PV market increased slightly compared to the previous year. However the PV market in 2007 was still far removed from the peak of 6,5 MW capacity installed in 2003. Off-grid and grid-connected PV systems with a total power of 2,1 MW were installed, which represents a 35 % growth of the domestic market compared to the year before.
The cumulative installed PV capacity in Austria reached 27,7 MW at the end of 2007. Grid-connected applications dominate the market; with 24,5 MW this sector accounts for about 88 % of the cumulative installed capacity. The off-grid sector plays a minor role in the Austrian PV market. In 2007 an estimated 0,06 MW were installed in this sector. In total approximately 3,2 MW of off-grid systems for domestic and non-domestic applications have been installed in Austria.
The policy environment for developing the domestic Austrian PV market remains complex and ineffective. The 2006 revision of the main RES support framework, the national Green Electricity Act, did not provide any substantial support for PV and further complicated the situation for its deployment. Despite the fact that 2007 feed-in tariffs ranged from 0,30 EUR/kWh to 0,46 EUR/kWh, the limited time-frame of the support (only ten years) and other factors created an unattractive framework for investments in PV. To overcome the lack of support under the federal programme, a few provinces are still running PV rebate programmes. However, in most cases, the provincial support is only granted when support via the federal feed-in tariff scheme is unavailable. No other new field test or demonstration programmes had been established before the end of 2007. Furthermore, the current draft of the 2008 revision of the Green Electricity Act does not contain any significant improvements for PV deployment.
A major trend regarding Austrian PV projects in recent years – optimal architectural integration of BIPV in newly constructed and refurbished buildings – continued during 2007. Several installations with PV innovatively and aesthetically integrated into the building design were developed. During 2007 Austria's largest PV plant was inaugurated at the new Fronius (PV inverter company) production and logistics centre, which consists of a two-axis tracking part, a façade integrated section and a flat roof-mounted unit with a total power of roughly 600 kW.

Canada (CAN)

A total of 5,3 MW of PV was installed in Canada in 2007, compared to 3,7 MW the previous year. Grid-connected systems accounted for about one quarter of capacity installed during the year and now account for about 11 % of installed capacity. Canadian PV exports increased from 990 kW in 2006 to 7,33 MW in 2007.

A sustainable, unsubsidized market in off-grid PV applications has developed over the last 15 years in Canada. The off-grid non-domestic PV market represented 53 % of sales in 2007 and presently accounts for 56 % of cumulative installed capacity. Major new businesses and markets continue to emerge in manufacturing and selling stand-alone PV systems for uses such as bus stop signaling and small illumination. The off-grid domestic sector remains at just over 30 % of cumulative installed capacity.

There were several grid-connected PV demonstrations installed in 2007 and this sector is expected to increase in the near future as a result of policy support. This market sector has been averaging growth rates of 38 % since 2000. In 2007 a total of 4,7 million CAD were spent on PV demonstration projects and market incentives.

The Province of Ontario's Renewable Energy Standard Offer Programme (RESOP) is viewed by the Canadian PV industry as a major step towards developing a competitive Canadian solar industry. By the end of 2007, after one year of implementation, 252 140 kW of PV had been contracted under the RESOP with a feed-in tariff of 0,42 CAD/kWh.

Public interest in PV continues to grow in Canada underpinned by the activities of organizations such as the Solar Buildings Research Network and the Canadian Solar Industries Association.

Denmark (DNK)

By the end of 2007 Denmark (including Greenland) reached a cumulative installed PV capacity of about 3,1 MW, an annual increase of less than 200 kW. Grid-connected distributed systems accounted for about 70 % of the new capacity and constitute about 90 % of all PV systems in Denmark.

During 2007 no national PV promotional activities existed resulting in the very slow progress in the main market of mainly roof-top systems. Only the regional electricity distribution utility EnergiMidt provided incentives in their own concessionary area through an investment subsidy of up to 40 % of the investment cost of a grid-connected PV system.

The national electricity grid covers practically all of Denmark and leaves little room for stand-alone applications. However, in Greenland stand-alone PV plays a major role as the power source for remote signalling and for the telecommunication network extending more than 2 000 km along the western coast line. In 2007 the off-grid professional and

domestic PV market sectors developed at the same level as in previous years.

Grid-connected PV applications are seen as the largest potential market in Denmark, in particular building integrated applications on single family houses, apartment buildings, commercial and office buildings. The public interest for building integrated PV is increasing and most efforts are focused on developing and demonstrating PV in the context of existing buildings. The EU directive on energy consumption in buildings, adopted in Denmark as a revised national building code, allocates PV electricity a factor of 2,5 in the calculation of the energy foot print of a building. Due to inertia in the construction sector it is too early to see any impact on PV deployment; however, a number of pilot building projects were realized during 2007.

France (FRA)

During 2007, 31,3 MW of PV were installed in France (mainland France, Corsica and the four French overseas departments Guadeloupe, Guyane, Martinique and Réunion), a significant increase compared to the 10,9 MW installed during 2006. The growth is mainly due to the national fiscal measures (new feed-in tariff and tax credit) launched in mid 2006. Grid-connected systems accounted for 30,3 MW (compared to 9,4 MW the previous year). Cumulative capacity at the end of 2007 was 75,2 MW of which 70 % are grid-connected.

Operating since 10 July 2006, the feed-in tariff for photovoltaic-generated electricity is 0,30 EUR per kWh with a building integrated PV (BIPV) bonus of 0,25 EUR per kWh. The French government decided to place an emphasis on BIPV and reflected this in the feed-in tariff structure. Feed-in tariff contracts are signed for a 20 year period and are to be revised every year on the basis of a specific inflation index. Other incentive measures include tax credits (applying to 50 % of PV module and other equipment costs, capped at 8000 EUR per income tax paying person) and EDF-ADEME support (FACE fund) for isolated off-grid dwellings. Local authorities such as regional councils and departmental councils have also developed new policies to promote PV through specific grants.

With the encouragement of building integration of PV, innovative products are coming on the market or are under development. In parallel, actors such as architects, designers and engineers are now paying attention to building integration of PV components. New actors such as financial institutions, energy operators, and private investors have developed ambitious projects. With the increase of the business new firms have been formed in engineering and consultancy.

Two important initiatives were unveiled during 2007. In March 2007, the European Commission launched a strategic plan (SET plan) covering new energy technology. One of the objectives is to achieve a contribution of 20 % of renewable energies in the energy mix by 2020. The French Government has adopted these objectives. In October 2007 the French Government stressed a willingness to promote the development of renewable energies in the conclusion speech of the Grenelle de l'environnement (a series of public meetings involving stakeholders from the environment field). Total PV power in France of 5,4 GW by 2020 is advocated by working groups of Grenelle de l'environnement. At the same time it was decided to reinforce R&D activity on crystalline silicon materials and new products for building integration.

159 kW PV system on a rescue station, Falun, Sweden (Courtesy Ulf Malm, Sweden)

Germany (DEU)

Germany continues to have the highest annual PV installation world-wide – about 1 100 MW in 2007, resulting in a cumulative installed capacity of 3,6 GW. This remarkable development is based on the market support measures promoting grid-connected rooftop systems and large PV power plants by means of a PV electricity feed-in tariff.

The Renewable Energy Sources Act (EEG) governs the favourable payments for renewable electricity. For PV rooftop systems smaller than 30 kW payments under the feed-in tariff have evolved as follows (in EUR/kWh): 2003 – 0,46; 2004 – 0,574; 2005 – 0,545; 2006 – 0,518; 2007 – 0,492; and 2008 – 0,4675. The rates are guaranteed for an operational period of 20 years. Larger systems receive lower tariffs; façade integrated systems get a bonus of 0,05 EUR/kWh. In order to stimulate PV system price reduction, the tariffs for newly installed PV systems currently drop by 5 % each year.

An amendment of the EEG for 2009 will be adopted soon. After significant growth rates the German PV market stagnated in 2006, apparently as a consequence of the short supply of solar PV grade silicon and the interdependency between PV system prices and the feed-in tariffs. However, the market grew again significantly in 2007. Consequently the degression rates for the PV feed-in tariff will be increased from the current 5 % per year to 8 % to 10 % per year from 2009 on. Also current plans foresee the

introduction of another class of PV system, namely rooftop systems larger than 1 MW.

The 100 000 Rooftops Solar Electricity Programme ended at the close of 2003. The continued support of PV systems by soft loans is now maintained by the Solar Power Generation programme. Under this programme a total of 43 000 loans representing 338,1 MW of PV and 1 335 million EUR worth of investments have been granted since 2005. In 2007 alone, 101,3 MW of PV were supported. Other measures such as the programmes of the Federal States (Länder) and the Federal German Environmental Foundation (DBU) are designed for local or application specific support of PV. In addition, a number of electricity utilities have launched initiatives to build PV demonstration and pilot systems or to provide advice and information.

In 2007 the renewables share in the electricity sector reached almost 15 %, exceeding the 2010 target set some years ago. In mid 2008 the German parliament decided to set a new target of 30 % for 2020. PV's share of this development is roughly 4 % of the renewable power currently generated in Germany.

The German PV industry plans to further increase domestic production capacities and from 2010 it is expected that an increasing share of the turnover will be earned from export activities. In the competitive global environment it is seen as important to offer high quality, state of the art products while enhancing production efficiency and lowering costs. Consequently both high-level R&D and ongoing domestic market support mechanisms such as the EEG are considered important in Germany.

Israel (ISR)

During 2007 about 500 kW of PV were installed in Israel, bringing the cumulative installed capacity to just over 1,8 MW. As in previous years the majority of systems installed were for remote homes, agriculture, security and alarm systems, communications and exterior lighting.

Although the legislation permitting grid-connection of PV was not completed in 2007, activity is now underway. The new legislation requires the electricity utility to purchase PV generated electricity at a rate about four times higher than the retail electricity price. Specific financial schemes will address the high initial cost of PV installation to provide a ten year payback period for PV systems. It is anticipated that both these measures will contribute to an increased demand for PV in Israel in 2008 and beyond.

Italy (ITA)

About 70 MW of PV were installed in Italy during 2007, more than doubling the country's cumulative installed capacity in one year. The rapid growth was due to operation of the feed-in tariff scheme, with about three quarters of the capacity installed comprising grid-connected distributed systems. Cumulative capacity has reached 120 MW with grid-connected distributed systems accounting for 70 % and grid-connected centralized systems making up almost 20 % of the total.

The market was driven by the changes to the feed-in tariff decree which were adopted in early 2007. The national target for PV was increased from 1 GW to 3 GW by 2016 and the annual limit (85 MW) and plant upper size limit (1 MW) were eliminated, amongst other things. Procedures were simplified, with applications for feed-in tariffs now required after the start of plant operation, permission is not necessary for plant installation, at least in areas without environmental constrains, and electricity utilities are compelled to pay penalties for delays associated with grid interconnection of PV systems.

New tariffs were adopted for PV electricity and market support amounted to over 20 million EUR during 2007. The new tariffs increased in value depending on the degree of PV integration in the building (up to 0,49 EUR/kWh), and were increased for small plants but reduced for large plants (for example, a large free-standing plant can earn 0,36 EUR/kWh). The tariffs remain valid for 20 years at a constant rate and are reduced by 2 % each calendar year after 2008. An additional 0,09 to 0,13 EUR/kWh are earned for the sale of electricity to the grid or 0,15 EUR/kWh can be earned for own consumption of the electricity. Further bonuses are also available: depending on the levels of energy efficiency achieved within a building the tariffs can be increased by up to 30 %, and a small bonus is also applied to public schools, hospitals, small municipalities and for substitution of asbestos roofs.

A new PV policy initiative is being developed to begin operation in 2009 that will require the installation of at least 1 kW of PV in new buildings. Further, the National Authority for Electric Energy and Gas is simplifying the procedure for the connection of PV plants to the electricity grid. It is expected that this will considerably reduce the time required for the development of PV plants.

It is considered that the feed-in tariff decree introduced in 2007 provides the stability required for a steady expansion of the domestic market (installation of about 150 MW of PV is anticipated for 2008), followed by growth and diversification of the national PV industry.

Japan (JPN)

During 2007 a total of about 210 MW of PV were installed in Japan, dropping from the 287 MW installed the previous year. The main factor cited as contributing to the decline was the completion of funding for the introduction of residential PV systems.

Most of these installations (around 90 %) continued to be (largely unsubsidized) residential PV systems, with a further 21 MW of PV installed at industrial and public facilities. Research and demonstration of large-scale grid-connected centralized systems accounted

for 2,6 MW of new installations. Off-grid systems comprised less than 1 % of the annual market. In 2007 cumulative installed PV capacity in Japan approached the 2 GW level.

The Ministry of Economy, Trade and Industry (METI) commenced the support of PV systems in non-residential facilities through the Field Test Project on New Photovoltaic Power Generation Technology. In this sector the deployment of PV systems had not been as advanced as in the residential market. During the year 374 PV systems, totaling 21 MW, were installed at industrial and public facilities. To date the project has applied to PV systems with a capacity of 10 kW or more whereas in 2008 the project will also cover PV systems with a capacity of 4 kW or more demonstrating new module types, building material-integration and new control methods. The New Energy and Industrial Technology Development Organization (NEDO) began projects concerning the Verification of Grid Stabilization with Large-Scale PV Power Generation Systems with the construction of a PV plant of around 5 MW in Wakkanai City, Hokkaido Prefecture and a PV plant of around 2 MW in Hokuto City, Yamanashi Prefecture. The Ministry of the Environment (MoE) continued the Solar Promotion Programme to promote the introduction of PV systems and also implemented the so-called Community Model Project of a Virtuous Circle for Environment and Economy.

The national budgets of METI and the MoE concerning PV deployment amounted to about 14 600 million JPY for demonstration/ field test programs and 4 800 million JPY for market revitalization. In addition to METI and the MoE, the Ministry of Land, Infrastructure and Transport (MLIT), the Ministry of Education, Culture, Sports, Science and Technology (MEXT) and other ministries and agencies are promoting the introduction of PV systems. 344 local governments continued to implement support programs for the dissemination of residential PV systems during 2007.

Public awareness of PV is high and perceptions are positive, as a result of the government's activities over the years and publicity in both the print and electronic media. Local governments are increasingly developing their own PV support schemes, such as subsidies depending on the amount of excess PV electricity produced, green power certificates for PV electricity for home consumption and subsidies per kW installed. The Tokyo Metropolitan Government started developing measures to introduce 1 000 MW of solar energy within its jurisdiction.
Housing manufacturers, building material manufacturers, construction companies and power supply equipment manufacturers develop and promote products using PV. In addition, electrical equipment stores, home electric appliance stores, building contractors, roofing contractors etc. promote

(Courtesy Ohta City Land Development Corporation, Japan)

the sale and installation of PV systems. The distribution chain for residential PV systems, from the PV cell manufacturers to the end uses, is now well established in Japan. The broad movement to recognize PV as a significant business opportunity for the future is expanding. A willingness to contribute to the environment by businesses is also growing. An increasing number of businesses such as the Aeon group and Sagawa Express are facilitating the introduction of PV systems through the Field Test Project on New Photovoltaic Power Generation. Electricity utilities continue to support the deployment of PV systems through their management of green power funds and some large-scale PV demonstration projects. Additionally, net billing is offered for surplus electricity generated by PV systems and PV electricity can meet obligations under the Renewables Portfolio Standard (RPS) Law. METI has revised the RPS Law, set a target amount of new and renewable energy in 2014 of 16 billion kWh and developed measures to double count electricity generated by PV systems. METI has also formulated Cool Earth 50, an energy technology innovation plan looking towards 2050, with a long-term strategy for PV cells to achieve conversion efficiencies of 40 %.

Korea (KOR)

Annual installed PV power in Korea reached 42,9 MW in 2007 – more than twice the size of the market the previous year. Grid-connected distributed installations showed a significant increase during the year.

The cumulative installed power of PV systems in Korea increased markedly to 77,6 MW by the end of 2007 from 34,7 MW the previous year. The share of grid-connected systems increased to 92 % of the total cumulative installed power from 83 % the previous year. Grid-connected centralized systems featured strongly in the annual market and also now in the cumulative installed power of PV systems. For off-grid non-domestic and domestic systems, the relative cumulative shares of these sectors decreased sharply. Although the off-grid non-domestic sector was the major market in Korea until 2002, it is no longer an area of interest for the major PV module manufacturers and system companies.

The feed-in tariff and 100 000 rooftop programmes played major roles in the dramatic 2007 growth. Under the feed-in tariff scheme, a total of 28,6 MW was installed in 2007 and the annual spending was 14 772 million KRW. Thirteen plants exceeded 1 MW in size; the largest being 3 MW, set up and operated by Dongyang Energy PV power, owned by the Dongyang Energy Company. The feed-in tariff amounted to 677,38 KRW/kWh for systems larger than 30 kW and 711,25 KRW/kWh for smaller systems. The scheme has a ceiling of 100 MW in total (installed post October 2006) and is guaranteed for 15 years for PV systems over 3 kW. Under the 100 000 rooftop programme, over 9,2 MW of PV were installed on single-family houses and public rental apartments, with a total budget of 49 000 million KRW. The aim of this programme is to install 100 000 rooftop PV systems in the period to 2012. The Government provides support amounting to 60 % of the installed system price for single-family houses and 100 % support for the public rental apartments.
Other important support measures in 2007 included the General Deployment Programme, the Public Building Obligation Programme and the Local Deployment Programme. Under the General Deployment Programme, the government supports 60 % of the installed cost for schools, public facilities, welfare facilities and universities. In 2007, 159 PV systems with a total capacity of almost 4 MW were installed. The Public Building Obligation Programme requires new public buildings larger than 3 000 square meters to spend 5 % of the total construction budget on installation of a renewable energy facility. In 2007, a total of 5,9 MW of PV was installed. The Local Deployment Programme includes PV installed on public buildings belonging to local authorities and aims to increase public awareness about PV as an indigenous renewable energy source for the local region. The Government supports 60 % of total system price, with the remainder shared by the local authority and the beneficiary. In 2007 several metropolitan cities such as Seoul, Daegu, Gwangju and Ulsan announced plans to build eco-friendly innovation cities incorporating renewable technologies. The public budget allocated for market stimulation in 2007 was 105 126 million KRW, with local authorities providing a further 6 012 million KRW for implementation of the deployment programme. The Government also provided low-interest loans for renewable energy production and PV system applications.

Korea plans to install 1 300 MW of PV by 2012 and also aims to secure 7 % of the world PV market share. Many Korean companies are preparing to enter into PV cell and module production, and there is an expectation of concrete and significant investments from large companies with a sound technological background in the semiconductor and LED industries.

Malaysia (MYS)
By the end of 2007 Malaysia had a total installed PV capacity of about 7 MW, of which about 640 kW in 32 installations were grid-connected. During 2007 there were 12 new grid-connected installations – three were for office buildings, seven for residential, and one each for a university and a school – installed under the Malaysian BIPV (MBIPV) Programme.

The grid-connected market is driven by a combination of the SURIA 1 000 Programme (bidding based), the Showcase Programme (100 % capital rebate) and demonstration incentives (25 % to 28 %). The target of the MBIPV Programme is the installation of 1,2 MW of PV. To date, the largest installation (362 kW) is at the Enterprise Four Building at Technology Park Malaysia; the second largest installation is a number of BIPV systems at the Zero Energy Office for the Malaysia Energy Centre with total PV capacity of 92 kW, commissioned in June 2007. SURIA 1 000 aims to catalyze the Malaysian BIPV market by targeting both the general public and property developers to install BIPV at their premises via a bidding of capital-based incentives.

From 2008 the Government has announced environment incentives comprising a ‘double tax’ allowance for companies generating electricity from renewable forms of energy.

Mexico (MEX)
During 2007 about 1 MW of PV were installed in Mexico, bringing the cumulative installed capacity to 20,75 MW. As in previous years the majority of systems installed (85 %) were for off-grid applications.

A programme of rural electrification with renewable energy sources (co-funded by the GEF, the World Bank and the Mexican Government) commenced with the selection of more than 40 rural communities as candidates for pilot projects. These communities are located in target states of southern Mexico – Oaxaca, Chiapas, Veracruz, and Guerrero.

The Energy Regulatory Commission (CRE) is investigating net metering models that could be used in Mexico. The first draft of technical guidelines for interconnection of PV systems (up to 30 kW capacity) to the electricity grid has been submitted to the national electric utility (CFE) for review and subsequent adoption as a standard. Innovative financial mechanisms for grid-connected PV are being studied as part of an UNDP-IIE project.

A new law to foster the use of renewable energy resources in Mexico is awaiting approval by the Mexican Senate and Congress.

The Netherlands (NLD)
During 2007 about 1,6 MW of PV (about two thirds grid-connected) were installed in the Netherlands, bringing the cumulative installed capacity to 53,3 MW.

The annual grid-connected market remains quite flat and has not recovered since the collapse post

2003. However a major policy change was agreed late in 2007 which should stimulate the market in future years. Commencing in 2008 a subsidy of 0,33 EUR/kWh will be paid for PV electricity delivered to the electricity grid, for a period of 15 years. The total budget for the first year amounts to 60 million EUR, corresponding to a total of 10 MW of PV installed. The aim is to promote roof top PV installations of between 0,6 kW and 3,5 kW.

While a large focus of the PV industry in the Netherlands is currently on export to the booming German market, the need has been identified to prepare the different local market players for the larger domestic roll-out of PV expected in the near future. During 2007 the Dutch Energy Research Center (ECN), together with regional partners, founded the 'Solar Academy' in Heerlen, Limburg to focus on the training of professionals in the solar industry. The partners are Solland Solar, the Institute of Semiconductor Electronics (RWTH, Aachen University) and the regional development bank of Limburg (LIOF).

The Dutch Government's long-term policy for the energy sector is oriented towards structural transition, involving major changes in electricity sector infrastructure and the integration of solar energy in the built environment.

Norway (NOR)

About 350 kW of PV were installed in Norway during 2007, mostly off-grid systems. The annual market remained at the same level as the two previous years. Off-grid domestic applications account for 93 % of Norway's cumulative installed PV capacity of about 8 MW.

Norwegians have used PV technology for more than three decades, especially in the recreational housing market. Some of the older existing PV equipment is likely to be decommissioned due to age, upgrading and also because an increasing number of these buildings are becoming connected to the electricity grid.

So far there are no policy measures specifically targeting the increased use of PV in Norway and the few existing demonstration projects have been motivated by educational or private interests (for example, the research sector, high schools, industry and utilities).

The highlight of 2007 is the same as for the previous five years – the remarkable positive industrial development of the Renewable Energy Corporation (REC). In addition, new production facilities owned by Elkem Solar and NorSun will come into operation in 2008.

Portugal (PRT)

During 2007 there was a dramatic increase in the amount of PV installed during the year and also in Portugal's cumulative installed PV capacity. Over 14 MW of grid-connected centralized applications were realized (over 98 % of capacity installed during 2007) and cumulative installed capacity jumped from about 3,4 MW to almost 18 MW.

The most significant PV policy initiatives driving this increase in 2007 were the independent power producer (IPP) law and the establishment of a new framework for the promotion of micro-generation systems, known as Renewables on Demand.

The IPP Law sets feed-in tariffs according to renewable technology and was revised in 2007 (after having been suspended by the Government since 2005). PV benefits from the highest feed-in tariff, typically guaranteed for 15 years. The value of the tariff ranges from a low of 0,317 EUR/kWh (for larger, non building integrated systems) to 0,469 EUR/kWh (for systems that are less than 5 kW and are building integrated). Large plants benefiting from the IPP Law include an 11 MW single-axis tracking PV power plant, a 2,15 MW two-axis tracking PV power plant and a 756 kW a-Si PV plant.

Late in 2007 Renewables on Demand was approved. While the IPP law mainly involves private businesses, this scheme is oriented towards electricity consumers, provided they have a commercial contract with an electricity supplier. Under this framework PV (limited to 3,68 kW for each installation) can earn 0,65 EUR/kWh initially, with revisions depending upon total micro-generation capacity installed over time. The new framework requires all the energy produced to be sold to the electricity supplier. Under the specific regime that applies to PV the installation of a solar water heating system is mandatory. The authorization process, simplified by an on-line registry platform, is expected to take no more than three to four months.

Other measures stimulating the PV market include a reduction of the VAT rate from 21 % to 12 % on renewable equipment, custom duties exemption and income tax reductions (up to 777 EUR) on solar equipment, and new building regulations requiring all new buildings to install solar thermal systems or a specified amount of energy produced from other renewable technologies such as PV.

Spain (ESP)

Annual installed PV power in Spain in 2007 reached 512 MW – more than five times the size of the market the previous year which, in turn, had been four times the size of the market in 2005. In 2007 Spain overtook both Japan and the US to now be ranked second behind Germany in terms of annual market size. Whereas 2006 was somewhat of a transition year in Spain, with the announcement of a new feed-in tariff scheme, momentum was quickly gained. Currently the distribution of PV installations in Spain is about 95 % grid-connected systems and 5 % off-grid systems.

Under the current feed-in tariff scheme large-scale PV plants, driven by investors, have recorded strong

growth. Whereas the installed capacity of PV systems less than 5 kW grew by 68 % between 2006 and 2007, the installed capacity of PV systems between 5 kW and100 kW grew five-fold and plants greater than 100 kW experienced an even more impressive increase. The Huertas Solares projects – large investor-owned PV farms made up of many individual PV systems between 5 kW and 100 kW – account for about 80 % of Spain's installed PV capacity. Their popularity is a straight reflection of the 100 kW boundary in the feed-in tariff scheme – systems of less than 100 kW attract a payment of 0,440381 EUR/kWh whereas those greater than 100 kW are paid 0,229764 EUR/kWh. Total payments under the feed-in tariff scheme amounted to almost 200 million EUR in 2007 (over four times the amount paid the previous year).

Regarding project implementation in 2007 two matters are particularly noteworthy. Firstly, the sheer magnitude of the developments – for example the 20 MW PV plants at Beneixama and Hoya de los Vicentes, each made up of 200 individual 100 kW installations. Other significant installations included the 13,8 MW PV plant at Salamanca, the 12,7 MW PV plant at Lobosillo, the 8,76 MW PV plant at Viana and the 6,27 MW PV plant at Aldea del Conde. Secondly, the interest in market implementation of high concentration PV systems is beginning to gain momentum, with the involvement of numerous industry partners in significant pilot plant developments.

There is some concern about the growth rates being experienced in the Spanish PV market, the relative lack of PV installations in the residential sector and the ability of locally produced PV products to compete with cheap imports (particularly from China). Targets set by the Government's Renewable Energy Plan have been exceeded and the objectives established by the Royal Decree have been surpassed. Consequently, revisions of the feed-in tariff scheme have been proposed to encourage smaller systems and applications on buildings. Under the scheme, Type 1 installations (those associated with buildings) will attract 0,44 EUR/kWh, 0,39 EUR/kWh and 0,33 EUR/kWh for installed PV capacities of less than or equal to 20 kW, 21 kW to 200 kW, and greater than 200 kW respectively. Free-standing installations of any size can earn 0,31 EUR/kWh.

Also of importance for Spain's future PV market is the Royal Decree providing a Technical Building Code (TBC) that establishes obligatory requirements to be met in the building sector. A section of the TBC regulates the incorporation of solar PV energy and enforces the installation of PV on new large buildings, such as offices, government buildings, hospitals etc. In given buildings the PV electricity may be for own use or supply to the grid. The minimum PV capacity required in each case depends on the climatic zone, the building floor area and the building use.

Sweden (SWE)

Annual installed PV power in Sweden in 2007 reached about 1,4 MW – more than twice the size of the market the previous year. Grid-connected distributed installations showed a sharp increase and accounted for 80 % of the market. The cumulative installed power of PV systems in Sweden increased to 6,2 MW by the end of 2007 from 4,8 MW the previous year. The share of grid-connected systems increased to 27 % of the total cumulative installed power from 11 % in the previous year. With few exceptions these projects were carried out with support from the investment subsidy for public buildings. The off-grid PV markets are quite stable with roughly 300 kW being installed each year.

The support for PV installations in Sweden comprises the investment subsidy that allows for 70 % of project costs to be covered up to a maximum of 5 million SEK per building. The costs covered include materials, mounting and external project management costs for projects in buildings that are classified as special buildings or exempt from taxation by the property taxation law. This includes hospitals, churches, sports stadiums, schools, museums and practically any other building that is designated for public use or in conjunction with activities such as public transport. The support system was previously capped at 150 million SEK of direct capital subsidies. The estimated amount of installed capacity within the programme is around 3MW. In 2007 45 million SEK were paid out in subsidies. The vast majority of the PV systems installed within the scheme would not have been carried out without the financial support. The future of the grid-connected market is very unclear, since there is no information on a possible continuation of the support after 2008.

The results from the support programme are generally positive, with new stakeholders entering the PV community. Property managers, municipalities and other actors have taken an interest in PV as a new method of alleviating their environmental impact. In particular, Malmö city has embraced PV technology as a means to build a more sustainable urban environment. The largest project to date in Sweden is called Sege park and consists of twin systems, retrofitted to two hospital buildings. Further, an association, Solar City Malmö, has been created in order to promote new projects in the region. Inaugurated in March 2007, the PV system at the Ullevi Arena in Gothenburg is one of the largest PV systems in Sweden, covering the roof of the VIP stand and designed to attract attention and generate positive publicity. A number of systems have been installed in Stockholm, with the most prominent being on two sports centres, Åkeshovshallen and Hovet. Another municipality where the public subsidy for PV has been embraced is Båstad in the south-west of Sweden. An attractive building integrated PV installation has been built with semi-transparent modules used as the roof

for one of the stands at the tennis stadium. Another new stakeholder that has come into the PV market with the subsidy scheme is Akademiska Hus, which owns and manages most university buildings in Sweden. Several large projects have been carried out at university campuses.

The future of PV market support in Sweden has been widely debated in the PV community, but the key to a continuation of the support system is that an extension be put in place swiftly following the end of the present programme. However this is not very likely to happen, since the lead time for preparing this kind of government support is often extensive. Consequently, there will most certainly be a gap in the support system that may in turn adversely affect the PV market and, in particular, the PV system installers.

Switzerland (CHE)

Annual installed PV power in Switzerland in 2007 reached 6,5 MW – two and a half times the size of the market the previous year. Nearly all the systems installed were grid-connected and grid-connected capacity now makes up 90 % of Switzerland's cumulative installed capacity of 36,2 MW.

In March 2007 the Swiss parliament adopted a revised Energy Act, including a preferential feed-in tariff scheme for renewable energies. During 2007 the PV market was driven by the fact that the newly adopted law on preferential feed in tariffs will also apply to PV installations dating back to the start of 2006. From 2009 a compensatory feed-in remuneration will be granted for electricity which is produced from renewable energies and fed into the Swiss electricity grid. Producers of renewable electricity from hydro power (up to 10 MW), photovoltaic electricity, wind power, geothermal power and biomass energy can register their facilities for the compensatory feed-in remuneration from May 2008. A surcharge of up to 0,006 CHF/kWh will be levied on high voltage grid transmission costs from 1 January 2009 to fund the compensatory feed-in remuneration. This will bring in up to 320 million CHF per year. For PV an expenditure cap has been set at 5 % of the yearly amount generated by this levy until the feed-in tariffs decrease below a certain level (approximately 0,60 CHF/kWh). After reaching this level, another 5 % of the yearly amount will be set aside for PV. It is estimated that within the first stage about 25 MW to 28 MW of PV will be eligible for payments.
In addition to the Federal Energy Act, the solar stock exchange schemes provided by several big utilities are continuing to function well and it is expected that these will provide an additional steadily growing market for PV. It is estimated that in 2007 this market accounted for about 25 % of the newly installed PV capacity. Within the solar stock exchange schemes in several Swiss cities and undertaken by the regional utilities, more than 1,5 MW were installed. The market leader is the electricity utility of Zürich (ewz) with more than 5 MW under contract and another 1 MW to be added in 2008. In Bern the regional utility BKW added another 450 kW of PV to the existing 850 kW on the roof of the football arena Stade de Suisse, with the whole of the PV electricity production to be sold within their solar stock exchange scheme.
It is expected that the Swiss PV market will continue to grow throughout 2008 but not to the same extent as in 2007, due to the cap built into the feed-in tariff law. This will also lead to a decrease in the market in subsequent years since the cap will remain limited until the PV electricity costs fall below the prescribed level.

United Kingdom (GBR)

The annual installed PV capacity in the UK in 2007 was 3,8 MW, compared to 3,4 MW in 2006. The cumulative installed PV generation capacity increased by just over 20 % during 2007 reaching a total of 18 MW. Government funding supported approximately 85 % of the total new capacity. 2007 saw the continued implementation of the Government's Microgeneration Strategy for Great Britain which aims to create conditions under which microgeneration technologies (including PV) become a realistic alternative or supplementary energy generation source for the householder, communities and small businesses.

During 2007 grant support from the Department for Business Enterprise and Regulatory Reform (BERR) and the Northern Ireland Department for Enterprise, Trade and Investment (DETI) for the demonstration and field trial programmes amounted to 9,9 million GBP. PV installations occurred under a range of specific programmes. The Major Demonstration Programme, now closed, provided up to 50 % capital grants for 1 433 kW of PV installations during 2007 with maximum levels per kW set for small-scale (<5 kW) installations. The Low Carbon Buildings Programme has proved to be very popular with householders and supported the installation of 1 295 kW of PV. The grants available to householders were reduced due to high demand. From May 2007 PV installations were eligible for a maximum of 2 000 GBP/kW of installed capacity, subject to an overall maximum of 2 500 GBP or 50 % of the relevant eligible costs, whichever is the lower. For larger projects under the programme (which totaled 193 kW), including community organizations and small and medium enterprises, successful applicants received up to 50 % of their total eligible installation cost, up to a maximum grant of 1 000 000 GBP. In Northern Ireland, the Reconnect scheme provided householders with up to 50 % of the total installed cost of PV. The total Reconnect grant support for PV during 2007 was 335 808 GBP for 124 kW installed. Northern Ireland Electricity (NIE) provided grants for 57 PV projects (273 kW) during 2007, involving an additional

326 000 GBP. The grants included top-up funding for projects receiving support under the Low Carbon Buildings Programme and the Reconnect scheme, plus contributions to the Switched on Schools programme which aims to install PV at 21 rural schools throughout Northern Ireland.

Other highlights included the Code for Sustainable Homes, a voluntary initiative of Government and industry in England, to actively promote the transformation of the building industry towards more sustainable practices. It sets standards for key elements of design and construction affecting the sustainability of a new home, the higher levels of which require the installation of generation technologies such as PV.

United States of America (USA)

Annual PV installations in the United States increased 42 % from 145 MW in 2006 to 206,5 MW in 2007. Most of the growth occurred in the grid-connected sector – to over 150 MW during 2007. This was largely due to large PV installations by retailers such as Wal-Mart, Best Buy, Safeway, Home Depot and Costco. In addition large utility-scale PV systems were completed. Off-grid installations accounted for about one quarter of the PV capacity installed. Total cumulative US PV installations grew by 33 % in 2007 to over 830 MW. California accounted for 70 % of all PV installations in the United States.

Federal tax credits for the purchase of PV went into effect in 2006 and include a 30 % investment tax credit for commercial grid-connected systems and a 30 % tax credit for residential grid-connected PV systems, with an annual cap of 2 000 USD per system. However, the federal tax credit, other investment tax credits or a Federal renewable portfolio standard were not included in the Energy Independence and Security Act signed in late 2007. The federal tax credit for installing both residential and commercial PV systems expires at the end of 2008. However, it is thought that Congress could extend the tax credit in late 2008.

At the State Government level, renewable portfolio standards (RPS) requiring electricity utilities or electricity providers to supply a certain quantity of their delivered energy from renewable energy sources such as PV have been adopted in 25 states and the District of Columbia. These requirements call for as much as 20 % to 30 % of electricity to come from renewable energy sources in the next 15 to 20 years. During 2007, many states revised their renewable portfolio standards to include solar technologies. Five states established new renewable energy generation requirements, three adopted voluntary programmes, and seven significantly increased (in many cases doubled) their commitment to renewable energy. Several states established ambitious PV goals, including California (3 000 MW in 10 years), New Jersey (2 300 MW by 2020), Maryland (1 500 MW by 2022) and Massachusetts (27 MW by 2011). The states with the largest amount of PV installed in 2007 were California (87,1 MW), New Jersey (16,4 MW), Nevada (14,6 MW), Colorado (12,4 MW) and New York (4,4 MW). With the exception of New York, these were also the states with the best net-metering policies. The number of states that are executing subsidy programmes for implementing clean energy technologies is growing annually. State funds are used as rebates for the purchase of PV systems, as well as for renewable energy education and outreach, research, and establishment of green pricing programmes.

Interest in utility-scale PV projects increased during 2007 as states created more incentive programmes for PV installations. Priority policy issues discussed at the state level included interconnection agreements, renewable portfolio standards and net metering. Electricity utility Pacific Gas & Electric (PG&E) announced an agreement with two developers of utility-scale PV solar power systems, Cleantech America LLC and GreenVolts Inc., to deliver up to 7 MW of PV power for its customers throughout northern and central California. The US-based SunEdison and the Canadian company SkyPower Corporation have joined forces to develop, build, own, and operate a PV farm of up to 50 MW capacity in Ontario, Canada. Xcel Energy began purchasing PV electricity from an 8,2 MW plant near Alamosa, Colorado. Nellis Air Force Base celebrated the completion of North America's largest utility-scale PV system. The 14 MW PV plant is a joint effort of the US Air Force, MMA Renewable Ventures LLC, SunPower, and the Nevada Power Company, and will supply about one quarter of the electricity used at the base.

Electricity utility green pricing programmes are one segment of a larger green power marketing industry that counts Fortune 500 companies, government agencies and colleges and universities among its customers, and helps support more than 3 000 MW of new renewable electricity generation capacity. More than 800 electricity utilities in the United States offer these programmes. In 2007, the utilities with the

Wooden House in Denmark (Courtesy Energimidt, DK)

highest green power sales as a percentage of total utility retail electricity sales were Austin Energy (Texas), Portland General Electric, PacifiCorp, Florida Power & Light, and Xcel Energy. In 2007, total electricity utility green power sales exceeded 4,5 billion kWh, about a 20 % increase over 2006. Approximately 600 000 customers are participating in these electricity utility programmes nationwide.

The immediate future for PV deployment in the US will be influenced by a continuation of the main issues affecting both the US PV industry and consumers during 2007 – extension of the federal tax credit, a surge in venture capital investment, development of new technologies, and significant progress on non-technical issues such as business models, codes and standards.

Other countries

Verifying total market volume and other data for non-IEA PVPS countries is challenging, especially due to the often large number of small systems involved. The following descriptions are not exhaustive and are by no means comprehensive. They are intended to give an overview of a selection of international markets outside the IEA PVPS Programme to allow the IEA PVPS data to be viewed in the context of global PV developments.

Bangladesh

Over two-thirds of the Bangladeshi population does not have access to electricity. For many remote and rural locations renewable energy technologies represent the best approach for delivering electrical services. A number of organizations including the Rural Electrification Board, the Bangladeshi Power Development Board and the Local Government Engineering Department have supported the delivery of PV-based rural electrification services to date, notably with Solar Home Systems (SHS).

The major roll-out of PV services to off-grid areas however has been achieved under the Solar Energy Programme of the World Bank/GEF/KfW/GTZ Rural Electrification and Renewable Energy Development Project (REREDP). The project is managed by the Infrastructure Development Company Limited (IDCOL) which provides refinancing, technical assistance and training to 15 partner organizations (POs) that sell SHS to householders and businesses in remote and rural areas. Typically this is achieved with a micro-credit financing arrangement.

By the end of 2007 some 175 000 SHS had been installed under the IDCOL Solar Programme. As of May 2008 the figure had reached 211 000, equivalent to more than 11 MW capacity, supplying electricity-based services to more than one million users. An interesting development towards the end of 2007 was the agreement reached between IDCOL and the International Bank for Reconstruction and Development, whereby IBRD will purchase Certified Emissions Reductions (CERs) for the carbon abatement achieved through the use of SHS compared to alternative technologies. IDCOL will act as an agent, bundling the abatement from these numerous small-scale systems. Every 1 000 SHS installed will avoid 425 tonnes of carbon dioxide emissions each year, which will in turn generate some 3 825 EUR for reinvestment in the programme.

China

The Chinese domestic market reportedly grew by 100 % in 2007 compared to 2006 (2006 figure revised downward from 15 MW to 10 MW). 20 MW of new capacity were installed during the year, taking the cumulative installed capacity to date to 100 MW. The cumulative total includes some 22 MW of 'PV consumer products'; this category of application is not generally reported by IEA PVPS countries and is not included in the applications analysis presented in this report.

Of the 14 MW installed in 2007 that were not used for consumer products, the rural electricity sector accounts for the majority share (9 MW). Telecoms and other industrial applications accounted for 3 MW. Grid-connected applications accounted for a relatively small proportion (<15 %) of the annual installed capacity. Nevertheless, this addition represents a 50 % increase in the total grid-connected capacity.

In November 2007, the National Development and Reform Commission issued a notice for the construction of eight large-scale PV power stations for provinces in the relatively less-developed west of the country. These are each expected to have a capacity of at least 5 MW.

The development plan for China's renewable energy sector envisages total installed PV capacity by 2010 of 220 MW (excluding PV products). This includes 80 MW of rural electricity generation, 50 MW of BIPV and 50 MW of 'Power Stations'. By 2020, the installed capacity is expected to amount to 1 500 MW, with two-thirds of this accounted for by the BIPV sector.

European Union – New Member States (NMS)

A detailed analysis of the Status of PV in the European Union New Member States 2007 has been prepared by the Centre of Photovoltaics at Warsaw University of Technology and the Polish Society for PV. This reports that '2007 brought further moderate progress in PV in NMS as a whole. The countries which have been most successful in stimulating deployment and encouraging the growth of renewable energy industries are those which have adopted an integrated package of market stimulation and promotion measures (Czech Republic, Slovenia, Cyprus), coupled with strong government support for Research and Development'.

As a whole, PV capacity increased three-fold throughout the twelve NMS to over 9,5 MW at year

end 2007, compared to under 3,2 MW at the end of 2006. The picture is heavily skewed, however, by the Czech Republic which alone saw an additional 4,5 MW of PV – almost entirely grid-connected – installed during the year. To put this in context, the Czech Republic installed more PV in 2007 than eight of the IEA PVPS participating countries. Slovenia and Cyprus both added approximately 0,5 MW of new PV capacity, also predominately grid-connected.

In all three countries, a feed-in tariff operates as the principal incentive for investments in PV systems. The Czech Republic offers a FiT rate fixed at 0,53 EUR/ kWh for 20 years. In Cyprus it is possible to opt for a FiT over fifteen years or a somewhat lower FiT over the same term in conjunction with a capital grant.

India

In 2005, India's government announced the Rajiv Gandhi Gramin Vidyutikaran Yojana (RGGVY), which aims to provide electricity access to all households within a five year timescale. At the time, some 78 million homes throughout the country were considered to be unelectrified. At the same time, national Rural Electrification policy has established a 'minimum lifeline' access to electricity of 1 kWh per household per day. However there are several thousand remote villages and hamlets where grid connection is not feasible or cost-effective in the foreseeable future.

For these 6 500 villages and hamlets that have been identified by the Rural Electrification Corporation (REC) to be beyond the reach of the electricity grid, basic electricity needs are to be met with a variety of decentralized renewable energy sources, including PV home lighting systems and solar lanterns under the Ministry of New and Renewable Energy's (MNRE) Electrification of Villages Programme. As of the end of 2007 close to 3 400 unelectrified villages and some 800 unelectrified hamlets have been covered under the programme.

To date MNRE programmes have reportedly resulted in the installation of approximately 110 MW of PV, including almost 70 000 street lighting systems, over 360 000 home lighting systems, 585 000 solar lanterns and over 7 000 PV pumps.

The Indian electricity supply situation is characterized by a serious shortage of supply and insufficient generation capacity to meet peak demands. The Western (Maharashtra and Gujarat) and Northern regions (notably Uttar Pradesh and Madhya Pradesh) are particularly constrained. The consequences of this situation are that many areas face rolling brownouts and periodic supply curtailment. Under the Electricity Act, 2003 State Electricity Regulatory Commissions (SERCs) have the power to take the necessary steps to promote renewable energy within their state. A number of SERCs have established Renewable Purchase Obligations to support procurement of renewable power. However these are predominately geared towards large-scale wind, small-hydro and biomass.

For the renewable energy sector, the detail of government expectations for capacity additions for the next five years are contained within the Working Group on Non-Conventional Energy's inputs to the 11th Five-Year Plan. This foresees a grid-interactive (centralized grid-connected) power capacity addition of 14 000 MW by 2012. This includes only 50 MW of PV. However, it is further expected that 1 000 MW of Distributed/ Decentralized Renewable Power Systems (DRPS) will come on-line during the same period, which presents an opportunity for building integrated PV if a suitable investment environment emerges.

Senegal

The Morrocan Utility, Office National d'Electricite (ONE), has been awarded a contract under a World Bank / Global Environment Facility project to operate a rural electrification project in Northern Senegal. This will bring electricity services to 550 villages.

Predominantly, electricity supply will be achieved by village mini-grid systems, though some remote solar home systems will also be installed. Under Phase 1 of the project, ONE intends to set up between 2 000 and 3 000 SHS, equivalent to 200 kW to 300 kW of PV total capacity.

Sri Lanka

The World Bank Renewable Energy for Rural Economic Development (RERED) Project was due to conclude at the end of 2007, having resulted in the installation of some 95 000 solar homes systems, equivalent to 4,2 MW of PV capacity. Systems are marketed, installed and serviced by a number of accredited solar companies, using products that meet pre-defined technical specifications and are accompanied by agreed warranty conditions. Systems are normally purchased over a number of years under a consumer finance arrangement using an external micro-credit organization.

For the Sri Lankan users of the PV SHS, the service displaces traditional kerosene lanterns, while also providing access to TV, radio and more recently the ability to recharge mobile phones. The project has been extended beyond the intended completion date having exceeded the original objective of servicing 85 000 households using SHS. As of mid 2008, almost 99 000 systems have been installed, increasing the PV capacity installed under RERED to almost 4,4 MW.

United Arab Emirates

In 2006, the Abu Dhabi government announced its intention to establish a new, carbon-neutral city in the desert. Within eight years and with some 22 billion USD of investment, Masdar City is planned to be home to 50 000 people, some 1 500 businesses and a new Institute of Science and Technology.

The city will incorporate traditional desert design principles to minimize building energy consumption, but it also presents an opportunity for Abu Dhabi to gain a strong foothold in the emerging sustainable technologies sector. The Abu Dhabi Future Energy Company (ADFEC) has established an agreement with the German firm Conergy to build a 40 MW solar power plant. PV systems are eventually expected to be incorporated in buildings across the city.

On the back of this guaranteed demand, as well as positioning for future export opportunity, 600 million USD are earmarked for investment in two new thin film manufacturing facilities that will be constructed over the next three years. Firstly a 50 MW plant will be constructed in Erfurt Germany. By 2010 Masdar plans to build another factory in Abu Dhabi itself, with an initial capacity of 100 MW.

1.4 R&D activities and funding

The public budgets for research and development in 2007 in the IEA PVPS countries are outlined in Table 4. In aggregate the 2007 expenditure was very similar to the R&D expenditure in 2006 – around 330 million USD. About half the countries reported increases in their budgets, and half reported decreases. The reader is directed to the individual national survey reports on the public website for a comprehensive summary of R&D activities in each of the countries. A brief overview of the activities in selected countries is presented below.

A clear leader in terms of R&D public funding, the US has expanded R&D efforts through the Department of Energy Solar Energy Technologies Programme (Solar Programme) and with industry and university partners through the Solar America Initiative (SAI) for fundamental research and development of next-generation, low-cost PV products. In addition the SAI works to transform the US PV market by increasing public awareness through education and training, provides technical assistance for large-scale PV projects, streamlines utility interconnection agreements for solar energy systems, and updates codes and standards. In 2007 the PV sub-programme was organized around three major research, development and deployment activities: fundamental research, advanced materials and devices, market transformation. The German PV R&D strategy focuses on wafer based silicon technologies, followed by thin film technologies, the development of system technology and, to a lesser degree, organic PV and concentrating PV. Japan's 'Four Year Plan for Photovoltaic Power Generation Technology Research and Development', running until 2009, contains projects such as R&D for next generation PV systems and PV system technology for mass deployment (phase II). A number of demonstration projects are also relevant - Verification of grid stabilization with large-scale PV power generation systems, Development of an electric energy storage system for grid-connection with new energy resources, Demonstrative project on grid-interconnection of clustered photovoltaic power generation systems and Demonstrative project of regional power grids with various new energies. The Korean PV R&D focus is on developing manufacturing technologies for PV cells, ingots and wafers, BIPV modules and power conditioning systems including inverters. The Norwegian situation is interesting, with publicly funded activities focusing on issues relating to silicon feedstock for crystalline cells, and wafer production and cell production technologies in support of the national industries. Within those industries themselves, it is reported that the Renewable Energy Corporation (REC) Group plans to invest 36 million USD in a new R&D facility and there are estimates that the company currently spends over 30 million USD annually on R&D, a significant proportion of which is carried out in Norway.

European Union R&D funding support for PV continued under the 7th Framework Programme which will operate from 2007 to 2013. Work includes development and demonstration of new processes, standardized and tested building components, demonstration of additional benefits of PV electricity and longer-term strategies for both high-efficiency and low-cost PV routes. In mid 2007 the European PV Technology Platform, which comprises stakeholders from research, industry and government, published a finalized Strategic Research Agenda that details the R&D efforts needed for continued cost reduction of PV systems with the aim of reaching grid parity in the south of Europe by 2015.

Table 4 – Public budgets for R&D in 2007 in selected IEA PVPS countries

Country	Million EUR	Million USD
AUS	4,5	6,2
CAN	3,8	5,1
CHE	8,2	11,3
DEU	44,5	61
DNK	3,4	4,6
FRA (ANR, ADEME)	9	12,3
GBR	11,1	15,2
ISR	0,07	0,1
ITA	5	6,8
JPN (METI)	28,4	38,9
KOR	13,4	18,4
MEX	0,2	0,27
NOR	4,6	6,3
SWE	2,6	3,5
USA	101	138,3

2 The PV Industry

This section provides information on the industry involved in the production of PV materials (feedstock, ingots, blocks/bricks and wafers), PV cells, PV modules and balance-of-system components (charge regulators, inverters, storage batteries, mounting structures, appliances etc.) during 2007. It is worth noting that three steps along the supply chain – production of the upstream materials, PV cell production and final manufacture of PV modules - each account for roughly one third of the cost of finished PV modules.

A national overview of PV material production and cell and module manufacturing in the IEA PVPS countries during 2007 is presented in Table 5 and is directly based on the information provided in the national survey reports. This likely accounts for approximately two-thirds of the worldwide production, down from about three-quarters in 2006 and at least 90 % previously.

In general terms, during 2007 the PV industry continued to demonstrate the traits of a maturing industry sector. In particular, businesses have actively pursued integration along the whole supply chain or at least multinational partnerships, joint ventures and long-term supply agreements. This is in contrast to the earlier stages of industry development with companies making one or two products for a limited number of markets. With time it would be expected that the smallest businesses may disappear altogether, the small to medium players get absorbed by others or specialize in PV niche markets and vertical integration of the industry is the norm.
An example of the modern PV business is Norway's Renewable Energy Corporation (REC). The REC Group is present throughout the entire PV supply chain. It is amongst the world's largest producers of silicon and wafers for PV applications, as well as being a producer of PV cells and modules. Only wafers and cells are produced by REC in Norway. Silicon feedstock is produced in the US and PV modules are manufactured in Sweden. At the end of 2007 REC was committed to expansion projects representing investments of 2 billion USD. These investments will cover new production capacity at existing locations in the US, Norway and Sweden plus an integrated solar manufacturing complex in Singapore. REC has long-term supply agreements in place with countries such as Taiwan.

Table 5 – Production of PV materials, cells and modules in 2007 in selected IEA PVPS countries

Country	Solar PV grade Si feedstock production (tonnes) ***(1)***	Production of ingots & wafers (MW) ***(1) (2)***	Cell production (all types, MW)	*Cell production capacity (MW/year)*	Module production (MW) ***(3)***		*Module production capacity (MW/year)*
					wafer based (sc-Si & mc-Si)	thin film (a-Si & other)	
AUS	-	-	36	*50*	9	-	*10*
AUT	-	-	-	-	47	-	*>52*
CAN	-	-	-	-	7	<1	*25*
CHE	-	approx. 120	n.a.	*n.a.*	n.a.	<1	*n.a.*
DEU	8 000	415	842	*1 456*	875	94	*1 333*
DNK	-	1	-	-	<1	-	*<1*
ESP			>120	*>120*	>400		*>400*
FRA	-	88	40	*>60*	50	<1	*>60*
GBR	-	190	<2	*2*	129	<2	*237*
ITA	-	-	13	*66*	72	-	*172*
JPN	1 391	670	923	*1 507*	>>333	89	*>>898*
KOR	-	11	25	*36*	53	-	*188*
NOR	-	503	135	*>135*	-	-	-
PRT	-	-	-	*8*	19	-	*38*
SWE	-	-	-	-	70	-	*190*
USA	5 100	142	266	*318*	89	177	*318*
Total	**14 491**	**2 140**	**>2 402**	***>3 758***	**>2 154**	**365**	***>3 922***

*Notes: **(1)** Although some IEA PVPS countries are reporting on production of feedstock, ingots and wafers, the picture from the national survey reports of these sections of the PV industry supply chain is not complete and consequently these data are provided more as background information. **(2)** 12 tonnes of ingot are equivalent to 1 MW of PV cells. **(3)** mc-Si (multicrystalline silicon) includes modules based on EFG and String Ribbon cells. 'Other' refers to technologies other than silicon based. The total module production and module production capacity for Japan were not available.*

Althegnenberg, Germany (Courtesy RTS corp., Japan)

The production of specialized equipment for the PV manufacturing industry has become a significant business in its own right. Activities and products in this sector of the PV industry value chain include chemical and gas supplies, abrasives and equipment for cutting wafers, pastes and inks for cells, encapsulation materials for modules and specialized measurement equipment for use in production processes.

2.1 Feedstock, ingots and wafers (upstream products)

Crystalline silicon wafers remain the dominant substrate technology for making PV cells and, for the time being, the discussion in this section does not refer to thin film technologies. Although some IEA PVPS countries are reporting on production of feedstock, ingots and wafers, the picture from the national survey reports of these sections of the PV industry supply chain is not complete and consequently this section is provided more as background information.

Feedstock

Today, the main source of solar photovoltaic grade silicon feedstock is virgin silicon. The process is the same as for producing semiconductor grade silicon. However, the producers have simplified some steps in their processes for supplies to the PV industry. There are many attempts to replace the current expensive purification process, based on chemical gaseous purification, by cheaper alternatives including metallurgical purification (condensed phase). Although significant progress has been achieved during recent years and several pilot plants have been put into operation, these new materials have not yet been introduced to the market.

In 2007 solar photovoltaic grade silicon feedstock supply remained dominated by the four major producers: Wacker in Germany, REC Solar Grade Silicon and Hemlock Semiconductor Corporation in the US, and Tokuyama in Japan. The US is a large exporter at this level of the PV industry supply chain.

It has been reported that the selling price of solar photovoltaic grade silicon in 2007 was at least two to three times the 2003 price, with increases of 20 % to 25 % each year. Analysts have predicted that 2008 will herald the end of the tight feedstock supply situation that has existed for several years. The large companies have all announced significant expansion programmes. Some of these expansion projects will make use of new technologies, particularly the replacement of hot filament reactors (the so-called Siemens reactors) by fluidized bed reactors for the preparation of pure silicon. The key current production countries – Germany, the US and Japan – have all also reported new entrants preparing to enter the market. Other IEA PVPS countries including Korea, Norway, France, Italy and Spain have flagged developments in the near future. Many other newcomers (for example, maybe ten companies in China alone) have also announced plans to enter the feedstock silicon business.

It is difficult to predict what may happen further along the industry supply chain as the current tight feedstock supply situation eases. Feedstock prices are fixed for a number of years and hedging contracts are in place – sudden drops in price should not be expected from these players. However order volumes should go up and consequently costs should go down. Further, an expectation of rapid price falls should be tempered by advice from the finance industry – some new start-ups can be expected to falter, particularly due to the effect that plant expansions by the major companies may have on the availability of venture capital.

Ingots and wafers

To make single crystal silicon ingots, multicrystalline silicon ingots or multicrystalline silicon ribbons the basic input material is highly purified silicon. The ingots need to be cut into bricks or blocks and then sawn into thin wafers, whereas the ribbons are cut directly to wafers of desirable size. Silicon ingots are of two types: single crystal and multicrystalline. The first type, although with different specifications regarding purity and specific dopants, is also produced for microelectronics applications, while multicrystalline ingots are only used in the PV industry. Ingot producers are in many cases also producers of wafers.

European (particularly Norway, Germany and the UK) and Japanese companies feature most prominently in this section of the industry value chain. Some companies are vertically-integrated, controlling the process from ingots to cells and modules. Under

current tight feedstock market conditions the companies having their own feedstock or having secured long-term contracts are strategically poised to grow. An interesting trend is the decrease of wafer thickness, strongly motivated by the rising price of silicon feedstock and an ongoing focus on improving manufacturing yield.

Norway's REC Wafer (ScanWafer) has become the world's leading producer and supplier of multicrystalline silicon wafers for the PV cell industry. In 2007 REC Wafer's plants produced multicrystalline wafers for approximately 468 MW of PV cells, a 61 % increase from 2006. At the end of 2007 REC Wafer had four expansion projects underway in Norway that will more than triple the production capacity to at least 1 500 MW by 2010. In Germany the main supplier of silicon wafers is Deutsche Solar AG in Freiberg. Japan's M.Setek, SUMCO and JFE Steel manufacture silicon ingots and wafers for supply to PV cell producers. Kyocera manufactures silicon ingots and wafers at its own manufacturing facilities. The UK's Crystalox Limited is one of the world's largest producers of multicrystalline silicon ingots, exporting to PV companies in Europe and Japan. Ingots and wafers are produced in Switzerland and France and wafer production is reported in the US.

2.2 Photovoltaic cell and module production

The total PV cell production volume for 2007 in the IEA PVPS countries was reported to be about 2 400 MW, up from 1 900 MW in 2006, an increase of 26 %. The largest increase in production took place in Germany (additional 330 MW) while Japan's production remained at the same level as in 2006.

Japan remained the leading producer of photovoltaic cells (923 MW) during 2007. Production of cells and modules in this country accounted for 39 % and 22 % respectively of the IEA PVPS countries' production, with Germany in second place for cell production with 35 % and first place for module production with a 36 % share. The relative German market share in 2007 has continued to increase at the expense of the Japanese market share. In the United States, the third largest PV cell producing country, production increased by 32 % from 2006. Spain's module production increased to overtake the US for the third position during 2007. However, US output of thin film technologies almost doubled to 177 MW, representing nearly one half of world thin film production.

Japan listed 11 companies as PV cell/module manufacturers: Sharp, Kyocera, Sanyo Electric, Mitsubishi Electric (MELCO), Kaneka, Mitsubishi Heavy Industries (MHI), Hitachi, Fuji Electric Systems, Honda Motor, Showa Shell Sekiyu and Clean Venture 21. It

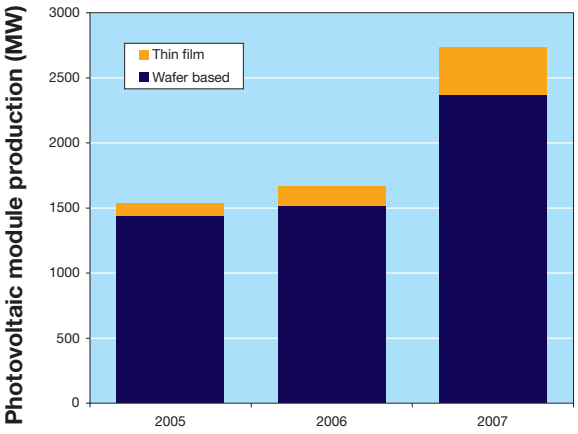

Figure 4 – Trends in photovoltaic module technologies 2005–2007

was reported that growth in 2007 was significantly affected by the shortage of solar photovoltaic grade silicon feedstock. However, in Germany steady growth was reported. Nine companies were engaged in PV cell production – Deutsche Cell, ErSol Solar Energy, EverQ, Q-Cells, Scheuten Solar, Schott Solar, Solarwatt Cells, Solland Solar Cells and Sunways. The production of PV modules grew strongly and many manufacturers are aiming for further production expansions. There was a significant increase in thin film production. The US reported that solar photovoltaic grade silicon feedstock shortages continued to plague the industry in 2007. Thin film producers took advantage of the higher solar photovoltaic grade silicon feedstock prices to increase their own production since they do not depend on this commodity. The major PV companies in the US in 2007 were First Solar, Uni-Solar Ovonics, Solar World (Shell) and Evergreen Solar. Spain reported healthy growth amongst its four cell producers – BP Solar, Isofoton, Inslaciones Pevafersa and Solaria – and its 20 module producers, including Solaria, Isofoton, Atersa and Siliken.

Sharp's module assembly plant in Wrexham in the UK doubled its production capacity during 2007. The UK's other major PV manufacturer is Romag's Building Integrated Photovoltaic (BIPV) lamination facility. Companies assembling and encapsulating standard or tailor-made and specially designed modules can now be found in Italy. In Sweden the module manufacturing industry is now growing, with companies starting to increase production following earlier problems with bottlenecks in the supply chain. The largest module company, REC ScanModule, is forging ahead with expansion plans that will make its Glava plant the second largest in Europe, with sister company REC Scan-Cell AS supplying the PV cells. In France Photowatt prepared to increase cell production and Tenesol planned for module production capacity increases. Austrian module

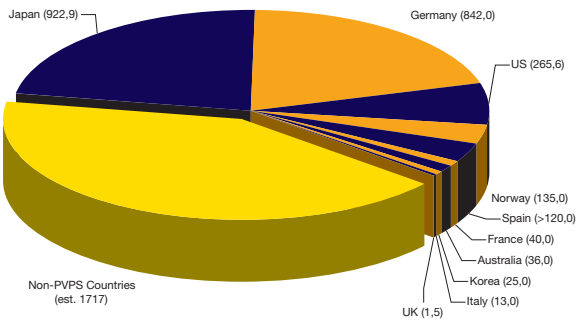

Figure 5 – World PV cell production (MW) by country in 2007

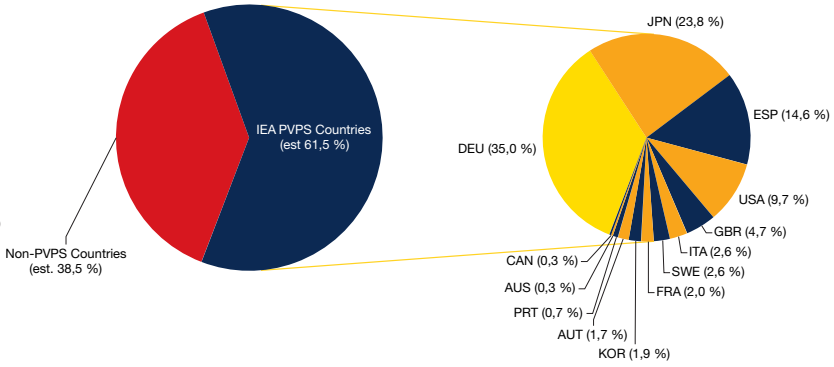

Figure 6 – Country shares (%) of world PV module production in 2007

manufacturers only slightly increased their output compared to 2006, mainly due to a lack of PV cell availability on the international market (PV cells are imported from Germany, Spain, the US, Taiwan, China and others). Almost all module production is exported, with the main markets in 2007 being Germany, Italy, Switzerland, Spain, the US, Hungary, Turkey, Korea, Sudan, Croatia and China.

In 2007 wafer-based crystalline silicon technologies maintained their dominance, accounting for about 87 % of the market for PV modules in the IEA PVPS countries. However, this percentage has slipped a further four percentage points from 2006, following a loss of three percentage points the previous year. This is due to thin film technologies increasing their share of the market. Total module production increased by over 50 % from 2006, following the sluggish growth of about 9 % the previous year. Over the last decade in the IEA PVPS countries, each year's installed market growth expressed as a percentage of total module production has ranged from 63 % in 1998 to 88 % in 2004. Over the past three years this figure has settled at around 84 % to 86 %.

The cell production capacity in the IEA PVPS countries, defined as the maximum output of manufacturing facilities, increased by about 35 %. Utilization of capacity was about 65 %, similar to the previous two years and down from a high of 86 % in 2004. The increase in the module production capacity and the utilization of capacity were over 40 % and about 65 % respectively. It would appear that, following flat module production and low new module capacity investments in 2006, the longer-term expectations concerning the health of the whole PV supply chain have become more positive. In this regard, 2007 provided some interesting growth stories in individual countries and also at the global level. The reader is directed to the individual national survey reports for a comprehensive summary of manufacturers and production in each of the countries. Some consistent themes emerged from amongst the range of countries reporting during 2007, despite the variations of their policies and markets:

- cell supply shortages have created difficult circumstances for many module producers but this appears to be easing (at least in some countries);
- foreign product and price offers continue to strongly impact domestic markets;
- access to a booming foreign market provides an ongoing lifeline for the industries in some countries where the domestic market has decreased.

The Trends report is not designed to undertake direct assessments of production developments in countries not participating in the IEA PVPS Programme. However, analysis of various industry commentators' findings in relation to production in the rest of the world highlights the continued growing importance of these other manufacturing centres and this brief summary is provided for completeness. Photon International, for example, suggests that some 1 900 MW of PV cells and over 2 000 MW of PV modules were manufactured outside of PVPS countries in 2006. Considering that some manufacturers reported production for 2007 equivalent to 100 % of their production capacity as installed at the end of 2007, some caution should be exercised when analyzing the apparent production. The need for caution is reinforced in the light of the previous years' data, as some of the responding companies had significantly lower production capacity at year end 2006 than that reported for 2007 and there is necessarily a lead-time in bringing new production capacity on line. There is also a wide range of figures reported by different sources. For example in comparison to Photon International's estimate for China's cell production of almost 1200 MW, a report compiled in mid 2008 by the China Renewable Energy Development Project places the figure 10 % lower, at about 1090 MW.

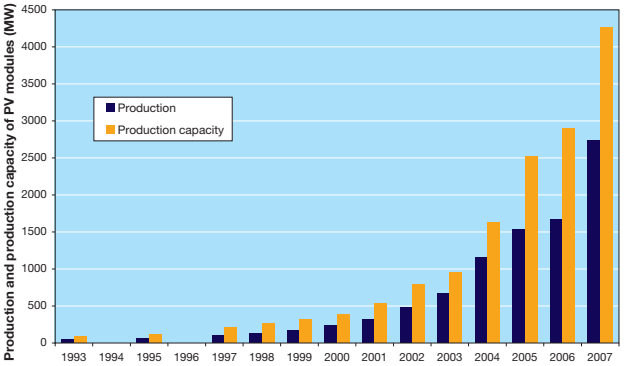

Figure 7 – Yearly PV module production and production capacity in the IEA PVPS reporting countries

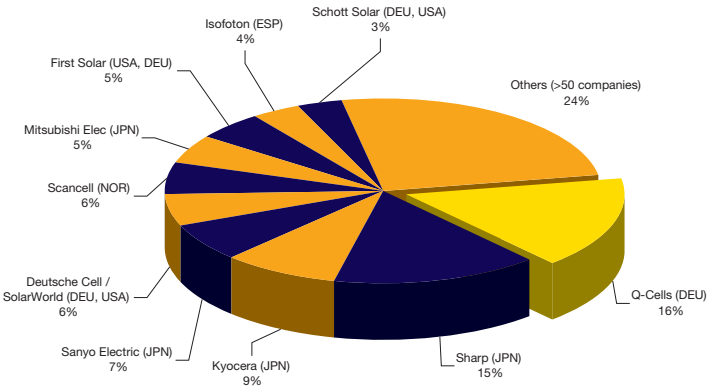

Figure 8 – Share of PV cell production in the IEA PVPS reporting countries by company in 2007 (%)

Nonetheless, even applying the average production utilization factor for non-PVPS manufacturers to the more doubtful information suggests that both PV cell and module production in 2007 are close to 1 720 MW throughout the non-PVPS countries. This equates to almost 42 % of total world PV cell production and 37 % of total world PV module production, up from 26 % and 29 % respectively the previous year.

Within the space of five years, China has grown from relative obscurity to apparently become the world's leading producer of both PV cells (estimated production of around 1 000 MW) and PV modules (estimated production over 1 300 MW). At least three Chinese companies (as well as one Taiwanese firm) would register on a global top 10 of world PV cell manufacturers. Equally significantly, the leading PV module manufacturer in the world is now based in China. Taiwan accounted for some 430 MW of PV cell production, placing it fourth in terms of national production behind China, Japan and Germany. Another significant player is the Philippines with 100 MW of cell production in 2007. After China, India is currently the leading non-PVPS producer of PV modules with close to 100 MW in 2007, while Taiwan and the central European countries of the Czech Republic and Hungary each reported between 50 MW and 60 MW.

As to future developments, Malaysia appears to have secured a major PV cell manufacturing facility. The announced 1 GW plant is expected to start production during 2010. As mentioned previously, REC will develop an integrated manufacturing complex for the production of wafers, cells and modules in Singapore. Full capacity of 740 MW of wafers, 550 MW of cells and 590 MW of modules should be reached before 2012. The Middle East also looks to be an emerging region to monitor in relation to manufacturing developments: feedstock silicon production for the PV industry is due to commence in Saudi Arabia within two years, while the United Arab Emirates anticipate that a large-scale thin film module facility (of the order of 100 MW capacity) will begin production in 2010 to help service the Abu Dhabi Government's Masdar initiative.

2.3 *Balance of system component manufacturers and suppliers*

Balance of system (BOS) components account for between 20 % (standard grid-connected system) and 70 % (off-grid installation) of the total PV system cost. Accordingly the production of BOS products has become an important sector of the PV industry. With the rapid expansion of the world-wide market for grid-connected PV systems, inverters are currently the focus of interest. Manufacturers of inverters again reported a considerable increase in their output during 2007.

In Europe the large inverter companies are located in Germany, Austria, Switzerland, Denmark and the Netherlands. Following the expansion of their national PV markets Italian and Spanish companies have also expanded their inverter businesses. Outside of Europe extensive activities in this field are reported from Japan, the US, Canada and Korea. In addition to the well known PV inverter producers a number of established electronics companies are recognizing PV as a promising business opportunity and have started developing new products. In addition to basic BOS components, the production of specialized components such as PV connectors, DC switchgear and monitoring systems is becoming a more important business for a number of large electrical equipment manufacturers.

Higashi-Matsudo, Japan (Courtesy RTS corp., Japan)

Today most of the inverter products are dedicated to the residential PV market and typically have rated capacities ranging from 1 kW to 5 kW, with single (Europe) or split phase (the US and Japan) grid-connection. For larger systems typical sizes are 10 kW, 30 kW and 100 kW and are usually installed in a three phase configuration. With the increasing number of MW scale PV systems being installed in countries such as Germany, Spain, Italy, Portugal, the US, Japan and Korea, larger inverters have been developed with capacities up to 1 MW. Increased production and new market entrants have led to the ongoing price reduction of inverter products. Prices quoted for 2007 range from less than 0,4 USD/W for large inverters, up to 1 USD/W; a typical price is 0,6 USD/W (for a 5 kW unit) or at least 10 % of the price of the less expensive grid-connected PV systems.

Tracking PV systems have recently become a more attractive proposition, particularly for PV applications in countries with a high share of direct solar irradiation and attractive PV market incentives. It is expected that by using such systems the energy yield of a PV system can be increased by up to 40 % compared with non-tracking PV systems.

With an increasing penetration of PV in electricity networks, R&D efforts are being directed at smoothing the fluctuations associated with PV generation and electric loads. Reports from Japan describe plans to combine PV systems with new long-life storage batteries with the aim of further increasing the amount of PV electricity that can be accommodated by the electricity network.

Table 6 – Indicative installed system prices in reporting countries in 2007

Country	Off-grid (EUR or USD per W)				Grid-connected (EUR or USD per W)			
	<1 kW		>1 kW		<10 kW		>10 kW	
	EUR	USD	EUR	USD	EUR	USD	EUR	USD
AUS	**12,2–15,2**	16,7–20,8	**11–14**	15–19,2	**6,1–7,3**	8,3–10	**4,9–6,1**	6,7–8,3
AUT	**8–15**	11–20,5	**8–15**	11–20,5	**4,8–6**	6,6–8,2	**4,8–5,5**	6,6–7,5
CAN	**10,2**	14	**5,3**	7,2	**5,8**	7,9	**6,8**	9,3
CHE	**10,4–13,4**	14,2–18,3	**9,1–10,4**	12,5–14,2	**5,7–5,9**	7,8–8	**4,6–5,5**	6,3–7,6
DEU					**4,4–5,2**	6–7,1	**4,3**	5,9
DNK	**9,4–12**	12,9–16,5	**20,1–26,9**	27,6–36,8	**4,7–11,4**	6,4–15,6	**6,7–13,4**	9,2–18,4
ESP	**15–20**	20,5–27,4	**15–20**	20,5–27,4	**7–9**	9,6–12,3	**5,5–7**	7,5–9,6
FRA	**11–19**	15–26	**13–15**	18–21	**5,5–6,5**	7,5–9	**5,5**	7,5
GBR	**7,3–11**	10–15	**7,3–16,1**	10–22	**5–13,6**	6,8–18,6	**6,7–13**	9,2–17,8
ISR	**6–9**	8,2–12,3						
ITA	**10–14**	13,7–19,2			**6–7**	8,2–9,6	**5–6**	6,8–8,2
JPN					**4,3**	5,9	**3,9**	5,4
KOR					**6,6–7,2**	9–9,8	**6,4**	8,7–8,8
MEX	**10,8**	14,8			**5,8**	7,9		
NOR	**15,5–22,4**	21,3–30,7			**11,2–15**	15,4–20,5		
PRT	**8–10**	11–13,7	**8–10**	11–13,7	**5–6**	6,8–8,2	**4,2–5,5**	5,8–7,5
SWE	**10,3**	14,1			**5,2–6,5**	7,1–8,9	**6,5**	8,9
USA	**7,3–14,6**	10–20	**7,3–14,6**	10–20	**5,1–6,6**	7–9	**4–5,5**	5,5–7,5

Notes: Additional information about the systems and prices reported for most countries can be found in the various national survey reports on the IEA PVPS website. Excludes VAT and sales taxes. More expensive grid-connected system prices are often associated with roof integrated slates or tiles or one-off building integrated designs or single projects, and figures can also relate to a single project.

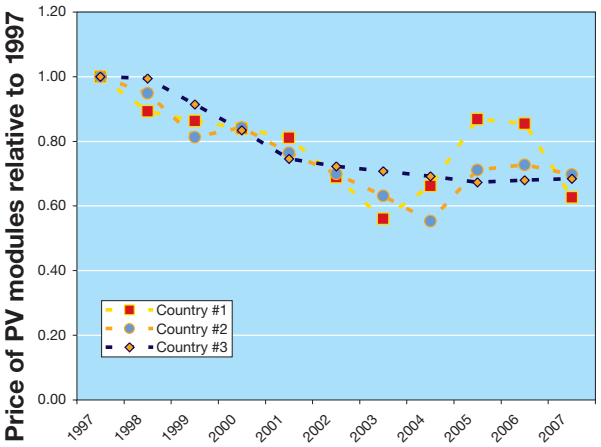

Figure 9 – Evolution of price of PV modules in selected reporting countries accounting for inflation effects – Years 1997–2007 (Normalized to 1997)

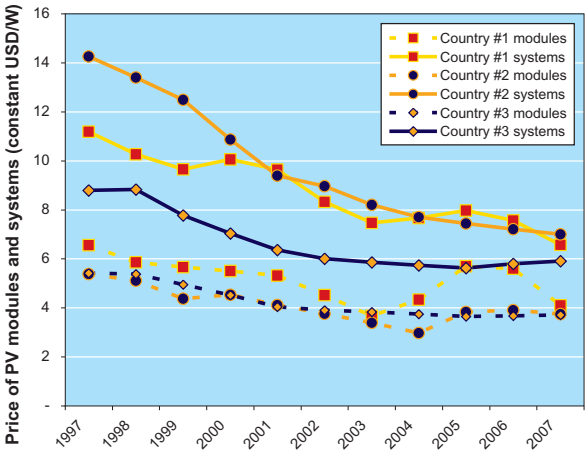

Figure 10 – Evolution of price of PV modules and systems in selected reporting countries accounting for inflation effects – Years 1997–2007

Table 7 – Indicative module prices (national currency, EUR and USD per watt) in selected reporting countries

Country	Currency	2007		
		national currency	EUR	USD
AUS	AUD	7–8	4,2–4,9	5,8–6,7
AUT	EUR	3,6–4,3	3,6–4,3	4,9–5,9
CAN	CAD	4,47	3,1	4,2
CHE	CHF	4,8–5	2,9–3,1	4–4,2
DEU	EUR	3–4,8	3–4,8	4,1–6,6
DNK	DKK	25–50	3,4–6,7	4,6–9,2
ESP	EUR	3–4,5	3–4,5	4,1–6,2
FRA	EUR	3–4	3–4	4,1–5,5
GBR	GBP	3–3,8	4,4–5,5	6–7,6
ISR	USD	6–9	4,4–6,6	6–9
ITA	EUR	3–3,8	3–3,8	4,1–5,2
JPN	JPY	436	2,7	3,7
KOR	KRW	3 900 – 4 000	3,1	4,2–4,3
MEX	MXP	50,8–70,8	3,4–4,7	4,6–6,5
PRT	EUR	2,8–3,5	2,8–3,5	3,8–4,8
SWE	SEK	28,5–63	3,1–6,8	4,2–9,3
USA	USD	3,75	2,7	3,75

Notes: Current prices. Excludes VAT and sales taxes. ISO currency codes are outlined in Table 14.
Single figures generally refer to 'typical' module prices; where there is a wide range in the figures presented for a given country, the lower value generally represents the lowest price achieved & reported (often for a large order) whereas a significantly higher figure can refer to special products, roof tiles etc.
Details are contained in the individual national survey reports.

2.4 System prices

Reported prices for entire PV systems vary widely (Table 6) and depend on a variety of factors including system size, location, customer type, connection to an electricity grid, technical specification and the extent to which end-user prices reflect the real costs of all the components. For more detailed information, the reader is directed to each country's national survey report.

On average, system prices for the lowest price off-grid applications are double those for the lowest price grid-connected applications. This is attributed to the fact that off-grid systems require storage batteries and associated equipment.

In 2007 the lowest system prices in the off-grid sector, irrespective of the type of application, typically ranged from about 10 USD/W to 15 USD/W. The large range of reported prices in Table 6 is a function of country and project specific factors. The average of these system prices is about 13 USD/W, much the same as the prices reported in 2005 and 2006.

The lowest achievable installed price of grid-connected systems in 2007 also varied between countries as shown in Table 6. The average price of these systems was 6,9 USD/W, much the same as the corresponding price in 2006, and about 5 % higher than the 2004 and 2005 prices. Prices lower than 6 USD/W were reported but typically prices were in the range 6,5 USD/W to 7,5 USD/W.

Large grid-connected installations can have either lower system prices depending on the economies of

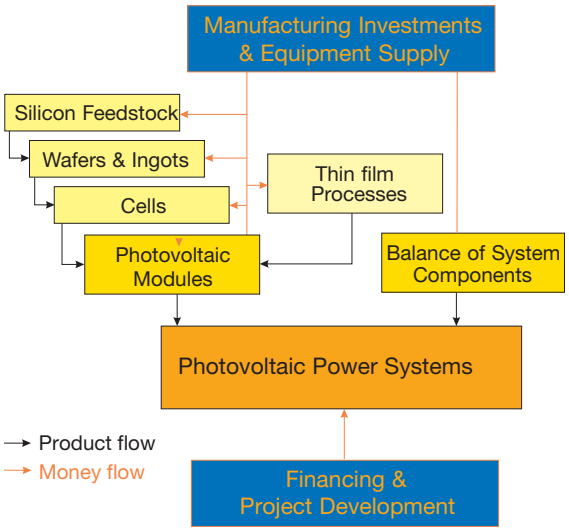

Figure 11 – Photovoltaic (PV) industry supply chain

scale achieved, or higher system prices where the nature of the building integration and installation, degree of innovation, learning costs in project management and the price of custom-made modules may be significant factors.

On average, the cost of the PV modules in 2007 (shown in Table 7) continues to account for about two-thirds of the lowest achievable prices that have been reported for grid-connected systems. In 2007 the average price of modules in the reporting countries was around 4,4 USD/W, a marginal decrease compared to the corresponding figure for 2006, which in itself represented a marginal increase from 2004 and 2005. The breakdown of number of countries showing a marginal increase, no change and marginal decrease in module prices from 2006 to 2007 was roughly 50 %, 25 % and 25 % respectively. Figure 9 shows the evolution of normalized prices for PV modules, accounting for inflation effects, in selected key markets. Figure 10 shows the trends in actual prices of modules and systems, accounting for inflation effects, in selected key markets.

2.5 *Economic benefits*

The PV industry supply chain provides many opportunities for economic activity, from feedstock production through to system deployment, as well as other supporting activities (Figure 11). This is highlighted by the variety of business models across the IEA PVPS countries. Business value calculations can be found in each national survey report.

Significant value of business has been reported by countries with healthy domestic PV market growth and/or large export of production from somewhere along the PV industry supply chain. Export activities appear to be playing an increasing role in an increasing number of countries. In absolute terms Germany is both a significant importer and exporter. Japanese exports are large but are facing rapidly mounting competition. Norway reports a high value of business because of its position as a major upstream product supplier. The total value of business in 2007 amongst the IEA PVPS countries approached 17 billion USD.

In parallel with the business value of PV production and markets, the economic value in the IEA PVPS countries can be characterized by the total direct employment (Table 8) of about 100 000 persons across research, manufacturing, development and installation – an increase of about 40 % compared to the 2006 figure which, in turn, had increased by 30 % over 2005. Manufacturing companies in Europe (and elsewhere) have continued to benefit from the strong level of demand within Germany, even when their domestic markets have stagnated. In addition, significant new markets have emerged in a number of countries, as outlined earlier in this report.

Table 8 – Estimates of PV labour places in selected reporting countries

Country	Research, development, manufacturing and deployment labour places
AUS	1 660
AUT	1 221
CAN	1 370
CHE	~ 4 000
DEU	42 600
DNK	240
ESP	17 000
GBR	1 066
ITA	1 080
JPN	18 000
KOR	1 616
NOR	1 080
PRT	~ 170
SWE	~ 500
USA	8 190

3 Policy and regulatory framework for deployment

Local, national and international policies, as well as availability of suitable standards and codes and the perception of the general public and utilities, all govern the rate of deployment of PV systems.

3.1 Initiatives supporting photovoltaic power systems

An outline of the range of PV support mechanisms in place in the IEA PVPS countries during 2007 can be found in Table 9. Specific details about many of these measures can be found in section 1.3 of this report and further details are available in the relevant national survey reports.

2007 saw a consolidation of the notion that the feed-in tariff (FiT) approach is the prime mechanism for promoting grid-connected PV applications. This was reinforced by strong growth in PV markets in France, Germany, Italy, Korea, Portugal and Spain. The term FiT simply refers to an explicit monetary reward for producing PV electricity, at a rate per kWh somewhat higher than the retail electricity rates being paid by the customer – which is why the measure is often more correctly termed an enhanced FiT. In principle the measure encourages efficient production of PV electricity with the output from the PV system being monitored and recorded, and has consequently been promoted as the performance-based market support measure. As can be seen in Table 9, the countries not currently employing or considering some form of FiT in the near-term are now clearly in the minority.

Table 9 – PV support mechanisms & indicative retail electricity prices reported by selected reporting countries

	AUS	AUT	CAN	CHE	DNK	DEU	ESP	FRA	GBR	ISR	ITA	JPN	KOR	MEX	NOR	PRT	SWE	USA
Enhanced feed–in tariffs	2.	•	•	•		•	•	•		2.	•		•			•		2.
Direct capital subsidies	•	•		•		•	•	•	•		•	•	•				•	•
Green electricity schemes	•	•	•	•		•			•		•	•						•
PV-specific green electricity schemes	•	•		•					•									•
Renewable portfolio standards (RPS)	•								•			•					•	•
PV requirement in RPS																		•
Investment funds for PV			•			•	•											•
Tax credits			•	•				•	•			•				•		•
Net metering	•	•	•	•	•				•		•			•				•
Net billing			•	•					•			•						•
Commercial bank activities	•					•			•			•						•
Electricity utility activities	•		•	•	•	•			•			•						•
Sustainable building requirements	•		•	•		•	•						•			•		•
Indicative household retail electricity price USD cents (1.)	10–14,2	22	6,4–13,3	~12,5	28,7	26	11–13,7	18,2	21,9	–	23,3	13,7	26,9	–	11,9–15,4	16,4	25,1	10,2

Notes:
1. Typical residential kWh price expressed in USD cents (1 USD/100), including all taxes but not including variations due to time of use, total electricity consumption or any fixed rates
2. Discussions have advanced considerably during 2007 regarding feed-in tariff (FiT) implementation.

There has been an interesting shift in policy discussions about the FiT approach. Rather than the concept as a whole attracting debate, it is now the fine detail concerning its implementation that is of interest, for example payment for all PV electricity generated or only the portion exported to the grid, how to control take-up rates without using a blunt 'cap' approach and how to best reward different types of PV plants. The details contained in section 1.3 of this report provide an overview of a number of FiT approaches – from those that drive private or electricity utility investments in large-scale (multi-MW) plants, to those that favour smaller-scale building-integrated applications and to combinations of both approaches.

During 2007, under feed-in tariff schemes in the IEA PVPS countries, payments of around 2,3 billion USD were made for PV electricity. To put this into perspective, one decade ago the total budget for PV market stimulation in the IEA PVPS countries was about 210 million USD. It is argued that the FiT's, and the decisions made in relatively few countries, to a large extent influence the evolution of world prices for PV modules (in conjunction with supply-demand dynamics and competition in the PV industry). Consequently a number of countries have looked at the structure of their schemes for future years with the aim of making the payments more reflective of true costs.

Direct capital subsidies can effectively tackle the up-front cost barrier, which is often the most significant hurdle facing PV deployment even with a FiT, and can be used in both the grid-connected and off-grid markets. They can be very effective (as the Japanese residential PV market has demonstrated over the years) and are relatively simple to implement. Criticisms include: they do not drive PV system performance (although schemes are now emerging in the US where performance is considered); they do not encourage broader consideration of customer energy usage (unless this is specifically addressed, for example through metering displays such as in the Danish SOL programmes); and they do not address the customer's willingness to pay for PV (unless a bidding mechanism is used, such as in Malaysia's SURIA 1000 Programme). Direct capital subsidies are also more broadly criticized for inflating prices and subsidizing more affluent consumers.

Similar to the direct capital subsidies, tax credits can, to a degree, tackle the up-front cost barrier and various forms of this measure have emerged in a number of countries. However, it assumes that entities with a tax liability are prime candidates for PV, which may or may not be the case depending on the particular market. Further, while more economically efficient, it is probably not as effective in the early stages of PV market development when deployment targeted on specific end-users may produce the best results.

The willingness to pay issue is starting to attract some attention. On the one hand, there is a question about how willing governments are to commit ever-increasing funds (albeit derived via electricity bills rather than consolidated revenue) to expanding the grid-connected PV market. On the other hand there is the notion that the customers' willingness to pay for PV systems is largely untested (whereas willingness to pay for PV electricity has been explored via green electricity schemes, discussed later). A report recently published by IEA PVPS Task 10, 'Analysis of PV systems' values beyond energy, by country and stakeholder', makes the point that currently, at the customer level, demand for PV is largely controlled by costs as seen by the customer and also the customer's voluntary willingness to pay. Willingness to pay directly relates to the particular added values of PV (beyond energy) that are significant for each individual, and these should be quantified. Different added values assume differing levels of significance according to the various groups of customers – residential customers, businesses, architects, electricity utilities and governments.

Table 10 provides a broad overview of some of the key PV support measures. In practice, public support can involve a combination of measures and will usually function more effectively when this is the case. Funding issues are significant and funding continuity is critical to the success of any mechanism. Additionally, any measure needs to be evaluated against a number of criteria: While outcomes have been achieved elsewhere are the local barriers to be addressed the same as those tackled in other markets? Is the local electricity industry structure compatible with the approach? Will the scheme be flexible enough to survive political change? Can the scheme alone transform the market? How costly is the administrative burden compared to that of other approaches? Is the free-rider effect minimized? And, what are the overall socio-economic-environmental impacts of the measure?

3.2 Indirect policy issues and their effect on the PV market

Two issues are particularly relevant to the market for PV – climate change policy deliberations and electricity utility developments.

A number of governments are implementing the regulatory approach commonly referred to as the 'renewable portfolio standard' (RPS) to increase renewable energy deployment in their countries, with the aim of reducing carbon emissions associated with electricity supply. However, in the absence of at least some concrete targets for installed capacity of PV or

special treatment for PV electricity, the RPS is unlikely to have a positive impact on PV deployment as the general requirement for renewable energy may simply encourage the lowest direct cost renewable energy options (and not PV) for consideration. However, in the US in particular, a number of PV-specific regulatory approaches have emerged. Details about these programmes can be found at www.dsireusa.org.

In addition, driven largely by the current round of climate change politics, sustainable building regulations are an emerging force in many countries. These include requirements on new building developments (residential and commercial) and also in some cases on properties for sale. The implications for PV deployment may be modest where, for example, PV is included in a suite of options for reducing the building's energy foot print, or dramatic as is the case in Spain and Italy where PV is specifically mandated as an inclusion in the building development.

Grid parity is the term that is used to describe the point in time when the cost of electricity from PV systems matches the price paid by consumers for retail electricity. It is regarded as an important target for the PV industry and various commentators anticipate that it will occur within five to ten years in a number of countries. On the one hand, the price of PV electricity should fall as manufacturing costs decrease (although this is not necessarily a foregone conclusion); on the other hand, in many countries the retail price of electricity should rise in response to a number of

Table 10 – Characteristics of some key support measures

	Enhanced feed-in tariffs	**Direct capital subsidies**	**Green electricity schemes**	**Renewable portfolio standards**	**Tax credits**	**Sustainable building requirements**
Target audience	Grid-connected PV customers with business cash flow requirements e.g. housing developers, investors, commercial entities.	PV customers with limited access to capital e.g. households, small businesses, public organizations.	Residential and commercial electricity customers.	Liable parties, typically the electricity retailing businesses.	Any entity with a tax liability, such as salary earners and businesses. However, may not be relevant for many prime candidates for PV.	New building developments (residential and commercial); also properties for sale.
Countries reporting use of this support measure, or similar	Austria, Canada, Switzerland, Germany, Spain, France, Italy, Korea, Portugal.	Australia, Austria, Switzerland, Germany, Spain, France, UK, Italy, Japan, Korea, Sweden, USA.	Australia, Austria, Canada, Switzerland, Germany, UK, Italy, Japan, USA.	Australia, UK, Japan, Sweden, USA.	Canada, Switzerland, France, UK, Japan, Portugal, USA.	Australia, Canada, Switzerland, Germany, Spain, Korea, Portugal, USA
Implementation	Typically administered by the electricity industry billing entity.	Requires considerable public administrative support to handle applications, approvals and disbursements.	Commercial business operation of the electricity utility; some public administrative support for accreditation of projects.	Public administrative support via a regulatory body.	Administered by the existing taxation bodies.	Typically administered by the local building consent authority.
Economic and political considerations	Method of internalizing the externalities associated with traditional energy supply	Up-front capital cost is seen as the main economic barrier to the deployment of PV. Can be used for both off-grid and grid-connected support programmes.	Government involvement in selective, customer-driven, electricity business commercial activities raises some interesting questions. However, utility projects may better realize the network benefits of PV.	Can be seen as a distortion in the functioning of the electricity market, especially if overly prescriptive.	Same benefits as the direct capital subsidies but without some of the negatives.	Appeal largely depends upon the degree to which property prices are impacted and the cultural acceptance of prescriptive approaches.
	There are varying political perceptions regarding the use of public funds or funds generated by the electricity industry.					

factors – incorporation of a carbon price in electricity prices, investments in aging electricity infrastructure, further commercialization of the electricity industry and so on. It is thought that grid parity will lead to a new, strong growth in consumer demand for PV within a truly sustainable market no longer requiring government support. Some questions remain about the ability of electricity networks to accept large amounts of PV electricity and this has driven the development of a number of solar cities or towns (e.g. Pal Town in Ota City, Japan) to investigate network issues. For the individual consumer's financial interest, the real benefits of PV electricity either for own-consumption or export to the electricity network are only going to become evident if supported by smart metering and an equally smart rate structure.

Already within the electricity utility sector, different business models of PV promotion are emerging, partly in response to public policy and regulation and partly to realize business opportunities. For a number of years 'green power' schemes have been offered by electricity businesses, allowing customers to purchase green electricity. However, to date, green power schemes are often characterized by the same problems for PV seen in the government-driven RPS approaches – they are usually characterized by a broad, least-cost approach favouring hydro, wind and biomass. However, a number of PV-specific approaches have emerged, for example in Denmark, the US and Australia. The Swiss solar stock exchanges, in which PV power is produced and sold to individuals and institutions interested in purchasing clean electricity, have proved to be a mainstay in the promotion of PV in Switzerland. Japanese electricity utilities introduced the 'Green Power Fund' based on contributions from supporting customers. In the US, in particular, electricity utilities are actively exploring a range of business models for their involvement with PV – from large-scale utility plants to ownership and financing options with select customers to various power purchase models.

As the PV market matures and opportunities for business are identified, various non-utility commercial initiatives are also emerging. These include activities such as preferential home mortgage terms and green loans from commercial banks, share offerings in private PV investment funds plus other schemes that all focus on wealth creation and business success using PV as a vehicle to achieve these ends.

Lastly, the vitally important role that PV can play in the developing countries continues to be highlighted. PV offers the ability, sometimes uniquely, to provide electricity to populations remote from electricity grids and also to enhance the quality of existing electricity supplies. Although not directly mentioned in the UN Millennium Development Goals access to electricity is a recognized prerequisite for meeting these goals and, with a steadily decreasing cost of PV technology, it is anticipated that PV should play an increasing role in meeting the electricity needs in developing countries.

3.3 Standards and codes

Established in 1981, the Technical Committee (TC) 82 of the International Electrotechnical Commission (IEC, www.iec.ch) has been the main promoter for world wide standardization in the field of PV. As of the end of 2007, 69 IEC International Standards and Technical Specifications (including versions in different languages) had been published covering a comprehensive range of issues. Currently 25 countries are active participants in TC 82 and a further 15 have observer status with 3 more observers joining in 2007.

The work on new and revised standards is carried out within six individual working groups (WG) consisting of experts dealing with issues ranging from Glossary to Balance-of-system components. Further cross-cutting issues such as Rural Electrification or Batteries are handled by a Joint Coordinating and Working Group (JCWG) of experts from different TCs. Conformity assessment and certifications are treated within the framework of the IECEE (Worldwide System for Conformity Testing and Certification of Electrical Equipment).

TC 82 has been very active during 2007 and has published the following new or revised IEC Standards or Technical Specifications (TS)

- Photovoltaic devices
  - Part 2: Requirements for reference solar devices (IEC 60904-2 Ed. 2.0)
  - Part 9: Solar simulator performance requirements (IEC 60904-9 Ed. 2.0)
- Solar photovoltaic energy systems – Terms, definitions and symbols (IEC/TS 61836 Ed. 2.0)
- Concentrator photovoltaic (CPV) modules and assemblies – Design qualification and type approval (IEC 62108 Ed. 1.0)
- Recommendations for small renewable energy and hybrid systems for rural electrification
  - Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems – Specific case of automotive flooded lead-acid batteries available in developing countries (IEC/TS 62257-8-1 Ed. 1.0)
  - Part 9-5: Integrated system – Selection of portable PV lanterns for rural electrification projects IEC/TS 62257-9-5 Ed. 1.0)
  - Part 12-1: Selection of self-ballasted lamps (CFL) for rural electrification systems and recommendations for household lighting equipment (IEC/TS 62257-12-1 Ed. 1.0)

Continuing the activities from the previous year, revisions to the IEC 60904-X series (which defines fundamental requirements such as measurement principles for photovoltaic devices) have been on top of TC 82's agenda. In 2007, two revised documents (IEC 60904-2 and -9) have been published. Further important work items include the power and energy rating of PV modules (IEC 61853-X) and safety of PV power converters, which will be covered by the IEC 62109-X series. New work approved in 2007 covers design qualification of PV pumping systems (IEC 62253), methods to assess the performance and functioning of PV battery charge controllers (IEC 62509) and installation and safety requirements for photovoltaic (PV) generators (IEC 62548).

On the European level the CLC/TC 82 of the European Committee for Electrotechnical Standardization (CENELEC) closely cooperates with its counterpart, the IEC TC 82, as well as the national committees. In areas where there is specific European concern, CLC/TC 82 is also developing its own standards. Recent projects deal with specifications for PV wafers, connectors for PV systems, data sheet information for grid-connected PV inverters and the performance of grid-connected PV inverters.

In the US standardization focuses on safety and interconnection issues of PV systems. The US Department of Energy Solar Programme supports a large proportion of the activities and has provided a consensus of utility and industry input to the National Electrical Code® (NEC®). In 2007 the industry forum headed by Sandia National Labs submitted changes to the sections of relevance to PV for the 2008 edition.

The Japanese Standards Association together with Japan Electrical Safety and Environment Technology Laboratories (JET) is very active in the field of PV standardization. Japanese PV standards are broadly consistent with the corresponding IEC documents; however some of them reflect unique Japanese circumstances. In addition to the current standards, that mostly cover component issues, efforts are made to establish standards for entire PV systems.

Despite the ongoing internationalization of PV standardization, grid interconnection of PV is still almost exclusively governed by national codes or utility guidelines – which are rarely harmonized amongst the IEA PVPS countries. However, with grid-connected PV becoming more widespread each year, national activities reported by some countries indicate that there is strong support for a smooth and straightforward approach to connection of PV systems to the electricity distribution networks.

Fronius production and logistics site in Sattledt, Austria

4 Summary of trends

The countries participating in the IEA PVPS Programme have a diversity of PV production, applications and policy interests.

- During 2007 installed PV power continued to enjoy a high rate of growth. The cumulative installed capacity in the IEA PVPS countries grew by 40 % reaching 7,8 GW, with about 2,3 GW added during the year. By far the greatest proportion in 2007 was installed in Germany and Spain alone (73 %). Spain's cumulative installed capacity increased more than four-fold. Other markets experiencing strong growth were France, Italy, Korea, Portugal and the US. Japan's annual market declined from the level of the previous year.

- Grid-connected applications dominated in the reporting countries (about 94 % of the 2007 market) but the largely unsubsidized off-grid markets continued to grow worldwide, albeit less vigorously than the publicly funded grid-connected PV markets. An interesting feature of the 2007 cumulative installed capacity compared to 2006 is the three-fold increase in capacity defined as grid-connected centralized.

- The 2007 R&D expenditure was very similar to the expenditure in 2006 – around 330 million USD (240 million EUR). During the year, under feed-in tariff schemes in the IEA PVPS countries, payments of around 2,3 billion USD (1,68 billion EUR) were made for PV electricity.

- In 2007 there continued to be four major producers of solar photovoltaic grade silicon. The large companies have all announced significant expansion programmes. The key current production countries plus other IEA PVPS countries have flagged developments in the near future. Many other newcomers have also announced plans to enter the feedstock silicon business.

- European (particularly Norway, Germany and the UK) and Japanese companies feature most prominently in the ingot and wafer section of the PV industry value chain. Some companies are vertically-integrated, controlling the process from ingots to cells and modules. Under current tight feedstock supply conditions the companies having their own feedstock or having secured long-term contracts are best placed to grow in the future.

- The total PV cell production volume for 2007 in the IEA PVPS countries was reported to be about 2 400 MW, up from 1 900 MW in 2006, an increase of 26 %. The largest increase in production took place in Germany while Japan's production remained at the same level as in 2006. Japan remained the leading producer of photovoltaic cells during 2007.

- Production of cells and modules in Japan accounted for 39 % and 22 % respectively of the IEA PVPS countries' production, with Germany in second place

Table 11 – Cumulative installed PV power and annual percentage increase

Year	Off-grid		Grid-connected		Total	
	Cumulative (MW)	Increase (%)	Cumulative (MW)	Increase (%)	Cumulative (MW)	Increase (%)
1992	78		27		105	
1993	94	21	37	37	131	25
1994	112	19	45	22	157	20
1995	132	18	59	31	191	22
1996	158	19	78	32	236	24
1997	187	19	118	51	305	29
1998	216	15	169	43	385	26
1999	244	13	265	68	509	32
2000	277	14	438	65	715	40
2001	319	15	655	50	974	36
2002	354	11	964	47	1 318	35
2003	410	16	1 399	45	1 809	37
2004	450	10	2 382	70	2 832	57
2005	485	8	3 669	54	4 154	47
2006	535	10	5 049	38	5 584	34
2007	663	24	7 178	42	7 841	40

for cell production with 35 % and first place for module production with a 36 % share. The relative German market share in 2007 continued to increase at the expense of the Japanese market share. In the United States, the third largest PV cell producing country, production increased by 32 % from 2006. Spain's module production increased to overtake the US for the third position during 2007. However, US output of thin film technologies almost doubled to 177 MW, representing nearly one half of world thin film production.

- In 2007 wafer-based crystalline silicon technologies maintained their dominance, accounting for about 87 % of the market for PV modules in the IEA PVPS countries. However, this percentage has slipped a further four percentage points from 2006, following a loss of three percentage points the previous year. Total photovoltaic module production increased by over 50 % from 2006, following the sluggish growth of about 9 % the previous year.

- Countries not part of the IEA PVPS reporting process now possibly account for around 40 % of both world cell and module productions.

- Some consistent themes emerged from amongst the range of countries reporting during 2007, despite the variations of their policies and markets. PV cell supply problems have created difficult circumstances for many module producers but this appears to be easing (at least in some countries). Foreign product and price offers continue to strongly impact domestic markets and access to a booming foreign market provides an ongoing lifeline for the industries in some countries where the domestic market has stagnated.

- On average, PV modules continued to make up about two-thirds of the lowest achievable grid-connected system prices that have been reported. In 2007 the average price of modules in the reporting countries was around 4,4 USD/W, a marginal decrease compared to the corresponding figure for 2006, which in itself represented a marginal increase from 2004 and 2005.

- The average lowest achievable installed price of grid-connected systems in 2007 was 6,9 USD/W, much the same as the corresponding price in 2006, and about 5 % higher than the 2004 and 2005 prices. Prices lower than 6 USD/W were reported but typically prices were in the range 6,5 USD/W to 7,5 USD/W. On average, system prices for the lowest price off-grid applications are double those for the lowest price grid-connected applications.

- The total value of business in 2007 amongst the IEA PVPS reporting countries approached 17 billion USD (12,4 billion EUR). In parallel with the business value of PV production and markets, the economic value in the IEA PVPS countries can be characterized by the total direct employment of about 100 000 persons across PV research, manufacturing, development and installation – an increase of about 40 % compared to the 2006 figure.

- 2007 saw a consolidation of the notion that the feed-in tariff (FiT) approach is the prime mechanism for promoting grid-connected PV; the countries not currently employing or considering some form of FiT in the near-term are now clearly in the minority. Direct capital subsidies also play an important role. Tax credits for PV deployment have emerged in a number of countries. Two broader issues are particularly relevant to the market for grid-connected PV – climate change policy deliberations and electricity utility developments (both with implications for movements in retail electricity prices).

Table 12 – Installed PV power and module production in the IEA PVPS reporting countries

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Power installed during year in IEA PVPS reporting countries (MW)	26	26	34	45	69	80	124	206	259	344	491	1 023	1 322	1 430	2 257
Module production during year in IEA PVPS reporting countries (MW)	52		56		100	126	169	238	319	482	667	1 160	1 532	1 668	2 690 *(estimate)*

Table 13 – IEA PVPS Task 1 participating countries and national survey report authors

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Task 1 national participants and their contact details can be found on the IEA PVPS website www.iea-pvps.org. This report has been prepared under the supervision of Task 1 by Task 1 participants Roland Bründlinger, Paul Cowley and Greg Watt.

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Exchange rates

Table 14 lists the reporting countries, corresponding ISO country and currency codes, and the exchange rates used to convert national currencies. Exchange rates represent the 2007 annual average of daily rates (source: OECD Main Economic Indicators June 2008).

Table 14 – Currency exchange rates

Country	Currency and code	Exchange rate (1 USD =)	Country	Currency and code	Exchange rate (1 USD =)
Australia	dollar (AUD)	1,19	Norway	krone (NOK)	5,86
Canada	dollar (CAD)	1,07	Sweden	krona (SEK)	6,76
Denmark	krone (DKK)	5,44	Switzerland	franc (CHF)	1,199
Japan	yen (JPY)	117,76	United Kingdom	pound (GBP)	0,499
Korea	won (KRW)	929,46	United States, Israel	dollar (USD)	1
Mexico	peso (MXP)	10,93	Austria, France, Germany, Italy, the Netherlands, Portugal, Spain	euro (EUR)	0,73

PV Technology Note

*The key components of a photovoltaic power system are the **photovoltaic cells** (sometimes also called solar cells) interconnected and encapsulated to form a **photovoltaic module** (the commercial product), the **mounting structure** for the module or array, the **inverter** (essential for grid-connected systems and required for most off-grid systems), the **storage battery** and **charge controller** (for off-grid systems only).*

Cells, modules and arrays

Photovoltaic cells represent the smallest unit in a photovoltaic power producing device, typically available in 12,5 cm, 15 cm and up to 20 cm square sizes. In general, cells can be classified as either wafer-based *crystalline (single crystal or multicrystalline)* or *thin film*. Currently wafer-based crystalline silicon technologies account for most of the overall cell production in the IEA PVPS countries.
Single crystal silicon (sc-Si) PV cells are manufactured using a single crystal growth method and have commercial efficiencies between 15 % and 18 %.
Multicrystalline silicon (mc-Si) cells, usually manufactured from a melting and solidification process, are becoming increasingly popular as they are less expensive to produce but are marginally less efficient, with an average conversion efficiency around 14 %.
Thin film cells are constructed by depositing extremely thin layers of photovoltaic semi-conductor materials onto a backing material such as glass, stainless steel or plastic. Module conversion efficiencies reported for thin film PV are currently ranging from 7 % (a-Si) to 13 % (CIS) but they are potentially cheaper to manufacture than crystalline cells. The disadvantage of low conversion efficiencies is that larger areas of photovoltaic arrays are required to produce the same amount of electricity. Thin film materials commercially used are amorphous silicon (a-Si), cadmium telluride (CdTe), and copper-indium-gallium-diselenide (CIGS).
Further research and development is being carried out to improve the efficiency of all the basic types of cells with laboratory efficiencies for single crystal cells over 25 %, and for *thin film* technologies over 19 % being achieved.

Photovoltaic modules are typically rated between 50 W and 300 W with specialized products for building integrated PV systems at even larger sizes. Crystalline silicon modules consist of individual PV cells connected together and encapsulated between a transparent front, usually glass, and a backing material, usually plastic or glass. Thin film modules are constructed from single sheets of thin film material and can be encapsulated in the form of a flexible or fixed module, with transparent plastic or glass as front material. Quality PV modules are typically guaranteed for up to 20 years by manufacturers and are type approved to IEC 61215 Ed. 2 or IEC 61646 International Standards.

A ***photovoltaic array*** consists of a number of modules connected in series (strings), then coupled in parallel to produce the required output power.

A wide range of ***mounting structures*** has been developed especially for building integrated PV systems (BIPV), including PV facades, sloped and flat roof mountings, integrated (opaque or semi-transparent) glass-glass modules and 'PV roof tiles'. Single or two-axis ***tracking systems*** have recently become more and more attractive, particularly for PV applications in countries with a high share of direct irradiation. By using such systems, the energy yield can typically be increased by about 30 % compared with non-tracking systems.

Grid-connected photovoltaic (PV) systems

In grid-connected PV-systems, an ***inverter*** is used to convert electricity from direct current (d.c.) as produced by the PV array to alternating current (a.c.) that is then supplied to the electricity network. The typical weighted conversion efficiency – often stated as 'European Efficiency' – of inverters is in the range of 95 %, with peak efficiencies up to 98 %. Inverters connected directly to the PV array incorporate a Maximum Power Point Tracker (MPPT), which continuously adjusts the load impedance to provide the maximum power from the PV array. One inverter can be used for the whole array or separate inverters may be used for each 'string' of modules. PV modules with integrated inverters, usually referred to as 'AC modules', can be directly connected to the electricity network (where approved by network operators) but still play a very limited role.

Off-grid photovoltaic (PV) systems

For off-grid systems a ***storage battery*** is required to provide energy during low-light periods. Nearly all batteries used for PV systems are of the deep discharge lead-acid type. Other types of batteries (e.g. NiCad, NiMH) are also suitable and have the advantage that they cannot be overcharged or deep-discharged, but are considerably more expensive. The lifetime of a battery varies depending on the operating regime and conditions but is typically between 5 and 10 years.

A ***charge controller*** (or regulator) is used to maintain the battery at the highest possible state of charge (SOC) and provide the user with the required quantity of electricity while protecting the battery from deep discharge or overcharging. Some charge controllers also have integrated MPP trackers to maximize the PV electricity generated. If there is the requirement for a.c. electricity, a ***'stand-alone inverter'*** can supply conventional a.c. appliances.

Further details

More detailed descriptions of photovoltaic technology and applications can be found on the IEA PVPS website at www.iea-pvps.org.

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