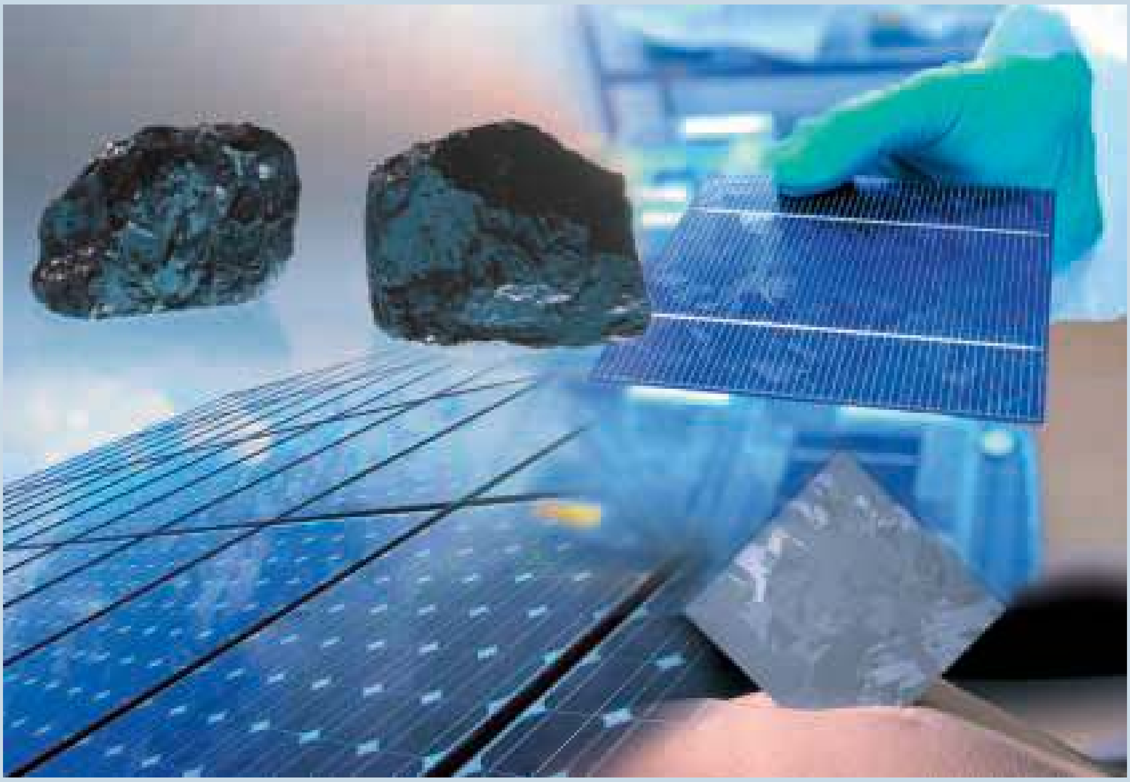
IEA INTERNATIONAL ENERGY AGENCY

TRENDS IN PHOTOVOLTAIC APPLICATIONS

Survey report of selected IEA countries between 1992 and 2004



PVPS

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PROGRAMME

Report IEA-PVPS T1-14:2005

TRENDS IN PHOTOVOLTAIC APPLICATIONS

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Foreword

The International Energy Agency (IEA), founded in 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD). The IEA carries out a comprehensive programme of energy co-operation 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". The underlying assumption is that the market for photovoltaic (PV) systems is in the process of expanding from the present niche markets of remote applications and consumer products, to the utility market, through building-integrated and other distributed and centralized PV generation systems.

In order to achieve this, the 19 countries participating in the programme and the European Commission 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.

The IEA PVPS Programme is pleased to herewith present the tenth edition of the international survey report on Trends in Photovoltaic Applications. As in previous years, a strong market growth can also be observed for 2004 with a further trend to grid-connected applications. For the first time, the annual shipment of photovoltaic modules has surpassed the 1 000 MW level. This strong growth has not been without effect along the supply chain: demand and supply have become increasingly unbalanced with continuing strong growth on the demand side and growing constraints in the supply of silicon raw material. While this is generally considered as a temporary phenomenon, it is nevertheless creating strong pressure for the industry. Investments into the supply chain are occurring but price increases have also been a result. In Japan on the other hand, there are indications of the emergence of a self-sustaining grid-connected market; this would be an important milestone for this market segment. Information collected on public support programmes for photovoltaics indicate an apparent trend to increased R,D&D expenditures, whereby a number of countries emphasise the long-term aspects and potential of the technology. Following the positive feedback from last year, this edition of the report presents additional information on the market situation in non-member countries, thereby providing a comprehensive and unique global overview. With all these new features, I trust that this new edition of Trends in Photovoltaic Applications will again find many interested readers and I would like to thank all experts who have contributed to this new edition.

Stefan Nowak
Chairman, IEA PVPS Programme

This report has been prepared by IEA PVPS Task 1 on the basis of National Survey Reports prepared by Task 1 participants and their assistants. 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.

September 2005

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 participating countries[1]. 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 %. Data on production levels and system prices vary depending on the willingness of the relevant national PV industry to provide data for the survey.

This report presents the results of the 10th international survey. It provides an overview of PV power systems applications, markets and production in the reporting countries and elsewhere at the end of 2004 and analyzes trends in the implementation of PV power systems between 1992 and 2004.

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 participating countries. These national 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 these data is somewhat lower than applies to IEA PVPS members.

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 module 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 modules, inverters, batteries and all associated mounting and control components as appropriate. 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.

PV system at NTT DoCoMo Tohoku Building, Japan

[1] Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), the United Kingdom (GBR), the United States of America (USA)

1 Implementation of photovoltaic systems

1.1 Applications for photovoltaics

There are four[2] primary applications for PV power systems:

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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.

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 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. They may be specifically designed for support of the distribution electricity network. Size is not a determining feature – while a 1 MW PV system on a rooftop may be large by PV standards, this is not the case for other forms of distributed generation.

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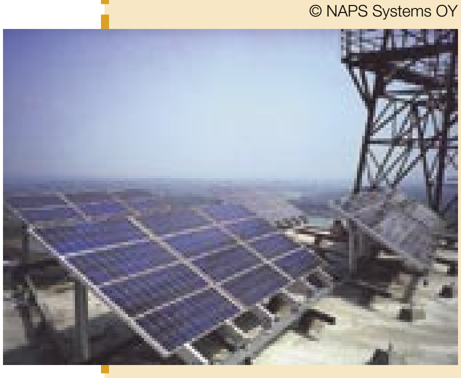

Off-grid non-domestic installations were the first commercial application for terrestrial PV systems. They provide power for a wide range of applications, such as telecommunication, water pumping, vaccine refrigeration and navigational aids. These are applications where small amounts of electricity have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

Grid-connected 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. Typically ground mounted and functioning independently of any nearby development.

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[2] *Defining systems is becoming more difficult where, for example, large urban grid-connected plants are made up of a number of smaller plants, and mini-grids in rural areas are developed by electric utilities.*

1.2 Total photovoltaic power installed

Another year of dramatic growth in installed PV capacity was reported by the IEA PVPS countries in 2004. The cumulative total grew by over 770 MW in the year, to just under 2,6 GW by the end of 2004. The vast majority (94 %) of this growth in capacity was installed in Germany, Japan and the USA and therefore care must be taken when interpreting the results, as most of the comments directly reflect the developments in these lead countries. Figure 1 illustrates the growth of installed capacity since 1992 and the split of this capacity between the two primary applications for PV. Particularly with the recent levels of growth seen in IEA PVPS member countries, this installed capacity reported represents a significant proportion of worldwide PV capacity

The cumulative market in IEA PVPS countries reached a new high growth rate of 42 % between 2003 and 2004, up from 37 % last year. In terms of annual sales the growth rate was even more spectacular

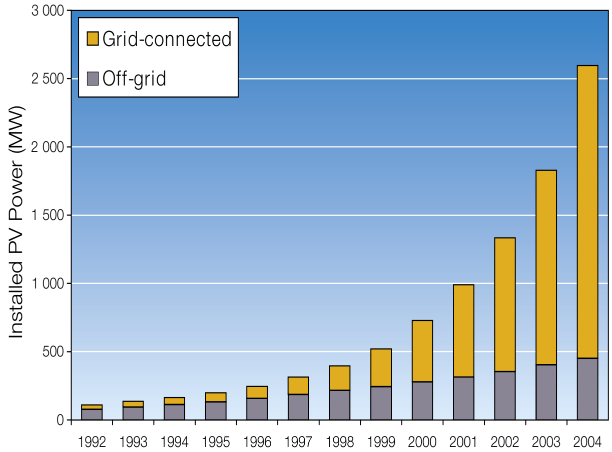

Figure 1 – Cumulative installed grid-connected and off-grid PV power in the reporting countries Years 1992 – 2004

Table 1 – Installed PV power in reporting IEA PVPS countries as of the end of 2004

Country	Cumulative off-grid PV capacity (kW)		Cumulative grid-connected PV capacity (kW)		Total installed PV power (kW)	Total installed per capita (W/Capita)	PV power installed in 2004 (kW)	Grid-connected PV power installed in 2004 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	15 900	29 640	5 410	1 350	52 300	2,60	6 670	780
AUT	2 687		15 340	1 153	19 180	2,37	2 347	1 833
CAN	5291	8 081	476	36	13 884	0,44	2 054	107
CHE	2 810	290	18 440	1 560	23 100	3,12	2 100	2 000
DNK	65	190	2 035	0	2 290	0,43	400	360
DEU	26 000		768 000		794 000	9,62	363 000	360 000
ESP	14 000		23 000		37 000	0,87	10 000	8460
FRA	12 500	5 800	8 000	0	26 300	0,44	5 228	4 183
GBR	193	585	7 386	0	8 164	0,14	2 261	2 197
ISR	653	210	9	14	886	0,13	353	3
ITA	5 300	6 700	12 000	6 700	30 700	0,53	4 700	4 400
JPN	1 136	83 109	1 044 846	2 900	1 131 991	8,87	272 368	267 016
KOR	461	4 898	4 533	0	9 892	0,21	3 454	3 106
MEX	14 169	4 003	10	0	18 182	0,17	1 041	0
NLD	4 769		41 830	2 480	49 079	3,01	3 162	3 071
NOR	6 438	375	75	0	6 888	1,50	273	0
PRT	1 657	569	417	0	2 643	0,25	574	20
SWE	3 070	602	194	0	3 866	0,43	285	0
USA	77 900	111 700	153 600	22 000	365 200	1,24	90 000	62 000
Estimated total	**170 730**	**281 021**	**2 064 201**	**79 593**	**2 595 545**		**770 270**	**719 536**

Notes: ISO country codes are outlined in Table 12. 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.

rising from 44 % in 2003 to 55 % in 2004. Amongst the largest markets, the annual rate of growth in Germany (137 %) indicates that, if sustained, installed capacity in this country may meet that of Japan by the end of next year (if Japan's reported growth rate is maintained at 22 %). These extraordinary levels of growth continue to be driven by market support mechanisms that initially focused on grid-connected domestic applications in the urban or suburban environment. The impacts – both positive and negative – of politically driven market support frameworks are clearly highlighted in Table 3. In terms of installed capacity per capita, Germany now leads the way at 10 W per capita, now ahead of Japan, Switzerland and the Netherlands at 9 W, 3 W and 3 W per capita respectively.

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

	Cumulative installed PV power (MW)												
Country	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
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
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	19,2
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
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
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
DEU	5,6	8,9	12,4	17,7	27,8	41,8	53,8	69,4	113,7	194,6	278	431	794,0
ESP	4,0	4,6	5,7	6,5	6,9	7,1	8,0	9,1	12,1	15,7	20,5	27,0	37,0
FIN	0,9	1,0	1,2	1,3	1,5	2,0	2,2	2,3	2,6	2,7	3,1	3,4	
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	26,3
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
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
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
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
KOR	1,5	1,6	1,7	1,8	2,1	2,5	3,0	3,5	4,0	4,8	5,4	6,4	9,9
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
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	49,1
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
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	2,6
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
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	365,2
Total	**110**	**136**	**164**	**199**	**245**	**314**	**396**	**520**	**729**	**989**	**1 334**	**1 829**	**2 596**

Notes: ISO country codes are outlined in Table 12. Source of Spanish data 2000–2004: IDEA. 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. Finland no longer included in total.

Table 3 – A decade of annual market growth in selected countries

	PV power (MW) installed in calendar year									
Country	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
AUS	2,0	3,0	3,0	3,8	2,8	3,9	4,4	5,5	6,5	6,7
AUT	0,3	0,3	0,5	0,7	0,8	1,2	1,2	4,2	6,5	2,4
DEU	5,3	10,1	14,0	12,0	15,6	44,3	80,9	83,4	153,0	363,0
ESP	0,8	0,4	0,2	0,9	1,1	3,0	3,6	4,8	6,5	10,0
FRA	0,5	1,5	1,7	1,5	1,5	2,2	2,6	3,3	3,9	5,2
JPN	12,2	16,2	31,7	42,1	75,2	121,6	122,6	184,0	222,8	272,4
NLD	0,4	0,9	0,7	2,5	2,7	3,6	7,7	5,8	19,6	3,2
USA	9,0	9,7	11,7	11,9	17,2	21,5	29,0	44,4	63,0	90,0

Notes: Countries that are experiencing (or have recorded) annual market demand of >5 MW

Box 1 – PV Applications and markets in selected non-PVPS countries

For a detailed description of the non-PVPS country markets the reader is directed to the website. In summary, similar to the vast majority of PV generation capacity installed in the PVPS countries, most PV installed in other parts of the world at present is being driven from the top-down (i.e. subsidized), through national targets and/or bilateral or multilateral development programmes. Kenya remains the only notable market where PV sales have emerged spontaneously without government or other subsidies.

For the remote or rural areas of developing countries which account for much of the market in non-PVPS countries, PV is often a cost effective energy service solution. Key applications for solar PV are small solar home systems, 'SHS', for households (typically 20–100 W), village power stations (typically 500-2 500 W), and power for health centres, schools and water pumping. Power for telecommunications systems is an important PV application in many countries, though data on such 'commercially' installed capacities are not always reflected in national statistics.

Verifying total market volume and annual sales figures for non IEA PVPS countries is extremely difficult due to the large number of small systems involved. The following information are not exhaustive. They are intended to give an indication of the scale of key international markets and an overview of market drivers to allow the IEA PVPS data to be viewed in the context of global PV developments.

Country	Total installed capacity (MW)	Annual sales
India	86 MW	Total approx 1,7 MW (2004)
China (inc. Tibet)	65 to 75 MW	10 to 20 MW (2004) Includes 1 MW grid-connected plant installed by Shenzen government
Thailand	Estimated 24,9 MW	
South Africa	12 MW	0,9 MW in 2004
Indonesia	≈ 5–6 MW (2003) (includes some 45 000 SHS)	
Morocco	7 MW (2003)	1 MW (projected 15 MW by 2010)
Zimbabwe	4 MW (1999)	
Kenya	3,2 MW (1999)	At least 20 000 SHS (>0,5 MW)
Nepal	3,1 MW	Order of 12 000 SHS (0,34 MW) under Danida/ESAP Solar Support Programme in 2004
Malaysia	3 MW Includes 0,44 MW BIPV, but not industrial application	MBIPV programme commences in July 2005, targeting 1 MW of new building integrated PV in the residential and commercial sectors
Brazil	3 MW	>0,5 MW (around 20 000 SHS)
Sri Lanka	At least 2,9 MW (63 000 SHS under ESD & RERED – see text)	1 MW (23 300 SHS) in 2004
Philippines	1,6 MW – includes 1 MW solar farm in Mindinao	
Vietnam	1,1 MW (April 2005)	
Laos	0,3 MW (>90 % SHS under World Bank JICA and private companies actions)	2 000 SHS per year to 2010, 150 000 SHS by 2020

China
China's installed PV power capacity has more than trebled since 2001 to between 65 and 75 MW, due to the launch in 2002 of the Song Dian Dao Xiang (SDDX – the National Township Electrification Programme) and the continuation of the Brightness programme. China is now the 5th largest PV user after Japan, Germany, USA and India. The SDDX will conclude in 2005, having completed electrification of 662 townships (15,7 MW), but will be superseded by the SDDC (National Village Electrification Programme), which will deliver solar power to 10 000 villages (265 MW) by 2010 and a further 18 000 villages (1 700 MW) by 2020 The Renewable Energy Law, which comes into effect on 1 January 2006, is expected to support PV via a feed-in tariff, preferential taxes and loans, and specific encouragement of building related solar.

India
MNES, a Government Ministry in India, has been supporting PV dissemination and development for over a decade. Almost 325 000 'solar home systems' (including simple solar lanterns) have been installed with grant support under the Solar PV Demonstration and Utilisation programme to date, with some 16 500 installed in 2004. A number of grid-interactive village power systems (totalling over 2,8 MW to date, with a further 400 kW under construction) have also been supported with 66 % funding from MNES. However, the grid-interactive plants are not yet commercially viable and this funding stream has been closed as of 2004.

Laos
Under the World Bank/GEF supported Southern Provinces Rural Electrification (SPRE1) project, the Lao Ministry of Industry and Handicrafts has installed some 4 500 PV solar home systems (SHS) since 2002. Delivery is achieved via private sector provincial-level Electricity Supply Companies (PESCOs), who establish a network of Village Electricity Managers (VEMs) to install and maintain systems and collect payments. SPRE2 is expected to commence shortly, extending the initiative to all provinces, with an initial objective to install a further 10 000 systems within three years. The longer-term aim is 150 000 SHS by 2020.

Malaysia
Malaysia is presently unique amongst non-OECD countries in that its domestic PV market development priorities are clearly focused on the grid-connected, building integrated sector. The five year 25 million USD Malaysian Building Integrated PV (MBIPV) project officially commences in July 2005 with a view towards reducing the cost and establishing the necessary mechanisms to create sustainable opportunities for BIPV in the Malaysian market. The Suria 1000 project will see an additional 1 MW of BIPV installed by 2010, and is seen as a precursor to integration of BIPV within the 10th Malaysia plan (from 2011 to 2015).

Sri Lanka
The primary driver of PV market development in Sri Lanka is currently the Renewable Energy for Rural Economic Development (RERED) Project. RERED aims to expand the commercial provision and use of renewable energy, particularly to increase rural access to electricity, with a focus on improving the quality of life and economic development. The project will provide around 28 million USD specifically for solar PV investments (alongside other RE technologies, energy efficiency and demand side management measures).

Thailand
Thailand's energy strategy has a strong environmental focus and a view towards energy security through more effective use of domestic energy resources. Incentives and an obligation on power producers are expected to deliver an additional 214 MW of PV by 2011. A separate project is already underway to provide 120 W solar home systems to 300 000 households by the end of 2005. The two measures would together put the nation-wide installed capacity at over 250 MW by 2011.

In light of the success of the market support mechanisms in Japan and Germany, the proportion of the PV capacity connected to utility grids continues to dominate as illustrated by Figure 2. However, Figure 3 shows that in over half of the reporting countries this is not the case. Such off-grid application types vary distinctly between these countries. In Sweden, Norway and Finland, the most common applications are for vacation cottages, whilst in Portugal, France and Mexico achieving rural electrification is a key objective of projects. In the USA, Canada, Australia and Korea, commercial applications dominate, such as for telecommunication applications.

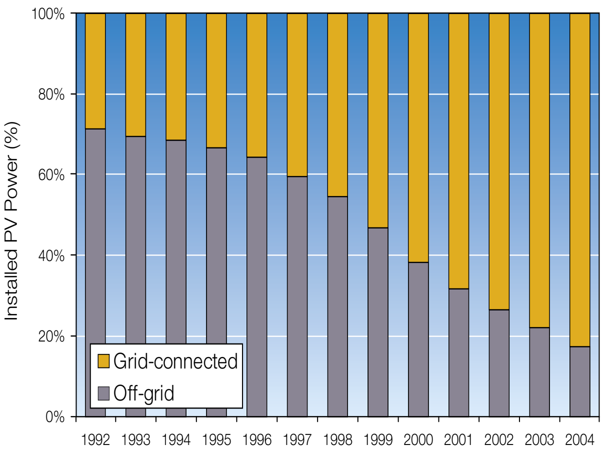

Figure 2 – Percentages of grid-connected and off-grid PV power in the reporting countries Years 1992 – 2004

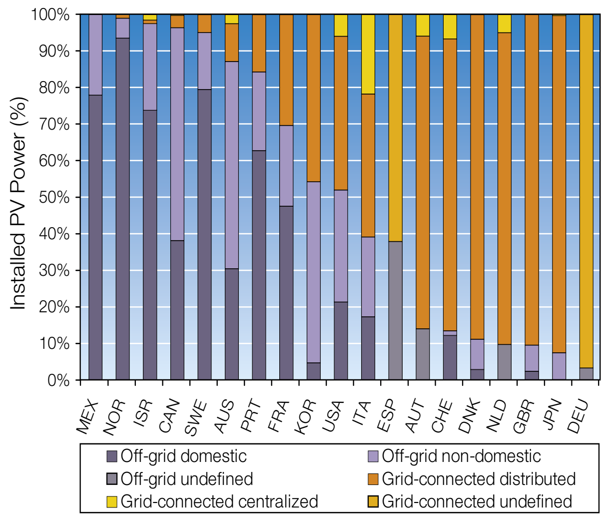

Figure 3 – Installed power in the reporting countries by application (%) in 2004

1.3 Market frameworks, major projects, demonstration and field test programmes

Over 93 % of capacity installed in 2004 was connected to the electricity network, and most projects and programmes reported in this section relate to grid-connected systems. This emphasizes the generally cost competitive nature of the off-grid market, in that state and utility support measures mainly target the grid-connected sector. The reader is directed to the national information and the case studies on the IEA PVPS website for further details about specific projects and programmes.

Australia (AUS)

Results of the review of the main policy mechanism supporting electricity generation from renewable sources, the Mandatory Renewable Energy Target (MRET) were published in January 2004. Although MRET does not particularly favour PV, the review recommended certain changes to the provisions relating to deemed energy output from PV generators that should effectively reduce the upfront system cost by the order of 500 AUD/kW for systems up to 100 kW.
The Federal PV Rebate Programme (PVRP), which provides capital rebates for homeowners of 4 000 AUD/kW capped at 1 kW continued to underpin sales in the grid-connected residential sector. PVRP, which also supports small installations (up to 2 kW) on public buildings was scheduled to conclude in 2005, but has been extended to 2007. PVRP requires systems be installed by accredited PV professionals.
The Federal Renewables Remote Power Generation Programme (RRPGP) continued to be a strong driver for PV deployment, particularly in Queensland and Western Australia. The off-grid diesel replacement programme provides capital grants of up to 50 % of hardware costs. Future impact of RRPGP is expected to be diminished by the removal of excise on diesel fuel for stationary applications.
The South Australian government initiated a Solar Schools programme in May 2004. 24 schools were equipped with 2 kW systems in 2004. The state Premier announced intent to support PV on at least 250 schools within ten years. The NSW Solar in Schools project continued in 2004, providing 1 kW systems to some 30 schools throughout the state.

Austria (AUT)

After the boom the previous year, 2004 marked a turnaround for the Austrian PV market. With the cap in nationwide PV support reached in early 2003, the newly installed capacity dropped from 6,5 MW in 2003 to 2,3 MW in 2004. For the first time since 1990, a slump in the domestic PV market occurred. With the introduction of the nationwide support for

electricity from RES (Green Electricity Act) in 2003, local and regional PV support programmes have ceased. Only one province out of nine re-established its incentives after the halt of the nationwide PV support.
Despite the difficult situation in the domestic market, the Austrian PV industry (especially inverter manufacturers and producers of components and materials) significantly expanded its business in 2004, relying almost exclusively on the German market.
A major trend observed in the previous years – optimal architectural integration of BIPV in buildings – also continued during 2004. Several installations with innovative design aesthetically integrated into buildings have been realized. One of the outstanding projects realized in 2004 was the façade integrated PV installation at a refurbished furniture store. With a covered area of 480 m^2 and an installed capacity of 53 kW the system is the largest PV façade in Austria in 2004.

Canada (CAN)
Canada's commitment in 2004 to ratifying the Kyoto Protocol made possible the funding of climate change programmes that have benefited PV. There has been a 15 % increase in the total public (federal and provincial combined) R&D and demonstration budget, with this funding focusing on technology and innovation with a 2025 horizon. There continues to be no public funding to stimulate the market for increased uptake of PV through deployment programmes.
The Net-Zero Energy Home (NZEH) Coalition, a partnership between the solar industry, home developers and builders, geothermal and solar energy industry associations, local utilities and university research centres was launched in the spring of 2004 with the goal of having all new home construction in Canada by 2030 meet a net-zero electricity standard. The Coalition has proposed a 1 500 NZEH early-adopters programme as a first step toward achieving their goal.

Denmark (DNK)
A national PV strategy including research, development and demonstration was drafted and finalized early in 2004. This is expected to lead to a much more consistent and concerted Danish effort in the field of PV, supported by the ongoing Danish participation in the EU supported programme PV-ERA-NET, targeting coordination and optimization of PV programmes in Europe.
An ambitious new programme is being investigated, SOL 5 000. Over a seven to eight year period the programme intends to bridge the gap between the present 40 % investment subsidy and a market situation with no investment subsidy. If successful this will lead to the situation in which PV roof top deployment in Denmark is supported solely by the net-metering scheme.

France (FRA)
During 2004 ADEME maintained its investment grant programme designed for BIPV systems through mobilizing complementary public funds from the regional councils. Private grid-connected PV systems are limited to 5 kW and private individuals also receive information on the benefits of an energy efficiency based approach. For more ambitious projects, ADEME has given priority to solutions of architectural quality with integration into the building shell.
Public subsidies in 2004 amounted on average to 57 % of the grid-connected installed cost. The 2004 grants from ADEME and regional councils enabled more than 4 MW of grid-connected projects to be implemented, twice as many as in 2003. Partnerships forged with the local communities have facilitated the appearance of new quality projects namely in regions such as Rhône-Alpes, Provence – Alpes – Côte d'Azur, Languedoc-Roussillon and Pays-de-la-Loire (including two grid-connected systems of 100 kW).

Germany (DEU)
In recent years, Germany has executed significant programmes which have triggered remarkable results in PV market development and technology progress. In 2004 the feed-in law was amended and the tariffs were adjusted according to changes in supporting market introduction programmes (PV tariffs were increased).
Following completion of the 100 000 Rooftops Solar Electricity Programme the continued support of PV systems by soft loans has been maintained by other programmes of the KfW Promotional Bank, and from 2005 by the new programme Solar Power Production.
The Sun at School programme is part of a federally run introduction programme. Using a simple application process schools get a fixed grant of 3 000 EUR for each PV system installed. Some of the Federal States (Länder) have defined their own programmes, mainly to support the application of renewable energy and energy conservation. The Federal German Environmental Foundation (DBU) supports development and demonstration in the fields of renewable energy sources and energy conservation.
A number of utilities have launched initiatives to build PV demonstration and pilot systems or to provide advice and information. In many cases financial support for the rational use of energy and for renewable energies is provided.
During 2004 at Espenhain near Leipzig the world's then largest PV plant became operational. The plant consists of 33 500 PV modules and has an installed power of 5 MW.

Israel (ISR)
Total installation of PV in Israel has shown a remarkable jump in reported installations for 2004, compared to low steady rates in the past few years. Some of this increase is due to greater public awareness finally leading to actual purchases, including several privately-funded PV projects connected to the public electricity network.
Two privately-financed grid-connected PV school projects were installed in 2004 with the twin purposes of providing an educational tool and contributing to environmental protection.
In Heraklion, Greece, several European partners together with an Israeli partner developed the EU sponsored Solar Powered Water Distillation System. The 4,8 kW system distills olive oil mill wastewater.

Italy (ITA)
The National Rooftop Programme was completed with 1,8 MW installed and 10,3 million EUR in funds provided by the Ministry of Environment and Land Protection (MATT). The programme aimed to improve procedures, develop public awareness and encourage the development of small grid-connected systems installed on building structures.
The Regional Rooftop Programmes are managed by all the 19 Italian Regions and the two Autonomous Provinces. Their purpose is to promote a wide diffusion of building integrated photovoltaic applications throughout Italy and to create a stable market with the aim of encouraging long term investment planning by interested companies.
Since 2001 applications have exceeded expectations and additional resources have been made available and targets revised. Nevertheless, despite very high public demand, the Regional Programmes are experiencing rather slow growth due to ongoing bureaucratic issues. As a consequence, at the end of 2004 only about 8,5 MW out of the anticipated 21 MW have so far been installed.
Since 1991 the Italian Demonstration Programme has been increasingly focused on medium and large size grid-connected plants, for utility applications, ranging from 100 kW to 3,3 MW. The activities currently underway include analysis, testing, long-term performance evaluations as well as operation and maintenance procedures carried out by ENEA on its own plants. Performance evaluation of photovoltaic components and plants is carried out by CESI, in order to assess long term behaviour of PV technology in different climatic conditions and in different electric configurations. As far as BIPV systems are concerned, the activities are mainly focused on 25 small grid-connected pilot plants and have been carried out since 2000 by ENEA and CESI in ENEA Centres and on public buildings of municipalities and universities in some prominent Italian cities.

Japan (JPN)
During 2004 the Ministry of Economy, Trade and Industry (METI) compiled the Energy Supply and Demand Outlook for 2030, including a New Energy advanced scenario. The Agency of Natural Resources and Energy of METI announced the Vision for New Energy Business to describe the future of the new energy industry toward the year 2030. The New Energy and Industrial Technology Development Organization (NEDO) developed a roadmap for technological development of PV systems, PV Roadmap toward 2030 (PV2030).
Major programme and market milestones were reached during the year – cumulative installed capacity of PV systems exceeded 1 GW, and applications to the Residential PV System Dissemination Programme reached the 60 000 level. Under this programme installation of a total of 230 MW is expected. Under the Field Test Project on New Photovoltaic Power Generation Technology, the number of projects to introduce PV systems for public and industrial facilities increased to 265, totalling 7,2 MW of installed capacity
The number of local governments providing financial support for the implementation of residential PV systems has increased to 350. Electricity utilities also supported the introduction of PV through the Green Power Fund.

Korea (KOR)
Since 1993 MOCIE (the Ministry of Commerce, Industry and Energy) has been implementing, via KEMCO, demonstrations and field tests of various renewable energy technologies. In addition, the government has been encouraging and supporting local authorities to implement their own demonstration or field test projects under the framework of the Local Energy Development Programme. This programme in part aims to raise public awareness about renewable energy technologies and to develop indigenous renewable energy sources for each region. In both of these programmes PV technology has been a top priority.
Under the Renewable Energy Demonstration Programme nine PV projects in schools and universities were installed in 2004. The Local Energy Development Programme, which has the objective to construct solar villages incorporating photovoltaic power systems and solar thermal systems, saw two local authorities – Gwangju and Daegu metropolitan cities – receiving funding for “Green Village” projects.
Under the Renewable Energy Field Test Programme several PV rooftop systems have been tested at the Solar Energy Field Test Site at Chosun University in Gwangju metropolitan city.
In 2004 the Rooftop Programme (with a target of 100 000 rooftop installations by 2012) saw 310 systems installed, each with a capacity 1 to 3 kW, and

with a budget of 6,3 billion KRW, compared to 21 systems in 2003.
A feed-in tariff programme has commenced for PV systems over 3 kW, with a fixed price of 716,4 KRW/kWh guaranteed for 15 years.

Mexico (MEX)

Distributed generation is attracting the attention of the national utility as an alternative to support the electricity network in some areas, and could become an important application in the near future. PV roofs are one of the technologies being considered. The first privately owned PV grid-connected system is under development and will be installed on a commercial building in Mexico City, with commissioning scheduled for mid 2005.
Rural electrification is back at the top of the priorities of the federal government, and a growth in capacity installed in this area is expected over the coming years. Preliminary studies looking at alternatives and implementation strategies will be ready mid 2005.

The Netherlands (NLD)

In order to stimulate measures favorable for energy reduction and implementation of renewable energy the central government supports municipalities and provinces through the BANS framework agreement [BestuursAkkoord Nieuwe Stijl]. By the end of 2004 about 200 municipalities had indicated their intent to actively participate in the programme. Since the actual activities are expected in 2005, the effect of BANS was rather limited in 2004. However, during 2004 a number of municipalities began to actively encourage building corporations and private citizens to invest in PV installations on their roofs. Examples are the municipalities of Eindhoven and Leiden offering investment subsidies of 1 to 1,50 EUR per watt.

Norway (NOR)

Presently there is no market introduction programme in Norway, and the few demonstration projects have been motivated by educational or private interests (research and high school sector, industry and utilities). The most exciting building integrated project currently being planned is the use of transparent double glass modules on the southern façade of the new Opera house of Norway, to be located in the Oslo Harbour area. This is part of the EU project, EcoCulture.

Portugal (PRT)

Despite the fact that there are not yet specific programmes or strategies defined for the development of PV in the country, a few projects and initiatives illustrate the development of the PV market in 2004.
The Solar Energy in Schools project in the municipality of Moura (Alentejo, south of Portugal) saw the implementation of grid-connected PV systems in three schools, with installed power of 15, 25 and 35 kW. The Renewable Energy Demonstration Platform, installed near Lisbon (Sacavém) at Labelec premises, comprises three different grid-connected PV systems: a 1,4 kW two-axis tracking system, a 1,4 kW fixed system and a hybrid PV (0,5 kW) / Wind (0,9 kW) system. Labelec is a laboratory and R&D services company within the EDP Group, the largest Portuguese electricity utility. The PV plant at Barcelinhos is an independent 4,8 kW system connected to the low voltage electricity network, notable for exposing the existence of unduly onerous administrative requirements and the lack of experience of the electricity network utility in dealing with this type of small scale project.

Schiestl Haus (mountain hut) at 2 154 m above sea level, Austria, pic courtesy ATB/TBB Becker

Sweden (SWE)

A special subsidy for PV in public buildings was announced in April 2004. A maximum of 100 million SEK was allocated for the 36 month scheme, due to commence in 2005, which would increase the current national installed capacity by some 50 %.
A number of grid-connected PV demonstration projects are now emerging in Sweden. Many of the major PV projects completed in the past few years have been located in Hammarby Sjöstad, a housing area in Stockholm that has been developed with a strong environmental profile. The projects, which have largely been commissioned by building companies, in some instances in cooperation with electricity companies, have provided important lessons on PV integration both within the building envelope and the construction process. Several innovative projects, such as NCC Grynnan and Lysande utilize PV on facades and rooftops, incorporating modules within balcony perimeter guards, semi-transparent windows and external shade devices.

Switzerland (CHE)
At the outset of 2004, a total of 35 PV pilot and demonstration (P+D) projects were still active. As a result of the Swiss government's plans to cut back expenditure, no new funding of P+D projects was possible in 2004, and by the end of the year only 25 projects were still active. The important link between research and development and the commercial deployment of new technologies has now been cut and will undoubtedly have a negative effect on the market.
Other means play an important role in continuing the demonstration and promotion of PV technology, in spite of the cut-backs in government funding. The solar stock exchanges, in which solar power is produced and sold to persons and institutions interested in purchasing clean electricity, are proving to be a mainstay in the promotion of PV in Switzerland. The Bernese power utility BKW is installing a large-scale PV power generation facility on the roof of the new Stade de Suisse soccer stadium in Berne. In 2004, an initial 850 kW were installed. The power produced is sold separately to customers who are willing to pay a higher price for it. The installation will be augmented to produce a total of 1 300 kW of PV power as customer demand increases.
Many of the P+D projects still running in 2004 concerned building integration aspects – the testing of new components for the integration of PV systems in building materials, combined traditional flat-roof waterproofing membranes and flexible amorphous thin-film solar cells, combinations of various types of thin-film modules with thermal insulation, and innovative module mounting systems.
In the area of off-grid systems, an ongoing project is investigating the use of a combined PV and fuel cell driven energy supply system for remote locations with no conventional electricity supply.
Ongoing measuring and monitoring projects in 2004 included a facade-mounted, 80 kW PV installation in Wittikofen near Berne, tests made in Zurich on various thin-film modules and measurements made on the recently refurbished 100 kW installations along the motorway near Chur and along a railway line in Southern Switzerland.

United Kingdom (GBR)
There was a significant increase in the annual installed PV generation capacity in 2004 and it is anticipated that further installations under the Major Demonstration Programme will facilitate a continued healthy rate of grid-connected PV installation during 2005. The current programme is due to end in March 2006 and will be replaced by a new programme which will support PV as well as other renewable energy technologies suitable for building integration.

United States of America (USA)
During 2004 the major PV programmes and projects in the US consisted of the continuation of those started in the 1995-1999 timeframe. These included the completion of the Sacramento Municipal Utility District (SMUD) Pioneer II programme, in which the utility offered PV systems for sale to customers at subsidized prices (as low as 3,50 USD/W installed). The programme is essentially complete with over 10 MW installed (Pioneer I and II).
There are a number of interesting State programmes. The programme initiated by the State of California for residential and commercial customers who install grid-connected PV systems on investor-owned utility electricity networks saw 18,8 MW installed in 2004. California also has a programme of renewable power set-asides administered by the California Public Utilities Commission. More than 14,2 MW were installed by the four key utilities: Pacific Gas and Electric, Southern California Edison, San Diego Gas and Electric, and Southern California Gas Company. The total PV installed by California was 38,5 MW. Arizona and Illinois have active PV programmes. New Jersey is implementing one of the most aggressive PV support programmes in the US. More than 100 million USD have been appropriated for the programme, and nearly 2 MW of PV were installed in 2004. New York and North Carolina offer subsidies and tax credits respectively.

1.4 Budgets for market stimulation, R&D and demonstration

The public budgets for market stimulation, research and development, and demonstration and field trials in 2004 in the IEA PVPS countries vary widely – from negligible to several hundred million USD being reported. In about half the cases the total budget showed an increase from the previous year. A few countries showed a decrease, which was significant in some cases. Table 3 clearly shows the dramatic effect on the markets that have yet to reach a self-sustaining state when market stimulation measures are halted, reduced or subject to political uncertainty.

As reported previously, an IEA report[3] identified cost reduction opportunities over a decade (expressed as a percentage of current costs) arising from R & D (up to about 25 %), manufacturing volume (up to 15 %) and other manufacturing elements (up to 10 %). Although the situation varies from country to country (see Table 4 for 2004 budgets) and although the boundaries of what constitutes 'research', 'development', 'demonstration / field trials' and 'market stimulation measures' often vary from country to country, some interesting general trends can be

[3] *Renewables for Power Generation: Status and Prospects (IEA 2003)*

Table 4 – Public budgets for R&D, demonstration / field trials and market stimulation in 2004

Country	R&D		Demonstration/field trials		Market stimulation		Total	
	EUR	USD	EUR	USD	EUR	USD	EUR	USD
AUS	2,5 M	3,1 M	0	0	9,6 M	11,9 M	12,1 M	15 M
AUT					Feed-in tariffs ~7,6 M	Feed-in tariffs ~9,4 M		
CAN	4,9 M	6 M	1,1 M	1,4 M	0,12 M	0,15 M	6,2 M	7,6 M
CHE	9,8 M	12,1 M	1,0 M	1,2 M	1,0 M	1,3 M	11,8 M	14,6 M
DNK	3,4 M	4,2 M	0,7 M	0,8 M	0	0	4,1 M	5 M
DEU	24,5 M	30,3 M	0	0	250 M (EEG + soft loans 24,5 M)	308,6 M (EEG + soft loans 30,2 M)	274,5 M	338,9 M
FRA	7,6 M	9,4 M	0	0	18,9 M	23,3 M	26,5 M	32,7 M
GBR	4,6 M	5,7 M	8,3 M	10,2 M	0	0	12,9 M	15,9 M
ISR	0,16 M	0,2 M	0	0	0	0	0,16 M	0,2 M
ITA	4,8 M	5,9 M	0,2 M	0,3 M	23 M	28,4 M	28 M	34,6 M
JPN (METI)	49,0 M	60,5 M	83,3 M	102,8 M	39,4 M	48,6 M	171,7 M	211,9 M
KOR	5,6 M	6,9 M	12,2 M	15 M	4,5 M	5,5 M	22,3 M	27,4 M
MEX	0,7 M	0,8 M	0	0	0,3 M	0,4 M	1,0 M	1,2 M
NLD	12,7 M	15,7 M	0,15 M	0,19 M	>1 M	>1,2 M	13,9 M	17,1 M
NOR	0,6 M	0,7 M	0	0	0	0	0,6 M	0,7 M
PRT								
SWE	2,5 M	3,1 M	0,11 M	0,14 M	0	0	2,6 M	3,2 M
USA	69,7 M	86,0 M	8,5 M	10,5 M	145,8 M	180,0 M	224,0 M	276,5 M

Notes: ISO country codes are outlined in Table 12. Portugal's data not PV specific. USA FY: Oct 2004 – Sept 2005.

observed for the IEA PVPS countries as whole:

- over a decade, public spending on PV has doubled, with relatively steady increases from year to year;
- initially this spending was largely focused on RD&D;
- the amount spent on market stimulation increased at the expense of RD&D (in both absolute and relative terms) until 2001;
- 2004 saw the previously steadily increasing budgets for market stimulation decrease for the first time in a decade;
- from 2001 RD&D expenditure has been steadily increasing again, and also increasing its share of the total PV public expenditure.

In addition to the public expenditure of the individual countries the European Commission of the EU supports a number of PV projects. The following commenced during 2004: Crystal Clear (16 million EUR over 5 years), HICONPV (2,7 million EUR over 3 years), BIPV-CIS (2,3 million EUR over 4 years), MOLYCELL (2,5 million EUR over 30 months), PV-MIPS (4,4 million EUR over 5 years), Solar Plots (1,8 million EUR over 2 years), BITHINK (1,9 million EUR over 3 years) and PV-ERA-NET (duration 4 years) – source and further information about these and ongoing programmes: http://europa.eu.int .

2 The PV industry

This section provides information on the industry involved in production of PV materials, cells, modules and system components during 2004. The industry may be subdivided into the following groups representing different steps in the PV value chain:

- producers of upstream materials, i.e. feedstock silicon, ingot, blocks/bricks and wafers
- producers of semi-finished and finished PV products, i.e. PV cells and modules
- producers of balance-of-system components for PV systems, i.e. charge regulators, inverters, storage batteries, mounting structures, appliances etc.

A regional overview is presented in Table 5, which is likely to account for about 90 % of worldwide production. Of the countries not covered by this table, India has a significant module manufacturing capacity, and the production development in China and Taiwan appears to be rapid.

2.1 Feedstock, ingots and wafers (upstream products)

IEA PVPS is now reporting on the industry for feedstock materials since they play a key role in the development of the crystalline silicon cell industry. Feedstock refers to the silicon prime material currently used in about 90 % of PV cells produced. The discussion in this section therefore does not apply to thin-film technologies.

In 2004 a tightening of supply of high purity, low cost feedstock silicon for solar photovoltaic cells started to become evident. At the same time demand grew strongly, putting further pressure on the supply / demand balance. Consequently most suppliers of so-called solar photovoltaic grade silicon feedstock have ambitious plans to increase capacity. At the same time industry wishes to cut costs through improved production processes.

The United States defended its position as the main producer of feedstock for silicon PV cells, with a total output of 5 100[5] tonnes in 2004. Of this total, 500 tonnes was scrap[6] silicon from the electronics industry. Amongst the US producers, Solar Grade Silicon LLC (SGS) is wholly owned by the Norway based Renewable Energy Corporation (REC), where Elkem, world leading supplier of metallurgical grade silicon and also Norway based, took a 23 % ownership position last year, signalling a wish to diversify its activities. SGS is planning a drastic capacity expansion in years to come.

Other companies supplying feedstock to the industry are the producers of electronics grade silicon – in total six companies with plants in the USA (4), Japan (3) and Germany (1). German company Wacker is the second largest supplier of electronics grade polysilicon to the PV and electronics industries and shipped 2 800 tonnes to the PV industry in 2004. This was an increase of 800 tonnes and there are plans to expand capacity by 1 500 tonnes over the next two years. Tokuyama, the only company in Japan manufacturing feedstock for the PV industry, contributed about 1 000 tonnes.

Much effort is dedicated to reducing the production cost of solar PV grade feedstock silicon. SGS in the past year commissioned a 200 t/year demonstration fluidised bed reactor, achieving satisfactory results.

Box 2 – manufacturing summary in selected non-PVPS countries

In respect of manufacturing developments outside of the IEA PVPS countries, the significant news in 2004 was the dramatic increase in production from China and Taiwan. The reader is directed to the IEA PVPS website for a more detailed description of manufacturing developments outside of the IEA PVPS countries.

China's monocrystalline ingot and wafer production amounted to about 57 MW in 2004, while domestic multicrystalline throughput was around 10 MW. The largest Chinese cell and module manufacturer increased its manufacturing capacity from 25 MW at the end of 2003 to a potential 50 MW of cells and 75 MW of modules by the end of 2004, and reported actual production for the year of 35 MW of both cells and modules. It is worth noting that the total module production capacity indicated by the ten main Chinese PV players in 2004 was over 270 MW (267 MW crystalline Si, 6 MW a-Si), against cell production capacity of around 60 MW and actual module production estimated to be about 65 MW. Indications are that additional production capacity of over 100 MW of crystalline silicon cells and at least 240 MW of modules is planned for 2005. The majority of China's module manufacturers are reliant on imported wafers or cells. Some companies may struggle to secure upstream silicon supplies over the next few years, to justify the planned capacity increases. China's main amorphous silicon cell manufacturers are expected to add some 23 MW of additional production capacity in 2005.

In terms of PV cells, Taiwan was again an important non IEA PVPS production country, reporting an increase of over 100 % to 35 MW of crystalline silicon (both single and multi-crystal) output alongside 3–4 MW of amorphous silicon[4] production. This places Taiwan sixth behind Japan, Germany, USA, Spain and China in the global cell production rankings. Crystalline silicon cell production capacity is expected to increase by a further 140 % by the end of 2005.

At approximately 30–37 MW, India's module output in 2004 was largely unchanged from 2003. Data from the Ministry of Non-conventional Energy Sources (MNES) annual report indicate that the vast majority of 2004 production was exported.

A US company, has established a 25 MW pa per year cell facility near Manila, Philippines, which delivered its first product to market in the second half of 2004. The initial cells from the new production line reportedly achieved close to 20 % efficiency.

[4] *Predominately small modules (low power applications <40 W) for OEM consumer products*
[5] *Currently about 12 – 14 tonnes of feedstock silicon are consumed for each MW of crystalline silicon PV cells.*
[6] *Top and tail from single crystals, single crystals from aborted runs, crucible residuals ("pot scrap") and various other material of minor quantities.*

Table 5 – PV industry production in 2004 by world region – IEA PVPS countries

		Japan	USA	Europe	Rest	Total
Silicon feedstock	**tonnes**	1 000	5 100	2 800	–	**8 900**
Ingots	**sc-Si, tonnes**	1 071	1 000	275	–	**(9 121)**
	mc-Si, tonnes	2 400	500	3 875	–	
Wafers	**sc-Si, MW**	150	181	352	–	**860**
	mc-Si, MW	177			–	
Cell Production	**All types, MW**	604	138	329	38	**1 109**
Cell Production Capacity	**MW / year**	*650*	*171*	*425*	*49*	***1 295***
Module Production	**sc-Si, MW**	109	86	126	1	**322**
	mc-Si, MW	396	30	86	1	**513**
	a-Si, MW	25	14	2	–	**41**
	Undefined, MW	60	–	198	9	**267**
	Other, MW	na	9	8	<1	**17**
	Total MW	590	139	420	11	**1 160**
Module Production Capacity	**MW / year**	*821*	*177*	*578*	*53*	***1 629***

Notes: The apparent imbalances in the upstream section of the production chain are due to firstly, feedstock being held by some manufacturers at the end of 2003 and also being sourced from electronics industry scrap in non-PVPS countries, and secondly, wafer production in the non-PVPS countries plus recycling and unreported contracted sawing of wafers. Figures for ingot production are difficult to compile as in-house use is not reported by some countries in the same manner as external sales. The mc-Si ingot figure reported here for Japan has been sourced independently and differs from the figure presented in the national report. mc-Si includes modules based on EFG and String Ribbon cells. 'Undefined' means the Si technology type was not clarified; 'other' refers to technologies other than silicon based. 'Rest' refers to Australia, Canada, Israel, Korea and Mexico.

Tokuyama is working on a new Vapour to Liquid Deposition technology, and a joint venture between Solar World AG and Degussa AG ordered a pilot scale reactor, to be installed during 2005, for a new technology for decomposition of silane. Elkem Solar of Norway has also commissioned a pilot plant for PV grade silicon through the metallurgical purification route.

There are also many research activities underway investigating potential low cost routes to solar PV grade silicon. In Europe alone there are at least three different technology development projects in addition to those mentioned above.

Ingot and wafer production are usually integrated in the same production facility and since the end of the 1990s there has been the emergence of several powerful players focusing on this value-chain step.

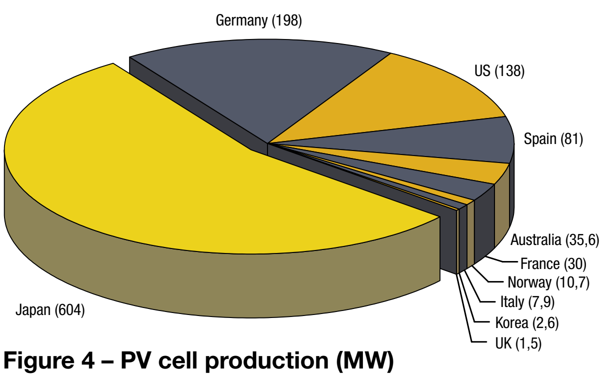

Figure 4 – PV cell production (MW) in the reporting countries by country in 2004

These companies market the wafers themselves rather than processing them into cells and modules, as done by some of the older, vertically integrated companies. Three European companies, PV Crystalox 170 MW (Germany, UK), ScanWafer 130 MW (Norway) and Deutsche Solar 120 MW (Germany) are competing for the global leadership of production of wafers.

The trend from 2003 of a resurgence of single crystal PV technologies has been sustained for a variety of reasons, such as efficiency and the availability of

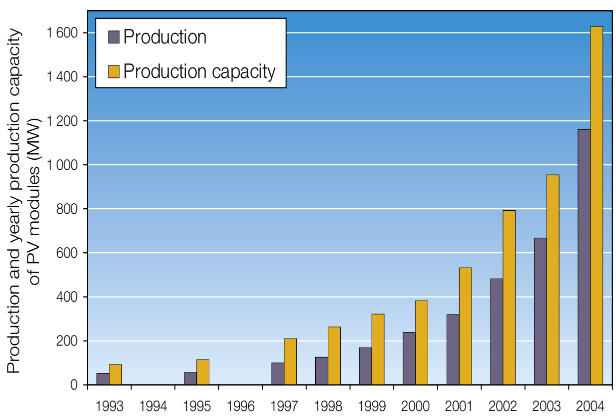

Figure 5 – PV module production and yearly module production capacity in the reporting countries (MW) between 1993 and 2004

electronics grade silicon wafers of high purity from a number of sources.

There are also significant, vertically integrated companies that have in-house production of ingots and/or wafers for further processing into PV cells. Notably these include Kyocera (Japan), BP Solar (USA), Shell Solar (USA) and Photowatt (France). Other companies are attempting to commercialize new processes that involve wafer production through a non-ingot route. RWE Schott (USA/Germany) with their silicon ribbon ("EFG" trade mark) is the most significant of these, but Evergreen Solar is also making progress with its proprietary string ribbon technology. General Electric (successor of AstroPower) continues to re-use 25 MW single crystal wafers from the semiconductor industry, whereas Silicon-Film, AstroPower's heralded technology seems to have vanished. As a consequence of the strong demand, ingot and wafer producers largely continue to plan capacity increases.

In summary Japan, the USA, the UK, Germany and Norway are the countries with significant production of feedstock silicon and up-stream materials for crystalline silicon cells. In comparison with cell and module producers there are relatively few actors in this step of the value chain. Outside the IEA PVPS countries significant silicon crystal pulling and wafer manufacturing occurs in Russia and the Ukraine.

2.2 *Photovoltaic cell and module production*

PV cell and module production continues to grow strongly. The total photovoltaic cell production volume in reporting countries for 2004 was reported to be 1 109 MW, up from 686 MW in 2003, an increase of 62 %, with significant growth in Japan (65 %) and Europe (71 %). The reader is directed to the individual national reports, available on the website www.iea-pvps.org, for a comprehensive summary of manufacturers and production in each of the countries.

The global production growth rate for PV cells has increased sharply following the rate of 32 % achieved the previous year. In reality growth is even stronger since production is also increasing in the non IEA PVPS member countries (see box 2).

Japan is the leading producer of cells and modules accounting for about 55 % and 51 % respectively of the IEA PVPS member country production in 2004. In Europe, the corresponding figures were 30 % and 36 %. The United States saw production of cells and modules increase (by 35 % and 96 % respectively) from 2003.

The cell production capacity increased significantly in Europe as well as in Japan and, to a lesser extent, the US. The worldwide capacity gain was 39 %. This is the second year in which capacity increase was significantly smaller than increase in output. The utilisation of capacity has thus improved and now averages about 86 %, up from last year. Notably, several of the major players now report that they are making a profit. Module production capacity jumped by an impressive 70 % – with close to 300 MW being added in each of Japan and Europe, and perhaps reflecting the strong market signals and previously unrealized investment plans.

The Japanese producers Sharp and Kyocera maintain their lead. With a number of large and small manufacturers Germany remains the second largest producer of cells and modules. Globally, beside well-established companies such as Mitsubishi Electric, Shell Solar, RWE Schott and BP Solar there has been an emergence of specific cell or module companies e.g. Q-Cells in Germany.
In 2004 at least three quarters of the modules produced in the countries covered by this survey

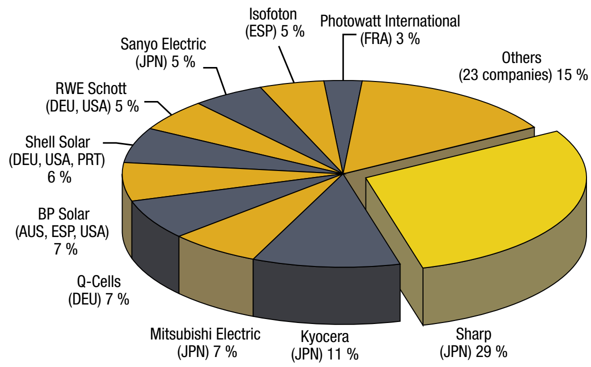

Figure 6 – Share of PV cell production in the reporting countries by company in 2004 (%)

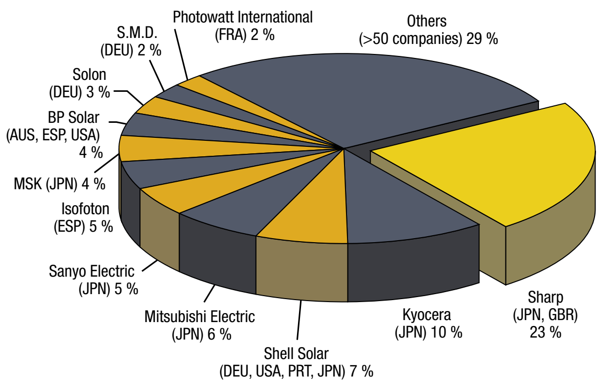

Figure 7 – Share of PV module production in the reporting countries by company in 2004 (%)

were based on crystalline silicon technologies, a similar result compared with 2003 and 2002. However, new technologies now show the same growth rate as crystalline silicon.

There are a number of interesting technological advances for both crystalline silicon and thin film technologies. For example, SunPower now markets a 20 % efficiency PV cell which translates into 16,8 % in modules. While the market breakthrough for thin film technologies is yet to be seen, all technologies remain on the market and production capacity continues to increase.

Canadian Spheral Solar Power (a division of ATS) is planning to introduce modules relying on micro spherical silicon technology in 2005. Australia's Origin Energy is commercializing the 'Sliver cell' PV technology. It is also worth noting that the ribbon technologies at both RWE Schott Solar and Evergreen Solar are making significant progress.

The trend from last year regarding production of PV components specifically designed for building integration has continued. On the end-user side a significant initiative is the General Electric partnership with the building industry to introduce "zero energy homes" featuring energy efficient appliances, heat pumps and PV.

It seems likely that the future will see a continued consolidation of the industry producing mainstream crystalline silicon photovoltaic cells, but the market may also provide fertile ground for companies marketing niche products. Difficulties in supplying low cost silicon feedstock to satisfy the traditional PV industry through 2005 may also provide a good entry point for thin-film technologies, since buyers might become focused on availability of alternative products.

2.3 Balance of system component manufacturers and suppliers

From a cost perspective, balance of system (BOS) components account for between 20 % (standard grid-connected system) and 70 % (off-grid installation) of the total system costs. Accordingly the production of BOS products has become an important sector of the overall PV industry. Particularly with the rapid expansion of the worldwide market for grid-connected PV systems, inverters are currently the focus of the interest. Manufacturers of PV inverters for grid connection faced a boom in 2004 and many companies more than doubled their output compared to 2003. In Europe the large manufacturing companies are located in Germany, Austria, Switzerland, the Netherlands and Denmark and produce almost exclusively for the German market. In total around 30 to 40 companies are currently active in this field with German SMA Technology the leading player.

Also Japan, the USA and Canada reported extensive activities in this field. It is likely that more than 20 companies are producing grid-connected inverters in these countries. The leading companies are Sharp and Xantrex.

Today most of the products are dedicated to the residential PV market, with typical system sizes from 2 kW up to 10 kW. However, with the increasing number of MW scale systems being installed in some countries, inverters have been developed with capacities up to 1 MW.

In the field of building integrated PV (BIPV) increasing attention is being paid by companies specializing in façade construction and roofing. These companies are now increasingly complementing their product range by developing new and innovative systems for PV integration.

In addition to basic BOS components such as inverters, charge controllers, support structures or storage batteries, specialized equipment for the PV manufacturing industry has become an important business. Products in this field 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 the production process.

2.4 System prices

Prices for entire PV systems vary widely (Table 6) and depend on a variety of factors including system size, location, customer type, grid connection, 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, both off-grid and grid-connected systems showed a slight increase in prices over the previous year; with two thirds of the countries showing price increases and one third decreases. This is reflected in Figures 8 and 9. A couple of countries showed dramatic price increases for grid-connected systems, reflecting reported significant rises in PV module prices. However, in 2004 this tended to be an exception rather than a general trend. System prices for off-grid applications in each country continue the tendency to be higher by about a factor of two than those for grid-connected applications as the latter do not require storage batteries and associated equipment. Some

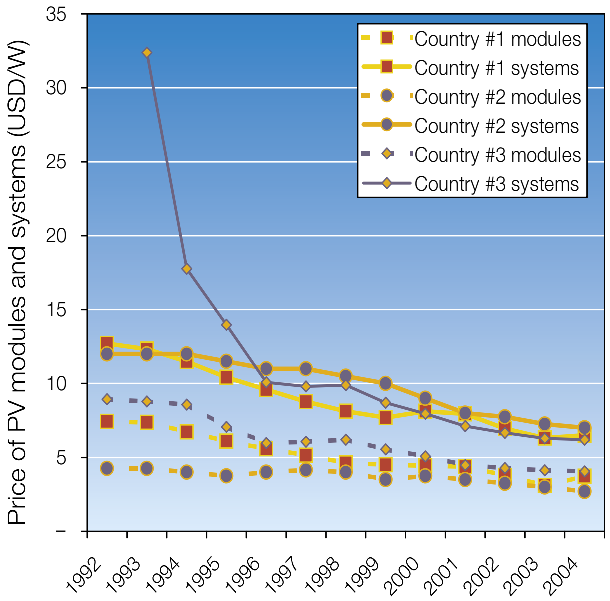

Figure 8 – Evolution of price of PV modules and systems in selected reporting countries

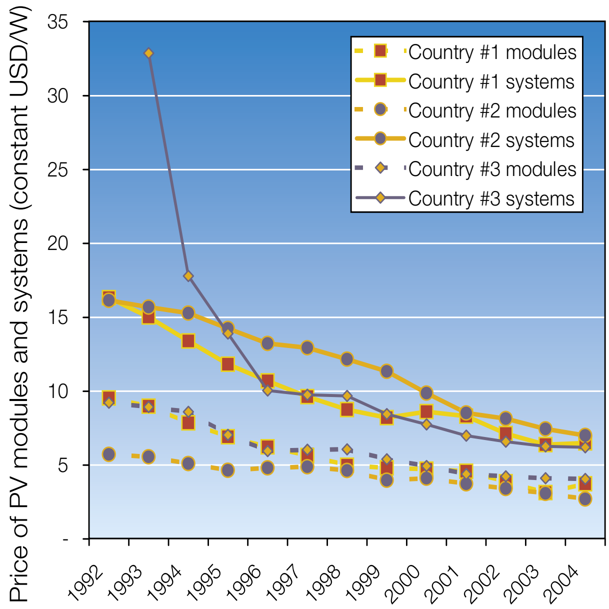

Figure 9 – Evolution of price of PV modules and systems in selected reporting countries accounting for inflation effects

Table 6 – Indicative installed system prices in selected countries in 2004

Country	Off-grid (per W)				Grid-connected (per W)			
	<1 kW		>1 kW		<10 kW		>10 kW	
	EUR	USD	EUR	USD	EUR	USD	EUR	USD
AUS	10,7–14,3	13,2–17,6	7,1–17,8	8,8–22	6,0–10,7	7,4–13,2	6,0–7,1	7,4–8,8
AUT	15	18,5	10–13	12,3–16	5,5–8,5	6,8–10,5	5–8,5	6,2–10,5
CAN	11,5	14,2			8,4–9,1	10,4–11,2	5,6	6,9
CHE	10,4	12,9	9,2	11,3	5,8–5,9	7,2–7,3	4,9	6,0
DNK	9,5–12,2	11,7–15	20,3–27,1	25–33,4	4,5–9,5	5,5–11,7	5,4–13,5	6,7–16,7
DEU					5,3	6,5		
FRA	15–20	18,5–24,7	15–20	18,5–24,7	4–12	4,9–14,8	5	6,2
GBR	7,9–14,7	9,8–18,2	7,7–13,3	9,5–16,4	7,4–16,8	9,1–20,7	7,0–15,9	8,7–19,6
ISR	7,1	8,8	5,6–7,1	6,9–8,8				
ITA	12–15	14,8–18,5	12–14	14,8–17,3	5,5–8	6,8–9,9	5,3–7	6,5–8,6
JPN					5,0	6,2	5,7	7,0
KOR	15,6	19,2	14,2	17,5	8,5	10,5	8,1	10
MEX	9,7–13,0	12,0–16,0						
NLD	10–50	12,3–61,7			4,5–6	5,6–7,4	4,5–4,7	5,6–5,8
NOR	7,8–13,2	9,6–16,3			9,6–13,2	11,9–16,3		
PRT	7–15	8,6–18,5	7–11	8,6–13,6	6–8,5	7,4–10,5	5–6,2	6,2–7,7
SWE	9,9–11,0	12,2–13,6			4,4–6,1	5,4–7,5		
USA	9,7–20,3	12–25	9,7–16,2	12–20	5,7–8,1	7–10	5,1–6,9	6,3–8,5

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. More expensive grid-connected system prices are associated with roof integrated slates or tiles, or one-off building integrated designs. ISO country codes are outlined in Table 12.

unique building integrated projects provide an exception to this situation.

In 2004 system prices in the off-grid sector up to 1 kW varied from around 9 USD to 25 USD per watt. The large range of reported prices is a function of country and project specific factors. A system price of about 13 USD per watt appears to be common. Off-grid systems greater than 1 kW tend to show similar variation and slightly lower prices.

The installed price of grid-connected systems in 2004 also varied, both within and between countries, as shown in Table 6. The lower reported prices were typically around 5,5 USD to 6,5 USD per watt. The cost structure of the system price continues to vary widely between countries (and between projects). Modules continue to make up around 50 % – 70 % of the reported grid-connected system prices in most but not all cases. Large grid-connected installations can have lower or higher system prices, depending on the economies of scale achieved or the degree of building integration, installation difficulty and innovation.
As foreshadowed by the reported increase in system prices in 2004, module prices also showed an increase – mostly ranging from little change to over 60 % increase compared to 2003 prices. Amongst the key markets, indicative prices for modules in both Japan and the US changed by less than 10 %; in Germany a 30 % increase for lowest priced modules must be viewed against a background of an unusually low price that was available during 2003 and reported.

It is too simplistic and convenient to explain the 2004 module price increases solely in terms of the tightening of silicon feedstock supply discussed earlier. The situation varies from country to country and from producer to producer however there are a number of factors that could be implicated in the price increases. Historically there has been a good balance between installed capacity in a given year and supply in the previous year (for example production in calendar year 2001 was close to the amount installed in 2002, production in 2002 was close to the amount installed in 2003) – however the gap between amount installed in 2004 and production in 2003 has widened considerably (mainly due to the market surge experienced in Germany) and this exceptional rate of growth may have had implications for the management of stock.

Table 7 – Indicative module prices in national currencies per watt in reporting countries

Country	Currency	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Typical or best prices	
															EUR	USD
AUS	AUD			7		8		8	8	8	8	7	7	10	6,0	7,4
AUT	EUR											4,5	3,1–3,2	3,6–3,7	3,6	4,4
CAN	CAD								11,09	10,7	9,41	7,14	6,18	5,53	3,5	4,3
CHE	CHF											7,5				
DNK	DKK									40	40	33	21–45	30–50	4,1	5,0
DEU	EUR	5,98	5,93	5,42	4,91	4,50	4,14	3,73	3,63	3,58	3,53	3,04	2,5–9,7	3,0–9,6	3,0	3,7
ESP	EUR												2,6–4,25			
GBR	GBP										4,1	4,1	3,9	2,3–3,7	3,4	4,2
ISR	NIS												22,5–28,4	13–27,3	2,4	2,9
ITA	EUR		4,65				4,13			4,13	4,25	3,9	3,1-3,9	2,9–3,6	2,9	3,6
JPN	JPY	966	950	927	764	646	656	670	600	548	484	463	446	439	3,3	4,1
KOR	KRW			9 400	9 400	8 200	8 500	9 200	7 500	7 100	7 200	7 200	7 000	6 500	4,6	5,7
MEX	MXP												65	68–80	4,9	6,0
NLD	EUR			9,5	7	7,5	6	5	4,75	4,73	4,73	4,62	4,5	3,5–4,5	3,5	4,3
NOR	NOK												55–100			
PRT	EUR										4	3,5	3,5	3,5–4	3,5	4,3
SWE	SEK												26–70	26–70	2,8	3,5
USA	USD	4,25	4,25	4,00	3,75	4,00	4,15	4,00	3,50	3,75	3,50	3,25	3,0–5,0	3,25	2,7	3,3

Notes: Current prices. ISO country codes are outlined in Table 12. ISO currency codes are outlined in Table 12. 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 reports.

Further, the PV industry has become increasingly global in nature, with many players now competing in a number of sections of the production chain. With increasing expectations of returns to stakeholders, areas of the business experiencing tight margins need to be offset by profitable business, especially within some support programmes where competition may be minimal, the market is buoyant and / or customers are not facing real costs. Also, as reported previously and as with any industry, competition (either within or from outside a country) can exert a noticeable downward pressure on prices, and secondly, supply monopolies are free to charge their local markets higher prices (until faced with competitive pressure) in order to achieve profits.

In 2004, and similar to the previous year, module prices of 3,5 USD to 4,5 USD per watt appear achievable in the majority of countries, and nearly all of the major markets, with indications that the lowest achieved prices of modules are somewhat higher than in 2003. Table 7 shows the change in module (current) prices in some of the reporting countries from year to year, and Figures 8 and 9 show the evolution of module prices, in current prices and accounting for inflation respectively, in selected countries.

The often-quoted technology learning curves suggest a cost decrease of 15 % to 20 % for each doubling of market size. With respect to PV, the global market has doubled four times over the previous decade. Consequently, expectations of the real cost of modules suggest a decrease to around 3,7 USD per watt – only slightly lower than the price currently being reported – and, correspondingly, grid-connected systems to about 6,7 USD per watt installed.

In a sense the price reductions achieved, not only for modules but also for the balance-of-system components, indicates that the policies of public subsidies have been successful. However, this does not imply that the policies have always been optimal. The massive injections of support have clearly created periods with more orders in the books of manufacturers than they could fill in a timely manner, and this is very likely the reason that the PV prices did not diminish during some of these periods with a high influx of money. Also, in addition to the issues raised earlier, the industry may even have seen an opportunity to recover its own development expenditures at a faster pace than anticipated or may have been limited by the time needed to resolve the technology perfection issues. The latter issue involves the hesitation of a responsible industry to sell too many units of a technology not yet fully developed, whether for reasons of warrantee obligations or for reasons of not loosing good reputation for reliable products.

2.5 Economic benefits

The economic impact of PV business has been measured in some of the reporting countries during 2004 both as a net value that includes the effect of imports and exports, and as labour place creation. The net business value measure is expected to show some interesting trends over time, as production shifts internationally to meet demand. For specific country details reference should be made to the individual country reports.

Most countries report a generally positive trade balance in PV equipment, although many have struggled to locate accurate data, particularly on imports. In most countries the proportion of net exports is small in comparison to the overall market size, at approximately 10 % – 20 % of total market turnover. The exception to this is Norway, which is a major manufacturer of wafers for further development elsewhere. For those countries with little or no equipment manufacturing capability, such as Denmark, the proportion is reduced.

In employment terms, many countries reported significant increases in persons directly employed in PV related industries, research and development and installation support. Total direct employment in the sector in the reporting countries may now exceed 50 000 persons, with rapid growth indicated in Germany and the USA. Many of the newer jobs in the sector are associated with the installation and marketing of PV products, rather than necessarily related to the manufacture of modules and components. This is partly due to the continued trend for the most labour intensive activities in the supply chain to move to low cost base economies which are often not IEA PVPS members – a trend common across all manufacturing sectors. For example a new module manufacturing facility opened in The Philippines in late 2004 to service the Japanese and South-East Asian markets.

In Europe, the dominant position of the supported market in Germany has continued to provide employment in Austria and The Netherlands, even though their domestic markets have decreased following the withdrawal of support mechanisms. There is evidence that the level of exposure of markets to political or policy change is such that this has restricted the appetite for investment. This has the impact in restricting supply and may therefore be yet another significant factor in the reported leveling off in the price decreases noted in previous years.

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, govern the rate of deployment of PV systems.

Public interest in promoting PV development has occurred in waves. Two main public support periods have occurred until now: the first during the early 1980s and a second one starting in the late 1990s. The motivations for support for PV R&D, for industry development and for demonstration projects have included the belief that this particular renewable energy technology would be desirable for societies in the long-term. The reasons given for this stance include concerns over the environmental side effects of conventional energy production and use, and concerns over energy supply security, whether due to political instability in supply regions, physical depletion of energy resources such as oil or uranium and, more recently, the integrity of local electricity networks.

The first support period followed steep price increases for crude oil and was largely directed at providing demonstration projects for grid-connected PV. A remote area niche market for stand-alone PV systems was already in existence, with occasional support from national and international aid programmes for helping developing countries. However, support was insignificant relative to the support given to rural electrification programmes based upon electricity network extensions.

These programmes were particularly helpful in directing the manufacturers' attention to a number of problems manifesting themselves at all levels (cells, modules, inverters, support systems). Hence the injection of public money can be said to have spurred the industrial effort to solve these problems and to pave the way for the next generation of systems being put into operation during the last 10 to 12 years.

The second support period has been characterized by a much larger injection of funds, and with the intention of involving the users of the systems directly. They may still be called demonstration programmes, but in cases such as Japan or Germany, the funds made available to assist private investors are better described as market creation subsidies. The explicit (or at least implied) purpose of this massive support has been to push price reductions, by forcing the manufacturers to install additional production capacity in order to meet a somewhat artificial demand. The rationale that this may reduce prices – and the underlying reason for the previously described technology learning curve – is that due to rapid technology progress, each new generation of production equipment has reduced cost and improved performance and presumably increased quality and durability. An indication of this trend may be seen in Figure 9, showing that price reduction comes in 'jumps' from one plateau to a lower one, consistent with the explanation in terms of new production technology being introduced at intervals. The development has been rapid and it should not be surprising that production capacity in periods has been substantialy higher than the actual PV production, at least in some countries. This is not a PV-specific phenomenon.

The impact of market support measures has been dramatic by any measure. Since the first issue of the Trends in Photovoltaic Applications report was published in 1992, the installed capacity in the IEA PVPS countries has grown by a factor of 23 and now at 2,6 GW represents a level that was difficult to foresee even ten years ago. Yet, as outlined, the rationale behind most market mechanisms is that a level of support is necessary to build the capacity of the industry to a point where such tariff or capital support is no longer necessary – the volume of products will drive the price down to a level that will result in a self sustaining industry. It has been demonstrated that the installed costs of grid-connected and off-grid systems have reduced over the period, in line with expectations. Many off-grid markets have been operating without public support for a number of years. However with regard to grid-connected domestic systems, evidence of any market self sustainability is only recently emerging (from Japan).

The level of support provided has proved critical in maintaining the momentum. In Austria and The Netherlands, a few months of frantic activity have been followed by a virtual standstill as the mechanisms changed or reached their predetermined target level (eg Table 3). Whilst in the UK, a less generous grant based scheme has been struggling to reach its modest target level. Additionally, uncertainties in the continued level of political support continue to hold investors back, acting against the downward price pressure of market volume as manufacturers strive to keep margins high enough to recoup investments as quickly as possible before the politicians, and their policies, move on.

However, there are more promising signs of a long term – but modest – market future emerging for PV in off-grid applications. The high level of activity fostered by supported markets has driven innovation in product design to such an extent that it is increasingly being transferred into new application-focused modules. This has been particularly evident with utility and monitoring uses in which the high cost of an initial installation can be measured against the disturbance, delay and cost of a traditional grid connection. As mentioned, this is a market that is already sustainable, but at a scale that is hardly noticed in the rush for the next gigawatt of grid-connected PV capacity.

3.1 New initiatives in photovoltaic power systems

Table 9 highlights the key initiatives reported in the participating countries during 2004. The main fiscal instruments being used to support or promote PV in the IEA PVPS countries continue to be the direct capital subsidies and, increasingly of interest, the enhanced feed-in tariffs. Much less widespread

Table 8 – Key market support measures: some observations and conclusions

	Enhanced feed-in tariffs	**Direct capital subsidies**	**Green electricity schemes**	**Renewable portfolio standards**
Target audience	Grid-connected PV customers with business cash flow requirements eg housing developers, investors, commercial entities.	PV customers with limited access to capital eg households, small businesses, public organizations.	Residential and commercial electricity customers.	Liable parties, typically the electricity retailing businesses.
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.
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.	The 'good public policy' aspect of government involvement in selective, customer-driven, electricity business commercial activities raises some interesting questions. 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.
	There are varying political perceptions regarding the use of public funds or funds generated by the electricity industry.			
Potential effectiveness	Function of the size of the enhancement.	Can be very effective as a simple but blunt approach to deployment – but not necessarily cost-effective.	Becoming commonplace and well understood with regard to renewables in general.	
Problems	Less predictable where specific results, such as limited capacity installed or rates of deployment are being sought. Can result in overheated markets on the one hand if rates are too high, but also to negligible impacts if rates are too low.	Often seen as too simplistic and not encouraging broader consideration of customer energy usage or willingness to pay for PV. Also criticized for inflating system prices and subsidizing more affluent consumers.	Less predictable where specific results are being sought. Unless PV specific, usually characterized by a broad, least-cost approach favouring hydro, wind and biomass.	The general requirement for renewable energy may simply encourage the lowest direct cost renewable energy options (and not PV) for consideration by the liable parties.
Solutions	Clearly target this approach on specific, limited market segments.	Explore willingness to pay and social equity issues. Clearly reduce subsidy rate over a period of time.	Encourage / create demand for PV specific electricity.	Consider a portfolio approach to the RPS, or at least PV specific measures.

Notes: In practice, support measures can involve a combination of the above, and will usually function more effectively when this is the case. Funding issues are significant and are critical to the success of any mechanism. PV funding needs to be stable over time, separate from political interference, transparent and clearly targeted.

are reduced interest rates on loans, tax credits, accelerated depreciation, and 'PV electricity' marketing schemes.

As noted elsewhere in this report, it would appear that there is a move to reduce the significance of market stimulation subsidies in many countries, maybe in the hope that the industry can survive in competition with alternative electricity generating systems without market interventions, and in some cases reflecting a longer-term R&D focus as part of climate change policies. This approach may not necessarily impact negatively on market growth, as feared by many, as PV systems are seen by some customers as having an environmentally positive value and thus a value as a status symbol, making these customers willing to pay an extra amount for a PV system. An indication of this behaviour can be seen in some countries, but similar indications are fading away in countries that previously made similar claims. However, the cost reduction has not yet reached a magnitude that allows many customers to install PV systems purely as status symbols; with the electricity production cost in some locations an order of magnitude higher than other environmentally friendly options (e.g. energy efficiency measures, green electricity purchases). The added values of PV are a critical – and still largely unexplored – aspect of grid-connected PV markets.

Table 9 – Initiatives and perceptions

	New initiatives and promotional activities	
AUS	*The PV Rebate Programme will now be extended until 2007, but with lower levels of grant support than were originally offered. Installations are now predominately grid-connected systems and the scheme is now being promoted to housing developers. Although originally conceived as a programme to displace remote diesel generation, a development in the Renewable Remote Power Generation Programme now allows the installation of grid-connected systems on the fringe of existing networks, where these meet certain criteria. A Solar Cities programme has been conceived to demonstrate high penetration of PV and energy conservation measures from 2006 onwards.*	*Utilities with diesel grids continue to strongly support the integration of PV into their systems, although the recent decision to reduce fuel excise duty from stationary diesel plant will reduce the financial incentive. Other utilities are engaged with the climate change debate, and actively exploring investment options. Knowledge and understanding of PV is now widespread at local authority level, with a large growth in on-street applications building familiarity. Changes in building codes are encouraging some housing developers to explore PV as a compliance option, and the general public is gaining confidence that PV is an option for today, rather than only for the future.*
AUT	*As there has been no extension to the 15 MW cap allocated to feed-in tariff support (which was reached in March 2003), the only new initiates have been capital support grants funded by Provinces. Upper Austria, with a grant level of up to 65 %, has had a reasonable uptake, but similar measures in Vienna and Lower Austria with lower grant levels (up to 40 %) have received no applications in 2004.*	*Utility and public perceptions of PV are excellent, but enthusiasm has only extended to investment when substantial financial support is available. For utilities, the connection of small embedded generation is routine, and electricity network management is not reported as giving high levels of concern. A net metering offering from a specialized electricity off-take company has attracted interest in combination with Upper Austria's capital grant support.*
CAN	*Both Federal and Provincial funding for R&D and demonstration continues to increase strongly, and is increasingly aimed at technology and innovation with a medium (2025) time horizon. There continues to be no market support mechanisms, but the Net Zero Home Coalition - a grouping of corporate and not for profit organizations – has launched a new home standard and is developing its strategy to encourage wide scale adoption.*	*With little grid-connected capacity, most utilities have no knowledge or confidence in PV connections – applications are treated as one off installations. Public perceptions are limited by the low level and visibility of projects, except for some remote commercial off-grid applications.*
CHE	*With no Federal promotional or funding schemes and only limited activities by Cantons, the market for PV is sustained by industry activities and private households. Whilst public funded R&D has been reduced, commercial investment in PV components for markets outside of Switzerland has paid dividends.*	*A growing number of utilities have experience of grid connection of PV. Utilities operating within the Solar Power "green market" (Basle, Geneva, Berne and Zurich) have been successful participants and have funded new capacity in their areas. A major sports stadium in Berne with a 850 kWp PV system is being commissioned and will help raise the profile to the general public*

Table 9 – continued

DEU	*An increase in the tariff payable under the Energy Sources Act to rooftop PV generation has compensated for the end of the previous soft loan programme. A number of Federal states have implemented their own grant & loan structures, and the new "Solar Production Programme" is set to commence in 2005.*	*Connections to the electricity network are seen as routine, and many utilities participate in the PV market. Public knowledge and perception of PV is high, mainly as a result of the high numbers of distributed grid-connected systems installed.*
DNK	*A new national strategy for PV RD&D and a revision of the Energy Policy should lead to a stronger lead and better coordination of actions. A SOL 5 000 initiative – which may target 5 MW over 5–7 years – is in preparation but requires new concepts for financing structures to be developed.*	*The oversubscription of the SOL 1 000 project has demonstrated the public interest in the sector, and the potential introduction of DIY kits could have a significant impact – with no incentives beyond net metering. Utilities still consider the sector as one for strong growth, particularly for modest scale home systems of a few hundred watts.*
FRA	*The system of capital grants made by ADEME and the regional councils allowed a substantial growth of grid-connected applications. Emphasis is placed on the development of building integrated products. New PV products developed by the construction industry and the PV industry have emerged.*	*The electricity utility EDF continues to be active in the development of publicly funded off-grid systems, the development of thin film and standards for PV. A new framework law on energy will be progressed during 2005 that will concentrate on energy efficiency and renewable energy. However, it remains to be seen as to how high a profile PV will have in the actions that follow, as bio-energy and solar thermal are expected to be the focus of the agenda.*
GBR	*The ongoing Major Demonstration Programme supported continued growth in the UK PV industry during 2004. The current programme will continue until March 2006 or until the current funding has been allocated, with installations continuing until March 2007. The scheme is to be superseded by a new building integrated renewables programme which will continue to provide support for PV. A consultation on the new scheme is taking place during 2005.*	*All UK Distribution Network Operators (DNOs) have experience of PV systems. Due to the low-level of PV penetration in the UK, the DNOs do not see solar electricity as a business priority at this time. Nevertheless, there is a general interest in PV issues, particularly by the DNOs in the south of the country where PV systems are more common, and all DNOs are keeping a watching brief to see how the sector develops.*
ISR	*The recently published Energy Master Plan sets the direction for energy policy over the next 20 years. In particular, it examines the prospect of mandatory implementation of PV (in a similar manner to solar hot water heating, where the household uptake is 80 %) and supports the implementation of centralized solar plants. The Public Utility Authority is close (May 2005) to finalizing the details of an action that will pay renewable energy premiums.*	*Whilst the state utility, IEC, has limited recent experience of PV and is recommending net metering for all grid-connected tariffs, the standards and codes for connection are not fully developed (the one formal application took 8 months to progress). Public awareness of PV is high but it is normally associated with off-grid applications.*
ITA	*The passing of legislation (decree law 387/03) implements the relevant European Directive that enables a range of promotional activities, some of which some are dedicated support measures for PV. However the specific legislation that would have fixed tariffs, due in August 2004, has yet to be issued (May 2005).*	*Both the state and local utilities have strongly supported the implementation of PV through jointly working with research institutes to overcome connection barriers. Public enthusiasm is widespread and leading to an unprecedented level of interest in the expected feed-in tariffs.*
JPN	*No new promotional activities were started in 2004, but wider dissemination projects that focus on the ability of town planning and technology to tackle climate change have been established. There is a continued focus on measures to encourage the uptake of PV in public, commercial and industrial facilities, where the level of market penetration is significantly lower than in the domestic sector.*	*PV is supported strongly by both utility companies and the general public. Utilities routinely invest in their own PV projects. The generous subsidy programmes available have meant that familiarity with the technology is widespread, and connection to the network routine.*
KOR	*To supplement existing programmes the Government allocated a separate budget for a residential roof top programme in 2004. It is intended that this will provide the first step in a 100 000 roof top programme to be implemented by 2012.*	*Utilities and the general public have had limited exposure to PV, although the impact of publicity surrounding Government programmes is starting to raise awareness.*

Table 9 – continued

MEX	*Whilst there are no specific programmes aimed at PV, rural electrification has risen on the political agenda. A new programme is under development and due for implementation in 2005.*	*There has been some interest from the national utility in grid-connected PV as a way of managing peak (summer cooling) loads. Most applications are for remote off-grid domestic and professional applications.*
NLD	*With the ending of direct investment support, the feed-in tariff and tax incentives remained the only support measure and have proved unsuccessful in maintaining the level of growth seen in 2003. However, a scheme supports municipal authorities' efforts to promote sustainable communities. Some authorities have already started supporting PV by capital grants, but the levels of support are around half those seen in 2003.*	*The majority of utilities discontinued financial support for PV as soon as the relevant legislation expired, although one (Eneco) are using their continued participation in the market as a product differentiator. Whilst public perception of the technology is high, the evidence of market collapse following the withdrawal of subsidy has reinforced the view that PV is for the future – and is currently unviable. There is a strong expectation that new incentives may be forthcoming, and many investors may be postponing projects in anticipation.*
NOR	*Apart from a general investment subsidy of up to 25 % available to a range of renewable energy technologies, there are no specific support measures. High profile projects – such as the new opera house in Oslo – are seen as one-off demonstrations of national environmental consciousness.*	*Some utilities have made selective investments in remote areas and are increasingly exposed to measures such as greenhouse gas emission trading and the grid connection of other variable generation, such as wind power. The majority of public perception regarding PV is centered on their use in vacation cottages.*
PRT	*Despite a large level of interest and applications made to participate in the generous PV feed-in tariffs offered, no applications had been determined during 2004. When combined with increased capital support measures also available, it is probable that 2005 will see a substantial increase in installed capacity*	*Utilities are generally aware and capable of undertaking grid connections, but bureaucratic delays and a lack of effective connection standards continue to frustrate. New climate change legislation enacted in 2004 is likely to provide additional policy support.*
SWE	*In 2004 a new market deployment initiative was announced that is part of a scheme to subsidize refurbishments for increased energy efficiency in buildings used for public activities, such as schools, libraries and community centres. The programme will provide up to 70 % of the capital costs, but has an overall programme cap for PV investments of 100 MSEK.*	*Utilities are generally positive regarding PV, with some demonstration projects partly funded by their investments to gain experience and to study the potential for business impact. Public perceptions are clouded by the misconception that PV is unsuitable for the Swedish climate, apart from vacation cottages in remote locations.*
USA	*State governments and utilities of many types continue to develop and support PV through a wide range of incentives, programmes and initiatives. The range and diversity of those in California remain the most far-reaching, but none of the States have any major initiatives that are new in 2004. Programmes range from funds for PV research, tax rebates, portfolio standards, green pricing structures and grant programmes.*	*The deregulation of the state monopolies for electricity supply is progressing, with a few enacting the legislation that positively supports renewable energy projects. More than 20 states now have renewable portfolio standards in place. Political interest in renewable energy is focused on security of supply issues. Public interest in PV is growing based on consumer interest in energy security and environmental benefits.*

3.2 Indirect policy issues and their effect on the PV market

Many governments are turning their attention to longer-term approaches to climate change issues and are now increasingly relying on the approach commonly referred to as the 'renewable portfolio standard' (RPS) to increase renewable energy deployment in their countries – often, but not solely, as a mandated mechanism for pursuing greenhouse gas emission reductions. However, in the absence of a national strategy for PV or at least some concrete targets for installed capacity of PV, the RPS is unlikely to have a positive impact on PV deployment and may even have unforeseen negative implications (Table 8). Other reported measures to promote renewables include disclosure on electricity bills, tradable certificates, and branding and labels, although their application is not widespread.

There are a number of 'green power' schemes offered by electricity businesses, in which customers can purchase green electricity. In principle, these rely on part of the customer base giving some environmental or other value to renewable energy – and paying a premium for the privilege. These also rely on the customer base having trust in the supply of their green electricity and, ideally, an understanding of what makes up their electricity supply. Electricity businesses also have an opportunity to maximize network benefits and promote other benefits when they support or invest in projects that will form part of their green power scheme. PV fits well with this approach because firstly, customers often seek 'solar energy' (compared with electricity from biomass or hydro plants, for example) and secondly, in the built environment the promotion of some of PV's added values can smooth the pathway to deployment. However green power schemes (especially in their infancy) are often characterized by the same problems for PV seen in the government-driven RPS approaches.

Many utilities are now offering net metering (where feed-in tariffs do not apply). Avoiding the costs of electricity network extensions in remote areas and reducing the effects of demand peaks in hot weather are more firmly on the agenda for electricity network regulations. Security of supply issues are again attracting increased attention in some countries.

3.3 Standards and codes

For more than 20 years 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. Established in 1981, TC 82 has been preparing international standards for "systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system". As of the end of 2004, 28 IEC International Standards and four Technical Specifications had been published covering a comprehensive range of issues.

With the world wide expansion of the PV market, the number of countries participating in the work of TC 82 has also been constantly increasing in recent years. Currently 24 countries are active participants and a further 12 have observer status.

The main 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 Working & Coordination Group (JWCG) of experts from different TCs. Conformity assessment and certification schemes are treated within the framework of the IECEE (Worldwide System for Conformity Testing and Certification of Electrical Equipment).

2004 was a very active year for TC 82 with the publication of seven new or revised International Standards or Technical Specifications (TS):

- Photovoltaic module safety qualification, requirements for construction & testing (IEC 61730-1/2)
- Characteristics of the utility interface for photovoltaic (PV) systems (IEC 61727 Ed. 2.0)
- Photovoltaic (PV) stand alone systems – Design verification (IEC 62124 Ed. 1.0)
- Balance-of-system components for photovoltaic systems – Design qualification natural environments (IEC 62093 Ed. 1.0)
- Recommendations for small renewable energy and hybrid systems for rural electrification – Part 2: From requirements to a range of electrification systems (IEC/TS 62257-2)
- Part 3: Project development and management (IEC/TS 62257-3)

Further topics that are currently on top of TC 82's list of projects include performance (power and energy rating) of PV modules, the traceability of PV reference devices and especially BOS components such as inverters and charge controllers. Finally, concentrating PV modules have gained increased attention and a dedicated standard for this type of PV is currently being developed.

On the European level the CLC/TC 82 of the European Committee for Electrotechnical Standardization (CENELEC) aims to support the market development by harmonization of standards. In this context CLC/TC 82 closely cooperates with its counterpart, the IEC TC 82 as well as the national committees. In areas where there is special European concern, CLC/TC 82 is also developing own standards. Currently these activities focus on solar cells and wafers – where a German working group is drafting a standard for specifications – and grid interconnection of PV systems.

In the USA standardization currently focuses on safety and interconnection issues of grid-connected PV systems. In the framework of the US DOE Solar Programme a large portion of the standards, codes and the USA certification activities was supported, including recent new developments such as the 2005 edition of the National Electrical Code and the progress of the IEEE 1547 series of interconnection standards. US representatives also actively participate in the IEC TC 82.

In Japan, the Japanese Standards Association published five Japanese Industrial Standards (JIS) related to various issues such as design and installation guidelines for PV modules – most of them consistent with the IEC documents. Further projects focus on performance and safety issues of systems and components.

As already mentioned, grid interconnection is the focus of the standardization activities in many of the PVPS countries, such as Australia, the USA and various European countries; however this issue remains controversial. The most serious problem seems to be that until today grid connection is mostly addressed by national documents and there is still a long way to go to achieve harmonized interconnection requirements and rules. However, some countries have established specific guidelines and requirements which allow a smooth and easy grid connection of PV systems. Nevertheless in many places the broad deployment of grid-connected PV is often constrained by inappropriate regulations, which can cause an unreasonable increase of system costs due to additional equipment requirements, long delays or bureaucratic barriers.

In the field of certification and conformity assessment a broad range of activities has been reported e.g. from the USA, where both hardware and practitioner certification programmes are being developed, and the Japanese JET laboratories which are currently running a certification programme for PV modules and inverters for grid-connected systems. Further initiatives on certification, accreditation, training and quality schemes are mentioned by various other PVPS countries.

PV GAP, the PV Global Approval Programme aims at promoting globally accepted standards, testing laboratories and reference manuals for PV manufacturers with a focus on developing countries. Based on the IECEE certification scheme a “PV Quality Mark” for PV components and a “PV Quality Seal” for PV systems are licensed to manufacturers if their product qualifies according to the requirements. So far five companies have received approval to display the label. Furthermore, PV GAP is also developing a broad range of “PV Recommended Specifications” (PVRS) in areas where an IEC standard does not exist. Since 2003 there is an official (category A) liaison between PV GAP and TC 82 of the IEC, which has been initiated to promote the global use of IEC PV Standards and extend the global PV standardization process to developing countries.

Stade de Suisse, 850 kWp, Switzerland, pic courtesy BKW/FMB

4 Summary of trends

The countries participating in the IEA PVPS Programme have a diversity of PV production, applications and policy interests. As reported in past years the ideal of the 'real' or 'self-sustaining' or 'competitive' PV market, standing on its own merits, lies somewhere in the future, with public support for the grid-connected market still important in the near-term. However, indications, at least from Japan and in many off-grid market segments, are that this situation may be more achievable than many government policies are suggesting.

- The market for PV power applications continues to expand in spectacular fashion: between 2003 and 2004 the total installed capacity in the IEA PVPS countries grew by a record 42 %, reaching just under 2,6 GW. Of the 770 MW installed during 2004, 94 % were installed in Japan, Germany and the US alone. Doubling of market size in the IEA PVPS countries has occurred four times over the previous decade.

- Between 1992 and 2004 the proportion of grid-connected PV capacity increased from 29 % to 83 % of the total, up from 78 % in 2003. This is mainly due to large scale, government programmes, especially in Japan, Germany and the USA, which focus on PV in the urban or suburban environment. However, in 2004 off-grid applications still accounted for the majority of the annual market in over one third of the reporting countries and are certainly most significant in the non PVPS countries described in this report.

- Total national budgets for R & D, demonstration / field trials and market stimulation measures remain strong but are changing in emphasis. 2004 saw the previously steadily increasing budgets for market stimulation decrease for the first time in a decade; RD&D expenditure continues to steadily increase in absolute terms, and also to increase its share of the total PV public expenditure.

- 2004 saw both unprecedented surges in market growth, and collapses of domestic markets – the consequences of political decisions on national programmes. 2004 also saw evidence that grid-connected markets may become self-sustaining in the right environment, even though the price of PV electricity has yet to reach retail electricity price levels.

- Annual photovoltaic cell production rose by 62 % in 2004 (compared to 32 % in 2003) to 1 109 MW and cell production capacity increased by 39 % (compared to 17 % in 2003). Module production capacity rose by a staggering 70 %. However, investor confidence regarding cell and module manufacturing must be looked at in the context of a considerable tightening of supply further upstream in the production value chain. Currently 55 % of cell production and 51 % of module production in the reporting countries occur in Japan.

- The trade balance of PV production (on a net basis) shows some interesting regional aspects in 2004 – the US produces a significant excess of silicon feedstock material, with Europe and especially Japan showing a need for product; Australia, and Japan to some extent, rely on wafer imports; Europe

Table 10 – Installed PV power and module production in the IEA PVPS reporting countries

Year	Cumulative installed power and percentage increase						Power installed during year in IEA PVPS reporting countries (MW)	Module production during year in IEA PVPS reporting countries (MW)
	Off-grid		Grid-connected		Total			
	MW	%	MW	%	MW	%		
1992	78		31		110			
1993	95	21	42	32	136	24	26	52
1994	112	19	51	24	164	20	28	
1995	132	18	66	29	199	21	35	56
1996	158	19	87	32	245	23	46	
1997	187	19	127	46	314	28	69	100
1998	216	15	180	42	396	26	82	126
1999	244	13	276	54	520	31	124	169
2000	277	14	452	64	729	40	206	238
2001	319	15	670	48	989	36	260	319
2002	354	11	980	46	1 334	35	345	482
2003	410	16	1 419	45	1 829	37	495	667
2004	452	10	2 144	51	2 596	42	770	1 160

Notes: 2004 figures no longer include Finland.

shows a deficit of cell production relative to module production.

- The vast majority of modules produced continue to be based on crystalline silicon. In 2004, and similar to the previous year, module prices of 3,5 USD to 4,5 USD per watt appear achievable in the majority of countries, and nearly all of the major markets, with indications that the lowest achieved prices of modules are somewhat higher than in 2003. There are a number of interesting technological advances for both crystalline silicon and thin film technologies. While the market breakthrough for thin film technologies is yet to be seen, all technologies remain on the market and production capacity continues to increase.

- On average, both off-grid and grid-connected systems showed a slight increase in prices over the previous year; with two thirds of the countries showing price increases and one third decreases. A couple of countries showed dramatic price increases for grid-connected systems, reflecting reported significant rises in module prices. The lower reported prices were typically around 5,5 USD to 6,5 USD per watt.

- It still remains the case that the added values of grid-connected PV – electricity network, architectural, environmental and socio / economic benefits – are not widely appreciated by policy makers and regulators, or the more recent prospective stakeholders including the building and finance sectors. Simple grid-connected PV support schemes, implemented without a broader PV policy framework or complementary industry support measures, may do little to decrease prices, promote innovation or develop sustained market demand – probably because these schemes alone do not send the right signals about value to the stakeholders (PV industry, electricity businesses and investors / end-users).

- What then are the long-term prospects for PV? Proclaimed breakthroughs in amorphous or non silicon-based PV cells including organic dye cells have turned out to be somewhat disappointing to date, and a sudden price reduction for PV systems does not appear likely in the near term. Whether or not the slower price reduction by progressive system perfection, materials reduction and mass production can continue enough to meet the financial break-even point with both the conventional energy supply systems and other competing renewable energies is yet to be confirmed. The nature of the development effort would indicate that long-term support policies are called for, rather than the occasional burst of programmes with large subsidies being made available for a few years at a time, and that the PV value proposition requires far more attention than has been forthcoming to date.

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Exchange rates

Table 12 lists the participating countries, corresponding ISO country and currency codes, and the exchange rates used to convert national currencies. Exchange rates represent the annual average of daily rates (source: OECD Main Economic Indicators June 2005).

Table 12 – Exchange rates

Country	ISO country code	Currency and code	Exchange rate (1 USD=)
Australia	*AUS*	*Dollar (AUD)*	*1,36*
Austria	*AUT*	*Euro (EUR)*	*0,81*
Canada	*CAN*	*Dollar (CAD)*	*1,30*
Denmark	*DNK*	*Krone (DKK)*	*5,99*
France	*FRA*	*Euro (EUR)*	*0,81*
Germany	*DEU*	*Euro (EUR)*	*0,81*
Israel	*ISR*	*New Israeli Shekel (NIS)*	*4,482*
Italy	*ITA*	*Euro (EUR)*	*0,81*
Japan	*JPN*	*Yen (JPY)*	*108,1*
Korea	*KOR*	*Won (KRW)*	*1 145*
Mexico	*MEX*	*Peso (MXP)*	*11,28*
Netherlands	*NLD*	*Euro (EUR)*	*0,81*
Norway	*NOR*	*Krone (NOK)*	*6,74*
Portugal	*PRT*	*Euro (EUR)*	*0,81*
Spain	*ESP*	*Euro (EUR)*	*0,81*
Sweden	*SWE*	*Krona (SEK)*	*7,35*
Switzerland	*CHE*	*Franc (CHF)*	*1,24*
United Kingdom	*GBR*	*Sterling (GBP)*	*0,55*
United States	*USA*	*Dollar (USD)*	*1*

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 system, typically available in 12,5 cm, 15 cm up to 20 cm square sizes. In general, cells can be classified as either *crystalline (single crystal or multicrystalline) or thin film.* At present, the vast majority of photovoltaic cells are made from silicon.
Currently crystalline silicon technologies account for most of the overall cell production in the PVPS countries.
Single crystal PV cells are manufactured using a single crystal growth method and have commercial efficiencies between 15 % and 18 %.
Multicrystalline 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 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 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 200 W but several manufacturers now offer modules up to 300 W. 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 approved to IEC 61215 or IEC 61646 International Standards.

Most complete systems consist of a number of modules connected together in the form of a PV array to give a higher power rating.

A **PV 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'.

Grid-connected 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 94 %, with peak efficiencies up to 97 %. 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).

Off-grid 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 (eg 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 PV technology and applications can be found on the IEA PVPS website at www.iea-pvps.org .

Notes

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