IEA INTERNATIONAL ENERGY AGENCY

TRENDS IN PHOTOVOLTAIC APPLICATIONS

Survey report of selected IEA countries between 1992 and 2003

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T1-13:2004

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Contents

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 20 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.

I am proud that the IEA PVPS Programme can, through its global network of independent experts, publish this ninth edition of the international survey report on Trends in Photovoltaic Applications.
The world-wide photovoltaic market can be seen to continue its strong growth, in particular for grid-connected applications. This edition contains a number of new features, namely an extended coverage of the applications beyond the IEA PVPS member countries. Such data have been requested by many parties over the past years. Although these data are more difficult to gather with the intended accuracy, this new feature corresponds to the IEA PVPS strategy to cover the global dimension of the photovoltaic market. Another area with new items covered is the chapter on the photovoltaic industry, looking both within and beyond IEA PVPS member countries. The important topic of feedstock for the PV industry is now summarized in this report. The economic aspects of photovoltaics have been analyzed in more detail, thus enabling new insights and comparisons. I am pleased that all these additional data and their analyses can for the first time be published in a condensed form.
I trust that this new edition of Trends in Photovoltaic Applications will find interested readers and I would like to thank all experts who have contributed to this new edition. The IEA PVPS Programme welcomes comments on the information published in this report and I trust that this will trigger discussion and result in an even more enhanced coverage in the years to come.

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 work 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 visit the IEA PVPS website at www.iea-pvps.org.
September 2004

Introduction

Survey 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 20 participating countries[1]. The objective of the survey reports is to present and interpret trends 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.

The survey 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 reports 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 9th international survey. It provides an overview of PV power systems applications and markets in the reporting countries at the end of 2003 and analyses trends in the implementation of PV power systems between 1992 and 2003.

Survey method

Key data for this publication were drawn from national survey reports[2] 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.

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 $W \cdot m^{-2}$ 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 US dollars (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 conversion from national currencies to USD in 2003 are given at the end of this report (Table 12).

Austria: Institute for Marketing

[1] Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), Finland (FIN), 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). [2] Spanish PV production data were supplied by ASIF.

1 Implementation of photovoltaic systems

1.1 Applications for photovoltaics

There are four[1] primary applications for PV power systems:

Typical Swedish summer cottage

Off-grid domestic systems provide electricity to households and villages that are not connected to the utility 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 grid at distances of more than 1 or 2 km from existing power lines.

Security light for an alpine airport near St. Moritz, Switzerland

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

Grid-connected distributed PV systems supply power to a building or other load that is also connected to the utility grid and account for most of the installed PV capacity amongst the IEA PVPS countries as a whole. These systems are usually integrated into the built environment and supply electricity to residential dwellings, commercial and industrial buildings. Typical systems are between 1 kW and 100 kW in size. Electricity is often fed back into the utility grid when the on-site generation exceeds the building loads. These systems offer a number of advantages: distribution losses are reduced because the systems are installed at the point of use, no extra land is required for the PV systems, costs for mounting systems can be reduced, and the PV array itself can be used as a cladding or roofing material as 'building integrated PV' (BIPV). Compared to an off-grid installation, system costs are lower as energy storage is not generally required, a factor that also improves system efficiency and decreases the environmental impact.

Saisyunkan Pharmaceuticals 480 kW, Japan

Grid-connected centralized systems have been installed for two main purposes: as an alternative to conventional centralized power generation, or for strengthening the utility distribution system. Utilities in a number of countries are investigating the feasibility of these types of power plants. Demonstration plants have been installed in Germany, Italy, Japan, Spain, Switzerland and the USA, generating reliable power for utility grids and providing experience in the construction, operation and performance of such systems.

NL: PV sound barrier along a railway line

[1] *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*

By the end of 2003, a cumulative total of more than 1,8 GW of PV capacity had been installed in the IEA PVPS countries. As in previous years, over 85 % of this capacity can be accounted for in just three countries and therefore care must be taken when interpreting the results in this section. Figure 1 illustrates the growth of installed capacity since 1992 and the split of this capacity between the four primary applications for PV. This installed capacity represents a significant proportion of worldwide PV capacity.

The annual rate of growth has varied between 20 % in 1994 to over 40 % in 2000, but the growth between 2002 and 2003 of 36 % has been similar for the latest three years. As in the previous year the vast majority of new capacity installed was installed in Japan, Germany and USA, with these three countries accounting for about 88 % of the total installed in the year. Not surprisingly, these are the countries with the continuing generous levels of grant or tariff support for projects that concentrate on grid-connected installations in the urban environment. In terms of

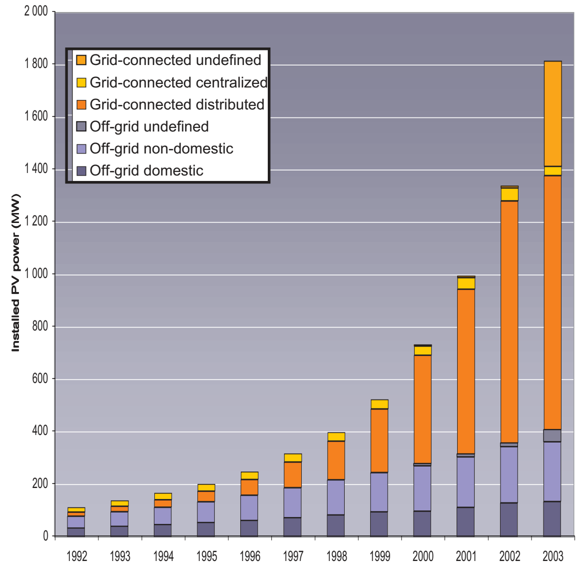

Figure 1 – Cumulative installed PV power in the reporting countries by application (MW). Years 1992 – 2003

Table 1 – Installed PV power in reporting IEA PVPS countries as of the end of 2003

Country[1]	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 2003 (kW)	Grid-connected PV power installed in 2003 (kW)
	domestic	non-domestic	distributed	centralized				
AUS	13 590	26 060	4 630	1 350	45 630	2,29	6 500	1 730
AUT	2 173		13 507	1 153	16 833	2,05	6 492	6 327
CAN	4 539	6 886	405	0	11 830	0,37	1 833	37
CHE	2 740	260	16 440	1 560	21 000	2,88	1 500	1 300
DNK	55	170	1 675	0	1 900	0,35	310	300
DEU	19 700		390 600		410 300	4,97	133 000	130 000
ESP	18 820		9 180		28 000	0,68	8 000	6 500
FIN	3 022	237	118	32	3 409	0,66	357	22
FRA	11 924	5 332	3 817	0	21 072	0,35	3 832	1 875
GBR	172	542	5 189	0	5 903	0,10	1 767	1 621
ISR	313	200	6	14	533	0,09	30	0
ITA	5 300	6 400	7 600	6 700	26 000	0,45	4 000	3 980
JPN	1 101	77 792	777 830	2 900	859 623	6,74	222 781	216 535
KOR	461	4 549	1 427	0	6 438	0,13	1 028	666
MEX	13 565	3 536	10	0	17 111	0,16	950	0
NLD	4 678		38 759	2 480	45 917	2,83	19 591	19 545
NOR	6 175	365	75	0	6 615	1,44	231	7
PRT	1 152	520	397	0	2 069	0,20	401	5
SWE	2 814	573	194	0	3 581	0,40	284	36
USA	67 900	93 700	95 600	18 000	275 200	0,94	63 000	38 000
Estimated total[2]	**158 084**	**249 232**	**1 347 269**	**54 379**	**1 808 964**		**475 887**	**428 486**

[1] ISO country codes are outlined in Table 12. [2] 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.

installed capacity per capita, Japan leads the way with 6,7 W per capita, ahead of Germany, Switzerland and The Netherlands with 5 W, 2,9 W and 2,8 W per capita respectively.

Since 1999, most of the PV capacity installed in the IEA PVPS countries has been connected to utility grids. This is illustrated by Figure 2. However, Figure 3 shows that in over half of the reporting countries this is not the case. Off-grid application types vary distinctly between these countries. In Sweden, Norway and Finland, the most common applications are for vacation cottages, whilst in Australia, France and Mexico achieving rural electrification is a key objective of projects. In Canada, Israel and Korea, commercial and telecommunications applications dominate.
Due to the impact of the large-scale support measures available in some countries, the proportion of capacity that is connected to the grid continues to rise, reaching 78 % in 2003, up from 74 % the previous year. Of this almost all (96 %) are distributed systems. Domestic applications continue to account for approximately 39 % of off-grid capacity.

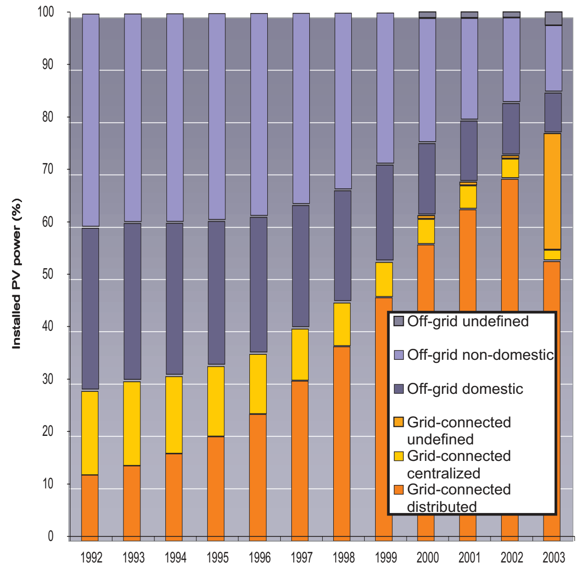

Figure 2 – Cumulative installed PV power in the reporting countries by application (%). Years 1992 – 2003

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

	Cumulative installed PV power (MW)											
Country[1]	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
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
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
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
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
DNK		0,1	0,1	0,1	0,2	0,4	0,5	1,1	1,5	1,5	1,6	1,9
DEU	5,6	8,9	12,4	17,8	27,9	41,9	53,9	69,5	113,8	194,7	277,3	410,3
ESP	4,0	4,6	5,7	6,5	6,9	7,1	8,0	9,1	11,6	16,0	20,0[2]	28,0
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
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
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
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
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
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
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
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
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
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
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
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
Total[3]	**110**	**136**	**164**	**199**	**245**	**314**	**396**	**520**	**728**	**990**	**1 333**	**1 809**

[1] ISO country codes are outlined in Table 12. [2] Figures for 2000 - 2002 deduced from available IEA data and other information. [3] Totals reflect conservative 'best estimates' based on the latest information made available to the IEA PVPS Programme from all countries for previous years, and are updated as required.

The rates of growth of installed capacity have remained relatively stable in the three largest markets, but the commencement of new support measures in Italy and Austria have lead to a high level of activity in these countries. In contrast, those countries without such incentives tend to have a lower level of growth which is mainly concentrated in the off-grid market. The Netherlands recorded a surge in growth in 2003 amounting to almost 43 % of the total size of its PV market.

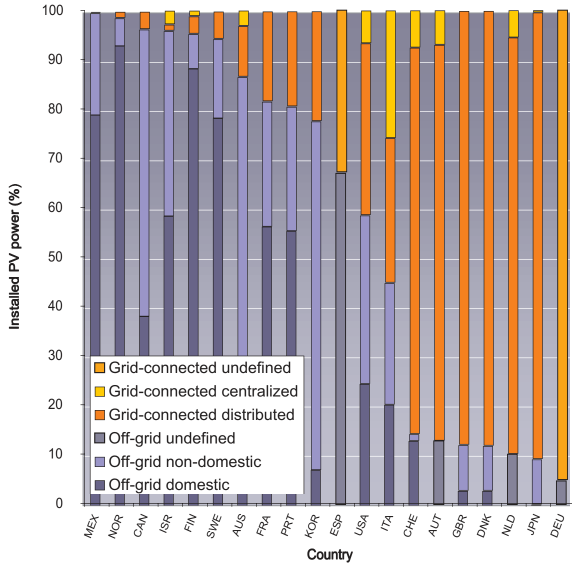

Figure 3 – Installed power in the reporting countries by application (%) in 2003

Like the vast majority of PV generation capacity installed in the IEA 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 is a notable market where PV sales have emerged spontaneously without government or official development assistance (ODA) subsidies. Key applications for solar PV outside the IEA PVPS countries are small solar home systems, 'SHS', for households (typically 20 W - 100 W), village power stations (typically 500 W - 2 500 W), and power for health centres, schools, water pumping and telecommunications systems. An important distinction is that for the remote or rural areas of developing countries which account for much of the market in non IEA PVPS countries, PV is often a cost effective solution to energy service provision. Establishing accurate annual sales figures by country or region (for non IEA PVPS countries) is extremely difficult given the large number of small systems involved. However the following information provides an indication of the scale of many of the key international markets to allow the IEA PVPS data to be viewed in context. Further information will be gathered and published by the IEA PVPS Programme over time.

Country	**Total installed capacity in the selected countries (MW)**	**Annual sales (MW) and key targets**
India	83	16 MW (2003); 280 MW of solar power by 2012 (includes solar thermal)
China (incl. Tibet)	58	10,5 MW (2003); 450 MW by 2010
Indonesia	28	
South Africa	11	10 000 SHS (0,5 MW)
Morocco	7	1 MW (projected 15 MW by 2010)
Thailand	6	250 MW by 2011, includes 300 000 SHS (36 MW) by end of 2005 and an RPS 200 MW
Vietnam	5,4	
Zimbabwe	4 (1999)	
Brazil	3	
Kenya	3,2 (1999)	>0,5 MW (around 20 000 SHS)
Nepal	2,7	0,7 MW (around 20 000 SHS)
Sri Lanka	40 000 SHS, (Est 2 MW)	1 MW (around 22 000 SHS)
other European countries[1]	0,7	

[1] Czech Republic, Slovenia, Malta, Cyprus, Hungary, Lithuania, Poland, Slovakia, Estonia, Latvia, Bulgaria, Romania.

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

Some 90 % of capacity installed in 2003 were connected to the grid, and most projects and programmes reported in this section are 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)
The Photovoltaic Rebate Programme, PVRP, is drawing to a close as the available funds for the grant allocations are exhausted. The funding uncertainty for the future has lead to a sharp decrease in industry promotion and a reduced level of application and installation rates. The funds available in the PVRP have supported both grid-connected and off-grid projects and around 5,7 MW of capacity have been installed. The other major programme - supporting projects that replace diesel generation in off-grid communities - continues to offer grant support to meet environmental and social objectives in the long term.

Austria (AUT)
The impact of a long-term tariff support can be seen by the high level of activity in Austria following the implementation of the Green Electricity Act on 1st January 2003. By the end of March the entire 15 MW target for PV in the legislation had been installed and the market immediately stagnated. Major projects were realized as a result of the generous tariffs available include 237 kW on Salzburg Airport roof and a 420 kW solar tracking plant in the Großes Walsertal Valley. To overcome the lack of ongoing federal support some provinces are again offering regional incentives to support PV deployment. However these initiatives have had only limited impact.

Canada (CAN)
Canada recently completed a three-year initiative to promote PV on government facilities. This aimed at creating awareness of grid-connected applications through installations on high visibility federal buildings and also development of a sustainable market for reliable, cost-effective renewable energy applications for off-grid federal facilities. There were 25 applications, of which 14 were PV installations due to be completed in 2004. Participating federal facilities and agencies include Industry Canada (NRC), Environment Canada, Departments of Health, Parks, Fisheries and Oceans, Natural Resources, Customs and Revenue Agency and the Royal Canadian Mounted Police.

Denmark (DNK)
Political uncertainty with respect to the energy policy in Denmark is drawing to a close and it is expected that by the end of 2004 a new energy strategy for reducing energy costs in an open market whilst meeting energy security and environmental objectives will be agreed. A new PV specific strategy will include research, development and demonstration elements, probably of a fairly limited nature. In the meantime, the SOL1000 domestic roof top project draws to a close with reduced funding and installation targets.

Finland (FIN)
The PV market in Finland remains small and is dominated by off-grid installations for vacation cottages and boats that are not supported by investment subsidies. A number of BIPV installations have been implemented in the last few years, mainly as demonstration or educational projects. However, most public investment is in the research and development sector only.

France (FRA)
The five-year programme that started in 2002 continued, aiming to install 20 MW of BIPV systems over the period. The programme provides an investment contribution of up to 80 % of the capital cost and tariff support measures. Grid-connected projects grew strongly in 2003, but from a low base.

Germany (DEU)
The end of investment support by low interest loans led to a rush of applications towards the closing date of the programme. However the desire of the German government to stabilize the market led to favourable alterations in the terms of the tariff support measures available to PV. Demonstration and field test programmes run by the Federal States have been reduced in recent years with only some specific educational, community or agricultural projects being supported.

Israel (ISR)
Most projects in Israel continue to be off-grid for commercial applications, agriculture and remote communities. R & D in photovoltaic cells, materials and various aspects of improving efficiency is being carried out at academic institutions, with increasing industry collaboration with a view towards commercialization. The proposed restructuring of the electricity generation industry to allow independent power producers (of all scales) to connect to the grid and receive benefits for clean generation may bring opportunities in the market in time.

Italy (ITA)
Legislation completed at the end of 2003 gave a strong set of incentives to renewables, and PV in particular, with technology specific feed-in tariffs and simplified grid connection procedures for small generators. The two main initiatives - the national Roof Top Programme and the Regional Roof Top Programmes, which are generous capital subsidy schemes, both launched in 2001 - have attracted a high level of public and commercial interest, but installation progress has been slow due to bureaucratic delays in the application and permitting procedures.

Japan (JPN)
The broad range of highly supported PV projects continued through 2003, delivering significant capacity across all sectors. These wide ranging support measures continue to also support research and development activities by the main cell and module manufacturers. One new innovative project to be started shortly aims to install a dense cluster of PV on residential properties. This will test the network response to high levels of PV penetration.

Korea (KOR)
Several grid-connected projects in the 5 kW to 30 kW range have been installed in 2003, mainly connected to research, development or educational facilities. However, the implementation of two major government initiatives, “Solar Land 2010” and targets contained in the recent national energy plan, set significant targets for domestic, public and commercial buildings to promote energy security and build a new export industry. How such ambitious targets will be delivered within the next few years in a sustainable and affordable way has yet to be detailed.

Mexico (MEX)
Rural electrification continues as the main but not the only PV application in Mexico. Professional installations within the national oil company to power unmanned oil rigs and telecommunications repeating stations at difficult sites are some of the applications where PV competes with traditional energy supplies. Small PV water pumps have been installed to irrigate small agricultural land holdings, provide livestock drinking water and energize fences. No further grid-connected systems were installed during 2003 but performance monitoring of existing systems continues.

The Netherlands (NLD)
Large scale projects were initiated as a market initiative of two consultant companies and established by four housing corporations under the attractive energy premium regulations. Total PV installed is 4 MW, made up of flat roof systems on apartment buildings and rooftop systems on 364 dwellings. A 500 kW system has been installed at The Oceanium in the Rotterdam Zoo.

Norway (NOR)
The first project to be supported under the PV-Nord programme was commissioned in 2003, representing the largest single grid-connected installation in a country where sales of PV are dominated by the sustainable, unsupported market for off-grid systems for vacation cottages, boats, communications and lighthouses.

Portugal (PRT)
The most significant project commissioned in 2003 was a grid-connected system in St. Brás, Barcelos which is the first installation licensed under independent power producer legislation that allows for a payment (of around 0,5 USD/kWh) for electricity generated and exported to the grid. Prior to this no payment was possible. This measure is one of a number that intends to support PV as part of the national sustainable development strategy. Of particular note is the setting of a specific installed PV target (150 MW by 2010) within the general targets for renewable energy.

Sweden (SWE)
As in Norway and Finland, the market for PV in Sweden continues to be dominated by the use of off-grid systems for vacation cottages and boats and which attracts no investment subsidy. Only one major PV project was commissioned as a demonstration project in the green housing area of Hammerby Sjöstad. This is a BIPV façade of 18 kW on a residential building and was supported by investment subsidies.

Switzerland (CHE)
With no national investment or specific tariff support measures in place, the PV market in Switzerland has been saturated over recent years and progress is largely driven by private initiatives or initiatives by utilities. An innovative solar ‘stock exchange’ leads to a limited but so far rather sustainable market share for PV. Some cantons have launched public support programmes for PV systems.

United Kingdom (GBR)
There was a significant increase in the annual installed PV generation capacity in the UK in 2003. Much of this increase was due to the rapid expansion of the grid-connected market, accounting for 92 % of the 2003 installations. This was driven largely by three key Government support programmes, in particular the Major Demonstration Programme (MDP) which was introduced in 2002. The MDP provides grants for both grid-connected

and off-grid applications (since June 2003) up to 100 kW. The UK's largest non-residential PV installation, 115 kW at the Centre for Engineering and Manufacturing Excellence (CEME) in Dagenham, Essex, was supported by MDP in 2003. It comprises 102 kW of BIPV on the two-storey building's roof and 13 kW of glass-glass PV modules as part of a glazed entrance canopy.

United States of America (USA)

There are both existing and new initiatives in the USA delivering grid-connected capacity over a number of states. Most programmes are based on a direct capital subsidy or tax relief and the details and level of this varies widely from state to state. California has a range of initiatives, with both long-running utility and state programmes delivering year on year increases in installed capacity. Deregulation of the electricity industry has been enacted in twelve states, but only seven of these have included measures to build market support for renewable energy through quota or green tariff measures.

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 2003 in the IEA PVPS countries vary widely - from negligible to several hundred million USD being reported. Table 3 gives these budgets for 2003 for reporting countries. It should be noted that the boundaries of what constitutes 'research', 'development', 'demonstration / field trials' and 'market stimulation measures' often vary from country to country and are thus not always comparable. In most (but not all) cases the total budget showed an increase from the previous year. For many of the countries the increase was very large.

Cost reduction remains an explicit and sometimes unstated aim of much public policy involving PV. A recent IEA report[1] identifies 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 %). During 2003 R & D spending received a clear emphasis in about one third of the reporting countries, and about one third of the countries were significantly focused on market stimulation (but also funded R & D). Market transformation efforts through targeted demonstration and knowledge generation did increase compared to 2002 but still receive far less attention than is needed.

Table 3 – Public budgets for R&D, demonstration / field trials and market stimulation in 2003

	Annual budget – thousand USD			
Country[2]	**R&D**	**Demonstration / field trials**	**Market stimulation**	**Total**
AUS	3 614	3 294	12 639	19 547
AUT	1 695		8 588[3]	10 283
CAN	4 714	643	743	6 100
CHE	11 136	1 114	2 301	14 551
DNK	3 797	759		4 556
DEU	33 559		757 062[4]	(790 621)
FIN	531		5	536
FRA	5 763		22 600	28 363
GBR	4 885	9 443		14 328
ISR	228			228
ITA	5 424	226	22 599	28 249
JPN (METI)	84 469	32 442	90 595	207 506
KOR	4 032	15 553	821	20 406
MEX	927		1 344	2 271
NLD	2 373	169	84 746	87 288
NOR	1 088	14		1 102
PRT[5]				
SWE	2 104			2 104
USA[6]	65 700		273 700[7]	339 400

[1] Renewabes for Power Generation: Status and Prospects (IEA 2003). [2] ISO country codes are outlined in Table 12. [3] Not including feed-in tariffs; these are funded by all electricity consumers and amounted to 7 596 thousand USD in 2003. [4] In the form of loans, so not directly comparable with other market stimulation figures. [5] Data not PV specific. [6] FY2003 (Oct 2002 – Sept 2003). [7] Includes 200 MUSD of state tax credits.

2 The PV Industry

This section provides information on all sections of the industry involved in production of PV materials, cells and modules, and system components during 2003. The industry may be subdivided into the following groups representing different steps in the PV value chain:

- producers of upstream materials, i.e. feedstock, 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, batteries, mounting structures, appliances etc.

A regional overview is presented in Table 4, while Table 5 summarizes the information provided in the national survey reports by the participating countries and likely accounts for about 90 % of worldwide production.

2.1 Feedstock, ingots and wafers (upstream products)

IEA PVPS is now reporting on the industry for upstream materials and wafers; however a comparison with previous years' data, as is done for cells and modules, is not currently possible. Feedstock refers to the silicon raw material currently used in about 90 % of PV cells produced. The discussion in this section therefore does not apply to thin-film technologies.

Presently there is only one company specifically dedicated to production of silicon feedstock for the photovoltaic industry. This company, Solar Grade Silicon LLC (SGS), is based in Moses Lake (Washington, USA) and is a joint venture formed in 2002 between Renewable Energy Corporation AS (Norway) and ASiMI LLC (USA). 2003 was the first year of operation for this company. After conversion from production of electronic grade silicon to photovoltaic grade silicon during the latter half of 2002, the company produced and sold approximately 2 000 metric tonnes[1] of silicon feedstock in 2003. The company has also ventured into a major development aimed at producing granular silicon in a fluidized bed reactor, which should decrease the cost and make more feedstock available. The company has announced plans to start pilot production of granular silicon in 2005, with full commercialization of the process taking place in 2006. Meanwhile the company says it will continue to produce with the classical Siemens process and make 2 000 - 2 500 metric tonnes of silicon per year available to the PV market.

Other companies supplying feedstock to the industry are the producers of electronic grade silicon - in total six companies with plants in the USA (4), Japan (3), Germany (1) and Italy (1). Most active are Hemlock (USA), Wacker (Germany) and Tokuyama Corporation

Outside of the IEA member countries, international PV manufacturing is almost wholly focused in Asia at present. India and China have had notable production for many years, while more recently Taiwan has emerged as a strong manufacturing centre with ambitious plans for future growth. Thailand also appears set for significant manufacturing growth in the next few years.

India's market share has historically been dominated by TATA BP Solar, a joint venture between the Tata Power Company and BP Solar. The firm has a module manufacturing capacity of 38 MW, relatively large even by international standards, and accounts for approximately 50 % of national production. Actual 2003 module production was in the order of 20 MW, cells from BP Solar's plants in Spain and Australia supplementing the 1,4 MW manufactured in-house. Bengal-based WEBEL reportedly increased its module production by 50 % in 2003 to 4,5 MW, while Maharishi Solar Technology made its presence felt on the local market for the first time with approximately 3 MW of sales. This includes modules, cells and wafers manufactured from ingots produced in-house. Other Indian players, each with annual cell/module production in the range of 1-2 MW include Bharat Electronics, Bharat Heavy Electrical, Central Electronics and Udhaya Semiconductors. These companies' production has been largely stable at this level for the past few years.

Despite enormous market potential, China has had a relatively small PV manufacturing industry to date. This situation appears to be on the verge of changing however. Combined annual production in 2003 was estimated to be about 8 MW, actually a downturn from over 15 MW in 2002. Over 96 % of the 2003 output was crystalline silicon cells. Nevertheless, production capacity was significantly increased in 2003 to an estimated 30 MW, and is expected to increase further to between 60 and 100 MW in 2004. Baoding Yingli is currently the largest Chinese PV cell/module manufacturing firm having increased its cell production capacity to 16 MW. Wuxi Snitch Solar Power company has also increased its output to 10 MW. A number of module encapsulation firms also now have production capacity of 10 MW; Xi'an Jiayang is one such, while Kyocera has recently established a PV module manufacturing plant in Tianjin that will have 10 MW capacity in 2004, using cells imported from the Japanese parent company. Shandong Linuo and Shenzhen Clean Energy Company are both constructing cell/module production plants with capacities of 10 MW to 12 MW. Currently China has very little feedstock solar grade silicon material production, relying largely on imports to produce both monocrystalline and multicrystalline ingots. Monocrystalline ingot and wafer production capacity nationwide is reported to be 57 MW, with Ningjin in Hebei accounting for almost 80 % of this.

In Taiwan, Motech is rapidly emerging as an important international cell manufacturer, increasing production from 3,5 MW in 2001 to 8,0 MW in 2002 and 17 MW in 2003. This is estimated to account for over a quarter of the non IEA PVPS production in 2003. The company's cells are supplied to module manufacturers worldwide. Planned further expansions are expected to take production capacity to 50 MW by the end of 2004.

In Thailand, Solartron has established a 15 MW module manufacturing (encapsulation) facility, while Bangkok Solar has bought the Hungarian firm Dunasolar's 5 MW amorphous silicon manufacturing plant.

[1] *Currently about 14 metric tonnes of photovoltaic solar grade silicon are consumed for each MW of installed PV systems based on crystalline silicon.*

(Japan). In 2003 all three companies had dedicated part of their silicon output to the photovoltaic industry and they have confirmed some commitment to this industry for the future. Both Wacker and Tokuyama have launched development programmes aimed at producing competitive granular silicon by proprietary technology (fluidized bed reactor for Wacker and vapor to liquid reactor for Tokuyama). Significant results were achieved and published in 2003 for these programmes. However, commercialization of these technologies is not likely to be achieved before 2006.

In addition to the output of photovoltaic solar grade silicon by SGS and the output from the classical electronic grade silicon producers, off-grade and rejected materials from the semiconductor production chain[1] still functions as a source of silicon feedstock, although a source that is decreasing.
There are sustained R & D efforts by several groups and companies, for example Elkem of Norway to develop new sources of PV grade silicon through the metallurgical purification route. Promising results have recently been achieved in terms of product quality, and the metallurgical purification route may offer lower production cost in large-scale plants than processes involving a gas-phase step, like the Siemens process.

With a sustained strong growth of the PV industry concern has been expressed about possible shortage of low cost silicon raw material. In the last few years the situation was relieved by the slump in the semiconductor industry. The suppliers of silicon feedstock to this industry took advantage of the booming PV business by using free production capacity for this market segment. With the semiconductor industry recovering, there will be less surplus capacity available.

Ingot and wafer production are usually integrated in the same production facility and since the end of the nineties there has been the emergence of several powerful players focusing on this value-chain step, particularly in Europe. Three companies, ScanWafer (Norway), Deutsche Solar (Germany) and PV Crystalox (Germany, UK) are competing for the global leadership of production of wafers. Challengers and newcomers are reported in Japan (Sumco and JFE), Ukraine (Pillar) and France (Emix). Except for Pillar all these companies focus on multicrystalline silicon. In 2003 there has been a resurgence of single crystal technologies with several companies in the US, Japan and Europe switching their focus from the semiconductor to the PV market.

In addition to the industry described above, which produces silicon wafers for sale to other companies that process them into PV cells, one must also take into account the vertically integrated "historical companies" with in-house production of ingots and wafers and the subsequent processing of these to PV cells. The most important of these companies are Kyocera (Japan), BP Solar (USA), Shell Solar (USA) and Photowatt (France). RWE Schott (USA/Germany) with their silicon ribbon ("EFG" trade mark) represents another similar industry player.

In Europe and Japan ingot and wafer producers are currently expanding capacity. For instance, in Norway ScanWafer is considering establishing a fourth production facility in response to the strong demand. The entire 2004 production and about half of the production in 2005 are already sold. While the major players are increasing capacity, there are also signs that capacity is being established in new countries. Italian Enitecnologie has transferred feedstock and wafer production to a Chinese-Italian joint venture.

Table 4 – PV industry production in 2003 by world region – IEA PVPS countries

		Japan	USA	Europe	Rest	Total
Silicon feedstock	**tonnes**	1 000	(3 000)[2]	(1 500 – 2 000)[2]	–	**(6 000)[3]**
Ingots	**sc-Si, tonnes**	565	no data	no data	–	**(565)[4]**
Ingots	**mc-Si, tonnes**	650	no data	no data	–	**(650)[4]**
Wafers	**sc-Si, MW**	80	70	–	–	**150**
Wafers	**mc-Si, MW**	97	88	280,5	–	**465,5**
Cell Production	**All types, MW**	365	102	192	27	**686**
Cell Production Capacity	**MW / year**	461	156	277	40	**934**
Module Production	**sc-Si, MW**	72	36	83	9	**200**
	mc-Si[5], MW	276	20	39	<1	**335**
	a-Si, MW	26	7	5	–	**38**
	Undefined[6], MW	29	–	51	1	**81**
	Other, MW	–	8	5	<1	**13**
	Total MW	402	71	183	11	**667**
Module Production Capacity	**MW / year**	511	122	(199)[7] (300)[8]	26	**959[8]**

[1] Top and tail from single crystals, single crystals from aborted runs, crucible residuals ("pot scrap") and various other material of minor quantities.
[2] Estimate – no data. [3] estimate. [4] part total due to lack of data. [5] includes modules based on EFG and String Ribbon cells. [6] 'undefined' means the Sii technology type was not clarified; 'other' refers to technologies other than silicon based. [7] Europe except for Germany (figures not made available).
[8] including an estimate for Germany.

2.2 Photovoltaic cell and module production

The PV cell and module manufacturers continue to grow strongly. The total photovoltaic cell production volume for 2003 was reported to be 686 MW, up from 520 MW in 2002, or an increase of 32 %. However, larger growth took place in Japan (50 %) and Germany (77 %). Production shrank in the US.

The growth rate of 32 % was lower than between 2001 and 2002 (51 %). However the data sets for these consecutive periods are not fully comparable since some production has been relocated out of the area covered by this report during 2003.

The production capacity increased in Europe (mainly Germany) as well as Japan. However, the worldwide growth in capacity was only 17 % compared to 62 % between 2001 and 2002. German plans for expansion of capacity that were expressed for the end of 2002 were to a large extent not realized, while US capacity was reduced. This has had implications for the availability of modules in some markets beyond the period reported by the participating countries (end 2003).

In 2003 at least 80 % of the modules produced in the countries covered by this survey were based on crystalline Si technologies, a similar result compared with 2002.

Japan is the leading producer of cells and modules. Production of cells and modules in this country accounted for 53 % and 60 % respectively of the

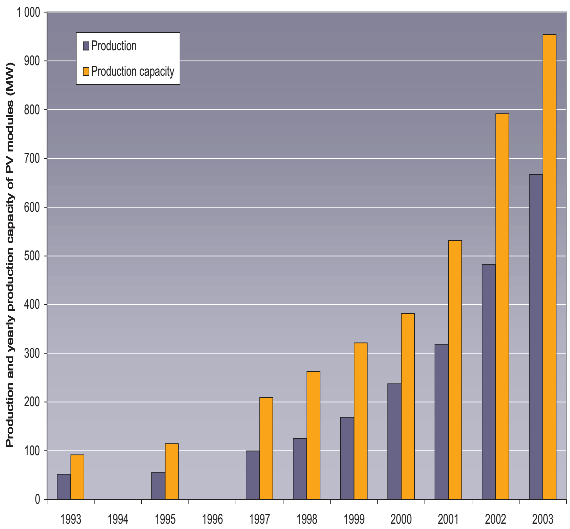

Figure 4 – PV module production and yearly module production capacity in the reporting countries (MW). Years 1993 – 2003

world production in 2003. The two largest producers in the world are Japanese, Sharp and Kyocera. Shell Solar in the US comes in third, while Mitsubishi Electric in Japan and RWE Schott Solar of Germany almost ties in fourth place. BP Solar produces almost as much as Kyocera, but with production split between facilities in four countries.

Germany remains the second largest producer of cells and modules. Beside well established companies like Shell Solar and RWE Schott there has been an entrance of new aggressive specific cell and module companies e.g. Q-Cells. However, production and sales slowed down through 2003 in Germany influencing the overall situation in Europe and the world. The reason for the caution in Germany was the uncertain situation with regard to subsidies, as the old programme for deployment of PV systems came to an end in 2003. After the adoption late in 2003 of the German Renewable Energy Law, effective from January 2004, the market recovered.

In the United States the production of cells and modules decreased by 16 % and 12 % respectively from 2002. The decrease was due to the bankruptcy of AstroPower and relocation of production out of the US. General Electric purchased the AstroPower assets early in 2004. General Electric, which was not previously involved in production of PV cells and modules, also purchased the wind power assets from Enron when that company defaulted. GE thus displays a clear ambition to diversify into the renewable energy business. Solec went from cell manufacturer to a producer of wafers for its Japanese owner. Several American companies are investing in production facilities outside the US.

In Spain, there are significant PV industrial activities, making this country second in Europe after Germany. The industry is dominated by two strong players Isofoton and BP Solar which both increased production and capacity in 2003. Pillar of Ukraine has also made an announcement to build a wafer plant near Madrid to serve the Spanish market.

In France and Italy pioneer companies such as Photowatt and EniTecnologie continued to loose market share and influence.

In 2003 Norway's ScanCell went from pilot to commercial production of multicrystalline silicon cells, and in Sweden two new module manufacturers were established. Sweden now has four module manufacturers, three being part of strong integrated players in the industry.

It seems likely that the future will see a continued consolidation of the industry producing mainstream crystalline silicon photovoltaic cells. This process will be driven by the economies of scale achieved in a few markets. It is interesting to note that a number of small companies are developing and introducing products for building integration of PV. Such initiatives can be found in France, Switzerland, Austria, Australia, Denmark, UK and the US[1]. While these initiatives are partly driven by demonstration programmes, they may also herald the upsurge of companies carving out specialized market niches. Another example is an application not covered by this report in which a Swiss company is producing flexible thin-film modules for applications such as charging mobile phones.

Two companies, one in Canada (Spheral Solar Power, a division of ATS) and one in Japan (Kyosemi) have announced aggressive plans to develop micro spherical PV cells based on crystalline silicon. This technology is characterized by low cost targets but successful commercialization has not yet (2003) been demonstrated.

The thin-film industry also showed some interesting developments. In the US, the situation is in the balance. Shell Solar shipped 3 MW of copper indium selenide (CIS) modules in 2003, and First Solar produced nearly 3 MW of CdTe modules in 2003 and expects to double production in 2004. However, it is still unclear if production from BP Solarex CdTe plant will be resumed. In Australia work continues on commercializing dye sensitized TiO2 thin-film cells. In Sweden a new company, Solibro AB, was started up in 2003 for scaling up and potential commercialization of CIS thin film solar modules within four to five years. Another interesting technology in a pre-commercial state is the Austrian company Powerquant's development of methods for optimizing the front contact patterns of mc-Si cells. By aligning contacts with respect to actual grain patterns losses can be reduced. The technique can also be used to improve the visual appearance of modules. This is not an exhaustive list, but some illustrative examples which will be followed up in the coming years.

2.3 Balance of system (BOS) component manufacturers and suppliers

There is a change in the market structure for the balance-of-system components. Inverters are becoming more and more important by virtue of the many programmes for grid-connected applications. In Japan there are more than ten producers of inverters with products mainly targeting residential systems with an output in the range 3 kVA to 5 kVA. A large number of 10 kVA units have also been supplied to public and industrial facilities. Generally, 10 kVA inverters are connected in parallel for installations up to 200 kW, but larger inverters are now being commercialized. In the United States there are several inverter manufacturers, while in Europe there are some 25 to 30 companies active in this area.

In addition to producers of the usual balance-of-system components such as storage batteries, charge controllers, supporting structures etc., which may be found in many countries, there are suppliers of specialized equipment for the production of wafers, cells and modules that are paying increasing attention to the PV market. These range from chemical and gas suppliers, abrasives and equipment for cutting wafers, pastes and inks for cells, encapsulation materials for modules to specialized measurement equipment for use in the production process, just to mention a few examples.

Table 5 – PV product manufacturers in reporting countries during 2003

Country	Company	Technology type	MW of PV produced during 2003		Maximum yearly capacity (MW) at full production	
			Cells	Modules	Cells	Modules
AUS	BP Solar	sc-Si	5,2	9,0	33,0	12,0
		mc-Si	21,0			
	STI	Titania Dye	0,1	0,1	0,5	0,5
	Solar Systems	Concentrator Si		0,5		5
AUT	PVT Austria	sc-Si, mc-Si		0,9		4
	SED	mc-Si		0,15		
CAN	ICP Global	sc-Si, mc-Si		0,5		2
	Spheral Solar Power	spheral				
CHE	Swiss Sustainable Systems	sc-Si, mc-Si		0,1		0,2
	Star Unity	mc-Si		0,02		0,1
	SES	sc-Si				
	Solterra SA	sc-Si				
	VHF Technologies	a-Si		0,002		0,01
DNK	Gaia Solar	mc-Si, sc-Si		0,125		0,33

[1] *Japanese corporations are also interested in the market for roof integrated PV.*

Table 5 - continued

Country	Company	Technology type	MW of PV produced during 2003		Maximum yearly capacity (MW) at full production	
			Cells	Modules	Cells	Modules
DEU	Solar Fabrik GmbH,	sc-Si		8,5		
	Solar Factory GmbH			7		
	SOLON AG, Berlin	misc. sc-Si and mc-Si		11		
	Shell Solar GmbH,	sc-Si	9		13	
	Solarwatt Solar-Systeme GmbH	misc. sc-Si and mc-Si		7,4		
	Solara AG	mc-Si		6		
	Alfasolar Vertriebsgesellschaft GmbH			3		
	Deutsche Cell GmbH		17		30	
	Schueten Solar Technology	sc-Si, mc-Si		2,9	8	
	GSS GmbH and IPEG GmbH	mc-Si		4		
	S.M.D. Solar-Manufaktur Deutschland GmbH			13		
	AnTec Solar GmbH	CdTe		5		10
	RWE (Schott) Solar GmbH	EFG mc-Si	40	5	43	
	Saint Gobain Glass Solar GmbH	mc-Si		<1		
	Solarnova GmbH	sc-Si, mc-Si		0,9		
	Webasto Systemkomp. GmbH	sc-Si		1,5		
	RWE Schott Solar GmbH,	a-Si	2	2		3
	Würth Solar GmbH	CIS		0,4		(0,35)
	Q-Cells AG,	mc-Si	28,2		(24)	
	Ersol Solar Energy GmbH	mc-Si	9		10	
	Sunways A.G.	mc-Si	6,7		7	
	Sunset Energietechnik			2,2		
	Others			2,23		
ESP Data source – ASIF (Spain)	Isofoton	sc-Si	35,2	30,3	45,0	45,0
	BP Solar	sc-Si	16,6	18,7	30	24
	Atersa	sc-Si	7,5	7,8	20	20
	Gamesa	sc-Si		1,8		3
	Siliken	mc-Si		0,3		1
FRA	Photowatt International	mc-Si	14	10	25	20
	Free Energy Europe	a-Si	0,6	0,6		1
GBR	ICP UK	a-Si	2,5	2,5	3,5	3,5
ITA	Helios Technology	sc-Si	2,9	2,9		4,5
	Enitecnologie	sc-Si	0,3	0,3		8,5
		mc-Si	1,1	1,1		
JPN	Sharp	sc-Si	42,6	30,5	248	225
		mc-Si	155,2	149,1		
		a-Si	0,1	0,1	–	–
	Kyocera	mc-Si	72	72	76	76
	Hitachi	sc-Si	0,02	0,01	5	3,5
	MSK	mc-Si		12		15
		sc-Si		40		50
		a-Si		3		5
	Sanyo Electric	a-Si/sc-Si	30	29	33	30
		a-Si	5	5	5,5	5,5
	Mitsubishi Electric	mc-Si	42	42	50	50
	Kaneka	a-Si	13,5	13,5	20	20
	Showa Shell Sekiyu	sc-Si		1		6
		CIS	Experimental facility			
	Matsushita Ecology Systems	sc-Si	0,6	0,6	3	3
	Canon	a-Si/micro-crystalline-Si	0	0	10	10
	Mitsubishi Heavy Industries	a-Si	4	4	10	10
	Kobe Steel	mc-Si		0,4		2

Table 5 - continued

Country	Company	Technology type	MW of PV produced during 2003		Maximum yearly capacity (MW) at full production	
			Cells	Modules	Cells	Modules
KOR	S-Energy Co.	mc-Si		0,35		1
	LG Industrial System Co.	sc-Si		0,25		0,5
	Haesung Solar Co.	sc-Si, mc-Si		0,07		0,5
	Solar Tech Co.	sc-Si, mc-Si		0,2		1
	Photon Semiconductor & Energy Co.	sc-Si	0,3		6	
	Neskor Solar	sc-Si	0,24		0,6	
	ATS Solar Co.	sc-Si, mc-Si		1,42		3
NLD						
NOR	ScanCell	mc-Si	1,8		5	
PRT	AJ Lobo / Shell Solar GmbH	sc-Si		10		15
SWE	Gällivare Photovoltaic AB	mc-Si		5,5		17,5
	ArcticSolar AB	mc-Si		3,75		14,5
	Scanmodule AB	mc-Si		0,8		5
	PV Enterprise Sweden AB	mc-Si		1		12
USA	Shell Solar	sc-Si	49	20	55	30
		CIS	3	3	5	5
	BP Solar	mc-Si	13,42	13	25	25
	AstroPower	sc-Si	17	15	25	25
	Sunpower	sc-Si	0,6	0,6	1	1
	RWE Schott (ASE)	mc-Si (ribbon)	4	4	5	5
	United Solar Systems (USSC)	a-Si	7	7	30	20
	Evergreen Solar	mc-Si (ribbon)	2,8	2,8	4	4
	First Solar	CdTe	3	3	4	4
	Iowa Thin Film Technologies	a-Si	0,1	0,1	pilot	pilot
	Global Solar	CIS on steel	2	2	2+	2+
	Amonix	Concentrator sc-Si		0,7		1

Notes: sc-Si (single crystal silicon); mc-Si (multicrystalline silicon); EFG (edge fed growth silicon); a-Si (amorphous silicon); CIS (copper indium selenide); CdTe (cadmium telluride).

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, as a consequence of creative marketing, 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. Most countries reported a fall in system prices over the previous year, as shown for selected countries in Figure 5.

System prices for off-grid applications in each country tend 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 unique building integrated projects provide an exception to this situation.

In 2003 system prices in the off-grid sector up to 1 kW varied from about 8 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 10 USD to 12 USD per watt appears to be common. Off-grid systems greater than 1 kW tend to show similar variation and prices.

The installed price of grid-connected systems in 2003 also varied, both within and between countries, as shown in Table 6. The lowest reported prices were close to 4 USD per watt and are unlikely to be a true reflection of costs; prices of 5 USD to 7 USD per watt are more typical prices. The cost structure of the system price continues to vary widely between countries (and between projects). In 2003 the reported price of modules made up anywhere from 45 - 100 % of the reported grid-connected system prices (compared with 50 - 80 % in 2002).

Larger grid-connected installations have lower or higher system prices, depending on the economies of scale achieved or the degree of building integration, installation difficulty and innovation.

The PV modules remain a significant proportion of system prices (generally about 50 - 60 % for grid-connected systems in 2003 and a little lower than reported for 2002) and, compared to the widely-varying non-technical and BOS costs, continue to present a useful 'international' indicator for tracking the changes in PV technology costs over time. However there are a number of factors that are becoming evident that influence any analysis of module price trends. Whereas from a global perspective (at least in the reporting countries) there appears to be a good balance between demand and supply (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) very few countries have a balance between local production and capacity installed (six or seven countries can be said to have significant production available for export, eight countries produce between zero and 40 % of their local demand). There are now a number of examples of imported modules selling for considerably less than the local product (which may be a short term phenomenon reflecting immature markets), and also of some exporting countries showing no annual movement in the prices offered locally despite producing an excess (while other exporting countries show steady local price decreases).

The typical price of modules in 2003 in the reporting countries shows more scatter than in previous years but only because more countries are now reporting this - and in more detail. Prices of 3,5 USD to 4 USD per watt appear achievable in the majority of countries, and nearly all of the major markets, with indications that the current lowest achieved prices of modules are less than 3 USD per watt. Table 7 shows the change in module (current) prices in some of the reporting countries from year to year. In 2003 prices generally decreased from the previous year, ranging from no change to falls of more than 30 %. This dynamic situation suggests that firstly, 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.

Comparing the results with those suggested by 'technology learning curves' (which suggest a cost decrease of 15 % to 20 % for a doubling of market size), in the larger markets reported module

Table 6 – Indicative installed system prices[1] in USD in selected countries in 2003

Country[3]	Off-grid (USD per W)		Grid-connected (USD per W)[2]	
	<1 kW	>1 kW	<10 kW	>10 kW
AUS	11,7 – 15,6	7,8 – 11,7	4,5 – 7,8	3,9 – 6,5
AUT	9 – 15,8	9 – 23,7	5,6 – 7,9	4,5 – 6,8
CHE	11,8	11,1	6,6 – 6,9	5,8
DNK	10,6 – 13,7	15 – 20	5,0 –10,6	6,1 – 15,2
DEU			5,7	
ESP	16,8 - 18	14 - 15	7 - 9	5,6 – 8,2
FIN	13,6 – 21,5		6,8 – 7,9	6,8 – 7,9
FRA	14 - 34 domestic; 11 – 28 non-domestic		8,2 – 9,7	5,6
GBR	8,9 – 16,4	8,5 – 14,8	7,0 – 19,7	8,2 – 21,5
ISR	7,9 - 11			
ITA	13,6 – 16,9	13,6 – 15,8	7,9 – 8,6	7,5 – 7,9
JPN			5,9	6,9
KOR	19,6	18,7	12,6	11,5
MEX	15,3	9,6		
NLD			5,1 – 6,8	5,1 – 5,6
NOR	8,5 – 22,6		10 – 15	
PRT	13,6	11,3	7,3	
SWE	12,4			
USA	12 - 25	12 - 20	7 - 10	6,5 – 9

[1] 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. [2] More expensive grid-connected system prices are associated with roof integrated slates or tiles, or one-off building integrated designs. [3] ISO country codes are outlined in Table 12.

(current) prices are now falling anywhere between 8 % and more than 30 % per doubling of market size, with more variation than in previous years. This is also shown for current module prices for selected countries in Figure 5.

Another issue with important consequences for prices comes from the start of the PV supply chain. While there are several plans for investment in specialized production capacity for PV solar grade silicon, the lead times for such investments may be too long to avoid a temporary lack of low cost feedstock in the next two years. A shortage would increase the production cost for PV modules, but this impact is not likely to be serious if it remains temporary. Permanent shortage of low cost high quality silicon would have a more negative influence on further growth of the industry and higher prices would be the logical response. On the one hand, this could have unpleasant political side effects since the PV market still remains strongly dependent on politically motivated subsidies; but a shortage of low cost silicon may also cause the market structure to alter by changing some of the current cost differentials between various PV technologies.

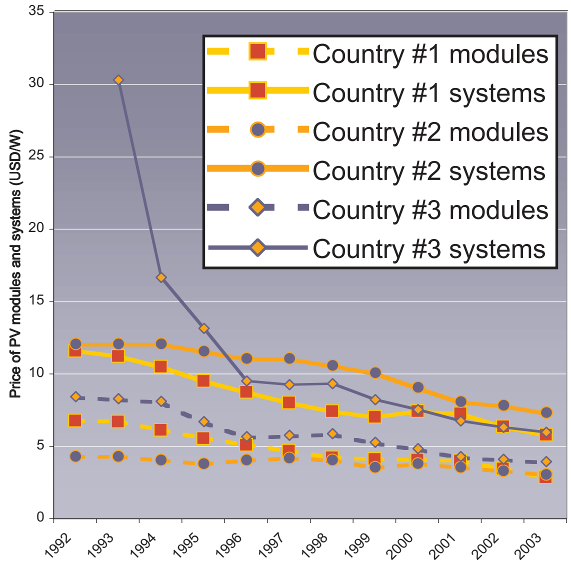

Figure 5 – Evolution of price of PV modules and systems in selected reporting countries (USD/W) Years 1992 – 2003

Table 7 - Indicative module prices[1] in national currencies per watt in reporting countries

Country[2]	Currency[3]	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003[4]	2003 USD ('lowest' prices in brackets)
AUS	AUD			7		8		8		8		7	7	4,5
AUT	EUR											4,5	3,1-6,7	(3,5)
CAN	CAD								11,09	10,7	9,41	7,14	6,18	4,4
CHE	CHF											7,5		
DNK	DKK									40	40	33	21-45	(3,2)
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	(2,8)
ESP	EUR												2,6-4,25	(2,9)
GBR	GBP										3,7	3,7	2,5-5	(3,6)
ISR	NIS												22,5-28,35	4,9
ITA	EUR		4,65				4,13			4,13	4,25	3,9	3,1-3,9	(3,5)
JPN	JPY	966	950	927	764	646	656	670	600	548	484	463	446	3,8
KOR	KRW			9 400	9 400	8 200	8 500	9 200	7 500	7 100	7 200	7 200	6 500	5,5
MEX	MXP												65	6,0
NLD	EUR			9,5	7	7,5	6	5	4,75	4,73	4,73	4,62	4,5	
NOR	NOK												55-100	(7,8)
PRT	EUR										4	3,5	3,5	
SWE	SEK												70	8,7
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	(3,0)

[1] Current prices. [2] ISO country codes are outlined in Table 12. [3] ISO currency codes are outlined in Table 12. [4] A single figure generally refers to a 'typical' module price; the lower figure in a range represents the lowest price achieved & reported whereas the higher figure often refers to special products, roof tiles etc

2.5 Economic benefits

The wide scale implementation of government programmes to support PV development has led to the creation of many direct and indirect labour places, and to the growth of a supply chain and associated cash flows. Both these items are high on the political agenda of most countries.

Table 8 gives estimates of PV industry employment in some of the reporting countries in 2003. While many countries show no significant change in labour places from the previous year, about one half of the countries show an increase and one quarter of the countries show a significant decrease. An increase in a country is often associated with establishment or expansion of a manufacturing base - sometimes to the detriment of the situation in other countries when plants relocate, reflecting a globalization[1] of the manufacturing business. New market deployment programmes have a more subtle influence on reported numbers. However large annual increases or decreases or even anticipated changes in market deployment programmes (reported by a number of countries this year) can have negative effects on the employment situation.

The financial value of PV business is now being reported by a number of countries and the reader is directed to the national survey reports for details. It is difficult to more generally relate dollar values to capacity installed or produced or labour positions as the situation is so different between the participating countries. Wealth is generated throughout the supply chain from production to end-user, and in many cases is offset by imports. Three countries can claim business value greater than or approaching the billion USD mark; a handful of countries are around the 100 million USD level; and for most of the reporting countries tens of millions USD are more appropriate. Interestingly the revenue generated by taxes operated by most governments (value added, income and business) from PV activity considerably counterbalances expenditure on the public budgets reported in Table 3 in the majority of (but not all) cases.

Table 8 – PV industry employment in some countries in 2003

Country[2]	R&D[3] persons[4]	Manufacturing[5] persons	Other[6] personnel	Total persons
AUS	85	350	260	695
AUT	20	150	50	220
CAN	45	410	160	615
CHE	140	10	290	440
DNK	10	25	20	55
DEU				10 000 – 12 000
ESP		1 530	1 150	2 680
FIN	15	20	50	85
FRA	100	580	70	750
GBR	66	171	166	403
ISR	70	0	20	90
ITA	80	60	420	560
JPN	300	3 000	8 000	11 300
KOR	52	122	49	223
MEX	20	25	80	125
NLD	150	120	160	430
NOR	15	370	20	405
PRT	29	90	50	169
SWE	25	115	15	155
USA	50	500	1 400	1 950

[1] *Including a growing development of PV manufacturing outside of the IEA PVPS reporting countries.* [2] *ISO country codes are outlined in Table 12.*
[3] *Research and development (not including companies).* [4] *Or person-years.* [5] *Manufacturing of PV system components (including company R&D).*
[6] *Including energy companies, distribution, installation and maintenance companies*

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.

3.1 New initiatives in photovoltaic power systems

Research and development support, funding of demonstration programmes, manufacturing support measures, formulation of standards and market growth initiatives are mainly aimed at achieving a longer-term, sustainable and significant penetration of PV into the general power supply sector. Table 9 highlights the key initiatives reported in the participating countries during 2003.

It is clear from the sometimes marked changes in funding orientation and support from year to year, and the dramatic surges in grid-connected installations in some countries in 2003 and the lack of new activity in others, that a strong political vision for the future role of PV is somewhat lacking in many of the reporting countries. In response to this many countries have formulated industry roadmaps which tend to rely on massive projected increases in publicly funded or electricity consumer funded grid-connected PV activity to underpin continued industry development in the host country. There is a political need to demonstrate that public expenditure (direct and indirect) will deliver the various benefits outlined in such strategies and this underlines the urgent need for targeted demonstrations and knowledge generation. The willingness to pay of end-users and investors remains an important but largely untested factor. Social awareness and sustainability in decision making are slowly becoming more widespread but the added values of grid-connected PV - electricity network, architectural, environmental and socio / economic benefits - are yet to be systematically incorporated in energy policies and programmes.

The main fiscal instruments being used to support or promote PV in the IEA PVPS countries include enhanced feed-in tariffs and direct capital subsidies. Less common are reduced interest rates on loans, tax credits, accelerated depreciation, and 'PV electricity' marketing schemes. There is a great deal of interest in what works best - but it is generally not appropriate to simply replicate an instrument from one country to another. For example, there are different political perceptions regarding the use of public funds or funds generated by the electricity industry; depending on the target group for PV deployment, either cash flow support or an investment subsidy may be more appropriate; and measures that are more market oriented could be less predictable where specific results, such as capacity installed, are being sought.

Table 9 - Initiatives and perceptions

	New initiatives and promotional activities	Utility and public perceptions
AUS	*There have been no new grant schemes launched during the year. The PV Rebate Programme has been heavily oversubscribed following successful promotion of the scheme for grid-connected applications by the PV industry and the scheme is likely to end in 2004. An existing remote power programme continues to deliver PV as a substitute to diesel generation for isolated communities.*	*A number of utilities are now entering the market for both grid-connected and off-grid applications, for example by offering installation kits. Those utilities with extensive rural grids are actively testing PV for grid reinforcement, whilst urban utilities are using PV generation to service a growing green electricity market. PV is well accepted and understood in remote areas as an effective power supply, whilst industry promotional activities have significantly raised wider interest in grid connected systems.*
AUT	*The long awaited legislation to allow long term feed in tariff support for PV came into effect at the start of 2003, and the target of 15 MW was installed and operational by the end of March. A number of federal provinces have launched limited regional support measures.*	*Perceptions of PV are excellent. For utilities, the connection of small embedded generations is routine, and grid management is not reported as to giving high levels of concern. There has been a high take up of green tariffs and interest in the feed in law by the general public.*

Table 9 - continued

CAN	*There have been no new subsidy schemes launched this year, however Canada's ratification and signing of the Kyoto Protocol to mitigate greenhouse gas emissions is providing funding opportunities through existing and new programmes for PV development and demonstration. Technology Early Actions Measures is entering its third phase of funding (2003-2008) and is continuing its role in financing the late stage development and first demonstration of new technology with strategic partnering through the zone between R&D and market implementation.*	*There are no regulations that allow for net metering in Canada, with Government regulations and utility attitudes the major barriers to net metering. Applications for grid-connection continue to be considered on a case-by-case basis. Public perception of PV is favourable. A coalition of corporate and not for profit organizations - the Net-Zero Energy Home Coalition - has been launched to help accelerate the economic development and environmental benefits of available onsite green energy technologies and energy efficiency applications and devices in the residential building sector. The coalition is comprised of a group of forward-looking home builders, developers of new decentralized energy systems and companies and organizations.*
CHE	*With no Federal promotional or funding schemes, the market for PV is sustained by grant funded projects, the limited success of the green power markets, and industry activities.*	*The green electricity market enjoys limited support, but with no incentives there is limited investor interest. Only a few utilities have experience of the grid connection of PV.*
DEU	*2003 saw the end of the highly popular 100 000 Roofs Solar Power Programme and brought about a surge of applications before its close, boosting a stagnating market. The terms of tariff support and maximum supported capacity were adjusted to meet the new government's commitment to a continued PV programme.*	*Connections to the grid 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	*With no new programmes starting in 2003, the most activity has been within the reduced SOL1000 project targeting 650 kW of standardised roof top systems. The Copenhagen area electricity utility has launched a certified PV only scheme. Although the end user needs to pay 3 – 4 times the normal electricity price, the scheme is reported as a success.*	*Public perception of renewable energy – and particularly PV – remains high due to a long standing interest and commitment to environmental issues. Utilities see the market for small PV kits as significant, perhaps with financing incentives to capture market share in an increasingly open electricity supply market.*
ESP	*The feed-in tariff support for PV electricity has been improved, reaching 0,4 EUR/kWh for plants of less than 100 kW and 0,21 EUR/kWh for larger plants. These tariffs are guaranteed for a period of 25 years from the date of commissioning (Royal Decree 436/2004). In addition, most Spanish Regional Authorities are supporting PV investments with grants covering more than 30 % of the total investment (for a 3 kW plant to achieve a payback period of 10 years, a grant covering approximately 40 % of the total investment is needed).*	*Public perception of PV is increasingly favourable, both among the community and local authorities.* *A number of entrepreneurs are offering the public small shares in grid-connected plants of 100 kW or less, with reasonable success. While the recent modification of PV feed-in tariffs should result in a significant increase of total installed capacity, grid-connection issues are still a problem due to bureaucratic difficulties, but with some progress being made.*
FIN	*An investment subsidy (of up to 40 %) is available to commercial and other organisations (but not private households), and building renovation grants can also focus on implementing renewable technologies, particularly PV.*	*Most public perceptions of PV are for vacation cottages, but the launch of further green power tariffs (there are now over ten), has raised awareness of grid connected technologies. Few utilities have any experience of grid connection issues.*
FRA	*The BIPV programme joined the long running support available for off-grid applications in 2003. The five year programme, which aims for the installation of 20 MW in France and its Overseas Departments, is supported by capital grants and a feed-in tariff and became fully operational with the publication of official contractual regulations for grid connection and electricity purchase.*	*EDF, the main French electricity utility, continues to be active in the development of publicly funded off-grid systems, and manages over 5 000 installations. It has also been active in the development of standards for PV. The Ministry of Industry presented a white paper following a national public debate on energy held during 2003, with the conclusion underlying the importance of energy management and renewables in the future French energy mix. An Energy Guidelines Act will be passed by the Parliament by 2004 and should include tax credit measures.*

Table 9 - continued

GBR	*Three UK Government support programmes continued to provide grants for PV during 2003: the Major Demonstration Programme, the Large Scale Building Integrated Photovoltaic Programme and the Domestic Field Trial.*	*Although all the regional Distribution Network Operators now have direct experience of grid-connected PV systems they do not see solar electricity as a business priority. However there is a general interest in PV issues and a number of electricity utilities offer to pay for exported electricity from PV systems. Promotional efforts of the government programmes and installation companies appear to be having a positive impact on public opinion. The increase in use of PV powered street furniture and lighting has also helped raise awareness of the technology.*
ISR	*Consultation has begun on the legal restructuring of the electricity generation industry. The draft regulations and legislation mandate connection of independent power producers to the grid and producers of renewable power will receive enhanced tariffs for renewable generation or net-metering for small private producers.*	*The state utility, IEC, has limited recent experience of PV and will have to establish working methodologies once restructuring of the industry goes ahead. Public awareness of PV is high but it is normally associated with off-grid applications.*
ITA	*There were no new programmes reported this year, but a range of existing initiatives delivered significant capacity during the year. The passing of legislation at the end of the year that allows for the commencement of a feed-in tariff holds the prospect of additional non granted investment from 2004.*	*ENEL, the main electric utility, has increased its experience significantly over the last year with the large scale implementation of grant funded programme. However, there have been unforeseen bureaucratic delays at many stages. Public interest and perception has grown rapidly.*
JPN	*A remodelled Field Trial for Advanced PV technologies over 10 kW capacity in the industrial commercial or institutional sector commenced in 2003, with a 50 % grant funding element. This joins the existing substantial programmes delivering subsidized capacity in all markets.*	*PV is supported strongly by both utility companies and the general public. The various subsidy programmes available have meant that familiarity with the technology is widespread, and connection to the network routine.*
KOR	*The long running Local Energy Development Programme was given a three-fold increase in budget in 2003, leading to a sharp increase in interest and a number of Green Village proposals. PV continues to attract the majority funding under the Renewable Energy Demonstration Programme*	*Whilst there was no change in the limited interest utility companies show for PV, growing public awareness through a number of events held in 2003 and a BIPV design competition widely covered by the media has been reported.*
NLD	*Like Germany, support measures for PV ended during 2003, leading to a rush of applications up to the closing date in October. However, from this date the market has all but evaporated. Research work on comparisons of domestic renewable energy sources (including PV) and support measures for BIPV installers commenced.*	*Utilities have participated in the recent strong PV market, by packaging PV with other green electricity products. Connection is seen as routine. The public perception remains that PV is only of interest with investment support and as an option for the long term.*
NOR	*With no national support programmes for the installation of PV, developments preceded either as off-grid supply to vacation cottages, or part of the EU wide PV-Nord programme or for educational purposes.*	*There is very little knowledge of PV amongst utilities, although some have made selective investments in remote areas. The majority of public perception is centred on their use in vacation cottages.*
PRT	*Policy support, in terms of a sustainable development framework and specific targets for PV installed capacity, coupled with a feed in tariff and limited capital subsidies have set the scene for more significant development.*	*Bureaucratic delays due to the need for the PV plant to be registered as an independent power producer to qualify for feed-in tariffs have delayed deployment. Grid connection can be difficult and may be limited. Public awareness remains low.*
SWE	*Whilst there are no promotional activities specifically for PV, apart from special demonstration projects, a more general renewables policy was implemented in 2003. This is a certificate based programme that required consumers of electricity to purchase a specified percentage of renewable electricity (currently 7,4 %, but this will rise to 16,9 % by 2010). Sweden is also actively raising energy taxation.*	*Whilst the integration of grid-connected systems is very unusual in Sweden, utilities are reported as being generally supportive of applications. The majority of public interest is for off grid systems for vacation cottages for which grid connection is not viable.*
USA	*Utilities and state governments continue to develop and support PV through a wide range of incentives. California perhaps has the most wide ranging programmes, but major programmes operate in Arizona, Illinois, New York, New Jersey, North Carolina, and Ohio.*	*Deregulation of the electricity supply industry has now been enacted in twelve US states, but only seven have made provisions in the legislation to support renewable energy through system benefits credits and/or renewable energy portfolios standards. Generally utilities are unfamiliar with the connection of PV, and public awareness - outside of California - remains generally low.*

3.2 Indirect policy issues and their effect on the PV market

The key factors that are reported that may have an indirect, but important, influence on the PV market include climate change policies, sustainable energy goals and reforms of the electricity industries. A number of countries have reported government (national or local) energy policy developments. As a consequence of one or more of these factors governments are increasingly implementing the mandated approach commonly referred to as the 'renewable portfolio standard' (RPS) to increase renewable energy deployment in their countries. However it can be seen from Table 9 that, with a few exceptions (for example the Swiss renewable electricity label scheme, the Danish scheme and the programmes in certain US states), RPS are not PV specific. Consequently a general requirement for renewable energy may simply encourage the lowest direct cost renewable energy options (and not PV) for consideration by the liable parties (the electricity businesses) so as to minimize electricity price rises. Other reported measures to promote renewables include disclosure on electricity bills, tradable certificates, and branding and labels.

While electricity supply industry reforms are creating environments worldwide that are more open to energy services approaches and distributed generation opportunities from the customers' perspective, electric utility support for PV remains mixed. Many utilities are now offering net metering (where feed-in tariffs do not apply), avoiding the costs of grid extensions in remote areas and reducing the effects of demand peaks in hot weather are more firmly on the agenda for electricity network regulations, and security of supply issues are again attracting some attention. From an electricity retailer perspective, green power schemes, in which customers can purchase green electricity, are now commonplace. However these are usually characterized by the same broad, least-cost approach that can be seen in most government-driven RPS approaches.

3.3 Standards and codes

The importance of standards and codes for promoting and enabling the continued development of markets for PV systems has long been recognized. In 1981, the International Electrotechnical Commission (IEC www.iec.ch) established a Technical Committee (TC82) to prepare international standards for "systems of photovoltaic conversion of solar energy into electrical energy and for all the elements in the entire photovoltaic energy system". Up to 2004 TC82 had published 26 international standards and several technical reports and specifications covering various matters concerning PV systems and components.

Currently 22 countries are participating in TC82, as well as 11 countries that have observer status. IEC standards development under TC82 is ongoing in six active working groups:
- WG 1 Glossary
- WG 2 Modules
- WG 3 Systems
- WG 4 PV energy storage systems
- WG 6 Balance-of-system components
- WG 7 Concentrators

WG 5 dealing with Accreditation and Certification recently completed its work and was disbanded at the end of 2003. All issues concerning conformity assessment were transferred to the IECEE, a worldwide system for conformity testing and certification of electrical equipment established by the Conformity Assessment Board of the IEC. The IECEE has a consumer product oriented approach which is better suited to the demands of the rapidly expanding PV systems market than the previously used IECQ-CECC scheme. The Committee of Testing Laboratories (CTL) of the IECEE has established a PV Experts Task Force (CTL-ETF9) drawn from the PV community. An IECEE PV Conformity Assessment Certificate will now be granted to a manufacturer who can then go on to seek PV GAP accreditation, discussed later.

Common areas of interest between TC82 and other TCs are covered by Joint Working Groups. In 2003 the Joint Working & Coordination Group (JWCG) - Decentralized Renewable Energy Systems involving experts from TC82 (photovoltaics), TC88 (wind energy), TC21 (storage batteries) and TC105 (Fuel cells) issued two new Technical Specifications, providing recommendations for small renewable energy and hybrid systems for rural electrification:
- Part 1: General introduction to rural electrification (IEC 62257-1 TS Ed. 1.0)
- Part 2: From requirements to a range of electrification systems (IEC 62257-2 TS Ed. 1.0).

The total range of the TC82's activities is wide and during 2003 several drafts for international standards were approved including
- Photovoltaic module safety qualification, requirements for construction & testing (IEC 61730-1/2, publication expected in late 2004)
- Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval (IEC 61215 Edition 2.0 publication expected in 2005)
- Characteristics of the utility interface for photovoltaic (PV) systems (IEC 61727 Ed. 2.0 publication expected in late 2004)
- Balance-of-system components for photovoltaic systems - Design qualification natural environments (IEC 62093 Ed. 1.0)

A new work item approved by the TC in 2003 covers procedures for establishing the traceability of the calibration of photovoltaic reference devices (IEC 60904-4 Ed. 1.0).

In 2003 the IEC TC82 formed an official liaison with PVGAP (see below) in order to promote the global use of IEC PV Standards, extend the global PV standardization process to developing countries and harmonize national standards. Furthermore the aim of the collaboration is to complement the development of specifications with standardized conformance criteria and recognized, accredited testing laboratories.

On a European level the CENELEC CLC/TC 82 is preparing European standards and codes for PV systems and components dealing with the European Union's EMC, Machine, Construction Products and Low Voltage directives. The CLC/TC 82 cooperates closely with IEC TC 82 and the national committees in order to support the accelerated market introduction by harmonization of standards. In the U.S. activities are coordinated by the Institute of Electrical and Electronic Engineers (IEEE), which also actively participates in the IEC Technical Committee 82 to encourage harmonization. Other national institutions involved in PV standardization include the Japanese Standards Association responsible for the development of Japanese Industrial Standards (JIS) and Standards Australia; both have issued a broad range of national standards covering various aspects of PV components and systems.

Although grid-connected PV now accounts for almost 80 % of the total installed PV capacity in the PVPS countries and despite the fact that various international bodies have been working intensively on standardized requirements, grid-connection of PV systems still remains one of the most controversial issues. While modules have been the focus of attention for a long time, BOS components and systems tend to lack appropriate standards, with consequent difficulties for manufacturers, suppliers and installers. To date no common international standard or code is foreseeable that will be widely accepted; instead grid-connection issues are mostly addressed by national laws, standards, codes or utility recommendations. Meanwhile, many of the PVPS countries have established guidelines for an easy and smooth connection of distributed generators in general or specifically for PV systems. One of the remarkable activities in this context was the approval of the IEEE 1547 "Standard for Interconnecting Distributed Resources with Electric Power Systems". This standard represents a broad consensus of utility and industry inputs, supported by the U.S. national laboratories. In Europe the European Commission (EC) recently identified the need for common rules and harmonized requirements for grid-connection and currently supports a large cluster of RTD projects dealing with the integration of renewable energy sources and distributed generation in the electricity networks. However several countries still lack suitable rules for the connection of PV to the grid. There, the broad deployment of PV systems is often constrained by inappropriate regulations and requirements, which can imply an unreasonable increase of system costs due to additional equipment, long delays or bureaucratic barriers.

To guarantee quality, reliability and safety of PV systems and their components, certification schemes are increasingly becoming popular in the PVPS countries. In the U.S. a programme for PV inverters as well as a national voluntary practitioner certification programme was jointly initiated by national organizations and policy makers. The Japanese JET laboratories are also running several certification programmes dealing with accredited performance and reliability of PV modules and power conditioners for residential PV systems. Among other countries the UK, Switzerland, France, Denmark, Austria and Australia also reported national activities on certification accreditation, training and quality schemes.

To develop appropriate requirements for the use of PV in developing countries, the PV Global Approval Programme (PV GAP www.pvgap.org) set up activities aimed at the promotion of globally accepted standards for PV, testing laboratories and reference manuals for PV manufacturers. While PV GAP was initiated by the PV industry in Europe, Japan and USA, the support base for the programme has widened to include international organizations, private foundations, government organizations and other stakeholders. Based on the requirements of the IECQ (now IECEE) certification scheme, a "PV Quality Mark" for PV components and a "PV Quality Seal" for PV systems are licensed to a manufacturer if the product qualifies according to the requirements. So far three manufacturers of PV modules received approval to display the PV GAP Quality Mark. Furthermore PV GAP also issued ten 'PV Recommended Specifications' dealing with practical design details, installation guidelines and qualification testing for components. The World Bank has published four manuals setting standards for manufacturing, system design, installation and testing.

4 Summary of trends

The countries participating in the IEA PVPS Programme have a diversity of PV production, applications and policy interests. Although this survey does not completely capture the global PV market, it does provide an indication of global trends. As reported in past years the ideal of the 'real' or 'self-sustaining' or 'competitive' PV market lies somewhere in the future, with public support still important in the near-term, but the signs - public interest, industry innovation and stakeholder engagement - are on the whole quite positive.

- The market for PV power applications continues to expand: between 2002 and 2003 the total installed capacity in the IEA PVPS countries grew by 36 %, reaching 1 809 MW. Of the 476 MW installed during 2003, 75 % were installed in Japan and Germany alone. Doubling of market size in the IEA PVPS countries has occurred a little more than every two years in recent years.

- Between 1992 and 2003 the proportion of grid-connected PV capacity increased from 29 % to 78 % of the total, up from 74 % in 2002. This is mainly due to large scale, government or utility supported programmes, especially in Japan, Germany and the USA, which focus on PV in the urban or suburban environment. However, off-grid applications still account for more total installed capacity and new capacity installed in 2003 in around one half of the reporting countries.

- Climate change policies have raised the profile of renewable energy in general and security of supply issues have raised political interest in all domestic and distributed energy supplies, but the implications specifically for PV remain uncertain. The industry development aspects of PV (including the opportunities to provide jobs) have received attention with the publication of a number of 'technology roadmaps'.

- Total national budgets for R & D, demonstration / field trials and market stimulation measures remain strong. In 2003 R & D spending received a clear emphasis in about one third of the reporting countries, and one third of the countries were significantly focused on market stimulation (but also funded R & D). Funding of targeted demonstration and knowledge generation did increase somewhat compared to 2002.

- Annual cell production rose by 32 % in 2003 to 686 MW and cell production capacity increased by 17 % in 2003 to 934 MW - both growth rates considerably lower than last year. Currently 53 % of cell production and 60 % of module production in the reporting countries occur in Japan (both proportions up on last year). While dominant countries - Japan and Germany - can serve as interesting examples for others to observe, the risks for a young publicly-funded global market associated with any political turn-around in one or two countries should not be understated.

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	449	63	726	40	206	238
2001	319	15	671	49	990	36	264	319
2002	343[1]	8	969[1]	44	1 333[2]	35	343	482
2003	407	19	1 402	45	1 809	36	476	667

[1] Does not include Spain. [2] Estimate for all IEA PVPS countries

- The vast majority of modules produced continue to be based on crystalline silicon material. A number of technology types other than silicon based are in production but at a much smaller scale (<2 % of production). 2003 saw a number of significant developments regarding silicon feedstocks but amongst a small number of market actors.

- System prices have continued their general downward trend, but include fluctuations and variations between countries, which should be expected given the stage of market deployment and the impact of non-technical factors. The trend in (current) price reduction for modules (which are internationally traded and can typically cost around 50 - 60 % of the system price) shows continued decreases and irrespective of the import / export position, the vigorous targeting of markets shows quite spectacular results. Grid-connected systems typically cost about 5 USD to 7 USD per watt, with off-grid systems costing twice this amount. The lowest reported system prices were close to 4 USD per watt and are unlikely to be a true reflection of costs.

- As reported previously, public opinion is supportive of photovoltaics and electricity utilities are generally interested in many of the opportunities provided by PV. However, 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.

Inverter manufacturing in Austria (Photo SIEMENS SIEMA)

Table 11 – IEA-PVPS Task 1: National report authors

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Task 1 national participants and their contact details can be found on the IEA PVPS website www.iea-pvps.org . This report has been prepared under the supervision of Task 1 by Roland Bruendlinger, Bruno Ceccaroli, Paul Cowley, Jonas Sandgren, Alan Taylor and Greg Watt. The views expressed in the report represent a consensus of opinion amongst the Task 1 participants.

Table 12 – Exchange rates

Country	ISO country code	Currency and code	Exchange rate (1 USD=)
Australia	*AUS*	*Dollar (AUD)*	*1,542*
Austria	*AUT*	*Euro (EUR)*	*0,885*
Canada	*CAN*	*Dollar (CAD)*	*1,400*
Denmark	*DNK*	*Krone (DKK)*	*6,584*
Finland	*FIN*	*Euro (EUR)*	*0,885*
France	*FRA*	*Euro (EUR)*	*0,885*
Germany	*DEU*	*Euro (EUR)*	*0,885*
Israel	*ISR*	*New Israeli Shekel (NIS)*	*4,5483*
Italy	*ITA*	*Euro (EUR)*	*0,885*
Japan	*JPN*	*Yen (JPY)*	*115,9*
Korea	*KOR*	*Won (KRW)*	*1191*
Mexico	*MEX*	*Peso (MXP)*	*10,79*
Netherlands	*NLD*	*Euro (EUR)*	*0,885*
Norway	*NOR*	*Krone (NOK)*	*7,078*
Portugal	*PRT*	*Euro (EUR)*	*0,885*
Spain	*ESP*	*Euro (EUR)*	*0,885*
Sweden	*SWE*	*Krona (SEK)*	*8,078*
Switzerland	*CHE*	*Franc (CHF)*	*1,347*
United Kingdom	*GBR*	*Sterling (GBP)*	*0,610*
United States	*USA*	*Dollar (USD)*	*1*

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 2004).

Solar Sailor, Sydney, Australia

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* ***mounting structure*** *for the module or modules, 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 device. 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, typically available in 10 cm, 12,5 cm and 15 cm square sizes. 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 12 % and 17 %.
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 efficiencies around 11 % to 16 %.

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 11 % (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 diselenide (CIS).
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 CIS 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. 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. PV modules are guaranteed up to 20 years by manufacturers and must qualify under the IEC 61215 International Standard for crystalline silicon and IEC 61646 for thin films.
A **PV array** consist 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 grid. The typical conversion efficiency of inverters is greater than 90 %, with maximum efficiencies up to 97 %. Inverters linked directly to the PV array incorporate a Maximum Power Point Tracker (MPP tracker), 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' or sub-array. PV modules with integrated inverters, usually referred to as 'AC modules', can be directly connected to the electricity grid.

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. Nickel-cadmium batteries 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 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