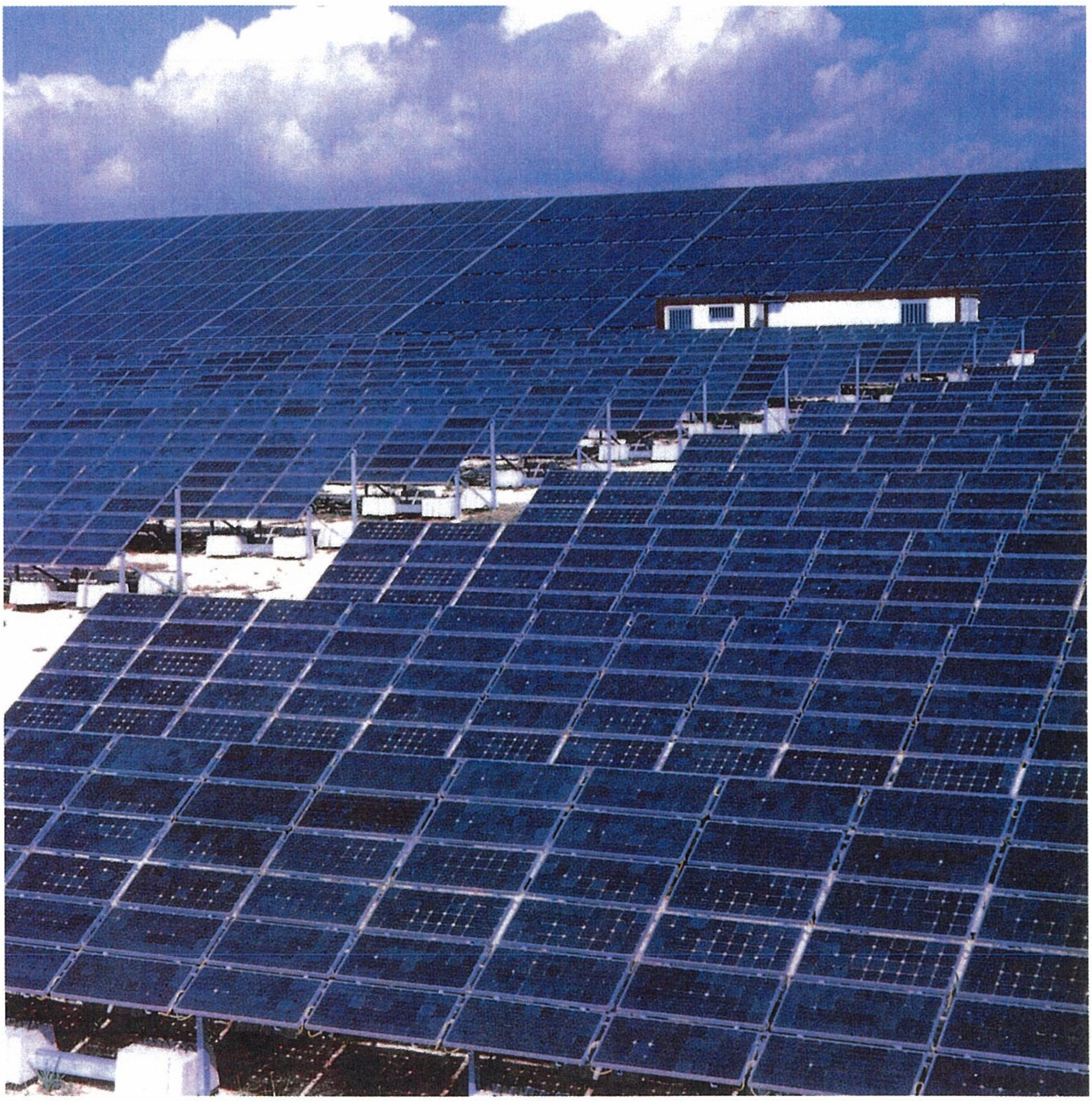
IEA INTERNATIONAL ENERGY AGENCY

IMPLEMENTING AGREEMENT ON
PHOTOVOLTAIC POWER SYSTEMS

TASK 1

# PHOTOVOLTAIC POWER SYSTEMS IN SELECTED IEA MEMBER COUNTRIES

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# Photovoltaic Power Systems in Selected IEA Member Countries

The First of a
Periodic Series
of Survey Reports

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## International Energy Agency

The International Energy Agency (IEA) was established in November 1974 as an autonomous agency within the Organization for Economic Co-operation and Development (OECD). The IEA carries out a comprehensive program of energy cooperation among its 23 member countries, and with a growing number of associated countries. Energy research, development and demonstration is an important element of that program and collaborative R&D agreements have been sponsored in four areas: renewable energy, end-use, fossil fuels, and thermonuclear fusion.

## Photovoltaic Power System Program

The IEA Photovoltaic Power System (PVPS) Program emerged from international meetings which aimed to clarify the opportunities for electric power production from photovoltaic (PV) systems and to establish a better planning basis for electric utilities, the PV industry and IEA Member governments. This program consists of research, development, demonstration, analysis and information exchange related to PV power systems for application by electric utilities and their customers.

This program builds on the application diffusion model endorsed at an IEA Executive Conference held in Taormina, Italy in 1990. This model described a new five niche market parallel-path strategy and described the way various factors will affect the rate at which these niche markets grow into significant energy markets. The niche markets are: off-grid service applications, local grid for remote villages and islands, grid-connected PV systems in buildings, distributed grid support, and peaking and bulk power. This model also incorporates the following important attributes: market-driven technology development, steady market growth, growth of the PV industry infrastructure, and a broad and successful utility experience base with PV systems and strong corporate acceptance.

At present, the PVPS Program consists of the following six collaborative projects, called Tasks. These Tasks are:

**Task 1:** Exchange and Dissemination of Information on Photovoltaic Power Systems
**Task 2:** Operational Performance and Design of Photovoltaic Power Systems and Subsystems
**Task 3:** Use of Photovoltaic Systems in Stand-Alone and Island Applications
**Task 4:** Modeling of Distributed Photovoltaic Power Generation in Support of the Electric Grid
**Task 5:** Grid Interconnection of Building Integrated and Other Dispersed Photovoltaic Power Systems
**Task 6:** Design and Operation of Modular Photovoltaic Plants for Large-Scale Power Generation

All of these tasks, with the exception of Task 4, are active at this time. This series of Survey Reports on Photovoltaic Power Systems in Selected IEA Member Countries is an activity of Task 1.

The objective of Task I is to facilitate the exchange and dissemination of information on the technical, economic and environmental aspects of PV power systems for utility applications in participating countries.

In this Task, analysts in the sixteen participating countries, plus the European Union collect information on technical, economic and environmental characteristics of photovoltaic power systems in their respective countries by means of published and unpublished materials and personal interviews. This information is then disseminated in several ways. Some is used as input material for the PVPS Program Newsletter, some is compiled by the Task participants into national reports, and some is exchanged at Task meetings in order to develop joint summary assessments of the impact of PVPS systems impacts and the factors affecting their use in various energy markets.

A major activity of Task 1 is to conduct a periodic survey of the status of photovoltaics power system applications in the electric utility sector of those countries participating in the PVPS Program. The data gathered in these surveys will be analyzed and published periodically. This document is the first in a series of survey reports.

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# Executive Summary

## Objectives and Scope

The objective of this IEA Survey Series is to present and interpret year-to-year trends in both the PV systems and components being used in the utility sector, as well as the changing applications within that sector, in the context of the business situations, policies and relevant non-technical factors in the reporting countries. This survey series is intended to meet the needs of those responsible for (1) developing business strategies for photovoltaic companies, (2) developing long-range plans and/or business plans for electric utilities or other providers of energy services, and (3) government officials responsible for setting energy policy and preparing national energy plans.

The objective of this first report of the series is to present an accurate, comprehensive and useful description of the PV products and applications in the utility sector of the reporting countries as of the end of 1993. It deals only with 15 IEA member countries, plus Korea and the European Union. In 1993, these sixteen countries produced almost all of the world's PV power modules (as measured in $MW_p$) and host the majority of the grid-connected systems. The survey, however, shows only a partial picture of the off-grid applications.

The first survey report covers:

- market and business as of 1993
- commercial and prototype photovoltaic power system products
- demonstration and field test systems
- non-technical factors

## Market and Business Situation

The total photovoltaic power system power capacity installed by the end of 1992 in the 16 reporting countries was slightly under 44 $MW_p$. By the end of 1993, the installed power capacity grew by about 33% to slightly over 58 $MW_p$. The installed capacity in 1992 and 1993 for the reporting countries in "Europe", "Pacific Rim" and "North America"[1] is illustrated in the figures on the next page.

This growth is dominated by Japan, Italy and Germany, and to a lesser extent, by the United States, and is primarily in the grid-connected applications. The growth in Europe was primarily due to the Italian utility scale demonstration program and the German 1000-Roofs program. In 1993, Germany, Canada, Italy and Japan experienced a growth in installed PV power greater than the survey average of 33 percent.

The countries with the most installed PV power, Germany, Italy, Japan and the United States, also have the largest PV module manufacturing capacities, due to supportive government policies and programs, and familiarity with grid-connected installations. However, the United Kingdom, which has one of the largest manufacturing companies, is one of the smallest markets.

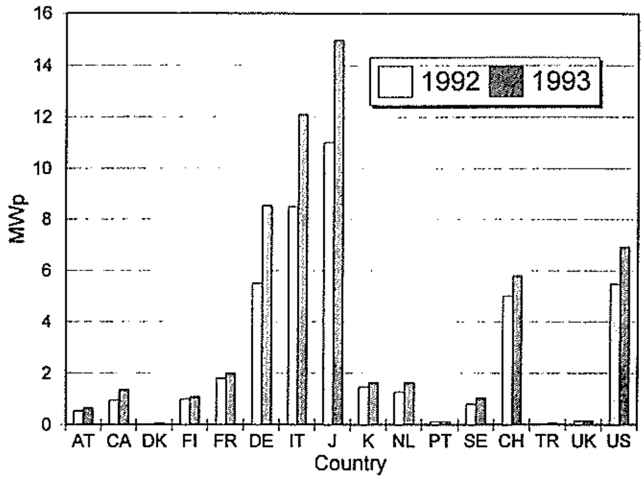
The total photovoltaic power capacity installed in the 16 reporting countries during 1993 was 14.6 $MW_p$, about 26% of the modules shipped in that year, and the installed capacity was 58.3 $MW_p$. However, over 400 $MW_p$ of modules have been produced during the last decade, most of it in the reporting countries, raising the question where did the rest of the modules go? The majority of modules produced in the 16 reporting countries were used in non-power applications, non-utility small power applications which are difficult to account for, or were exported to unsurveyed countries.

Prices of PV systems depend on the system, the customer, the location, the total quantity sold at one time, technical specifications, etc. and therefore they vary widely. For the reporting countries, the average turn-key price of installed PV systems varied greatly, from 6.65 $/$W_p$ to 37.00 $/$W_p$.[2] Caution must

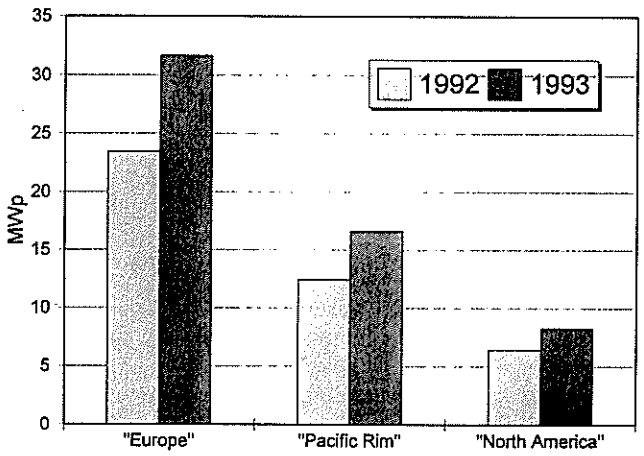
[1] Throughout this report, the words "Europe", "Pacific Rim" and "North America" refer to those reporting countries in each region. Note that "Europe" lacks important data from Spain which is not a reporting country, that the "Pacific Rim" only includes Japan and Korea, and that data from Mexico is not included in "North America".

[2] The symbol "$" denotes United States dollars.

## Reported Installed PV Power Capacity by the end 1992 and 1993




## Reported Installed PV Power Capacity, Aggregated into Three Regions, by the end of 1992 and 1993




be used when comparing or averaging PV component or system price data presented in this report. The reasons for the large variation in installed system costs include, the variations in the size of the installed systems, the type of system (grid-connected or off-grid), the availability of subsidies, and the lack of common definitions and standardization in reporting system cost data.

In this survey, the utility market has been divided into four market sectors:

- off-grid service applications
- off-grid residential systems
- small distributed grid-connected systems
- medium and large grid-connected systems

If each of these four market sectors is examined separately, Italy reported the largest amount of installed photovoltaic power capacity in the off-grid service applications market sector, followed by Korea and the Netherlands. Italy, Switzerland and France reported the most PV power capacity installed in off-grid systems. Germany, Japan and Switzerland reported the most installed PV power capacity in the small distributed grid-connected market, while Germany, Italy and Switzerland reported the greatest installed PV power capacity in the medium and large grid-connected market sector.

Between 90 and 100% of the photovoltaic power system installations in Denmark, Finland, France, Korea, the Netherlands, Portugal, Sweden, Turkey and the United Kingdom are off-grid. This is to be expected as the current price of PV is still relatively high for grid-connected applications. Only five countries have more than 15% of their photovoltaic power systems grid-connected. The United States, Austria, Germany and Switzerland have more than 50% of their PV power capacity grid-connected, most of which is subsidized. In the European Union countries, there were very few grid-connected systems before the early 1990s. The difficulty in reporting data for off-grid PV systems is, in fact, a positive indication of an active commercial market.

In many ways, off-grid vs. grid-connected markets can be seen as representing two different perspectives on market forces. The off-grid approach, which is a response to market forces, usually provides cost-competitive power for remote sites that are not easily accessible to the grid. The grid-connected approach, which anticipates future market forces, and which only a few of the reporting countries presently favor, represents a longer-term strategy to support the development of photovoltaic power systems as part of the utility company or an energy service company's distributed or central generation business.

## PV Modules

There are 37 module manufacturers in 12 of the 16 reporting countries, who shipped a total of 52.2 $MW_p$ in 1993. This was almost all of the world's total module shipments for non-consumer product power applications. These 37 companies have a combined production capacity estimated to be almost 92 $MW_p$. All 12 countries that have module manufacturers produced crystalline silicon modules. France, Germany, Japan, the United Kingdom and the United States also have module manufacturers who shipped amorphous silicon modules for non-consumer product power applications. Eight of the 37 companies produced amorphous silicon modules, while 29 produced mono- or multi-crystalline silicon modules.

Module manufacturers in the "Pacific Rim" and "North America" operate their facilities two shifts per day, while those in "Europe" average one shift per day or less.

Twelve companies each produced at least 1 $MW_p$ of modules in 1993. Together these 12 companies have a production volume of about 39 $MW_p$/yr, which is about 75% of the total production volume of the 16 reporting countries. The majority of these companies are integrated module manufacturers producing crystalline silicon modules.

Crystalline silicon module manufacturers with production capacity greater than 1 $MW_p$ tend to produce and/or process both cells and modules and are therefore designated as "integrated" manufacturers. The largest integrated manufacturer of crystalline silicon modules shipped 12.5 $MW_p$ in 1993. The largest assembler of crystalline silicon modules shipped 1 $MW_p$ in 1993. Because of the way amorphous silicon modules are produced, all manufacturers of such modules are integrated, with the largest manufacturer shipping 3 $MW_p$ in 1993.

Module prices represent a significant portion of photovoltaic power system prices, and as such, are of great interest to utilities and energy service companies. While it is possible to gather module price data from the reporting countries, it is very difficult to compare them or to draw conclusions about them. Because the PV industry is still quite new, there simply is no such thing as standard module prices. Just as for PV systems, module prices depend on the size of the order, the customer's specifications, the application (off-grid or grid-connected) and whether the price is based on a turn-key project or on the subsystem and component prices quoted by the primary or end distributor.

In this first survey, the lowest module price reported for a large order was 4.10 $/$W_p$ and the highest was 8.00 $/$W_p$. The lowest price, 4.10 $/$W_p$, was for a very large order from the national utility company for a 3.3 $MW_p$ major system in Italy. On the other hand, the highest price reported for a large order, 8.00 $/$W_p$ in Japan, is the price paid by government-subsidized PV power projects and is intended to reflect actual manufacturing costs.

It seems that as a country's module production capacity rises, the price of modules produced by its manufacturers decreases, following the classical "learning curve". Module prices decrease to 4.10 $/$W_p$ at about 10 $MW_p$ per year production volume. The only data points for larger production volumes are for Japan at about 20 $MW_p$ per year and the United States at about 33 $MW_p$ per year. However, for both of these countries, their lowest module price is considerably above the projection of this trend.

Crystalline silicon modules range in output from 1.5 $W_p$ to 300 $W_p$, and in physical size from 0.02 $m^2$ to 3.0 $m^2$. Amorphous silicon modules are typically smaller, with the largest output being 60 $W_p$. Crystalline silicon modules produce 2-3 times more power per unit area than do amorphous silicon modules. The operating voltage of the modules being produced today generally range from 10-34 volts, sufficient to charge batteries. Higher voltages are now also available.

The most commonly used modules for photovoltaic power system applications are mono-crystalline and multi-crystalline silicon modules. The most common power modules range in size from 0.36-0.87 $m^2$ and are rated at 37-110 $W_p$. Three manufacturers out of a total of 27 make larger modules for utility applications. With few exceptions, standardized utility specifications for modules do not yet exist.

## Balance of System Components

A specialized industry exists today that manufactures PV system components including off-grid and grid-connected dc-to-ac inverters and battery charge controllers. Most batteries used are not designed primarily for PV applications. Most module array support structures are custom designed by the system installer.

All countries with substantial in-country installations have system suppliers and PV inverter and charge controller manufacturers. The inverse is also found; several countries with relatively small in-country markets, such as France and Finland, also have a BOS industry.

The inverters manufactured in the responding countries are designed to be connected to the grid or to be operated as part of an off-grid system with batteries. The most common batteries used in photovoltaic power systems are 2, 6, 12 and 24 volts, lead-acid type and most are deep discharge varieties. Many battery charge controllers incorporate other features to increase battery protection and enhance the PV system operation. These include maximum-power tracking, temperature compensation, etc.

## PV Power Systems

The photovoltaic power systems available today come in a wide variety of system configurations, most of which are custom designed. The noteworthy exception is Italy's Photovoltaic Low-cost Utility Generator (PLUG) which incorporates factory pre-assembly of components and subsystems, and simple support structures. Utility defined specifications have been developed for specific projects, but have not been standardized for various photovoltaic power system applications. However, both off-grid and grid-connected systems must conform to a large set of system and plant specifications, regulations and standards, such as safety.

Data provided by Germany illustrates the dependency of system price on system type and size. The lowest system price of 8.13 $/W_p$ was for a standard high power grid-connected photovoltaic power system while the higher system price of 48.90 $/W_p$ was for an off-grid photovoltaic power system with an auxiliary generator. Low power grid-connected photovoltaic power system prices are 9.80-12.50 $/W_p$ and standardized off-grid photovoltaic power systems are 12.20-13.10 $/W_p$.

## Demonstrations and Field Tests

There is a great variety in the number and type of objectives for the demonstration and field test programs in the reporting countries. Eighty-two percent of the citations pertain primarily to field test and demonstration programs while 18% pertain to commercial systems, with and without subsidies.

Government sponsored demonstration and field test programs predominated with a few notable exceptions: utilities take the funding lead in the United States and Austria and to a lesser degree in Germany and Sweden. Private sector funding is relatively important in Finland and to a lesser degree in the Netherlands and Canada.

The capacity range of demonstration and field test systems was large, from a 50 $W_p$ rural electrification system in Portugal to a 3.3 $MW_p$ grid-connected system in Italy. There is a large range in the total power of the installed demonstration and field test systems in the reporting countries, from 3 $kW_p$ in Turkey and 16 $kW_p$ in the United Kingdom on the low end, up to 1.58 $MW_p$ in Switzerland, 3.95 $MW_p$ in Italy, 4.92 $MW_p$ in the United States and 6.4 $MW_p$ in Germany.

System suppliers seem flexible in pricing their demonstration and field test systems from 8 to 20 $/W_p$, with a few exceptions. Italy was able to install for 9.40 $/W_p$, a small margin (25%) over their highest price of 7.50 $/W_p$ for components only, and about 75% over their lowest component-only price of 6.60 $/W_p$. Canada and Germany were able to install systems for between 12.00-13.00 $/W_p$ or about 40-50% over their lowest component-only prices.

An often quoted parameter is the ratio of installed system cost to module cost. If this ratio is computed based on the lower end of the module price range, this parameter ranges from a low of 1.6 for the United States to about 2 to 3 for Austria, Canada, Germany, Italy, Sweden and Switzerland. The low value for the United States is likely due to the use of data from grid-connected systems only.

The balance of system components were the source of most of the reported problems, suggesting that the PV modules are performing very well.

## Policy

International treaties and agreements were viewed to have a positive, if indirect, impact on the future use of photovoltaic power systems. Austria, Canada and the United States also reported that certain legally binding regional agreements, such as the European Union policies and the North American Free Trade Agreement (NAFTA), respectively, will have a positive effect on photovoltaic markets. Only Finland and Sweden reported that they had no specific local or regional plans to promote the use of photovoltaic power systems.

Eight countries have specific targets for photovoltaic power systems, ranging from 50 $MW_p$ (grid-connected) by 2000 in Switzerland and in the United States, 25 $MW_p$ by 1995 in Italy, and 20 $MW_p$ by 2000 for island applications in Korea. The Netherlands has a target of 250 $MW_p$ for all renewable energy sources by 2010. Denmark and Japan have specific goals to make building-integrated PV competitive by 2000. With such aggressive targets it can be expected that the level of PV activity in these eight countries will be relatively high in the near future.

The United States has the PV module production capacity to meet its target, though to do so in even increments it would have had to increase its installed PV power capacity by almost 4 times in 1994. Italy's module manufacturing would have to double or imports would be required to meet Italy's target. But Korea, Canada, the Netherlands and Switzerland will have to rely heavily on imports or dramatically increase their domestic production as well as a greatly increased rate of installations to meet their national targets for PV.

## Subsidies and Rates

Significant investment subsidies are available in most of the reporting countries for the initial capital cost of photovoltaic power systems. Only Canada, Sweden and Turkey do not provide subsidies for the construction of photovoltaic power systems. Buy-back rates (the price that utilities pay for PV-generated electricity fed into their grids) vary considerably from country to country. Italy has the most positive rates, significantly exceeding parity (the rate that utilities charge their customers) for peak power for the first 8 years. Some local utilities in Germany and Switzerland can also exceed parity for 10 years while for Canada, Finland, Sweden and the United States, the utilities must pay only their avoided costs.

## Standards

Work to develop standards for photovoltaic components continues. The International Electrotechnical Commission (TC-82) has issued standards covering various aspects of performance measurement, design qualification and type approval for crystalline silicon modules. Work is also underway to develop a standard for PV systems and for batteries.

Safety is the major concern regarding construction and operation of photovoltaic power systems, and where present regulations apply, they seem adequate. Seven of the sixteen responding countries indicated that there were no specific regulations or standards for connecting photovoltaic power systems to the grid, nor were there any regulatory problems that required attention.

## Environmental Aspects

Environmental regulations favor photovoltaic power systems in Austria, Canada, Denmark, Italy, the Netherlands and Portugal, but do not infuence the market. Most of the reporting countries do not have pollution taxes. In Finland, such taxes are being introduced in 1994 and they should favor photovoltaic power systems. In Sweden, pollution taxes exist but do not affect the use of photovoltaic power systems because the price of electricity from such systems is still too high.

## Limiting Factors

The high initial cost, limited subsidies, unsatisfactory payment for the energy sold to the grid, certain grid-connection requirements, lack of awareness of the capabilities of photovoltaic power systems, lack of standard photovoltaic power systems on the market, lack of qualified system designers and installers, and difficulties in finding BOS components on the market are the market limiting factors for PV power system suppliers.

## Utility and Public Perceptions of Photovoltaic Power Systems

Austria, Canada, Finland, Italy, the Netherlands and the United States report favorable utility perception of photovoltaic power systems due, to a great extent, to their successful involvement in the past and present photovoltaic power system projects.

As a result of many successful demonstration programs and projects, public perceptions of photovoltaic power systems are good in Austria, Finland, Germany, Italy, Switzerland and the United States.

# Chapter 1

# Introduction

## Objectives

The objective of this IEA Survey Series is to present year to year trends in photovoltaic (PV) systems and components used in the utility sector, and to interpret changing applications within that sector, in the context of the business situations, policies and relevant non-technical factors in the reporting countries. These countries are primarily IEA member countries and Korea, which is a participating country in the IEA Photovoltaic Power Systems Program.

The objective of this first report of the series is to present an objective, accurate, comprehensive and useful description of the PV products and applications in the utility sector of the reporting countries as of the end of 1993. Since not all of the reporting countries include PV power in their utility sector, or only in their utility sector, this report includes those applications that might reasonably be expected to fall within the utility sector.

## Background

Photovoltaic products and systems are produced in many countries around the world and the applications for this technology are global. A truly comprehensive survey of photovoltaic power system applications would therefore require global input and analysis. As this approach was not considered to be feasible, this survey deals only with 15 IEA member countries, plus Korea and the European Union. In 1993, these sixteen countries produced almost all of the world's PV modules (by $MW_p$) and hosted the majority of the grid-connected systems. The survey, however, shows only a partial picture of the off-grid applications.

The situation concerning the utility companies today is very different from that in 1990. The number of utility companies with photovoltaic programs has grown dramatically. Most of the major photovoltaic companies are now designing, installing and evaluating power systems to meet emerging utility service requirements. But perhaps the most profound driver of change is the emergence of restructuring and competition in the utility industry in the United States and in Europe. Utility companies are trying to understand how to best position themselves for the future and how to retain their customer base and attract new customers.

The IEA's goals and focus have also changed in the past four years. There is a greater interest in climate change issues and the role that renewable energy technologies could play in reducing greenhouse gas emissions. IEA member governments are interested in understanding the factors that control the rate at which photovoltaic systems could be deployed for various utility applications. In many of the IEA member countries, utility executives and government policy-makers, in response to growing environmental concerns, are re-evaluating the contribution that photovoltaics can make to their electricity service requirements.

## Scope of Survey

"Photovoltaic power systems" are defined, for this survey, to be any system that is designed to convert solar energy into electricity using photovoltaic cells for all applications except consumer products, such as watches, calculators, toys, etc. Applications ranging from a few tens of watts to megawatts are included for service applications (such as navigational aids, telecommunications, cathodic protection, etc.); off-grid applications (such as individual homes, or islands); distributed generation for grid-support and grid-connected buildings; and modular multi-megawatt systems for central power plants.

This survey report is not intended to serve as an introduction to photovoltaic power systems, nor is it intended to serve as a policy document. It is intended to provide data, in tabular and graphical form, and related analysis, that will allow those interested in the use of photovoltaic power systems to draw their own conclusions about the state of particular applications.

This survey does not deal with photovoltaic products from, or applications in countries other than the 16 countries that have agreed to provide the required input information.

This first survey report covers:

- PV power market and business as of 1993
- commercial and prototype photovoltaic power system products
- demonstration and field test systems
- non-technical factors

## Survey Series Audience

The survey series is intended to meet the needs of those responsible for:

- developing business strategies for photovoltaic companies,
- developing long-range plans and/or business plans for electric utilities or other providers of energy services,
- setting energy policy and preparing national energy plans,

who therefore must know the present status of photovoltaic power systems and the major trends for applications.

It is the intent of this survey series to be comprehensive enough to provide information that the above audience can use to make their future plans regarding utility applications. This series should be a valuable resource for assessing future investment opportunities for utilities and market opportunities for the PV industry, and to assist government officials to assess the opportunities for photovoltaic power systems to respond to national and international initiatives.

Furthermore, this survey series is intended to provide information and insight to assist electric utility senior executives, photovoltaic system suppliers and government policy-makers to assess the new business opportunities that will be opened by photovoltaics and the key issues associated with these emerging opportunities.

## Market Strategies

The first international executive conference on Photovoltaic Systems for Electric Utility Applications was held in Taormina, Italy on 2-5 December 1990. Participants included presidents, vice presidents and general managers from eighteen of the major public and private electric utilities from ten countries, and of seventeen of the world's largest photovoltaic companies from eight countries. Senior executives from twenty-four government organizations, representing the ministries of finance, industry, energy, trade, science and research from fifteen countries, and from the IEA and the European Union were also present.

A major outcome of that conference was the recognition that the most promising development paths for photovoltaics in the utility sector could be described via a new five part, parallel strategy which identifies the various applications most suitable for power generation (referred to as market sectors or niche markets) and describes the way various factors will affect the rate of deployment in each sector. This strategy was given the name "diffusion model" at the conference.

Since 1990, several countries, including Austria, Germany, the Netherlands and the United States initiated programs in the distributed generation niche market. The national electric utility company in Italy and many electric utility companies in the United States initiated projects related to the grid-support niche market. A large number of public and private utilities in the United States initiated a collaborative venture to structure the initial market for photovoltaics following the diffusion model, with the active involvement of the United States photovoltaic industry. And in 1993, fifteen countries plus the European Union, initiated a major collaborative program to advance the performance of PV power systems. This survey series, a major activity of this IEA Photovoltaic Power Systems Program, is intended to document the continuing evolution of photovoltaics in the utility and related energy-services area.

The diffusion model incorporates the following important attributes: market-driven technology development, steady market growth, growth of the photovoltaic industry infrastructure, a base of successful utility experiences with photovoltaic systems and strong corporate acceptance. Furthermore, the model postulates that as the costs for reducing the environmental impacts of combustion-based production or the societal costs of non-domestic production of energy are considered in the price of electricity, the competitiveness of renewable technologies will improve, and the niche markets will expand.

### Initial and current niche market: Remote customer applications

In the diffusion model, the initial and current market is the cost-effective use of photovoltaics by utilities and end users to meet remote customer applications (10 $W_p$ to 10 $kW_p$). Utilities already use photovoltaics in a variety of small applications to power remote communications, safety, and control devices involved in operating their systems and in various applications serving customer-owned loads (residential, commercial and industrial). These are early high-value applications where photovoltaics is cost effective today. As photovoltaic technologies continue to improve and more such applications are identified, the size of this market sector will grow. In this survey report, this niche market is called the off-grid service applications market sector.

**Second niche market: Local grid for remote villages and small islands**

A second market sector is for those applications that are close to competing with other energy sources, such as a local grid for remote villages and small islands, with power levels ranging from 10 $kW_p$ to 1 $MW_p$. These systems have been installed throughout the world, particularly in developing countries, where they represent the technology most appropriate to meet the energy demands of rural communities. They also have significant potential in industrialized countries, to provide power on islands where the cost of energy and environmental constraints may make them competitive. This niche market is called the off-grid residential market sector.

**Third niche market: Grid-connected PV systems on buildings**

The third market sector pertains to photovoltaic systems on the demand-side of the meter. These applications are grid-connected roof-top systems for residential and commercial buildings of 1 kWp to 50 $kW_p$ per site. This application will be particularly attractive if the photovoltaic system can be structurally, architecturally and electrically integrated into the building and its energy services.

**Fourth niche market: Strengthen utility distribution grid**

The fourth niche market uses photovoltaic systems to strengthen the utility's distribution grid. PV systems for this market have a power output from 100 $kW_p$ to 1 $MW_p$ each, and are located at the electrical periphery of the utility system where they can support the local energy, capacity, voltage, or reliability needs. For example, there are situations in which installing photovoltaic power systems near the end of a feeder line that is experiencing heavy peak loads may be a cost-effective alternative to upgrading the line. The value of the photovoltaics is thereby increased by various benefits, such as relief of thermal loads, electrical loss savings, voltage support and higher reliability, all of which add to the traditionally acknowledged capacity and energy credits. In this survey report, the third and fourth niche markets are grouped together into the small distributed grid-connected market sector.

**Fifth niche market: Peaking and bulk power**

The peaking and bulk power market requires additional design, testing and demonstration of photovoltaic plant segments scalable to multi-megawatt size. Several pioneering megawatt-scale photovoltaic plants are already generating reliable power for utility grids, providing essential field construction and operating experience, and giving a realistic picture of current total system costs and performance. This sector is called the medium and large grid-connected market sector in this report.

# CHAPTER 2

# PV Power Market and Business as of 1993

## Overall Photovoltaic Power System Market

Table 1 shows the data provided by the responding countries for the total power systems installed by the end of 1992 and 1993, and the installed power added in 1993 (which is the difference between these two quantities).

The photovoltaic power systems installed during 1993 in the reporting countries totals 14.6 $MW_p$, a 33% increase over that which was installed by the end of 1992. In absolute numbers, the growth in installed PV power is dominated by Japan, Italy, Germany, and the United States. In a relative sense Turkey (+75%), Germany (+55%), Canada (+42%), Italy (+42%) and Japan (+36%) were all above the survey average in growth of installed power systems. This growth is strongly supported by government subsidies in Germany, Italy, Japan and the United States. The growth was primarily in grid-connected applications.

**TABLE 1**
**Photovoltaic Power Capacity Installed in The Reporting Countries, by the end of 1992 and by the end of 1993. See Figures 1-4.**

| | Reported Installed Capacity by the End of 1992, $MW_p$ | Reported Installed Capacity by the End of 1993, $MW_p$ | Reported Installed during 1993, $MW_p$ | Percent Increase 1992-1993 |
|---|---|---|---|---|
| Austria | 0.54 | 0.66 | 0.12 | 22 |
| Canada | 0.96 | 1.37 | 0.41 | 42 |
| Denmark | | 0.085 | 0.085 | - |
| Finland | 1.0 | 1.1 | 0.1 | 10 |
| France[3] | 1.8 | 2.0 | 0.2 | 11 |
| Germany | 5.51 | 8.54 | 3.03 | 55 |
| Italy | 8.5 | 12.1 | 3.6 | 42 |
| Japan | 11.0 | 15.0 | 4.0 | 36 |
| Korea | 1.47 | 1.64 | 0.17 | 12 |
| Netherlands | 1.27 | 1.64 | 0.37 | 29 |
| Portugal | 0.12 | 0.125 | 0.005 | 4 |
| Sweden | 0.8 | 1.04 | 0.24 | 30 |
| Switzerland | 5.0 | 5.8 | 0.8 | 16 |
| Turkey | 0.04 | 0.07 | 0.03 | 75 |
| United Kingdom | 0.145 | 0.162 | 0.02 | 14 |
| United States | 5.48 | 6.94 | 1.46 | 27 |
| Total/Average[4] | 43.7 | 58.3 | 14.6 | 33 |

[3] "France" includes continental France and Corsica and its overseas departments are the islands of Guadeloupe, Martinique and Réunion.

[4] The totals presented in the tables are often rounded and therefore may differ slightly from the exact total of the columns.

**FIGURE 1**
**Reported Installed PV Power Capacity by the end 1992 and 1993**

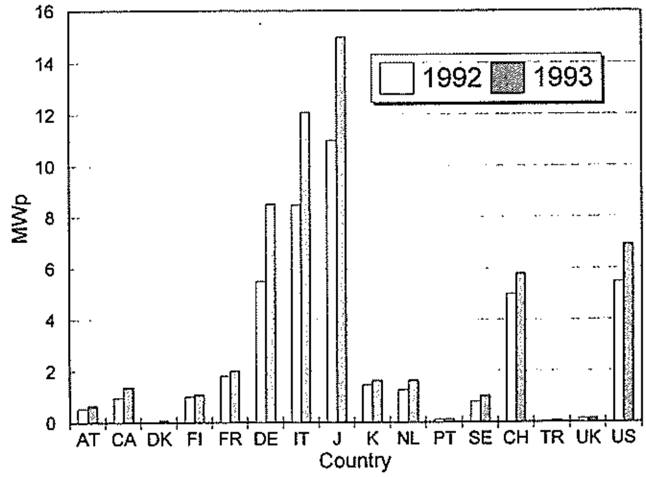
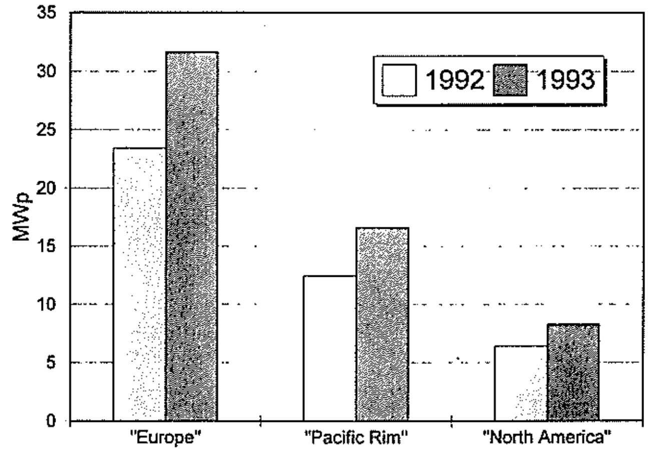



**FIGURE 2**
**Reported Installed PV Power Capacity, Aggregated into Three Regions, by the end of 1992 and 1993**




Turkey's high percent growth was due to an addition of 30 $kW_p$ to their very low initial installation level of 40 $kW_p$. Germany's growth is primarily due to the success of their 1000-Roofs program which added over 1.73 $MW_p$ in 1993. By the end of 1993, that program alone was at 4.03 $MW_p$.

Figure 1[5] shows the installed power capacity, by country, by the end of 1992 and by the end of 1993. Figure 2 shows the same data aggregated by region.[6] It is clear from this figure that most of the installed power added in 1993 was in "Europe". The European" installed power grew by 59%, the "Pacific Rim" installed power grew by 28% and "North American" installed power had more moderate growth of 13%. The Italian utility scale demonstration program and the German projects are the reasons for the "European" growth. Figure 3 shows the photovoltaic system power installed in the reporting countries during 1993. Figure 4 aggregates the installed photovoltaic power for the reporting countries.

Table 2 shows the investment made in the photovoltaic power systems installed in 1993 and the average turn-key system price of those systems. The total reported investment in PV power systems installed in 1993 was approximately 185 M$. The average was derived by dividing the investment made in photovoltaic power systems installed in 1993 by the capacity of those systems. This formula can be used to account for the data from all of the reporting countries except France, Japan, Korea and the United Kingdom. These countries arrived at their averages via another approach.

As prices of PV systems depend on many different conditions, caution must be taken when such prices are compared. Specifically, the installed system

[5] The following country abbreviations are used throughout this report: Austria (AT); Canada (CA); Denmark (DK); Finland (FI); France (FR); Germany (DE); Italy (IT); Japan (J); Korea (K); Netherlands (NL); Portugal (PT); Sweden (SE); Switzerland (CH); Turkey (TR); United Kingdom (UK); and United States (US).

[6] Throughout this report, the words "Europe", "Pacific Rim" and "North America" refer to those reporting countries that are located in that region. Note that "Europe" lacks important data from Spain which is not a reporting country, that the "Pacific Rim" only includes Japan and Korea, and that data from Mexico is not included in "North America".

**TABLE 2**
**Photovoltaic Power Systems Installed during 1993**

| | Turn-key Systems Investment, M$ | Average Turn-key System Price, $/W$_p$ |
|---|---|---|
| Austria | 1.9 | 15.90 |
| Canada | 4.8 | 11.80 |
| Denmark | 0.6 | 7.30 |
| Finland | 3.0 | 17.00 |
| France | 7.14 | 37.00 |
| Germany | 39.0 | 12.90 |
| Italy | 33.8 | 9.40 |
| Japan | 56.0 | 35.00 |
| Korea | 2.4 | 18.75 |
| Netherlands | 5.5 | 14.85 |
| Portugal | | |
| Sweden | 3.9 | 16.05 |
| Switzerland | 13.8 | 17.25 |
| Turkey | 0.2 | 6.65 |
| United Kingdom | 0.2 | 12.35 |
| United States | 12.3 | 8.42 |

prices are influenced by any or all of the following: the size of the installed system (e.g., the relatively high per watt costs of very small remote power systems which make up many of the installations and the relatively lower prices for the multi-megawatt projects), the type of system installed, (grid-connected or off-grid), the availability of local subsidies which can serve as price supports thereby resulting in elevated prices, and the lack of consistent definitions and good system cost data. Subsequent survey reports will attempt to arrive at separate prices for off-grid and grid-connected systems.

It is interesting to interpret the reported system costs with respect to their underlying causes. Of the major users of photovoltaics power systems, only Italy and the United States reported a weighted average installed system price below 10.00 $/W$_p$. Italy's reported price appears credible based on the quality of their national input report and the size of the large grid-connected system just installed. The data from the United States also appears to be credible as they are based on specific known systems installed by SMUD, a large utility in the United States, or come from the data base of the Utility Photovoltaic Power Group in the United States.

The very low weighted average turn-key system price of 6.65 $/W$_p$ reported by Turkey is based on modules imported at a very low introductory price. Not only would the modules have to be almost free, but the system would have to be rather simple to achieve such a low installed price. The price reported by Denmark also raises questions.

The Japanese installed system price of 35.00 $/W$_p$ seems well out of range for larger power installations as do their module prices of 8.00-18.00 $/W$_p$ (see Chapter 3). This is probably due to the presence of significant government subsidies for such systems sold and installed in Japan.

The 12.90 $/W$_p$ weighted average turn-key system price reported by Germany is based on predominantly grid-connected systems. That is 2,961 kW$_p$ of grid-connected photovoltaic power systems at 12.50 $/W$_p$ and only 5 kW$_p$ of off-grid photovoltaic power systems at 30.00 $/W$_p$. The converse is true for France, whose weighted average turn-key price is essentially for all off-grid systems.

## Photovoltaics Market Sectors

It is of interest to understand how the photovoltaic power systems described in the previous section are used. To do this, it is necessary to separate grid-connected from off-grid systems since their hardware specifications and costs are generally quite distinct. Another reason for examining the uses is to assure

**FIGURE 3**
**Reported Installed PV Power Capacity during 1993, $MW_p$**

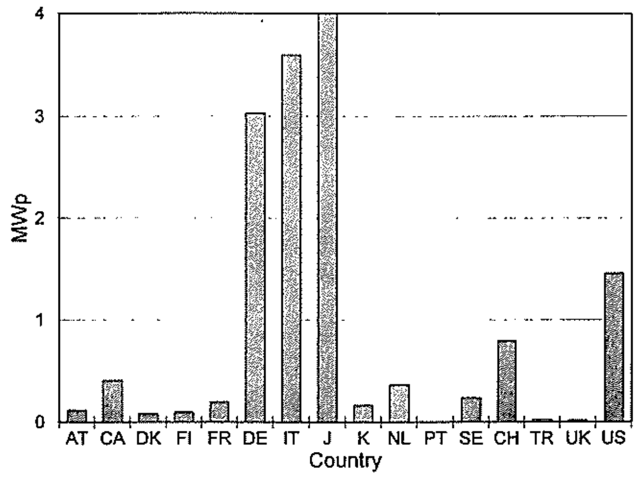
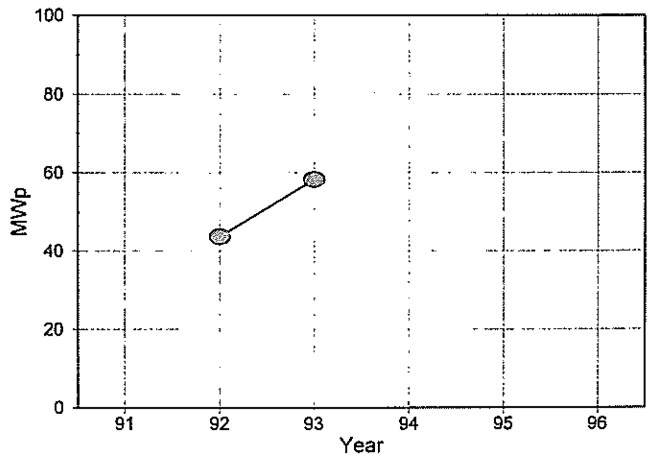



**FIGURE 4**
**Total Installed PV Power Capacity, $MW_p$**




the reader that only photovoltaic power systems are included in this survey; that is, that calculators, watches, etc., are not included in the power system totals.

Table 3 presents the data submitted on installed photovoltaics systems, as of the end of 1993, in each of the following four market sectors:

- off-grid service applications
- off-grid residential systems
- small distributed grid-connected systems
- medium and large grid-connected systems

The national input reports provided market-sector data concerning installed grid-connected systems that were more complete than market-sector data concerning installed off-grid systems. Some of the reporting countries did not even attempt to estimate the power installed in the off-grid service application sector or off-grid residential sector and some provided information only for off-grid systems greater than 1 $kW_p$. The difficulty in reporting data for off-grid PV systems is, in fact, a positive indication of an active commercial market.

A useful indicator of energy production is the capacity factor, defined as the ratio of the annual energy produced to that which would be produced if the system operated at rated capacity continuously during the 8760 hours of the year. Italy reported capacity factors of 13% while Japan reported typical capacity factors to be 14%. However, these capacity factors are relatively low compared to systems in the sunnier parts of the United States where several individual photovoltaic power systems have capacity factors well above 20%. Relatively higher capacity factors are indicators of greater available insolation at the site or better designed and operating systems.

Figures 5 and 6 graphically show the installed capacity data as found in Table 3. In these figures, the percentage of each reporting country's installed photovoltaic power system power in each of the four market sectors, and the total amounts in each of the three regions, are shown. It must be pointed out that the data provided by some countries were not adequate to complete Table 3 and the related figures. The indicated reporting countries have most installed power in each of these four sectors:

**TABLE 3**
**Installed PV Power Systems Capacity by Market Sector, by the End of 1993. See Figures 5-7.**

| | Off-Grid Service Applications $MW_p$ | Off-Grid Residential $MW_p$ | Small Distributed Grid-Connected $MW_p$ | Medium and Large Grid-Connected $MW_p$ |
|---|---|---|---|---|
| Austria | 0.132 | 0.183 | 0.15 | 0.195 |
| Canada | 0.880 | 0.295 | 0.06 | 0.135 |
| Denmark | 0.060 | 0.025 | 0 | 0 |
| Finland | 0.150 | 0.95 | 0.005 | 0.03 |
| France | 0.545 | 1.45 | 0.005 | 0 |
| Germany | - | 0.276 | 5.44 | 2.827 |
| Italy | 4.15 | 4.35 | 0.1 | 3.48 |
| Japan | - | - | 3.4 | 0.75 |
| Korea | 1.62 | 0.016 | 0 | 0 |
| Netherlands | 1.55 | - | 0.049 | 0.045 |
| Portugal | 0.025 | 0.10 | 0 | 0 |
| Sweden | 0.265 | 0.76 | 0.015 | 0 |
| Switzerland | 0 | 2.0 | 1.292 | 2.50 |
| Turkey | 0.07 | 0 | 0 | 0 |
| United Kingdom | 0.162 | 0.006 | 0 | 0 |
| United States | - | - | 0.81 | 6.13 |
| Total | 9.5 | 10.4 | 11.3 | 16.1 |

- off-grid service applications
  Italy, Korea and the Netherlands
- off-grid residential
  Italy, Switzerland and France
- small distributed grid-connected
  Germany, Japan and Switzerland
- medium and large grid-connected
  United States, Italy, Germany, and Switzerland

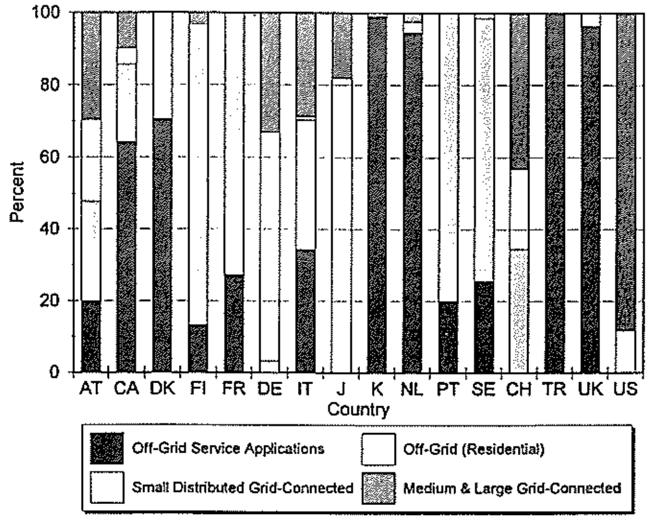
Figure 7 is a pie-chart description of the various niche markets for photovoltaic power. While this figure lacks complete data for the off-grid applications from several countries, it is included because it illustrates how interesting such an graphic would be if complete data were available. It will be interesting to see how this distribution changes in the coming years. The relatively large grid-connected percentage reflects the strength of the emerging interest in utility applications.

### Grid-connected vs. off-grid photovoltaic power system applications

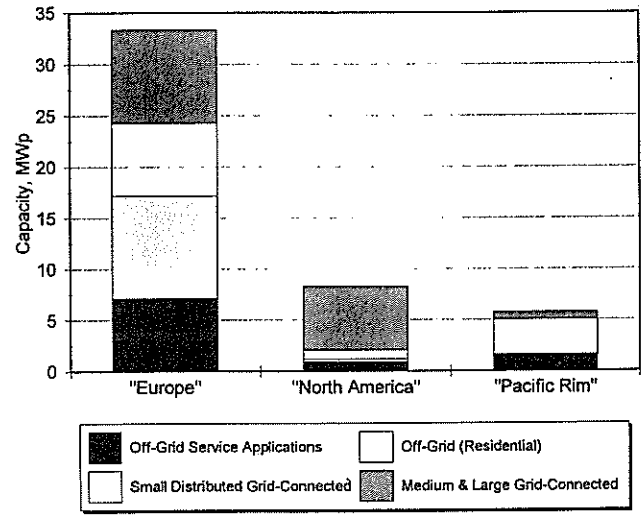
As seen in Table 4 and illustrated in Figure 8, most countries have either predominantly off-grid systems or have predominantly grid-connected systems. For example, the reported installed PV power by the end of 1993 in Denmark, Finland, France, Korea, the Netherlands, Portugal, Sweden, Turkey and the United Kingdom was from 90-100% off-grid systems. Only five countries reported to have at least 15% of their installed PV power grid-connected, with Austria, Germany, Switzerland and the United States reporting more than 50% grid-connected (most of which were subsidized). The United States has a significant off-grid PV power capacity that was not reported, making its grid-connected percentage appear too high. As Germany only reported off-grid PV power systems greater than 1 $kW_p$, its off-grid percentage is understated in Tables 3 and 4.

In many ways, off-grid vs. grid-connected can be seen as representing two different perspectives on market forces. The off-grid approach, which is a response to market forces, usually provides power for remote sites that are not easily accessible to the grid. The grid-connected approach, which only a few of the reporting countries presently favor, represents a longer-term strategy to support the development of photovoltaic power systems as part of the utility company or the energy service company's distributed or central generation business.

## FIGURE 5
## Percent Installed Power Capacity in the Four Market Sectors by the End of 1993




## FIGURES 6
## Installed Power Capacity in the Four Market Sectors by the End of 1993




## FIGURE 7
## Percent Installed Power Capacity in the Four Market Sectors by the End of 1993

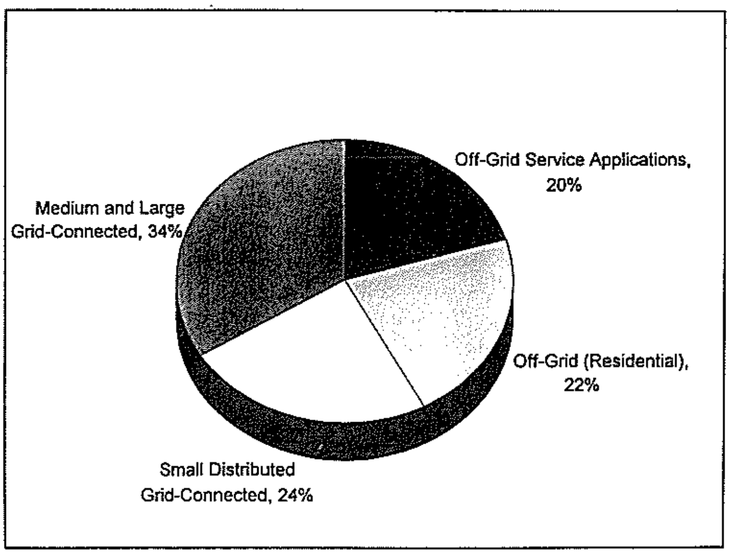


**TABLE 4**
**1993 Distribution of Reported Installed PV Power Systems. See Figure 8.**

| | Percent of Total Capacity | |
|---|---|---|
| | Grid-Connected | Off-Grid |
| Austria | 52 | 48 |
| Canada | 14 | 86 |
| Denmark | 6 | 94 |
| Finland | 3 | 97 |
| France | 1 | 99 |
| Germany | 97 | 3 |
| Italy | 30 | 70 |
| Japan | | |
| Korea | 0 | 100 |
| Netherlands | 6 | 94 |
| Portugal | 0 | 100 |
| Sweden | 1 | 99 |
| Switzerland | 66 | 34 |
| Turkey | 0 | 100 |
| United Kingdom | 0 | 100 |
| United States | 100 | 0 |

Figure 8 illustrates the degree to which each of the reporting countries is responding to these market forces. The reader should keep in mind that some countries did not report some or all of their off-grid installations.

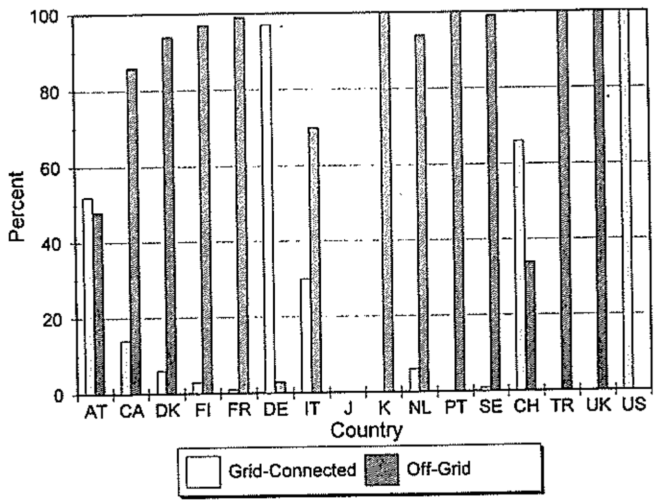
As the near-term market in most of the responding countries is off-grid applications, it is not surprising to note that most countries' photovoltaic power uses are dominated by off-grid installations; this is to be expected in the present phase of photovoltaic development where costs are high compared to power from the grid. These remote niche markets are much easier to penetrate since the alternative of long grid extensions is more expensive than photovoltaics. As costs drop and as externalities such as emissions from fossil fuel plants are accounted for in utility planning, photovoltaics will likely become more and more grid-connected. The optimal balance between grid and non-grid will reflect national strategies and market realities, but is expected to continue to evolve toward more grid-connected systems, on a $MW_p$ basis. For some countries, a high-percentage of grid-connected systems simply reflects the reality of a grid system that essentially covers the entire country.

### Interpretation

Interpretation of preferred market sectors by country is complicated by incomplete reporting as well as by the several market forces that are at work simultaneously; the desire to maximize photovoltaic exports, the needs for short term corporate profitability, government policy, and indigenous photovoltaic production capacity. The dominant force is apparently export, since exports dwarf local photovoltaic module use.

Approximately one-fourth of the annual module production (see Chapter 3) is used domestically by the reporting countries. Also, the PV companies in most of the reporting countries are producing appreciably less photovoltaics than their current maximum capabilities. Although no data was requested to confirm this, it seems safe to assume that manufacturers are seeking the most profitable markets, presumably exports. Given this over-capacity situation it appears that many manufacturers sell as many systems abroad as possible, and to as many high-value, high-cost domestic remote systems as possible. Only a few countries (the United States, Germany, Switzerland, and Austria) have mostly grid-connected systems, and Japan and Italy have a significant and apparently growing percentage of grid-connected systems. These grid-connected installations are a reflection of

**FIGURE 8**
**Percent of Total PV Power Capacity Grid-Connected and Off-Grid**




environmental concerns prompting utilities and governments to work together to evaluate PV for cleaner power generation. Government policies, subsidies, high buy-back rates, mandates, etc., also play a role.

Another interesting observation is that, with the exception of the United Kingdom, the four largest PV manufacturing countries (Germany, Italy, Japan and the United States; see Chapter 3) are also the four largest installing countries. Several factors contribute to this:

- long-term familiarity with the technology has overcome some of the hurdles to more and larger PV installations;
- favorable government policies that support both in-country installations and export; and/or
- overall high photovoltaics cost, and balance of trade problems discourage the other smaller installation countries from buying and installing more and larger photovoltaic power systems.

## Major Findings[7]

✔ The total photovoltaic power system power installed by the end of 1992 in the 16 reporting countries was slightly under 44 $MW_p$. By the end of 1993, the installed power capacity grew by about 33% to slightly over 58 $MW_p$.

✔ This growth is dominated by Japan, Italy and Germany, and to a lesser extent, by the United States, and is primarily in the grid-connected applications. The growth in Europe was primarily due to the Italian utility scale demonstration program and the German 1000-Roofs program. In 1993, Germany, Canada, Italy and Japan experienced a growth in installed PV power greater than the survey average of 33 percent.

✔ Caution must be used when comparing or averaging PV system price data presented in this report. For the reporting countries, the average turn-key price of installed PV systems varied greatly, from 6.65 $\$/W_p$ to 37.00 $\$/W_p$. The reasons for the large variation in installed system costs include, the variations in the size of the installed systems, the type of system (grid-connected or off-grid), the availability of subsidies, and the lack of common definitions and good system cost data.

✔ Italy reported the largest amount of installed PV power capacity in the off-grid service applications market sector, followed by Korea and the Netherlands. Italy, Switzerland and France have the most PV power installed in off-grid residential systems. Germany, Japan and Switzerland have the most installed PV power capacity in the small distributed grid-connected market, while the United States, Italy, Germany and Switzerland have the greatest amount of installed capacity in the medium and large grid-connected market sector.

✔ Between 90 and 100% of the installed PV power systems in Denmark, Finland, France, Korea, the Netherlands, Portugal, Sweden, Turkey and the United Kingdom are off-grid. This is to be expected as the current price of PV is still relatively high. Only five countries have more than 15% of their photovoltaic power systems grid-connected, with the United States, Austria, Germany and Switzerland having more than 50% grid-connected, most of which are subsidized.

[7] With the exception of the Introduction, each chapter closes with a "Major Findings" section in which the most important information, in the author's opinion, is extracted and repeated herein.

✓ In many ways, off-grid vs. grid-connected markets can be seen as representing two different perspectives on market forces. The off-grid approach, which is a response to market forces, usually provides cost-competitive power for remote sites that are not easily accessible to the grid. The grid-connected approach, which anticipates future market forces, and which only a few of the reporting countries presently favor, represents a longer-term strategy to support the development of photovoltaic power systems as part of the utility company or the energy service company's distributed or central generation business.

# Chapter 3

## Commercial and Prototype Photovoltaic Power Systems and Products

The purpose of this chapter is to provide an overview of the current commercial and prototype photovoltaic power system components and systems that are being used in the utility sector in the responding countries. Modules and other system components being used today for utility applications generally undergo some form of certification, but to date utilities have not issued standardized PV module specifications. In several countries, such as Italy and the United States, individual utilities have issued specifications for a single or a series of module purchases and the total system or plant. This differs, however, from utilities issuing standard module or system purchase specifications. The data presented in this chapter will define the starting situation for the analysis of key trends in the evolving commercial and prototype PV power systems market.

### Module Industry

#### Cell and module manufacture

PV module manufacturers can be divided into two broad types: module assemblers, who purchase solar cells and use them to fabricate modules, and integrated manufacturers who also manufacture the solar cells used in their modules. Manufacturers of crystalline silicon (cSi) modules fall into either or both of these two categories. However, all manufacturers of amorphous silicon (aSi) modules are integrated manufacturers because the distinction between cell and module disappears in the manufacture of amorphous silicon modules. The aSi modules are prepared by depositing layers of materials on a substrate which also serves as one side of the module encapsulation. Individual "cells" are then created by etching through layers of deposited material of the module.

Among the main module manufacturers in the reporting countries, crystalline silicon module manufacturers with production volumes greater than 1 MWp per year tend to fall into the integrated category, while almost all small producers (less than 0.5 $MW_p$ per year) are module assemblers.

Table 5 presents the silicon module manufacturers with 1993 production greater than 1 $MW_p$. These twelve companies produced almost 75% of the total production of the 37 main manufacturing companies in the reporting countries. In this table, the module manufacturers are associated with the country of ownership.

In several instances, module manufacturing facilities of companies that are owned, managed and operated in one country are located outside of that country. For the reporting countries, this is the situation for (1) Finland, which has a major manufacturing plant in France (NAPS), (2) the United Kingdom, which has major manufacturing plants in Spain and Australia (BP Solar), (3) Germany, which has a manufacturing plant in the United States (Siemens Solar Industries), and (4) the United States, which has a facility in Canada (AstroPower).

However, the guidelines established for this Survey Report require that module production be associated with the country where the plant is located. Therefore, in all of the following tables, figures and analyses, the NAPS production is included under France, some of the Siemens Solar production is included under the United States, and some of AstroPower's production is included under Canada. However, because Spain and Australia are not among the reporting countries in this survey, and because BP Solar's module production is very large, BP Solar's production is included under the United Kingdom.

Integrated manufacturers are found in countries with a national commitment to PV development, where subsidies in the form of research grants are available to the manufacturer, and/or public subsidies are available to promote demonstration projects. An in-country market also tends to exist where integrated manufacturers are found, although no cause-and-effect relationship has been demonstrated.

Table 6 presents key information about PV module production for each responding country. This table includes both cSi and aSi modules. The total number of module manufacturers is shown in the second

**TABLE 5**
**Manufacturers of Silicon Modules Whose 1993 Production Was Equal to or Greater than 1 $MW_p$**

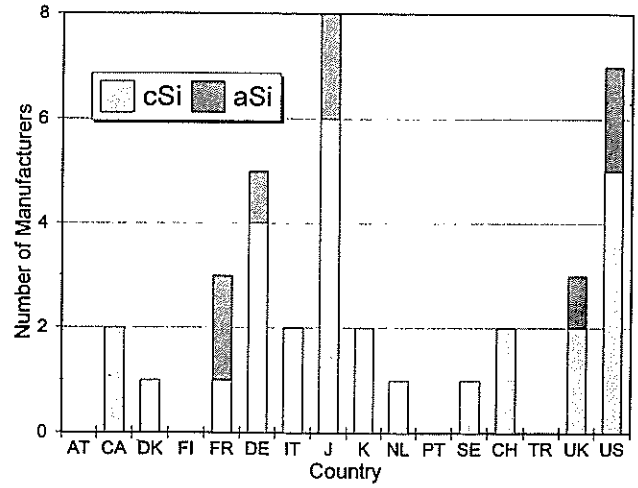
| Manufacturer | Country | 1993 Production, $MW_p$ |
|---|---|---|
| Siemens Solar Industries | Germany | 12.5[8] |
| Solarex | United States | 6.5 |
| Kyocera | Japan | 4.8 |
| BP Solar | United Kingdom | 4.5[9] |
| Eurosolare | Italy | 2.3 |
| ASE | Germany | 1.9 |
| Photowatt International SA | France | 1.5 |
| Solec International | United States | 1.3 |
| NAPS | Finland | 1.1[10] |
| Sanyo | Japan | 1.0[11] |
| Sharp | Japan | 1.0 |
| Showa Shell Sekiyu | Japan | 1.0[12] |

**TABLE 6**
**1993 Module Manufacturers by Country.** **See Figures 9-18.**

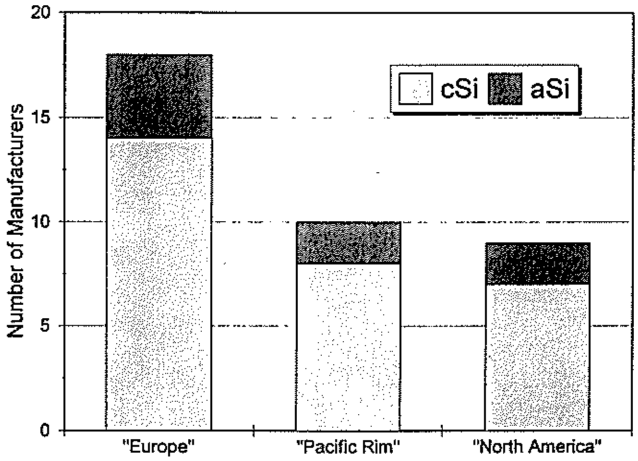
| | Module Manufacturers Number | Type | Module shipments in 1993 M$ | MWp | Module Production Capacity, $MW_p$/yr |
|---|---|---|---|---|---|
| Canada | 2 | A | 0.91 | 0.16 | 1.2 |
| Denmark | 1 | I | 2.92 | 0.4 | 3.0 |
| France | 3 (2 aSi) | A, I | 10.53 | 1.95 | 7.1 |
| Germany | 5 (1 aSi) | A, I | 24.69 | 2.77 | 5.2 |
| Italy | 2 | I | 16.48 | 3.2 | 10.5 |
| Japan | 8 (2 aSi) | A, I | 130.4 | 16.3 | 19.3 |
| Korea | 2 | A | 3.0 | 0.5 | 1.0 |
| Netherlands | 1 | I | 2.95 | 0.5 | 1.5 |
| Sweden | 1 | A | 5.01 | 0.825 | 4.5 |
| Switzerland | 2 | A | 1.34 | 0.15 | 0.5 |
| United Kingdom | 3 (1 aSi) | A, I | 33.7 | 4.535 | 5.0 |
| United States | 7 (2 aSi) | A, I | 109.8 | 20.95 | 32.8 |
| Total | 37 (8 aSi) | | 342 | 52.2 | 91.6 |

8 The 12.5 $MW_p$ were produced in the United States. Siemens Solar produced an additional 0.7 $MW_p$ in Germany.
9 While BP Solar's production is in Spain and Australia, it is listed here as a United Kingdom company.
10 NAPS is a Finnish company with its aSi module production in France.
11 Combines cSi and aSi production.
12 Module assembler rather than integrated manufacturer.

## FIGURE 9
## Module Manufacturers, 1993




## FIGURE 10
## Module Manufacturers, 1993




column of Table 6, with the number of aSi manufacturers shown in brackets. The type of module manufacturing capabilities of the PV industry in each country is indicated in Table 6 using the symbol I for integrated and A for assembler. While only modules for power applications were to be included in Table 6, Japan and the United States indicated that they could not, in some cases, distinguish between modules for power applications and those for consumer products.

Figures 9 and 10 show the number of module manufacturers, both integrated and assembler, by country and by the three regions. The reader should note that these regions are to be interpreted as "those reporting countries, which are members of the IEA Photovoltaic Power System Program and are located in 'Europe', the 'Pacific Rim' or 'North America'." Manufacturers of both crystalline silicon and amorphous silicon are shown. Figures 11 and 12 show 1993 module shipments by country and by region. "Europe" produced about 28% of the rated power of the modules, while having about 40% of the collective production capacity (see Figures 13 and 14).

The reporting countries produced many more modules than they installed in their countries. Of the 52.2 $MW_p$ produced and shipped (i.e., sold) in 1993 (see Table 6), 14.6 $MW_p$ of modules were installed in the reporting countries. Furthermore, the total of all the reporting countries' installed power systems at the end of 1993, 58.3 $MW_p$, is well below the over 400 $MW_p$ of photovoltaic modules manufactured over the last 15 years, leading to three interpretations, all of which are likely to be correct to some degree:

- many modules were used in non-power applications, which are not within the scope of this survey report
- some may be used in non-utility applications or small power applications which are difficult to account for
- exports to unsurveyed countries account for most of the eventual consumption and installation of modules

The four countries with the greatest installed PV power capacity, Germany, Italy, Japan and the United States, are also the four largest manufacturing coun-

**FIGURE 11**
**1993 Module Shipments, $MW_p$**

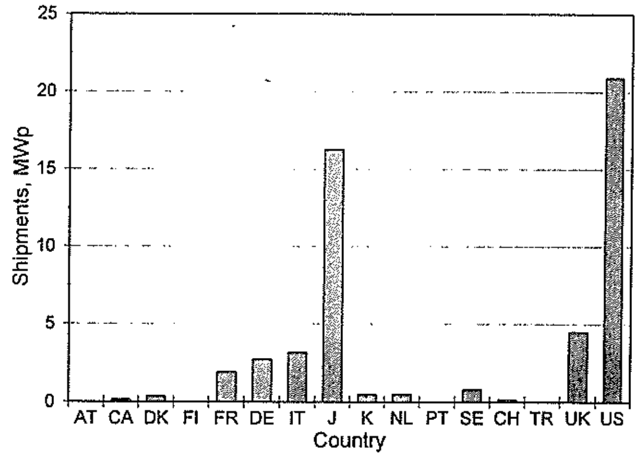
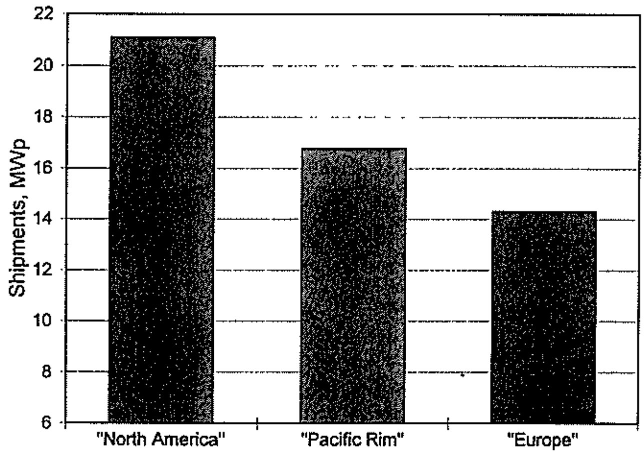



**FIGURE 12**
**1993 Module Shipments, $MW_p$**




tries, due to supportive government policies and programs, and familiarity with the grid-connection installations. The relatively high cost of photovoltaic power systems is keeping other countries from installing more and larger systems.

In 1993, module manufacturers from countries participating in this study shipped 52.2 $MW_p$ of PV modules for non-consumer product applications in 1993, which was almost all of such modules sold worldwide.6 "North America", the "Pacific Rim" and "Europe" manufactured 41%, 32% and 27% respectively of the modules shipped worldwide during 1993, and received 32%, 39% and 29% of the financial value of that module production (see Figures 15 and 16). The dominant position of "North America" and the "Pacific Rim" in module manufacturing reflects both their significant photovoltaic industries and strong national programs to foster PV research, development, and demonstration. In "Europe", France, Germany, Italy and the United Kingdom together produced 87% of the modules shipped by "European" manufacturers during 1993.

The total combined PV production capacity of all countries participating in this study is about 92 MWp/year, based on three shifts per day.

Figures 17 and 18 show the national average production capacities of countries participating in this study, indicating three very different approaches to building and using manufacturing facilities. Japan and the United Kingdom utilize 75-80% of their existing production capacity, suggesting that they operate their facilities at an average of more than two shifts/day. The United States, Germany and Korea use 50-65% of their production capacity, operating an average of just under two shifts/day, while the remaining "European" countries use a third or less of their manufacturing capacity, averaging one shift or less per day. Of course, individual companies in any reporting country may operate differently from the inferred national average. For example, the production in Germany is based on one shift per day.

[13] Based on total 1993 shipments of 52.8 MWp (not including aSi for indoor products) reported by *Photovoltaic Insider's Report*, February 1994.

**FIGURE 13**
**1993 Module Production Capacity, $MW_p$/yr**

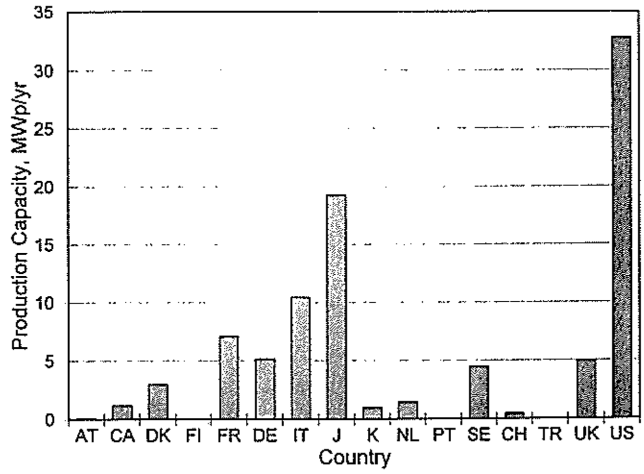
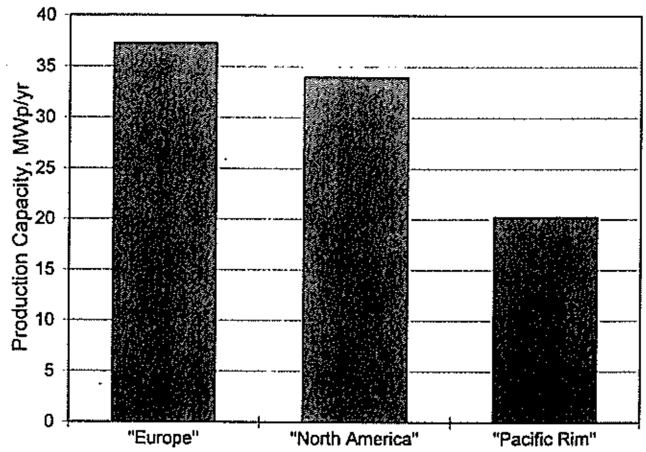



**FIGURE 14**
**1993 Module Production Capacity, $MW_p$/yr**




### Module prices

Module prices represent a significant part of photovoltaic power system prices, and therefore they are of great interest to utilities and energy service companies. While it is possible to gather module prices from the reporting countries, it is very difficult to compare them or to draw conclusions about them. Because the PV industry is still quite new, there simply is no such thing as standard module prices. System prices depend on the size of the order, the customer's specifications, the application (off-grid or grid-connected) and whether the price is based on a turn-key project or on the subsystem and component costs quoted by the primary or end distributor. Thus, module prices generally do not accurately represent production costs.

For this first survey, the participants decided to request that module prices be provided according to the size of actual purchases. The dividing line was set at 1 $kW_p$, that is, module prices were requested for actual purchases of less than 1 $kW_p$ and of more than 1 $kW_p$. While the intent of the guidelines was to provide prices paid by the end-user, without VAT, some participants provided wholesale prices.

Table 7 shows reported prices received for small (less than 1 $kW_p$) and large (more than 1 $kW_p$) module orders. This table must be viewed with caution, as the prices indicated have many different qualifications.

Some comments about the entries in Table 7 are in order. The lowest price listed, 4.10 $/$W_p$ in Italy is for a very large order from a utility company for a major system. On the other hand, the highest price listed, 18.00 $/$W_p$ in Japan, is the price paid by government subsidized PV power projects and is intended to reflect the actual manufacturing costs. However, when pricing modules for sale in the other reporting countries, the price drops to be competitive. In subsequent survey reports, the issue of how best to present module prices will be addressed and better approaches will be tried.

If it could be defined in a meaningful way, the average module price could be a very important indicator. Tracking the change of the average module price over time could provide insight into the evolv-

**FIGURE 15**
**1993 Module Shipments, M$**

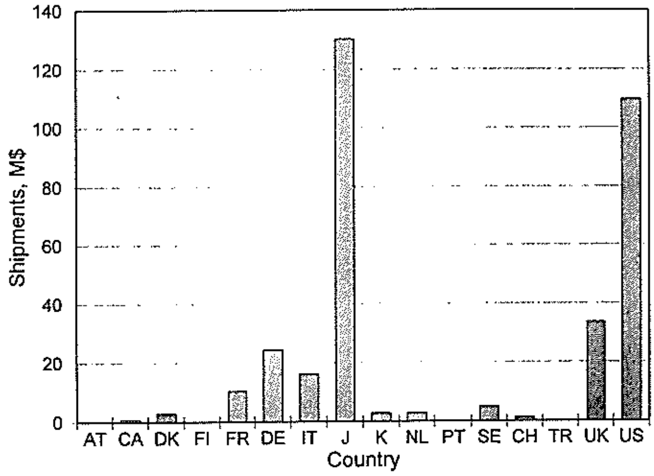



**FIGURE 16**
**1993 Module Shipments, M$**

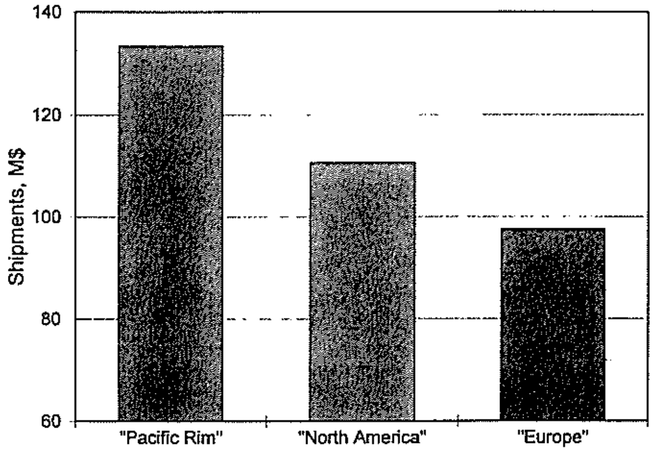



**TABLE 7**
**1993 Module Price. See Figures 19 and 20.**

| | Price for a large Module Order, $\$/W_p$ | Price for a small Module Order, $\$/W_p$ |
|---|---|---|
| Austria | 6.00 | 10.00 |
| Canada | 5.12 | 7.15 |
| Denmark | 5.28 | 9.32 |
| France | 4.60 | 10.00 |
| Germany | 5.68 | 7.79 |
| Italy | 4.10 | 5.60 |
| Japan | 8.00 | 18.00 |
| Korea | 6.00 | 7.20 |
| Netherlands | 5.90 | 7.00 |
| Sweden | 5.12 | 7.04 |
| Switzerland | 7.14 | 10.71 |
| United Kingdom | 5.00 | 5.00 |
| United States | 5.24 | 5.24 |

**FIGURE 17**
**Ratio of Shipments to Production Capacity, 1993**

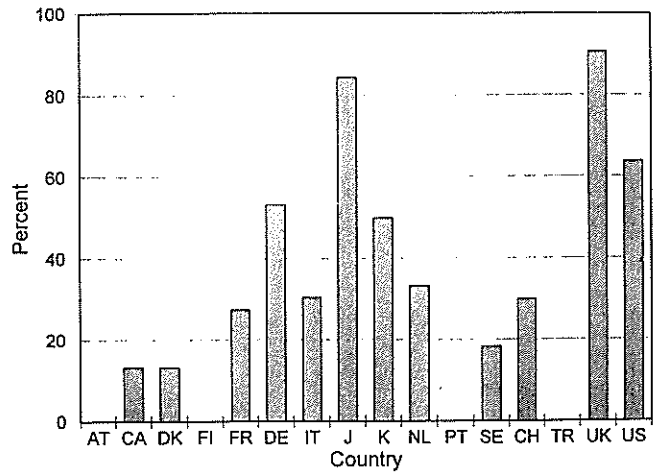
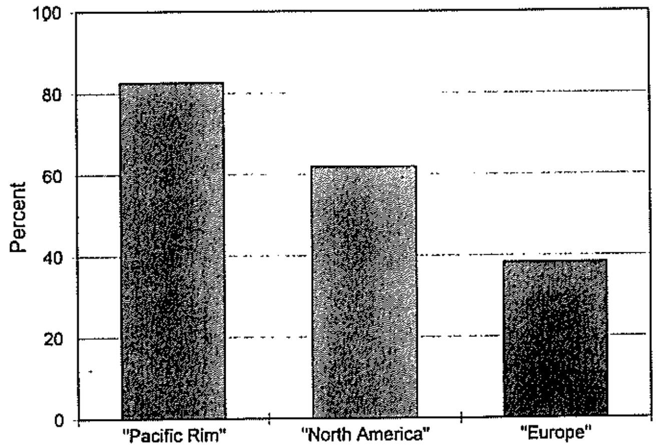



**FIGURE 18**
**Ratio of Shipments to Production Capacity, 1993**




ing economics of photovoltaic power systems. The methodology to determine this average, however, was not addressed in the guidelines, therefore the data required to arrive at a meaningful average module price was not requested. In preparing for future survey reports, a methodology for determining the average module price will be developed and the necessary data to estimate it will be requested.

Figure 19 shows each country's module price data. Figure 20 presents each reporting country's lowest reported (for orders greater than 1 $kW_p$) module price as a function of their total production capacity. Module prices decrease to 4.10 $\$/W_p$ at about 10 $MW_p$ per year. The only data points for greater production volumes are for Japan at about 20 $MW_p$ per year and the United States at about 33 $MW_p$ per year. However, both of these countries' lowest module price falls considerably above the projection of a "learning curve". As learning curves generally apply to single companies, it is likely that if the single data points for Japan and for the United States were disaggregated by major module manufacturer, their data points would fall closer to the "learning curve" suggested in Figure 9. Recent projections by the United States National Renewable Energy Laboratory are 2.70 $\$/W_p$ as a result of the intensive R&D efforts on manufacturing technologies. If the United States provides such data for the next Survey Report, their data point will fall very close to the projection of a "learning curve". As mentioned above, the export price for large orders of modules from Japanese manufacturers falls into the competitive range. Such data will be requested in the next survey.

It will be interesting to see if this "learning curve" trend continues as various countries' production capacities double or triple. A more interesting exercise would be to see how module price varies as a function of production facility output. This would be possible if each country would report an average module price from facilities producing 1 $MW_p$/year and less, from facilities producing between 1-5 $MW_p$/year, and from future facilities producing more than 5 $MW_p$/year. Data for this analysis will be gathered in subsequent surveys.

**FIGURE 19**
**1993 Module Price, $\$/W_p$**

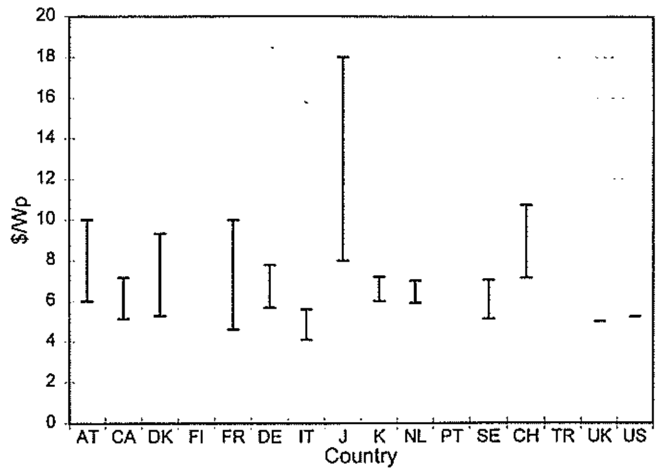
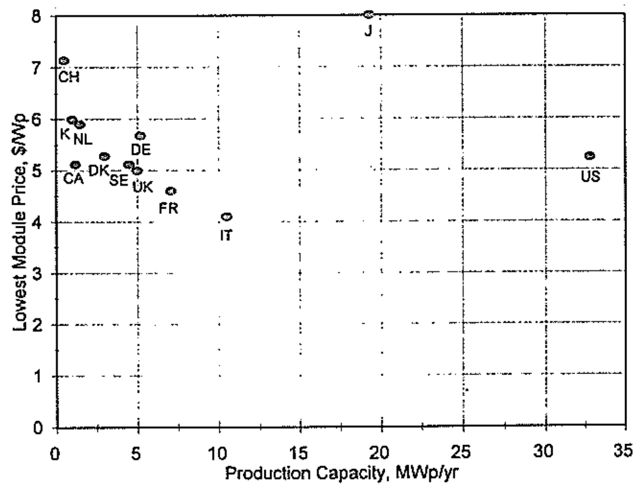



**FIGURE 20**
**Lowest 1993 Module Price vs. Country Production Capacity**




### Module imports and exports

Table 8, and Figures 21 and 22 pertain to module imports and exports. Note that production from the Finnish company NAPS, which has its factory in France, appears as export from France and import to Finland, and BP Solar's production appears as internal to the United Kingdom. Germany reported that it was unable to obtain reliable export and import data from its manufacturers.

For a given year, assuming no significant storage of modules, by adding a country's module production number to its imports, and subtracting exports, the result should be the amount of grid-connected and off-grid PV used *within the country* in that year. This is shown in Table 9.

For Austria, Canada, Denmark, Finland, France, Germany, Italy, the Netherlands, Portugal, Sweden, Switzerland and Turkey, the inferred $MW_p$ used in that country in 1993 is relatively consistent with the $MW_p$ reported to be installed in 1993. Korea reported that the 0.47 $MW_p$ were not all installed in Korea in 1993; only 0.17 $MW_p$ was installed and the remainder was kept in stock. Large inconsistencies, however, exist for the United States and Japan. For the United States, 1.46 $MW_p$ were reported installed by utilities for grid-connected applications in 1993, yet 15.55 $MW_p$ seems to have been used in the country in 1993. While no explanation for this discrepancy was offered by the United States, it is possible that some of this inconsistency can be explained by off-grid residential applications. For Japan, their national input report stated that 4.0 $MW_p$ were installed in 1993, yet the inferred use in Japan seems to be 9.26 $MW_p$. Such discrepancies will be resolved in the next survey report.

Two of the five largest producers, Germany and Italy, have appreciable internal markets for their PV modules, using essentially all that they produce. France, Sweden and the United Kingdom export nearly all of the modules they produce. Japan and the United States have both large in-country markets and large export markets. Austria, Portugal, Switzerland and Turkey import most of their PV modules.

### Comparison of the crystalline silicon and amorphous silicon industries

Tables 10 and 11 show technical characteristics of crystalline silicon (cSi) and amorphous silicon (aSi) PV modules.

## TABLE 8
## 1993 Module Imports and Exports. See Figures 21-22.

| | Modules Imported, $MW_p$ | Modules Imported, M$ | Modules Exported, $MW_p$ | Modules Exported, M$ |
|---|---|---|---|---|
| Austria | 0.12 | 0.9 | 0 | 0 |
| Canada | 0.50 | 2.35 | 0.23 | 1.26 |
| Denmark | 0.02 | 0.16 | 0.34 | |
| Finland | 0.1 | 0.50 | 0 | 0 |
| France | 0.04 | 0.2 | 1.75 | 8.0 |
| Germany | | | | |
| Italy | 1.2 | 5.6 | 0.2 | 1.0 |
| Japan | 1.96 | | 9.0 | |
| Korea | 0 | 0 | 0.03 | 0.15 |
| Netherlands | 0.2 | 1.2 | 0.2 | 1.4 |
| Portugal | 0.005 | 0.04 | 0 | 0 |
| Sweden | 0.205 | 1.25 | 0.79 | 4.80 |
| Switzerland | 0.7 | 4.00 | 0 | 0 |
| Turkey | 0.03 | 0.15 | 0 | 0 |
| United Kingdom | 0.02 | | 4.54 | |
| United States | 1.6 | | 6.986 | 42.68 |

## TABLE 9
## 1993 Module Balance in Reporting Countries. See Figures 11 and 21.

| | Modules Produced, $MW_p$ | Imports, $MW_p$ | Exports, $MW_p$ | Inferred Use in Country, $MW_p$ |
|---|---|---|---|---|
| Austria | 0 | 0.12 | 0 | 0.12 |
| Canada | 0.16 | 0.50 | 0.23 | 0.43 |
| Denmark | 0.4 | 0.02 | 0.34 | 0.08 |
| Finland | 0 | 0.1 | 0 | 0.1 |
| France | 1.95 | 0.04 | 1.75 | 0.24 |
| Germany | 2.77 | | | |
| Italy | 3.2 | 1.2 | 0.2 | 4.2 |
| Japan | 16.3 | 1.96 | 9.0 | 9.26 |
| Korea | 0.5 | 0 | 0.03 | 0.47 |
| Netherlands | 0.37 | 0.2 | 0.2 | 0.37 |
| Portugal | 0 | 0.01 | 0 | 0.01 |
| Sweden | 0.825 | 0.205 | 0.79 | 0.24 |
| Switzerland | 0.15 | 0.7 | 0 | 0.85 |
| Turkey | 0 | 0.03 | 0 | 0.03 |
| United Kingdom | 4.54 | 0.02 | 4.54 | 0.02 |
| United States | 20.95 | 1.6 | 6.99 | 15.55 |

**FIGURE 21**
**Modules Imported and Exported, 1993**

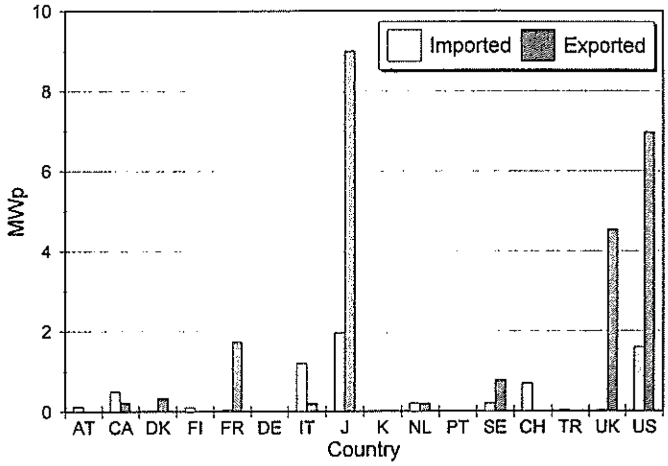
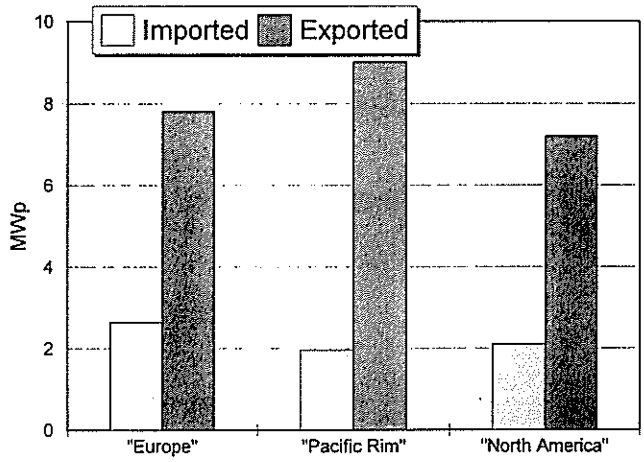



**FIGURE 22**
**Modules Imported and Exported, 1993**




Countries may have one or more module certification programs available to their module manufacturers, or those selling modules to be installed in their country. The most frequently cited source of crystalline silicon module certification is the European Joint Research Center, ISPRA. Every European reporting country cited ESTI/ISPRA 502 or 503, as did Canada and the United States. Canada, Germany and the United States also cited their own national organization(s); CSA F380 for Canada; RWE/Toledo, Kobern-Gondorf, Neurather See were cited for Germany; and the Underwriters laboratory and several other organizations for the United States. France cited NFC 57 100-IEC, and Korea cited the Korean Institute of Energy Research.

Only Germany and the United States provided certification information for amorphous silicon modules. Germany cited ESTI/ISPRA 701 and the United States cited ESTI/CFS 503.

A wide variety of sizes and voltage configurations exists in both crystalline and amorphous silicon modules from IEA countries. Because of the much larger number of manufacturers and the increased performance per unit area, the ranges are broadest among crystalline silicon modules. Crystalline silicon modules range in output from 1.5 to 300 $W_p$, and in physical size from 0.02 to 3.0 m2. Amorphous silicon modules are typically smaller, from 0.1 to 1.2 m2, with the highest output power being a 60 $W_p$ module from the United States.

Figures 23 and 24 show module output performance for crystalline silicon and amorphous silicon modules. Crystalline silicon modules from reporting countries range in output performance from 75 to 147 $W_p$/m2, with an average value of 112 $W_p$/m2. This rather large spread in module performance reflects the different efficiencies for mono- and multi-crystalline PV cells and the different packing densities attributable to round, pseudo-square and rectangular shaped solar cells. Amorphous silicon modules are much more closely grouped in output performance, ranging from 37 to 54 $W_p$/m2, with an average value of 43 $W_p$/m2. When comparing the module output performance of crystalline and amorphous silicon modules, the relatively higher cost of the crystalline silicon modules must be considered. If the market for grid-connected applications eventually begins to impact the design of PV modules, the broad range seen now in size, voltage, and output performance may change. At such time data such as in Tables 10 and 11 could be used to analyze these changes. However, for now, several observations can be made:

- the operating voltage of modules ranges from 6 to 75 volts, with 17 volts being the most common
- the most common encapsulation materials are EVA, glass, and plastic laminate
- crystalline silicon modules produce 2 to 3 times more power per unit area than amorphous silicon modules
- module warranties range from 3 to 20 years, with 10 years being quite common
- in Europe, most countries certify their modules by ESTI 503 for cSi and ESTI 701 for aSi; in the United States, manufacturers certify their modules by the above, as well as/or by Underwriters Laboratories, and by several other organizations

All 12 countries that produced PV modules shipped crystalline silicon modules. Only France, Germany, Japan, the United Kingdom and the United States reported production from manufacturers producing amorphous silicon modules for power applications. Manufacturers in these countries produced more crystalline silicon than amorphous silicon modules. The largest producer of amorphous silicon, a Japanese manufacturer, shipped about 3 $MW_p$ of modules; the largest integrated producer of crystalline silicon modules, the United States factory of a German owned company, shipped 12.5 $MW_p$; the largest crystalline silicon module assembler, a Japanese manufacturer, shipped 1 $MW_p$.

## Balance of System Components

Before presenting and analyzing the information provided by the reporting countries, it is important to point out that during the course of this first survey, it became evident that the balance of system (BOS) components and terms were not adequately defined in the guidelines. The next version of these guidelines will correct this problem.

Table 12 presents information on the inverter, battery and charge controller manufacturers, in 1993, for each reporting country and the three regions. Table 13 presents the number of major PV system suppliers reported by each country. It is obviously important to distinguish between manufacturers, as opposed to suppliers or distributors. The intent was to identify manufacturers of BOS components in each reporting country. Both Table 12 and Table 13

**TABLE 10**
**Typical Crystalline Silicon PV Module Technical Characteristics**

| | Typical Module Output Range, $W_p$ | Module Size Range, m² | Operating Voltage Range, Vdc | Encapsulation | Warranty, number of years |
|---|---|---|---|---|---|
| Canada | 1.5-100 | 0.02-0.84 | 7.4-34.8 | Glass/EVA/Tedlar<br>Tefzel/EVA/Tedlar | 5-12 |
| Denmark | 72 | 0.62 | | Glass/EVA/Glass | 10 |
| Finland | 50 | | 15 | EVA/Plastic | Variable |
| France | 48-52 | 0.46 | 16 | Glass/EVA/Glass | 10 |
| Germany | 5-300 | 0.05-3.0 | 14.5-74.8 | Glass/EVA/Glass<br>Glass/Resin/Glass | 5-20 |
| Italy | 46-100 | 0.42-0.97 | 17 | Glass/EVA/Glass<br>Glass/EVA/Tedlar | 10 |
| Japan | 48-56 | 0.41-0.44 | 17 | Glass/EVA/Tedlar | data not available |
| Korea | 43-63 | 0.43 | 17.4 | EVA/Glass | 3-10 |
| Netherlands | 50 | 0.48 | 16.5 | Glass/EVA/Tedlar | 10 |
| Sweden | 55-110 | 0.43-0.79 | 17-34 | Glass/EVA/Tedlar | 10 |
| Switzerland | 1.5-300 | 0.02-2.21 | 20-90 | Laminated, PMMA | 5-10 |
| United Kingdom | 6-85 | 0.08-0.63 | 6-22 | Glass/EVA/Tedlar | Variable |
| United States | 37.5-285 | 0.36-2.43 | 6-24 and other | EVA | 5-20 |

**TABLE 11**
**Typical Amorphous Silicon PV Module Technical Characteristics**

| | Typical Module Output Range, $W_p$ | Module Size Range, $m^2$ | Operating Voltage Range, Vdc | Encapsulation | Warranty, number of years |
|---|---|---|---|---|---|
| France | 4-12 | 0.10-0.29 | 6-12 | 2-glass laminated Glass/EVA/Glass | 5-10 |
| Germany | 25-29 | 0.6 | 68 | Glass/EVA | 10 |
| Japan | 18-25 | 0.46-0.56 | 10-15 | | |
| United Kingdom | 3.7-11 | 0.1-0.29 | 12 | Glass/Glass | 6 |
| United States | 22-60 | 0.41-1.22 | 6-24 and other | EVA | 10-12 |

**FIGURE 23**
**cSi Module Peak Output Performance**

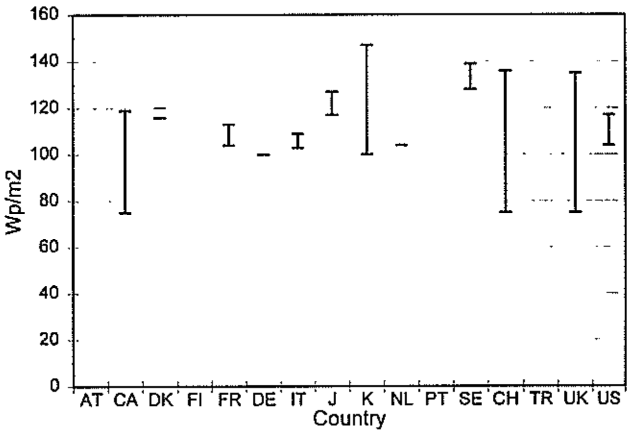
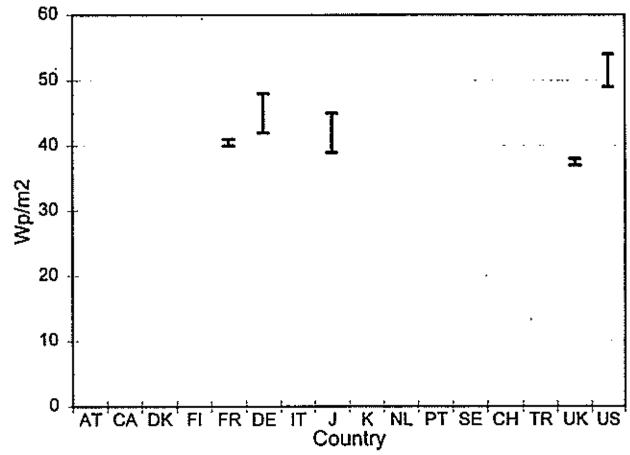



**FIGURE 24**
**aSi Module Peak Output Performance**




present price information based on specific purchases for these BOS components and the price range of turn-key systems.

A specialized industry exists today manufacturing PV system components including off-grid and grid-interconnect dc-to-ac inverters and battery charge controllers. No PV-specialized industry exists for dc switchgear, as such products are readily available. A few battery manufacturers carry a line of batteries specifically designed for PV use. However, the PV market for batteries is generally a very small percentage of any manufacturer's sales, so little pressure has been put on manufacturers to design PV-specific batteries. PV system suppliers generally use batteries already on the market. Lead-acid, deep discharge, gel cell sealed, and industrial quality chloride batteries are all suitable for PV applications.

Twelve of the 16 reporting countries reported having two or more battery manufacturers.

In many countries, charge controllers are most commonly built by the system supplier, and everywhere PV array support structures are most commonly built by the system installer. Very few companies sell packaged support structures. In Switzerland, there are seven manufacturers of support structures, but they only do custom work.

### BOS Component Manufacturers and System Suppliers

Figures 25 and 26 show the number of inverter, battery and charge controller manufacturers reported by each country in 1993. Figures 27 and 28 show the number of PV system suppliers reported by each country in 1993.

All countries with substantial in-country use of PV have system suppliers, inverter and charge controller manufacturers. However, several countries with relatively small in-country markets also have a BOS industry and system suppliers. For example, Finland, with a 100 $kW_p$/year internal market, has nine system supply companies, one inverter manufacturer, and four manufacturers of PV charge controllers. France, with around 200 $kW_p$ of PV modules installed yearly in-country, has 10 companies that supply PV systems within France and abroad. Five of these companies manufacture their own charge controllers.

Having a PV systems industry does not depend on in-country manufacture of PV modules. Canada and the Netherlands, whose 1993 module output and in-country use was equal to or less than 0.5 $MW_p$ per year, each have more than 15 system suppliers. A strong government program to encourage PV use can result in a non-module manufacturing country to have a strong BOS and system supplier industry. Austria, with no internal manufacture of PV modules, has one inverter manufacturer and 21 system suppliers.

Information provided in the national input reports on dc switchgear and support structure manufacturers did not lend itself to tabulation. Because switchgear is not manufactured specifically for the PV industry, and because it is readily available, many countries chose not to report data on switchgear manufacturers. One country, Austria, indicated dc switchgear is available at 0.15-0.45 $/$W_p$ for bus voltage. Likewise, little information was reported on support structure manufacturers because most array support structures are built by the system installers instead of purchased from specific manufacturers. Costs reported for array support structures ranged from 0.35-1.90 $/$W_p$.

Germany, Italy and Switzerland combined have 82% of the inverter manufacturers reported by participating countries. This can be attributed to a strong emphasis on roof-top and off-grid system demonstrations by the government and plant owners in these three countries.

The PV system supplier industry is comparatively robust, with 197 major system supply companies identified in the reporting countries. The dispersed nature of the off-grid system market is presumed to be responsible for the large number of primarily small companies that supply PV systems. Nearly every PV module dealer is a system supplier and hundreds of such exist in Canada, Germany and the United States. The Task participants from those countries therefore made some decisions to arrive at their numbers of 22, 31 and 15 respectively.

Packaged PV systems exist for a few specific off-grid service applications. Vaccine refrigeration, outdoor lighting, utility line sectionalizing switches, and navigation aids are examples. Even within such categories, however, system variations are common. Most PV power systems are still custom-designed.

### BOS component prices

The situation for the prices of BOS components is almost as complex as it is for module prices. For that reason caution must be used when comparing any of the prices provided for the main BOS components by the reporting countries. While the guidelines for this report requested information that distinguished between inverters designed for grid-connection applications and for off-grid applications, or between low-power and high-power applications, the tables and figures showing inverter prices do not carry those details. The same is true for batteries and charge controllers, that is, the tables and figures showing those prices do not carry the necessary details to allow comparisons to be properly made. These details are presented in the national input reports listed in Appendix D.

Prices of charge controllers generally increase as more high quality electronic components and microprocessors are used. These controllers also provide more functions, such as remote control, forced charge, programmable levels of charge, etc.

Figures 29-31 show the prices paid for specific purchases of BOS equipment. Figure 29 presents the reported inverter prices for eight countries, ranging from 0.22 to 2.96 $/VA. The relatively high prices of the top of the range inverters in Germany and Switzerland probably coincide either with the relatively low rated power (1.5-3 kW), high-technology products or low production volumes. Italy, on the other hand, reported the lowest inverter prices, perhaps due to a combination of higher rated power

## TABLE 12
**Number of Inverter, Battery and Charge Control Manufacturers and Price for Specific Purchases in 1993. See Figures 25, 26 and 29-31.**

| | Inverter Manufacturers | Inverter Price, US$/VA | Battery Manufacturers | Battery Price, $/kWh | Charge Controller Manufacturers | Controller Price, $/$W_p$ |
|---|---|---|---|---|---|---|
| Austria | 1 | 1.00 | 3 | 150-500 | 1 | 0.60 |
| Canada | 2 | 0.35-0.73 | 2 | 75-200 | 2 | 0.30-0.65 |
| Denmark | | | 0 | | 1 | 1.28 |
| Finland | 1 | | 0 | | 4 | |
| France | 0 | | 4 | 100-200 | 5 | 0.30-1.60 |
| Germany | 11 | 0.73-2.96 | 8 | 90-1350 | 8 | 0.22-2.84 |
| Italy | 9 | 0.22-0.63 | 4 | 80-220 | 3 | 0.31-1.19 |
| Japan | 6 | | 3 | | 1 | |
| Korea | 3 | 0.53-0.73 | 4 | 100-122 | 3 | 0.35-0.48 |
| Netherlands | 4 | 0.80-1.20 | 0 | | 5 | 0.60-0.86 |
| Portugal | 0 | - | 2 | 90-250 | 0 | - |
| Sweden | 0 | - | 3 | 141-967 | 2 | 0.21-0.85 |
| Switzerland | 7 | 0.68-1.93 | 5 | 214-827 | 6 | 1.44-3.35 |
| Turkey | 0 | | 0 | | 0 | |
| United Kingdom | 0 | | 3 | 110-260 | 3 | 0.53-1.52 |
| United States | 4 | 0.75-1.50 | 7 | 34-518 | 15 | 0.15-3.75 |
| Total/Range | 48 | 0.22-2.96 | 48 | 34-1350 | 59 | 0.15-3.35 |

## TABLE 13
**Companies Marketing PV Systems. See Figures 27, 28 and 32.**

| | Number of Companies Marketing Off-Grid, Grid-Connected, or Specialized Systems | Turn-Key System PriceRange, $/$W_p$ |
|---|---|---|
| Austria | 21 | 13.60-22.00 |
| Canada | 22 | 7.75-22.00 |
| Denmark | 1 | 16.40 |
| Finland | 9 | 17.00 |
| France | 10 | 30.00-44.00 |
| Germany | 31 | 8.20-35.00 |
| Italy | 7 | 8.75-21.90 |
| Japan | 22 | 18.00-40.00 |
| Korea | 3 | 12.50-18.75 |
| Netherlands | 16 | 10.80-13.00 |
| Portugal | 8 | 14.65-17.55 |
| Sweden | 4 | 8.60-16.70 |
| Switzerland | 15 | 9.50-21.85 |
| United Kingdom | 13 | 5.55-22.75 |
| United States | 15 | 7.70-12.34 |
| Total/Range | 197 | 5.55-44.00 |

**FIGURES 25**
**Inverter, Battery and Charge Controller Manufacturers, 1993**

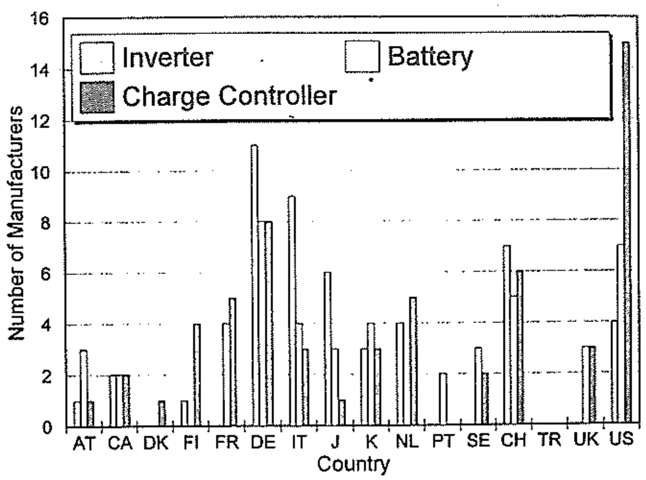
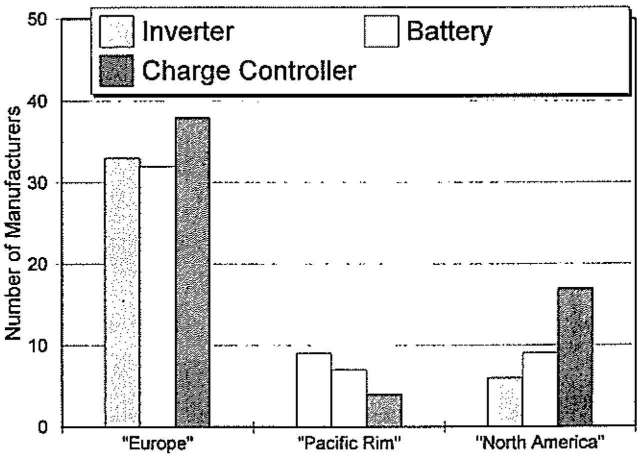



**FIGURE 26**
**Inverter, Battery and Charge Controller Manufacturers, 1993**




(100-300 kW) using less expensive thyristor technology, as well as pressure from ENEL to reduce BOS costs. Also, a wide range of power qualities and safety features are available in inverters today, contributing to a fairly wide range of prices.

Figure 30 shows prices for specific battery purchases. Eleven countries submitted data. The high end of the range reported in Germany of nearly 1,400 \$/kWh is for a lead-acid VRLA sealed battery. The low end of the price ranges for several countries is just under 100 \$/kWh. The very large spread in prices for battery charge controllers shown in Figure 31 is caused primarily by a wide variation in the complexity and functions of different charge controllers on the market.

### PV system prices

Figure 32 shows the range of turn-key photovoltaic power system prices. System prices depend on the type of photovoltaic power system and application. As the guidelines did not define what was to be included in the system price, it was generally assumed that the turnkey price does not include costs such as purchasing land, preparing the site (fencing, grading, gravel, etc.), installing any grid interconnection equipment other than the inverter, or obtaining required permits. However, the prices quoted by Italy and Japan include the transformer and the grid-interconnection equipment.

If the range of turn-key system prices shown in Table 13 for each of the reporting countries is compared to the average turn-key system price for that country (shown in Table 2), one would expect the average to fall within that range. Where that does not occur, as for the Netherlands, questions may be raised about the data or how it was interpreted by the Survey Report author.

The data from Germany illustrate the dependency of turn-key system price on system type. The lower system price of 8.20 \$/$W_p$ is for a high-power grid-connected photovoltaic power system while the higher system price of 35.00 \$/$W_p$ is for an off-grid photovoltaic power system with an auxiliary generator. Low-power grid-connected photovoltaic power system prices are 9.80-12.50 \$/$W_p$ and typical off-grid photovoltaic power systems are 12.20-13.20 \$/$W_p$. The turn-key system price data from the United States are for grid-connected photovoltaic power systems only.

**FIGURE 27**
**Off-Grid, Grid-Connected and Specialized PV System Suppliers**

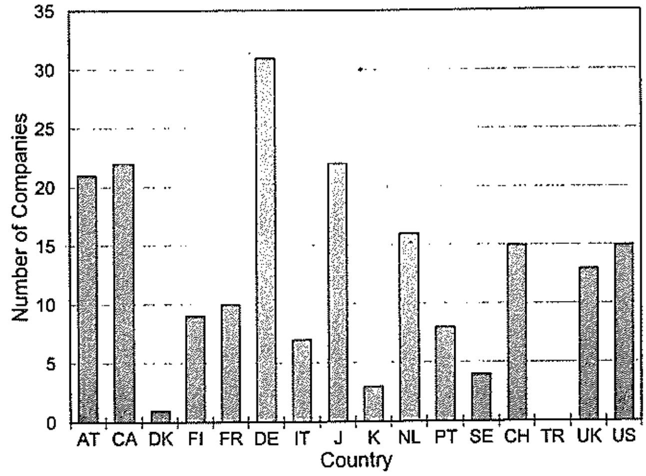
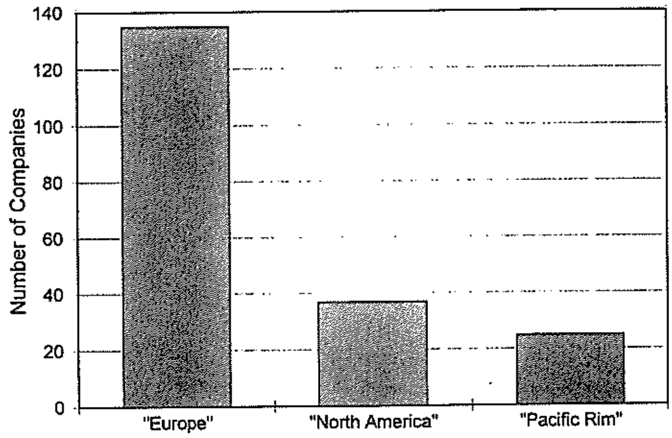



**FIGURE 28**
**Off-Grid, Grid-Connected and Specialized PV System Suppliers**




## Photovoltaic Power System Products as of 1993

### Crystalline silicon modules

Mono-crystalline and multi-crystalline silicon modules are the most common in the reported PV power systems. Power modules most commonly range in size from 1/3 to 2/3 m² and are rated from 48-100 $W_p$. Three manufacturers (in Germany, Switzerland and the United States) make larger (2-3 m²), higher output (300 $W_p$) modules for utility demonstration and field test projects. Crystalline silicon modules typically produce 100-125 $W_p/m^2$.

Nearly all modules sold today are designed to have an operating voltage high enough to charge 12 volt batteries, and this is reflected in Tables 10 and 11. Sweden, Canada and Switzerland reported operating voltages as high as 34, 35 and 90 volts, respectively, representing modules with voltages high enough to charge 12 and 24 volt batteries.

Crystalline silicon modules from the reporting countries are encapsulated using EVA and glass, EVA and plastic, EVA and glass and Tedlar, or acrylic. It will be interesting to see if the yellowing of EVA over time, first noticed at the Carrisa Plains photovoltaic power system in the United States during the late 1980s, results in some new encapsulation materials appearing over the next several years.

A variety of certification standards are used by various manufacturers of crystalline silicon modules. Most modules from "Europe", and some from other countries, are certified by the European Joint Research Centre, ISPRA, to their specification 503, which is based on IEC 1215. Some United States manufactures use Underwriters Lab, Factory Materials, and IQT specifications.

### Amorphous silicon modules

Amorphous silicon modules generally range from 1/10-1/2 m², with corresponding output power of 3-60 $W_p$. The performance of commercial amorphous silicon modules ranges from 37-54 $W_p/m^2$. These modules, like crystalline silicon modules, are configured to have an operating voltage sufficient for charging 12 volt or, less frequently, 24 volt batteries. Encapsulation materials for amorphous silicon are more broad-ranging than for crystalline modules, primarily because the amorphous materials are deposited directly onto a substrate or superstrate. The sub-

**FIGURE 29**
**1993 Prices for Inverters with Various Technologies, $/VA**

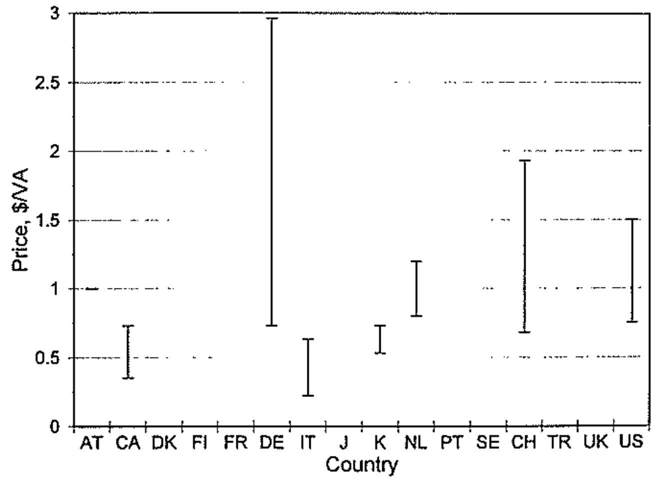



**FIGURE 30**
**1993 Prices for Batteries with Various Technologies, $/kWh**

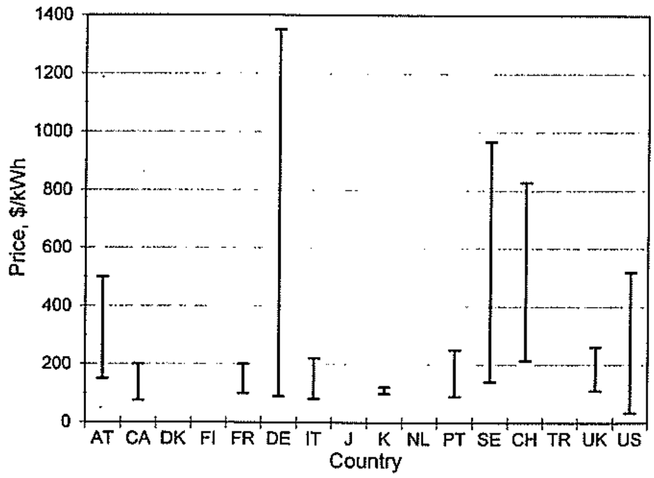
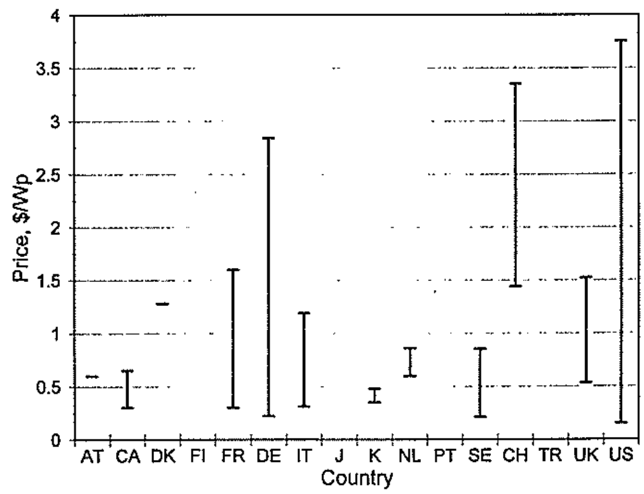



**FIGURE 31**
**1993 Prices for Battery Charge Controllers with Various Technologies, $/$W_p$**

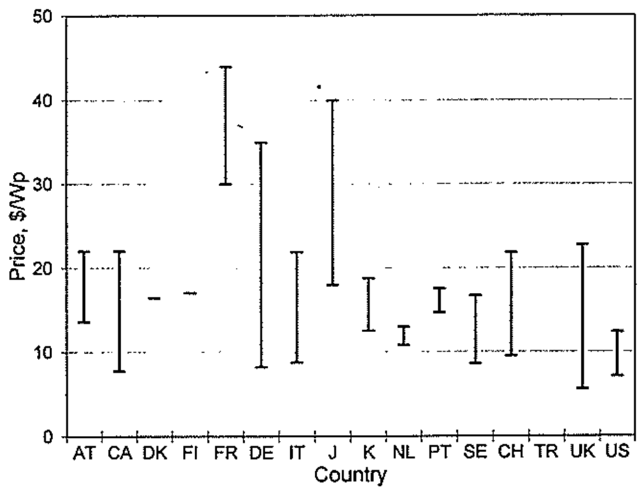



strate or superstrate material is often used to form one side of the module's outside surface. Glass, stainless steel, and plastic are all used as substrate materials for amorphous silicon. Glass and EVA are commonly used to complete the encapsulation.

### Inverters

Most PV installations worldwide are battery-charging applications, and do not use dc-to-ac inverters. However, most of the photovoltaic power systems installed in the reporting countries are either grid-connected with an inverter, or power remote homes, usually with an inverter. The inverters manufactured in the reporting countries are designed to be either connected to the utility grid or to operate as part of an off-grid system that includes batteries and often a gasoline, diesel, or propane-powered generator.

**FIGURE 32**
**Turn-key System Price Range, $/W$_p$**




Grid-connected inverters can be line-commutated, or self-commutated, while off-grid inverters are self-commutated. Switching components in today's inverters include IGBTs, GTOs, SCRs, Thyristors, power MOSFETs, MOSFET/IGBTs. Power factors range from 0.8 to 1, and harmonic content ranges from less than 3% up to 30%. Efficiencies are typically 85-96% at rated power, with grid-connected inverters 88-96% efficient. Inverters designed for the remote power market are commonly in the 200-1500 VA range, but can be as large as in the 40 kVA unit at Italy's Volcano demonstration project, and as small as an 80 VA unit from Finland used to power TV sets for remote homes. Grid-connected inverters are most commonly sized in the 0.4-9 kVA range, but are built in small quantities in larger sizes, up to 1 MVA. Single-phase, two-phase and three-phase inverters were reported, with most manufacturers building only single-phase inverters. Inverter output voltages include 100, 120, 200, 208, 240, and 400 volts.

Grid-connected inverters built in the reporting countries typically have under- and over-voltage protection, and under- and over-frequency protection, whereby the inverter automatically shuts down and disconnects from the utility grid when utility line voltage or frequency go out of specified limits.

### Batteries

Batteries used with PV systems in the reporting countries included 2, 4, 6, 8, 12, and 24 volt units, with 2, 6, 12 and 24 volts being the most common. Most of the batteries reported are deep discharge varieties, a few of which have special thicker plates built in to increase cycle life when used with PV charging systems. Sealed PbCa with gelled electrolyte, sealed lead-acid with gelled electrolyte with and without antimony, flooded lead-acid with and without antimony, and NiCd batteries were mentioned specifically by various countries. Sealed cell lead-acid batteries are commonly used for photovoltaic power systems of 5 kW$_p$ and higher. Capacities of batteries described included 130 to 12,000 Ah for 2V batteries, and 35 to 260 Ah for 12V batteries.

### Charge controllers

Battery charge controllers perform the basic function of controlling how the battery is charged, either by limiting the current, or by holding the voltage constant. Almost all chargers also protect the battery from being discharged too deeply. Charge controllers come in 12V, 24V, 36V, and 48V versions, with current capacities ranging from 3 A to 240 A. Battery protection is achieved through a load-disconnect feature, or through shunt-type regulation.

A great number of other features can also be built into charge controllers to increase battery protection and enhance PV system operation. Charge controllers described in the country reports have one or more of the following features: maximum-power tracking, temperature compensation for charging voltage, low-voltage disconnect, automatic sub-array switching, separate controls for multiple load circuits, automatic equalizing following deep discharge, timer-controlled equalizing, different adjustments for charging sealed or vented batteries, dynamic battery discharge voltage depending on discharge rate, state-of-charge indicator, automatic load turn-on and -off depending on irradiance level and timer or IR sensor input.

Individual companies offer: an integrated charge controller with data acquisition/system monitoring and programmable and/or remote control system; a controller integrated into the PV module junction box; an "ac battery" packaged inverter, batteries and charge controller; charge controller built into a medical refrigeration unit, and a charge controller built into a dc-to-ac inverter.

### Systems

A wide range of PV systems are available from system suppliers in all but one country surveyed. Of the 197 system suppliers described in country reports, 60% supply systems for remote homes or vacation cottages, 61% supply service (non-residential) power systems (for applications such as telecommunications, navigational aids, water pumping, cathodic protection, utility line sectionalizing switches, outdoor lighting, etc.), and 30% supply grid-connected systems. Of the grid-connected system suppliers, nearly half were located in four countries: Germany, Japan, Canada and Austria. For Japan, 14 of the 22 system suppliers listed in the Japanese input report seemed to be involved in service, remote residential and grid-connected applications, and the rest of them involved only in grid-connected applications. It appeared that 50% are involved in the export of service and remote residential systems.

A wide range of system configurations are represented by the systems available commercially. Packaged systems are the exception; most PV systems sold are custom designed, although the designs are often quite similar. Italy has, however, developed a standard 100 $kW_p$ power plant, called the Photovoltaic Low-cost Utility Generator, or PLUG, which, due to its size, can be used both as a single power system or the modular unit for a larger power system. The PLUG design incorporates several innovative features, such as the systematic use of factory pre-assembled components and subsystems, or the use of simple support structures. Such characteristics, along with the advantages that come with a standard design, allow significant reductions in plant construction, operation and maintenance. It is anticipated that more of such packaged or standardized systems will be seen in the next surveys.

The service applications, on the other hand, usually involve a single supplier packaging a specific product, such as a vaccine refrigeration unit with built-in PV/battery system, outdoor lights, navigation warning lights, recreational vehicle retrofit systems, or any other very-small-power application with wide market appeal.

A de facto standard exists for system voltages in off-grid systems, since these systems almost always depend on the charging of some number of 12 or 24 volt batteries. Systems are most commonly 12 volts, although as system size increases above a few hundred watts, 24, 36 and 48 volt configurations are seen.

Although utilities have been involved in several countries in planning, designing, constructing, and/or approving designs for grid-connected demonstration systems, no standards are yet in place describing appropriate systems for utilities. However, safety features of inverters interconnected to the utility are spelled out in many cases by individual utilities.

The wide range of system prices noted in Table 13 is primarily due to the different system configurations associated with the photovoltaic power system concept. High-power, comparatively large grid-connected PV systems are the least expensive in terms of $/$W_p$, benefiting from quantity prices. Small grid-connected systems are almost as inexpensive, benefiting from simplicity of required components and from the economies of mass production. Small, packaged off-grid systems are higher in price, reflecting the need for battery storage and higher marketing costs. Custom-designed off-grid PV-hybrid systems include battery storage, back-up generator, sometimes elaborate controls, and often some amount of customer education. The "turnkey" price of such a system may also include transportation to, and installation at, very remote sites.

## Major Findings

✔ There are 37 module manufacturers in 12 of the 16 reporting countries, who shipped a total of 52.2 $MW_p$ in 1993. This was almost all of the world's total module shipments for non-consumer product power applications. These 37 companies have a combined potential (using three shifts) production capacity estimated to be almost 92 $MW_p$.

✔ All 12 countries that have module manufacturers produced crystalline silicon modules. France, Germany, Japan, the United Kingdom and the United States also have module manufacturers who shipped amorphous silicon modules for non-consumer product power applications. Eight of the 37 companies produced amorphous silicon modules, while 29 produced mono- or multi-crystalline silicon modules.

✔ Module manufacturers in the "Pacific Rim" and "North America" operate their facilities around two-shifts per day, while those in "Europe" average one shift per day or less.

✔ Twelve companies each produced at least 1 $MW_p$ of modules in 1993. Together these 12 companies have a production volume of about 39 $MW_p$/yr, which is about 75% of the total production volume of the 16 reporting countries. The majority of these companies are integrated module manufacturers producing crystalline silicon modules.

✔ Crystalline silicon module manufacturers with production capacity greater than 1 $MW_p$ tend to produce and/or process both cells and modules and are therefore designated as "integrated" manufacturers. The largest integrated manufacturer of crystalline silicon modules shipped 12.5 $MW_p$ in 1993. The largest assembler of crystalline silicon modules shipped 1 $MW_p$ in 1993. Because of the way amorphous silicon modules are produced, all manufacturers of such modules are integrated, with the largest manufacturer shipping 3 $MW_p$ in 1993.

✔ Module prices represent a significant portion of photovoltaic power system prices, and as such, are of great interest to utilities and energy service companies. While it is possible to gather module price data from the reporting countries, it is very difficult to compare them or to draw conclusions about them. Because the PV industry is still quite new, there simply is no such thing as standard module prices. Module prices depend on the size of the order, the customer's specifications, the application (off-grid or grid-connected) and whether the price is based on a turn-key project or on the sub-system and components quoted by the primary or end distributor.

✔ In this first survey, the lowest module price reported for large orders was 4.10 $/W_p$ and the highest was 8.00 $/W_p$. The lowest price, 4.10 $/W_p$, was for a very large order from the national utility company for a 3.3 $MW_p$ major system in Italy. On the other hand, the highest price listed, 8.00 $/W_p$ in Japan, is the price paid by government-subsidized PV power projects and is intended to reflect actual manufacturing costs.

✔ It seems that as a country's module production capacity rises, the price of modules produced by its manufacturers decreases, following the classical "learning curve". Module prices decrease to 4.10 $/W_p$ at about 10 $MW_p$ per year production volume. The only data points for large production volumes are for Japan at about 20 $MW_p$ per year and the United States at about 33 $MW_p$ per year. However, for both of these countries, their lowest module price is considerably above the projection of this trend.

✔ In spite of government subsidies and targets for photovoltaic power system installations, module manufacturers can not sell all that they would produce if operating at full capacity. It appears that, in some countries, the present strategy is to export as much as possible and sell the rest to high-value (subsidized) domestic demonstration programs. The data provided indicate that the 1993 module production was about four times larger than what was installed in 1993 in the reporting countries.

✔ Crystalline silicon modules range in output from 1.5 $W_p$ to 300 $W_p$, and in physical size from 0.02 $m^2$ to 3.0 $m^2$. Amorphous silicon modules are typically smaller, with the largest output being 60 $W_p$. Crystalline silicon modules produce 2-3 times more power per unit area than do amorphous silicon modules. The operating voltage of the modules being produced today generally range from 10-34 volts, sufficient to charge batteries. Higher voltages are now also available.

✔ The most commonly used modules for photovoltaic power system applications are mono-crystalline and multi-crystalline silicon modules. The most common power modules range in size from 0.36-0.87 m2 and are rated at 37-110 $W_p$. Three manufacturers out of a total of 27 make larger modules for utility applications. With few exceptions, standardized utility specifications for modules do not yet exist.

✔ A specialized industry exists today that manufactures PV system components including off-grid and grid-connected dc-to-ac inverters and battery charge controllers. The inverters manufactured in the responding countries are designed to be connected to the grid or to be operated as part of an off-grid system with batteries. The most common batteries used in photovoltaic power systems are 2, 6, 12 and 24 volts, lead-acid type and most are deep discharge varieties. Many battery charge controllers incorporate other features to increase battery protection and enhance the PV system operation. These include maximum-power tracking, temperature compensation, etc. Most module array support structures are custom designed by the system installer.

✔ All countries with substantial in-country installations have system suppliers and PV inverter and charge controller manufacturers. The inverse is also found; several countries with relatively small in-country markets, such as France and Finland, also have a BOS industry.

✔ The photovoltaic power systems available today come in a wide variety of system configurations, most of which are custom designed. Utility defined specifications have been developed for specific projects, but have not been standardized for various photovoltaic power system applications. The noteworthy exception is Italy's Photovoltaic Low-cost Utility Generator (PLUG) which incorporates factory pre-assembly of components and sub-systems, and simple support structures. However, both off-grid and grid-connected systems must conform to a large set of system and plant specifications, regulations and standards, such as safety.

✓ The data from Germany illustrate the dependency of system price on system type and size. The lower system price of 8.13 $\$/W_p$ was for a standard high power grid-connected photovoltaic power system while the highest system price of 48.90 $\$/W_p$ was for an off-grid photovoltaic power system with an auxiliary generator. Low power grid-connected photovoltaic power system prices are 9.80-12.50 $\$/W_p$ and standardized off-grid photovoltaic power systems are 12.20-13.10 $\$/W_p$.

# CHAPTER 4

## Demonstration and Field Tests

Chapter 2 provided information about the PV power market and business as of the end of 1993. The installed systems were described and associated with four market sector applications:

- off-grid service
- off-grid residential
- small distributed grid-connected
- medium and large grid-connected

The specific PV power systems that were addressed in Chapter 2 included commercial systems, subsidized commercial systems, demonstration systems and field test systems. The following definitions were used in this report for these four terms:

**Commercial systems** are those that are cost-effective today to meet a specific need and are purchased by a user without subsidies.

**Subsidized commercial systems** are on the market as any other commercial product but require a subsidy in order to be accepted by the customer.

**Demonstration systems** are designed and operated to show that a particular PV system is either a potentially cost-effective option for utility or energy service applications (cost-effectiveness demonstration) or to show what can be done from a technological point of view and the potential (technology demonstration). The objective of both types of demonstrations is to encourage utility or energy service companies to adopt this technology. Frequently these demonstrations involve systems with unique designs, complicated procurement processes, etc. Instrumentation and analysis is a common aspect of demonstrations.

**Field test systems** or pilot projects are designed and operated as part of an R&D program to verify some aspect of system performance. The cost of these systems are often quite high as their purpose is further performance improvement or cost reduction, etc. They are frequently highly instrumented to be able to address specific scientific or engineering issues.

As these four types of systems reflect the development process from R&D to the marketplace, there should be a relationship between the four market sectors and these four system types. Based on the information in Chapter 2, it would be reasonable to expect to find the commercial systems primarily in the off-grid service applications and off-grid residential sectors, and to find the grid-connected applications to involve a large number of demonstration and field test systems. As the PV technology improves and costs continue to fall, it is reasonable to expect that future survey reports will see several shifts: (1) a greater percentage of the installed power in the two grid-connected market sectors will be subsidized commercial and commercial and a smaller percentage will be demonstration and field test systems, and (2) a greater percentage of the off-grid residential systems will become commercial and not require subsidies nor much further demonstration or field tests.

The last two categories, demonstration and field test systems are addressed in this chapter since their objectives, size and number are good measures of the advances being made in photovoltaic power systems. In subsequent survey reports, data will be requested on commercial systems to track the evolving maturity of photovoltaic power systems.

### Demonstration and Field Test Objectives

The reporting countries were asked to identify their main demonstration programs and projects and to describe the objectives of those demonstrations. Ninety-five demonstration programs involving over 3,000 specific systems were reported. A large number of diverse objectives were reported, suggesting that these programs are both field tests as well as demonstrations. Furthermore, many of the reported objectives pertain more to R&D than to commercial systems. These objectives were grouped into one of six general objectives, listed below:

(1) Special Applications
(2) Performance Issues
(3) Operation and Maintenance

(4) Technical and Economic Feasibility
(5) Market Development
(6) General Information

The specific objectives, common to four or more countries, and associated with the above general objectives are listed below. The numbers in parenthesis are the number of countries reporting that specific objective:

### Special Applications

Study integration aspects of building-integrated PV:
Canada, Denmark, Finland, France, Germany, Netherlands (6)

Explore use of existing structures:
Austria, France, Japan, Switzerland (4)

### Performance Issues

Evaluate performance of systems and new components:
Austria, Canada, Denmark, France, Finland, Germany, Italy, Japan, Netherlands, Portugal (10)

Analyze grid-connection issues and impacts:
Austria, Denmark, France, Germany, Japan, Netherlands (6)

Evaluate performance of standard system designs:
Austria, France, Italy, Netherlands (4)

### Operation and Maintenance

Study operation, reliability and performance of utility grid-connected, or off-grid applications:
Denmark, France, Germany, Japan, Netherlands, Portugal, United States (7)

Evaluate feasibility, reliability and operations cost:
France, Germany, Italy, Japan, Netherlands, United Kingdom (6)

Analyze plant O&M costs and requirements:
Austria, France, Germany, Italy, United States (5)

### Technical and Economic Feasibility

Seek competitive solutions for isolated houses:
Finland, France, Germany, Italy, Korea, Portugal, Sweden (7)

Develop own experience with technology:
Denmark, Finland, France, Italy, Netherlands, Portugal, Sweden, United Kingdom (8)

Provide technical feedback to industry:
France, Italy, Germany, Netherlands, United Kingdom, United States (6)

Establish installed cost, and ways to reduce it:
Austria, Canada, Germany, Netherlands (4)

### Market Development

Promote market diffusion of PV:
Canada, France, Finland, Italy, United States (5)

### General Information

Information transfer, public information, teaching:
Austria, Canada, Denmark, Finland, France, Germany, Italy, Netherlands, Portugal, United Kingdom, United States (11)

The above fourteen most commonly mentioned specific objectives represent eighty nine objective-country citations. If the first four general objective categories are associated with field tests and demonstrations and the last two to subsidized and non-subsidized commercial systems, then 82% of the citations pertain primarily to field test and demonstration programs, while 18% pertain primarily to commercial systems, with our without subsidies. It will be interesting to see how this distribution changes over time.

## Lessons Learned and Problems Encountered

Information concerning the lessons learned and problems encountered in the demonstration programs and projects were provided by ten of the reporting countries. There was very little commonality of problems encountered and/or lessons learned. Many countries did not report any encountered problems nor any lessons learned.

As is common with most photovoltaic power systems, the BOS was cited as the source of most problems. The kind of problems encountered include initial inverter failures, audible inverter noises, control and/or power conditioning failures, a dc switchgear fire, broken cover glass caused by high winds, and cable connection corrosion.

The lessons learned can be grouped into performance-related, cost-related or operation and maintenance. The following typical observations regarding performance were reported: (1) quite often the actual performance was less than predicted, (2) power conditioner losses were low, (3) the availability for photovoltaic power systems was 90-95%, and was often limited by the performance of the inverter, (4) an observation of current leakage to the module frame, and (5) that aSi modules fall short of manufacturer specifications. The same country can find some photovoltaic system to work perfectly while another system suffers inverter problems (using different inverter manufacturers and different system designers). The same country can find actual performance to be what was predicted while for another

**TABLE 14**
**Primary Funding Source foe Major Demonstration Programs, to the End of 1993[13]**

| | AT | CA | DK | FI | FR | DE | IT | J | K | NL | PT | SE | CH | TR | UK | US |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Primarily government | 2 | 2 | 4 | 3 | 5 | 2 | 2 | 4 | 1 | 14 | 5 | 1 | 3 | 1 | 3 | 3 |
| Primarily utility | 10 | 1 | 1 | 0 | 0 | 3 | 1 | 0 | 0 | 4 | 0 | 2 | 2 | 0 | 1 | 9 |
| Primarily private sector | 0 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |

system it is less than expected or predicted.

Some positive performance-related lessons learned were also reported, including (1) urban dirt does not seem to degrade the photovoltaic power system's performance, (2) snow cover causes minimum annual performance loss, and (3) lightning strikes did not damage a particular PV system. Another positive lesson learned is that it is not necessary to penetrate the membrane on flat roof in order to install a PV system. The most positive observation, reported by several countries, was that there were no major problems with their photovoltaic power systems.

The major lesson learned about operation and maintenance of photovoltaic power systems is that aside from the need for battery and instrument maintenance, the rest of the system requires little to no maintenance, and that PV grid-connected plants can operate safely, provided dc safety matters are carefully addressed.

Regarding cost, it was proven that factory pre-assembly can reduce the cost of photovoltaic power systems, and that standard components and systems are necessary for reduced installed system cost.

## Primary Funding Source

In order to draw conclusions from this chapter, the demonstration and field test programs and projects were divided into three major types:

- primarily government sponsored
- primarily utility sponsored
- primarily private sector sponsored

Table 14 was prepared to show the number of demonstration programs that received the majority of their funding from either the government, a utility company or organization, or the private sector.

The majority, 55 out of 95 demonstration programs, or 58%, were funded primarily by the government. This is not surprising as the government in most of the participating countries has policies supporting the development and demonstration of photovoltaic power systems. The utility sector was the primary sponsor of 34 out of 95 demonstrations programs or projects or 36%. The private sector provided the primary funding for the smallest number of demonstration projects, 6 out of 95, or 6%.

Considering the number of demonstration programs only, not their size, government sponsorship predominated in almost all countries with a few notable exceptions: utilities take the lead in photovoltaic power system funding in the United States and Austria and to a lesser degree in Germany and Sweden. Private sector funding is relatively important in Finland and to a lesser degree in the Netherlands and Canada. In Germany, the federal government funds two major programs, the German PV Demonstration Program (1988-1994) and the 1000-Roofs Program; the three other major demonstration projects are funded by the utilities. In Austria, federal ministries are involved in funding the largest single demonstration (200 $kW_p$) but utilities are very much in the lead on most of the rest. In Sweden, two of the three reported demonstrations are funded by utilities but all three of these systems taken together are less than 15 $kW_p$. In Italy, a balanced effort involving the national utility company, ENEL and the government agency, ENEA, led to a series of demonstration projects.

The United States reported twelve demonstration programs involving 117 systems. These programs include the collaborative Department of Energy/utility PVUSA, the collaborative Environmental Protection Agency/utilities program, the Cape Canaveral project, Arizona Power Systems STAR program, the City of Austin, Texas program, Virginia Solar program, Tennessee Valley Authority program, the Las Cruces project, the Gardner, Massachusetts program, the Washington Power and Light program, and two programs at the Sacramento Municipal Utility District.

## Demonstrations and Field Tests

Tables 15 and 16 present the statistical data gath-

[13] The numbers represent major demonstration programs, but not necessarily individual PV demonstration systems.

## TABLE 15

**Major Demonstrations and Field Tests, by the End of 1993. See Figures 33 and 34.**

| | Number of Major Demo Programs and/or Projects | Installed Demo Capacity, $MW_p$ | Range of Demo Systems, $kW_p$ |
|---|---|---|---|
| Austria | 12 | 0.307 | 1.3-40 |
| Canada | 4 | 0.118 | 1-75 |
| Denmark | 5 | 0.144 | 1.8-5 |
| Finland | 6 | 0.038 | 1-30 |
| France | 5 | 0.52 | 0.5-2.0 |
| Germany | 5 | 6.424 | 1-600 |
| Italy | 3 | 3.95 | 1-3300 |
| Japan | 4 | 1.7 | 0.2-750 |
| Korea | 1 | 0.159 | 4-100 |
| Netherlands | 20 | 0.53 | 0.4-55 |
| Portugal | 5 | 0.067 | 0.05-15 |
| Sweden | 3 | 0.013 | 1-10 |
| Switzerland | 5 | 1.584 | 10-560 |
| Turkey | 1 | 0.003 | 3 |
| United Kingdom | 4 | 0.016 | 0.2-6.5 |
| United States | 12 | 4.92 | 0.2-1180 |

ered from the survey countries on their demonstration programs. The reader is referred to the national input reports for details of these diverse programs. No attempt was made in this table to distinguish between demonstration programs and field test programs. Table 15 presents key information about the demonstration (and field test) programs and/or projects gathered from the national input reports. A demonstration or field test program may involve many systems, sometimes hundreds or thousands of individual, similar installations. Demonstration or field test projects, on the other hand, are often one of a kind. The author attempted to list in Table 15 only the major program and/or projects, and not individual systems.

Column 2 in Table 15 shows that the demonstration programs range from one (Korea and Turkey) to twenty (the Netherlands). The number of individual systems is much higher, ranging from less than ten in Denmark, Finland, Italy, Korea, Sweden, Turkey and the United Kingdom, to less than a hundred in Portugal, Switzerland, and the United States, to a hundred or more in Austria, France, Japan and the Netherlands, and over a thousand in Germany.

The demonstration and field test system sizes are as small as 50 $W_p$ in Portugal and as large as 3.3 $MW_p$ in Italy. The smallest Portuguese systems are for off-grid rural electrification and the largest Italian installation is the grid-connected plant at Serre.

Table 15 also shows the total installed PV demonstration (and field test) power capacity in each country. Figure 33 and Figure 34 present this information by country and regionally. The installed capacity in demonstration systems ranges from 3 $kW_p$ in Turkey and 16 $kW_p$ in the United Kingdom on the low end, up to 1.58 $MW_p$ in Switzerland, 3.95 $MW_p$ in Italy, 4.92 $MW_p$ in the United States and 6.42 $MW_p$ in Germany. Despite the fact that France has a very large number of demonstrations systems, as of the end of 1993, they totaled a moderate 0.52 $MW_p$ since they are mostly for off-grid residences of 1 to 2 kW each. The Italian total will soon increase because the largest plant (at Serre) is still being constructed; the Serre plant was about 1.32 $MW_p$ in early 1994 but should be about 3.0 $MW_p$ by the end of 1994.

By comparing the data in Table 1 with that in Table 15 it is possible to estimate the fraction of the total installed power capacity (Table 1) that is devoted to demonstrations (Table 15). It can be seen that about 75% of the total installed PV power capacity by the end of 1993 in Germany and in the United States was installed as demonstration systems. Austria,

**FIGURE 33**
**Installed PV Demonstration Power Capacity, $MW_p$, at End of 1993**

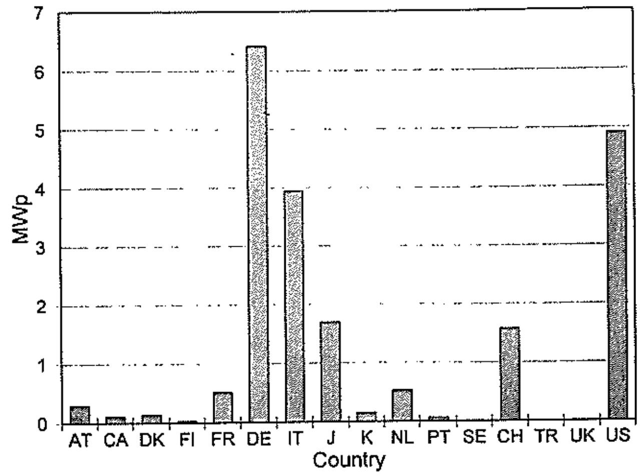
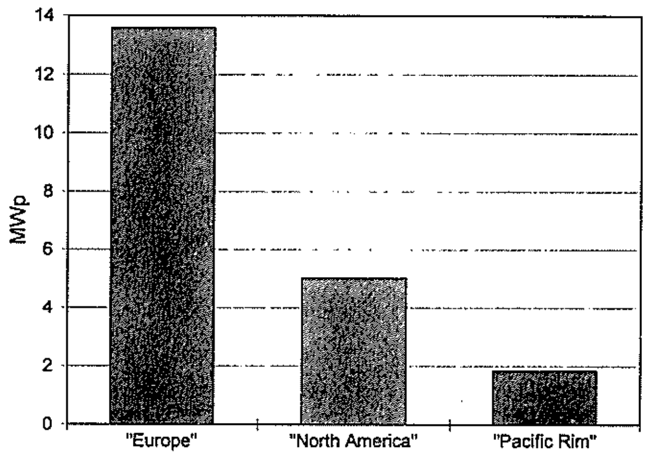



**FIGURE 34**
**Installed PV Demonstration Power Capacity, $MW_p$, at End of 1993**




France, Italy, the Netherlands, Portugal and Switzerland had between 20 and 50% of their PV power capacity installed as demonstrations, and the remaining countries had less than 10% of their installed PV power capacity in demonstrations.

Table 16 presents data on the investment in demonstration or field test programs by the end of 1993, as well as the range of installed costs, and the average $\$/W_p$ price for these systems. When possible, countries provided weighted average $\$/W_p$ data. As with all cost data, caution must be used when attempting to make comparisons. The wide range of installed demonstration system price, as well as in the weighted average prices is probably due to the relative size of systems, non-photovoltaic hardware being included for very remote power systems, and the age of the systems. For example, the Japanese data for investment and installed price range included labor and travel expenses for the researchers, land preparation costs, dummy load and simulated grid for research on grid-connection issues, etc., while other countries did not.

One would expect there to be a logical relationship between the price paid for modules, for the other components necessary to make a system, for a complete system, and for an installed system. Table 17 is designed to help the reader sort out the photovoltaic power system prices and their relationships.

The approach taken to develop Table 17 was:

- to use data provided by each of the listed countries, wherever possible
- the BOS component prices (included in column 3) were based on the average price if the country presented a range of values
- where a country did not provide data for BOS component prices, the average of those countries providing such data was used

The range of module prices from Table 7 is repeated in column 2 and these module prices are obviously included in the total component prices in column 3 which includes: modules, inverter, dc switchgear, and supporting structures. Column 3 does not include batteries, controls, installation, engineering, instrumentation, shipping, or construction management. Thus an actual installed photovoltaic power system would cost appreciably more than what is shown in column 3. It appears that the total of the

**TABLE 16**
**Demonstration and Field Tests Financial Data, by the End of 1993**

| | Investment, $M | Installed Cost, Range $/W_p$ | Weighted Average, $/W_p$ |
|---|---|---|---|
| Austria | 5.19 | 14-45 | 17 |
| Canada | 1.65 | 8-50 | 14 |
| Finland | 0.5 | 20 | 20 |
| France | 19 | 36-54 | 37 |
| Germany | 110 | 11-50 | 15 |
| Italy | 44.5 | 7-22 | 11 |
| Japan | 86.4 | 7-50 | 43 |
| Korea | . 2.56 | 15-24 | 16 |
| Netherlands | 3.0 | 11-18 | 12 |
| Portugal | 0.32 | 20-44 | 32 |
| Sweden | 0.27 | 16-41 | 21 |
| Switzerland | 21.1 | 11-19 | 13 |
| United States | | 8-30 | 12 |

**TABLE 17**
**Component and System Price Analysis for Selected Survey Countries, 1993 data**

| | Module Price, $/W_p$ | Total price of the main system components, $/W_p$ | Prices of specific systems offered for sale in 1993, $/W_p$ | Cost average of systems installed in 1993, $/W_p$ | Demo and field test system costs, $/W_p$ |
|---|---|---|---|---|---|
| Austria | 6.00-10.00 | 9.00-13.00 | 13.60-22.00 | 15.90 | 17.00 |
| Canada | 5.12-6.25 | 7.61-8.74 | 7.75-22.00 | 11.80 | 14.00 |
| Germany | 5.68-7.79 | 9.43-11.54 | 8.20-35.00 | 12.90 | 15.00 |
| Italy | 4.10-5.60 | 6.60-7.50 | 8.75-21.90 | 9.40 | 11.00 |
| Sweden | 5.12-7.04 | 8.10-10.00 | 8.60-16.70 | 16.05 | 21.00 |
| Switzerland | 7.14-10.71 | 10.40-14.00 | 9.50-21.85 | 17.25 | 13.00 |
| United States | 5.24 | 8.00-8.70 | 7.70-12.34 | 8.12 | 12.00 |

component costs in column 3 are the lowest for Italy (6.60-7.50 $/W_p$) and highest for Switzerland (10.40-14.00 $/W_p$) due to the higher prices of the modules in Switzerland.

The last three columns repeat data for photovoltaics power systems from Tables 2, 13, and 16. Column 4 shows the 1993 prices system suppliers were offering (taken from Table 13); the costs never get below 7.70 $/W_p$ or above 35.00 $/W_p$. Considering the scatter of the rest of the data in this survey, the similarity of the lower prices is noteworthy. The minimum price is very much in line with the sum of the component prices shown in column 3. It seems fair to speculate that system suppliers are flexible in their pricing over the range of 8.00-20.00 $/W_p$, and can occasionally receive up to 35.00 $/W_p$ for complete systems, especially if they include non-PV components.

The costs for systems installed in these countries in 1993 (taken from Table 2) is shown in the fifth column, and presents a totally different picture. Some of the PV systems in the United States were apparently installed with little or no profit margin. Italy was able to install a grid-connected system for 9.40 $/W_p$, a small margin (25%) over their highest price of 7.50 $/W_p$ for just the components, and about 75% over their low end component-only price of 6.60 $/W_p$. Canada and Germany were able to install systems for between 12.00-13.00 $/W_p$ or about 40-50% over their lowest component-only prices. Sweden, Austria and Switzerland purchased systems at some-what higher prices (column 3) and up to 70-90% above the lower price for components only, and for about 20-60% more than the price of the high end of their component-only prices.

The last column, showing the system prices of demonstration and field tests (taken from Table 16), is even more extreme with system prices ranging up to 21 $/W_p$. Demonstrations and field test systems should cost more than commercial sales due to higher procurement costs, instrumentation, etc. Another reason for high costs and wide ranges is the variation in photovoltaic power system costs over the past decades. Many of these demonstration systems were installed when module prices were well above the 1993 levels.

## Major Findings

- ✔ There is a great variety in the number and type of objectives for the demonstration and field test programs in the reporting countries. Eighty-two percent of the citations pertain primarily to field test and demonstration programs while 18% pertain to commercial systems, with and without subsidies.

- ✔ The major reported performance results were that the PV modules are performing very well and that the balance of system components were the source of most of the reported problems.

- ✔ Government sponsored demonstration and field test programs predominated with a few notable exceptions: utilities take the funding lead in the United States and Austria and to a lesser degree in Germany and Sweden. Private sector funding is relatively important in Finland and to a lesser degree in the Netherlands and Canada.

- ✔ The capacity range of demonstration and field test systems was large, from a 50 $W_p$ rural electrification system in Portugal to a 3.3 $MW_p$ grid-connected system in Italy. There is a large range in the total power of the installed demonstration and field test systems in the reporting countries, from 3 $kW_p$ in Turkey and 16 $kW_p$ in the United Kingdom on the low end, up to 1.58 $MW_p$ in Switzerland, 3.95 $MW_p$ in Italy, 4.92 $MW_p$ in the United States and 6.4 $MW_p$ in Germany.

- ✔ System suppliers seem flexible in pricing their demonstration and field test systems from 8 to 20 $/$W_p$, with a few exceptions. Italy was able to install for 9.40 $/$W_p$, a small margin (25%) over their highest component-only price of 7.50 $/$W_p$, and about 75% over their lowest component-only price of 6.60 $/$W_p$. Canada and Germany were able to install systems for between 12.00-13.00 $/$W_p$ or about 40-50% over their lowest component prices.

- ✔ An often quoted parameter is the ratio of installed system cost to module cost. If this ratio is computed based on the lower end of the module price range, this parameter ranges from a low of 1.6 for the United States to between two and three for Austria, Canada, Germany, Italy, Sweden and Switzerland.

# Chapter 5

## Non-Technical Factors

### International Policies

Many of the reporting countries have signed various international agreements and participate in a number of international programs. It therefore seems reasonable to expect that some of the recent international and regional policies dealing with the environment, CO2 reduction, sustainable development, as well as with trade will, either directly or indirectly, affect the use of photovoltaic power systems.

In 13 of the 16 reporting countries, their country's signing of various legally binding international treaties and agreements is viewed to have a positive, if indirect, impact on the future use of photovoltaic power systems. However, regarding non-legally binding treaties and agreements such as the Toronto Agreement, the UNCED Climate Convention and the Luxembourg Agreement, all of the reporting countries felt there would be no effect on photovoltaic power systems. The most positive responses were from Austria who felt these treaties and agreements will move Austria's energy supply towards renewables, and the United States who stated that commercialization of photovoltaics was seen as a fundamental part of reaching the UNCED Climate Convention goals. Denmark, Italy, Korea and the Netherlands felt these treaties and agreements will accentuate interest in photovoltaics in their countries and could, in the future, help promote the wider use of photovoltaic power systems. The United Kingdom and Switzerland did not elaborate on their positive responses.

France pointed out that the Global Environmental Facility of the World Bank is expected to present new business opportunities for the photovoltaic industry which would have a positive effect on the use of photovoltaic power systems.

Austria and the United States also believed that certain legally binding regional agreements, such as the European Union policies and the North American Free Trade Agreement (NAFTA), respectively, will have a positive affect on photovoltaic markets. For example, Canada and the United States stated that the requirement in NAFTA that all tariffs and trade barriers between the United States, Canada and Mexico be eliminated should facilitate the sale of photovoltaic products.

All reporting countries that are EU members mentioned positive affects of the European Union R&D programs while Canada and Japan commented on the positive impact that their Green Aid programs, dealing with off-grid rural electrification and portable power, could have on photovoltaic power systems.

It seems clear that the existing relevant international policies, treaties and agreements do not present any significant negative forces against photovoltaic power systems. However, in spite of the various positive responses, all in all, it appears that international policies have not yet had much of a positive impact in photovoltaic power systems. It will be interesting to track this topic in the future as it is logical to expect that such agreements will have a growing positive influence on the use of photovoltaic power systems.

### National and Local Policies

While there is a difference between national R&D programs and national policies, both can have a major impact on the use of photovoltaic power systems in a particular country and therefore this section will deal with both.

National R&D programs support photovoltaics by providing financial resources for the cost reductions and performance improvements that are so vital for greater diffusion into the utility market. Of the eleven countries that provided information on this specific item, only Finland, Portugal and Sweden reported that they had no specific local or regional plans to promote the use of photovoltaic power systems. The other thirteen countries provided detailed information about their national promotion plans. Some plans set targets for increased contributions by renewable energy sources (Austria, Denmark) and some even for photovoltaic power systems (Italy, Japan, and Switzerland). Others, such

**TABLE 18**
**Energy Plans and PV Power Production Targets in Reporting Countries**

| | Energy Plan | PV Targets |
|---|---|---|
| Austria | Favors renewables | None |
| Canada | Under development | 15 MWp by 2000 |
| Denmark | Favors renewables | BIPV competitive by 2000 |
| Finland | None | None |
| France | None | None |
| Germany | Unclear | None |
| Italy | Favors renewables | 25 MWp by 1995 |
| Japan | Favors renewables | BIPV competitive by 2000 |
| Korea | Emphasizes PV | 20 MWp island by 2000 |
| Netherlands | Favors renewables | 250 MWp renewables by 2010 |
| Portugal | Favors renewables | None |
| Sweden | None | None |
| Switzerland | Addresses PV | 50 MWp grid-connected by 2000 |
| Turkey | None | None |
| United Kingdom | None | None |
| United States | Favors renewables | UPVG 50 MWp by 2000 |

as France, Turkey, the United Kingdom and the United States reported on plans that promoted photovoltaic power systems without setting targets. Targets for a specific amount of photovoltaic power capacity required by a specific date are valuable provided that funds are available to facilitate the achievement of those targets.

In view of the major changes that are taking place in the utility sector in many of the participating countries, the issue of national or local laws that regulate the generation of electricity by non-utility companies is critical to the diffusion of photovoltaics in the utility sector. Austria, Denmark, Finland, France, Germany, Italy, Portugal, Sweden, Switzerland, the United Kingdom and the United States indicated that access to the grid for a photovoltaic power system can not be denied provided that the rules are followed. In most countries, photovoltaics is treated the same as small-hydro and wind generation. The issue of how much non-utility generators are paid for their electricity is addressed in a following section in this chapter.

Table 18 summarizes the energy plans and targets for photovoltaic power production, if any, for the reporting countries. The term "BIPV" means building-integrated photovoltaic systems.

Eight countries have some kind of target for photovoltaic power systems, ranging from specific photovoltaic power system targets of 50 $MW_p$ power production by 2000 in Switzerland and in the United States, 25 $MW_p$ by 1995 in Italy, and 20 $MW_p$ by 2000 for island applications in Korea. The Netherlands has a target of 250 $MW_p$ of renewable energy by 2010. Denmark and Japan have specific goals to make building-integrated PV competitive by 2000. With such aggressive targets it can be expected that the level of PV activity will be relatively high and likely to increase in the near future.

## Subsidies and Rates

This section covers two different issues. The first is the subsidies available for construction of photovoltaic power systems and the second is the regulations governing the price paid for the electricity generated by photovoltaic power systems.

Most countries have significant investment subsidies for the initial capital cost. And in many countries subsidies are available from the national and/or the state governments. In some cases additional subsidies are available, such as exemption from property taxes, sales taxes or VAT, etc. Only Canada, and Turkey are without subsidies for the construction of photovoltaic power systems.

In Denmark such subsidies can be provided but none have been so far. France has the largest subsidy, providing 90% of the cost of an off-grid photovoltaic

**TABLE 19**
**Subsidies and Buy-back Rates**

| | Subsidies[14] | Buy-back Rates |
|---|---|---|
| Austria | Up to 40% national plus 15-40% provincial | 6-7 ¢/kWh, considering parity |
| Canada | None | Negotiated avoided costs |
| Denmark | Yes, project specific | 8 ¢/kWh |
| Finland | Up to 50% to utilities and industry | Avoided costs |
| France | up to 90% for off-grid rural PV systems | 4.6 ¢/kWh |
| Germany | 40-70% national, 35-70% states, 10-30% in cities, within budget limits, and additional up to 40% for off-grid | 10 ¢/kWh federal, some states up to 12 ¢/kWh for 10 yrs, some cities offer 1.25 $/kWh |
| Italy | 30-80% national | Exceeds parity for 8 yrs, up to 29 ¢/kWh for peak surplus power |
| Japan | 50-67% for grid-connected systems | Almost parity with local utility's price |
| Korea | 50-80% plus 5% interest rate for 8-year loan, plus up to 50% of operating costs are covered. | Negligible |
| Netherlands | 4.32/$Wp investment subsidy for off-grid systems, 40-60% for grid-connected systems | Parity or close to parity |
| Portugal | 15-25%, plus some tax benefits | None quoted |
| Sweden | Up to 50% for demonstration systems | Avoided costs (3 ¢/kWh) |
| Switzerland | 30-50% national, 15-50% in some cantons (states), for grid-connected systems | Min. 11 ¢/kWh (80% of parity) some utilities can exceed parity |
| Turkey | None specified | None specified |
| United Kingdom | Modest | Negotiated case by case |
| United States | 10% plus 1.5 ¢/kWh for 10 yrs, up to 35% state, plus various tax exemptions; 35% federal for grid-connected (UPVG) | Avoided cost as defined by each state |

power system with funds from the local authorities, EDF and ADEME, provided that the photovoltaic power system is cheaper than extension of the grid. The subsidy in Italy is almost as great. For example, a building that is not connected to the grid is eligible for an 80% subsidy on the total cost of the installed system. In Finland a subsidy of up to 50% of the cost of the system is available to industry or the utility involved with a specific photovoltaic power system. In Korea, very significant government support is available for the construction of photovoltaic power systems on certain Korean islands.

The situation regarding the prices paid by the utility company for energy delivered to the grid from photovoltaic power systems, referred to in this report as the buy-back rate, vary considerably from country to country. In Austria, Denmark, Finland, France, Japan and the United Kingdom, the price paid is less than the price charged for electricity. Parity describes the situation where the price paid for PV-generated electricity is equal to the price charged for electricity. In Japan, buy-back rates are close to parity with the local utility's rates, and in Austria, parity buy-back rates are under consideration. Italy seems to have the most positive rates, significantly exceeding parity (the rate that utilities charge their customers) for peak power for the first eight years.

14 As percent of total capital cost, unless noted.

**TABLE 20**
**Required Growth in Module Shipments and PV Power System Installations in Specific Countries**

| | CA | IT | K | NL | CH | US |
|---|---|---|---|---|---|---|
| Average annual target, $MW_p$ | 2.1 | 6.5 | 3 | 14.6 | 6.6 | 5.3 |
| 1993 increase in installed PV power capacity, $MW_p$ | 0.41 | 3.6 | 0.17 | 0.37 | 0.5 | 1.46 |
| Attained installation target, % | 20 | 55 | 6 | 3 | 8 | 28 |
| 1993 module shipments, $MW_p$ | 0.16 | 3.2 | 0.5 | 0.5 | 0.15 | 21 |
| Attained module shipment target, % | 8 | 49 | 17 | 3 | 2 | 100 |
| Subsidies | Low | Very good | Good | Good | Good | Low |
| Buy-back rates | Low | Very good | Very low | Very good | Very good | Good |

Some local utilities in Germany and Switzerland can also exceed parity for ten years while for Canada, Finland, Sweden and the United States, the utilities must, or usually agree to pay a rate equal to their avoided costs.

Table 19 summarizes the input reports for these two issues.

At present, avoided costs tend to be low as they mainly reflect avoided fuel costs. In view of the relatively high cost of electricity from photovoltaic power system plants, high buy-back rates will be required until installed system costs decrease significantly.

It is interesting to ask if it is reasonable to expect a given country to be able to reach their target power level, based on their 1993 shipments and the percentage growth between 1992 and 1993. And, by comparing the availability and magnitude of subsidies and buy-back rates it should be possible to assess their importance to the achievement of the national targets. The relevant data are shown in Table 20 for six countries with specific (numerical) PV targets and described below.

In creating Table 20, the "Average annual target, $MW_p$" was obtained by dividing the additional $MW_p$ required to reach the target by the number of years between 1994 and the target year. It was assumed that 10% of the Netherlands' target, that is 25 $MW_p$, is met by PV. In actuality, countries may very well plan to meet their target capacities with most of the growth in the last year or two when module prices should be lower. The second row repeats the installed PV power capacity in 1993 from Table 1.

The third row, "Attained installation target, %", shows the percentage of the installed power capacity required to meet the target that would be attained using the 1993 installation data. The fourth row, "Attained module shipment target, %", shows the percentage of the installed power capacity required to meet the target that would be attained using 1993 module shipment data.

For example, the target installed grid-connected power capacity for PV in Switzerland is 50 $MW_p$ by the year 2000. Of the 5.8 $MW_p$ installed in Switzerland by the end of 1993, 3.8 $MW_p$ was grid-connected (see Table 3), an increase of 0.5 $MW_p$ over the 3.3 $MW_p$ grid-connected installed by the end of 1992. If this target were to be met with the same amount of power capacity installed each year between 1994 and 2000, 6.6 $MW_p$ would have to be installed each year. The percentage attained of the installation target is 8% (0.5/6.6), suggesting a significant challenge to the Swiss utilities. In 1993, the module production in Switzerland was 0.15 $MW_p$/yr. The percentage of the module shipment target is 2% (0.15/6.6), suggesting either a very large increase in module imports (Switzerland imported 0.7 $MW_p$ in 1993) or a dramatic growth in module production capacity in Switzerland would be required. By comparing the percent increase in installed grid-connected capacity between 1992 and 1993 (15%) and what would be required in 1993-1994 (174%), the challenge to both the PV industry and the utilities in Switzerland is apparent. Of course, the target may be met in a non-linear manner, with most of the increase in installed capacity coming in the last years. This is part of the strategy to take advantage of anticipated lower installed system prices.

The United States has the module production rate to meet its target but would have to increase its 1993 installed PV power capacity by 3.6 times in 1994. Italy's module manufacturing would have to double or imports would be required to meet Italy's target. Italy would also have to double its installed PV power capacity. Korea, Canada and the Netherlands, however, will have to rely heavily on imports or dramatically increased domestic production as well as a greatly increased rate of installations to meet their national targets for PV. Subsequent survey reports will track the actual growth vs. the target or planned growth to assess the degree to which those targets are being met.

Table 20 indicates the degree to which the subsidies and buy-back rates are supportive in achieving those national targets, using the terms, low, good and very good. The situation regarding the adequacy of the subsidies and buy-back rates to support the achievement of the national targets seems most favorable in Italy, the Netherlands and Switzerland, less so in the United States and Japan, and questionable in Canada and Korea.

## Standards

The mature and significant use of photovoltaics in the utility sector will require a series of national and/or international (as in the case of the European Union) standards that facilitate the construction, grid-connection and operation of photovoltaic power systems. In this survey, the following two aspects are addressed:

- the technical regulations for the construction and operation of photovoltaic power systems
- the regulations and/or standards for grid-connection of photovoltaic power systems

Table 21 highlights some of the information provided by the reporting countries regarding the main technical aspects of standards for photovoltaic power systems.

Regarding construction and operation of photovoltaic power systems, safety seems to be the major concern and present regulations seem adequate for, photovoltaic power systems. Some countries have or are developing (e.g., France) regulations specific for off-grid photovoltaic power systems. The most straightforward approach is in Finland, where people who buy photovoltaic power systems are allowed to install their systems by themselves assuming that the seller has included instructions approved by the Finnish Electrical Power Inspection Office. A similar approach is used in Switzerland for off-grid photovoltaic power systems. Austria has regulations for small grid-connected photovoltaic power systems, Germany has such regulations in preparation while in Italy these systems are designed to operate at voltages below those that require meeting very restrictive safety requirements. In Switzerland, while there are no regulations specifically for grid-connected photovoltaic power systems, provisional safety regulations exist and will soon be replaced with new standards.

Seven of the sixteen reporting countries, indicated that there were no specific regulations or standards for connection to the grid. In France, the electric utility company, EDF, has not yet worked on specific regulations for grid-connection, as their program with ADEME is targeted towards off-grid photovoltaic power systems. Denmark, Turkey, the Netherlands and the United States have no such regulations, Austria has special instructions for photovoltaic power systems, while Finland, Germany, Italy, Switzerland, Sweden and the United Kingdom follow the same requirements that exist for any small power generating system.

Austria sees no constraints that might impede the diffusion of photovoltaic power systems. Italy, France and the United Kingdom, on the other hand, feel that the present regulations for grid-connection should be revised to reflect the unique nature of photovoltaics as opposed to rotating generating technologies. Denmark, Finland, France, Japan, Switzerland, Sweden, Turkey and the United States reported that there were no grid-connection regulatory problems that required attention.

It should be mentioned that work is underway to develop standards for photovoltaic components. The International Electrotechnical Commission has issued standards (IEC-891 and IEC-904-1, -2, -3 and -4) covering various aspects of PV performance measurement. A recent publication, IEC 1215 covers the design qualification and type approval of cSi modules. Work is also underway to develop a standard for PV systems and for batteries.

## Non-technical Factors Limiting PV Applications

Few non-technical factors were identified that might limit the diffusion of photovoltaics into the various utility market sectors. No land use or ownership/liability issues were identified in the national reports. In Austria, Canada, Denmark, Finland, the Netherlands, Sweden and the United Kingdom, compliance with regular building codes was not seen as a limiting factor for photovoltaic power systems. In France, special rules and requirements are being studied for roof-mounted modules. Italy reported that compliance with the regular building codes often results in over-specifying the support structure for photovoltaic power systems, which increases the cost of installed systems. In Japan, fire safety and

**TABLE 21**
**Country-Specific Information on Standards**

| | |
|---|---|
| Austria | ÖNORM E-2750 is followed for small grid-connected photovoltaic power systems. Safety requirements of photovoltaic power system installations are addressed in ÖNORM E-2750, based on IEC TC-82 and the electric code EN1, issued by the Austrian Institute of Standardization, and the Preliminary Safety Regulations for Photovoltaic Power Systems issued by the Swiss Electric Power Inspectorate, June 1990 |
| Canada | Any system larger than 100 Wp is subject to inspection by a representative of the relevant provincial utility. There is a proposal that inspectors will automatically approve certainsize systems. Periodic inspections will then be carried out. The Canadian Electrical Code requires that components used must be certified by CSA or be subject to a special inspection and approval for use. Most inverters used in off-grid systems are modified sine-wave. The CSA standards apply only for sine wave inverters. Thus certification by CSA has not been possible to date for these, hence special inspections are necessary. |
| Finland | Only authorized persons can install ac electrical systems. But persons who buy photovoltaic power systems are allowed to install their systems by themselves assuming that the seller has included instructions approved by the Finnish Electrical Power Inspection Office. |
| France | A specification for off-grid photovoltaic power systems has been developed by PV companies, with the existing French Standard NF C 15-100 as the starting point, and is part of a "Charter of Quality" that the PV system companies must adhere to. |
| Germany | The installed photovoltaic power system must meet the basic Germany safety code VDE-0100 (IEC 364). Special training materials and courses have been developed in the frame of the 1000 Roof program that cover the safety guidelines to be followed for grid-connected photovoltaic power system. Specific standards and regulations for PV systems are being developed. |
| Italy | Italian Rule DPR n.547 sets very restrictive safety conditions for systems with dc voltages over 600 V. Rules for grid-connection of non-utility generation are set by the Italian Electrotechnical Committee, CEI 11-20. The rules of CEI 11-20 were designed to deal with rotating equipment, and therefore presents problems for photovoltaic power system grid interconnection. For example, they require three-phase connection even for small photovoltaic power systems, (e.g., 2 kW as used for roof-top applications). A PV industry-ENEL working group is drafting new rules for review and approval by CEI. A new rule is anticipated by mid-1994. |
| Japan | Informal standards for installation and operation of photovoltaic power systems are proposed by a "responsible agency". A technical requirement for grid-connection has been established by MITI. |
| Portugal | There is a law concerning the production of electrical power up to 10 MW (Decreto-Lei 198/88). The authorization for grid-connection of photovoltaic power systems is the same as for other sources of power up to 10 MW. The activity of production of electrical energy can be done by everyone provided some technical and security rules are followed. The entity which uses the public grid must accept the energy delivered if the project presented to the Directorate General for Energy was approved. Nevertheless this legislation must be adapted for the photovoltaic power system. |
| Switzerland | There are no specific safety regulations for photovoltaic power systems. The Federal Inspectorate of High-Current Installations has issued provisional safety regulations which are to be respected. Authorization for grid-connection of photovoltaic power systems is the same as for any other generating facility. Grid connection for a photovoltaic power system on the owner's land (if the power does not exceed 3 KVA monophase and 10 KVA triphase) does not require a report to be submitted. If it is located on another's land, a report is required. |
| United Kingdom | Engineering recommendations G59/1 and ETR 113. Aimed primarily at rotating generating plant. |
| United States | Utility owned photovoltaic power systems on utility property must meet the National Electric Safety Code NESC-ANSI/NFPA C2-1993. Photovoltaic power systems not on utility property are governed by the national Electric Code NEC-ANSI/NFSA 70-1993. Where local codes exceed this code, the local code takes precedence. Article 690 addresses unique safety issues of photovoltaic power systems. There are a list of standards and codes that deal with the installation of photovoltaic power systems. |

structural matters require special attention, and in Switzerland certain aesthetic concerns must be addressed. None of these were presented as limiting factors. Both Korea and Japan indicated that lack of suitable land may become a limiting factor. Korea stated that land availability is perceived as the most serious obstacle to photovoltaic power systems. As about 70% of Korea is mountainous, the remaining area is heavily populated and land is very expensive, making roof-top applications an important strategy. However, it was pointed out by Austria, that the high initial cost, limited subsidies, unsatisfactory payment for the energy sold to the grid, certain grid-connection requirements, lack of awareness of the capabilities of photovoltaic power systems, lack of standard photovoltaic power systems on the market, lack of qualified system designers and installers, and difficulties in finding BOS components on the market are the real limiting factors. Most of the responding countries mentioned the same or some of these factors.

## Environmental Aspects

The guidelines in this category raised three issues; the existence of favorable environmental regulations, the existence of studies that pertain to externalities, both environmental and societal, and the existence of taxes on pollution. While there are a few exceptions, the existence of these three factors seems to have little or no impact on the use of photovoltaic power systems in the reporting countries.

At best, environmental regulations favor photovoltaic power systems in Austria, Canada, Denmark, Italy, the Netherlands and Portugal, but do not influence the market. The same is true with studies on externalities—they exist in Austria, Canada, Denmark, Italy, Japan, the Netherlands and Switzerland, they favor photovoltaic power systems, but not enough to matter. Most of the reporting countries do not have pollution taxes. In Finland, such taxes are being introduced this year and they should favor photovoltaic power systems. In Sweden, pollution taxes exist but do not affect the use of these systems because the price of electricity from such systems is still too high.

## Utility and Public Perceptions of Photovoltaic Power Systems

The further diffusion of photovoltaics into the utility sector depends upon a favorable perception of PV technology by the electric utilities.

In Austria, the perception of the utilities of photovoltaic power systems is favorable. The utilities were the first to use PV for various applications, spent more money on photovoltaic power systems than any other group, and in doing so acquired much know-how and experience. Further investment by the utility companies is limited by the low cost of conventional fuels. Finland reported that as utilities participate in the Finnish R&D program, which has a strong emphasis on PV, they have a positive perception of PV. But this perception of PV may be more as a future technology, rather than one which is relevant today.

The national utility company of France, EDF, sees PV as relevant for use where line extension is too costly. The Italian national utility company, ENEL, and some of the municipal utilities have been involved in a large number of photovoltaic power systems. Their perception of photovoltaic power systems is therefore quite favorable. The utilities in the Netherlands are very actively involved in the realization of pilot plants. In 1990 the first (10 PV houses) pilot plant was contracted. Since then the attention of the utility sector has grown substantially. Six Dutch utilities are involved with ten current photovoltaic power system projects, while other projects are in preparation.

The perception of PV by a large number of electric utilities in the United States is excellent, as proven by the formation by the utilities of an organization called the Utility Photovoltaic Group (UPVG). As of January 1995 eighty nine utilities have joined this organization whose mission is to accelerate the use of cost-effective, small-scale and emerging large-scale applications of photovoltaics for the benefit of the electric utilities and their customers. Ontario Hydro, Canada's largest utility company, is launching a new program to acquire over 100 $MW_P$ of renewables, including PV) by 2000. The perception of photovoltaic power systems by other Canadian utility companies varies from viewing photovoltaic power systems as a business opportunity for exports, to having little impact on their operations, to an option for remote customers, to something to help them look good to their customers, or to something to experiment with in case it becomes economically viable.

In addition to the electric utilities, there are other service utilities, such as telecommunications, navigational aids, etc. that have long been users of photovoltaic power systems. They are generally satisfied with the performance of these systems, which also provide significant business to the PV manufacturers.

The market segments that require a positive public perception are off-grid systems and distributed grid-connected systems. As a result of many successful programs and projects, this perception is good in Austria, Finland, France and Italy. Public perception of photovoltaic power systems in Germany is good, due to their roof-top program and its publicity. Because so many vacation homes now have photovoltaic power systems, public perception in Finland and Switzerland is positive. Italy and the United States report that public perception of these systems is rather good, while in Denmark it is rather low. In Japan, the small number who use these systems are satisfied, but the general public still associates photovoltaic power systems with space satellites and high cost.

Two important indicators of the successful diffusion of photovoltaic power systems in the utility sector are the degree of R&D that the utilities support and the number and size of the photovoltaic power system projects that they fund and manage. The national reports did not provide much information about these two issues. Italy reported a significant utility (ENEL) R&D photovoltaic power system program and reported a significant number of utility projects, both supply-side and demand-side. In Korea, the national utility company, KEPCO, plans to conduct an R&D project on PV utility inter-connection beginning in 1995. KEPCO also has plans to implement a PV/wind/diesel hybrid power generation project for remote rural communities. Several countries reported that their utilities R&D activities are only in the field of PV system research. The main R&D items are the performance of inverters, the requirements for grid-connected systems and the effect of PV power of the quality of the grid. Japan reported some utility activity related to isolated systems.

Denmark and Japan reported that there have not been enough projects to influence public opinion.

## Major Findings

✔ International treaties and agreements were viewed to have a positive, if indirect, impact on the future use of photovoltaic power systems. Austria, Canada and the United States also believed that certain legally binding regional agreements, such as the European Union policies and the North American Free Trade Agreement (NAFTA), respectively, will have a positive effect on the photovoltaics market.

✔ Only Finland and Sweden reported that they had no specific local or regional plans to promote the use of photovoltaic power systems.

✔ Eight countries have specific targets for photovoltaic power systems, ranging from specific photovoltaic power system targets of 50 $MW_p$ (grid-connected) by 2000 in Switzerland and in the United States, 25 $MW_p$ by 1995 in Italy, and 20 $MW_p$ by 2000 for island applications in Korea. The Netherlands has a target of 250 $MW_p$ for all renewable energy sources by 2010. Denmark and Japan have specific goals to make building-integrated PV competitive by 2000. With such aggressive targets it can be expected that the level of PV activity in these eight countries will be relatively high in the near future.

✔ The United States has the module production rate to meet its target but would have to increase its 1993 installed PV power capacity by 3.6 times in 1994. Italy's module manufacturing would have to double or imports would be required to meet Italy's target. Italy would also have to double its installed PV power capacity. Korea, Canada and the Netherlands, however, will have to rely heavily on imports or dramatically increased domestic production as well as a greatly increased rate of installations to meet their national targets for PV. Subsequent survey reports will track the actual growth vs. the target or planned growth to assess the degree to which those targets are being met.

✔ Most countries have significant investment subsidies for the initial capital cost of photovoltaic power systems. Only Canada, Sweden and Turkey do not have subsidies for the construction of photovoltaic power systems.

✔ Buy-back rates (the price that utilities pay for PV-generated electricity fed into their grids) vary considerably from country to country. Italy has the most positive rates, significantly exceeding parity (the rate that utilities charge their customers) for peak power for the first 8 years. Some local utilities in Germany and Switzerland can also exceed parity for 10 years while in Canada, Finland, Sweden and the United States, the utilities must pay only their avoided costs.

✔ Work to develop standards for photovoltaic components continues. The International Electrotechnical Commission has issued standards covering various aspects of performance measurement, design qualification and type approval for cSi modules. Work is also underway to develop a standard for PV systems and for batteries.

✔ Safety is the major concern regarding construction and operation of photovoltaic power systems, and where existing regulations apply, they seem adequate.

✔ Seven of the sixteen responding countries indicated that there were no specific regulations or standards for connecting photovoltaic power systems to the grid, nor were there any regulatory problems that required attention.

✔ The high initial cost, limited subsidies, unsatisfactory payment for the energy sold to the grid, certain grid-connection requirements, lack of awareness of the capabilities of photovoltaic power systems, lack of standard photovoltaic power systems on the market, lack of qualified system designers and installers, and difficulties in finding BOS components on the market are the limiting factors for PV power systems recognized by most of the reporting countries.

✔ Environmental regulations favor photovoltaic power systems in Austria, Canada, Denmark, Italy, the Netherlands and Portugal, but do not influence the market. Most of the reporting countries do not have pollution taxes. In Finland, such taxes are being introduced in 1994 and they should favor photovoltaic power systems. In Sweden, pollution taxes exist but do not affect the use of photovoltaic power systems because the price of electricity from such systems is still too high.

✔ Austria, Canada, Finland, Italy, the Netherlands and the United States report favorable utility perception of photovoltaic power systems, due to a great extent, to their successful involvement in the past and present photovoltaic power system projects.

✔ As a result of many successful demonstration programs and projects, public perceptions of photovoltaic power systems are good in Austria, Finland, Germany, Italy, Switzerland and the United States.

# APPENDIX A

## Acknowledgements

This report is based on the national reports provided by the Task 1 participants:

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Peter Ahm, Denmark
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In some cases, the Task 1 participant was assisted by one or more experts in their country. These experts are listed below:

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- Don Anderson, Performance Associates, Inc. for assistance with the initial data compilation.

# Appendix B

Process and Guidelines for First Survey

## Process and Guidelines for First Survey

It was agreed by the Task 1 participants that guidelines were required to aid the participants in gathering the necessary information and data for their national survey reports. The Operating Agent prepared draft Guidelines which were reviewed by the Task 1 participants, with input from selected PV companies, utilities and government representatives in their countries. The Guidelines were then revised and distributed.

Eleven Task 1 participants from Austria, Canada, Denmark, Finland, France, Italy, Japan, Portugal, Sweden, Switzerland, and the United Kingdom prepared national survey reports. The data provided was reviewed by the Survey Report author and missing information was identified. The information requirements were reviewed at a Task 1 meeting and the participants agreed to revise and resubmit their national survey reports. Two additional countries, Turkey and the United States, plus the European Union, agreed to provide a national survey report.

Using the information in the revised national survey reports, and new national survey reports from three additional countries, Korea, the Netherlands and Germany, the Survey Report author prepared the first draft. This first draft had major limitations due to missing or unclear information. As information gaps were uncovered during the preparation of the first draft, every attempt was made to work with the Task experts to fill them. Special care was taken when interpreting data with missing information. Many of the tables and figures in this first draft were incomplete or contained data that had to be verified.

The first draft was reviewed by representatives from the PV industry, the utility sector, and government, as identified by the Task Participants from each country. Their comments were integrated and provided, in writing, to the Survey Report author. Each Task participant was asked to provide the missing and requested information for inclusion in the second draft of this report. A second draft of the Survey Report was prepared based on those comments and suggestions and was distributed to the Task Participants. A Task experts meeting was then held to discuss this second draft and resolve all open issues.

After this Task meeting, final written comments were provided to the Survey Report author. A camera-ready final draft, based on these comments, was then prepared. This draft was given to ENEA in Italy for printing and distribution.

## Guidelines to be Used by the National Experts to Gather the Information Necessary to Prepare the Status Review of PV Power Applications

The Status Report will present, bi-annually, important information about the products, markets, utility application experiences, major factors affecting PV diffusion, and national policies related to photovoltaic power systems and applications. The information will be gathered annually on the basis of the Guidelines defined and approved by the Task 1 participants.

The Guidelines are designed to collect information about photovoltaic products and applications in the utility sector. Accordingly, the emphasis is on grid-connected power systems.

The Guidelines will cover the following main topics:
1) Commercial and prototype PV power system products
2) Market and business today
3) Demonstration and field tests
4) Non-technical factors

### 1. Commercial and Prototype PV Power Systems Products

**a) Modules**

The information to be collected should pertain only to manufacturers having production facilities in the responding country and should include the following items:

- list of main manufacturers
- general description of the main steps of the production process employed by each manufacturer (feedstock, ingot crystallization, wafer cutting, cell fabrication, module fabrication and other appropriate steps)
- production capacity and total shipments of each manufacturer for modules (and wafers and cells if they constitute a significant fraction of shipments)
- technical characteristics of standard commercial modules (cell material, typical module output power and size, operating voltage, type of encapsulation, year warranty, certification)
- availability of modules specially designed for utility applications (large size modules, high insulation modules, facade and roof top modules, etc.) and their characteristics; if such modules are available, it should be specified whether or not module specification have been issued (or approved) by utilities
- module prices paid for specific small (< 1 $kW_p$) and large shipments; prices should be in national currency/$W_p$ (NC/$W_p$) and US$/$W_p$ and should not include VAT

### b) BOS Components

Collected data should concern only PV-oriented manufacturers having production facilities in the responding country and should include the following items:

■ Inverters
- list of manufacturers with a specific experience in the PV sector
- technical characteristics of commercial inverters (typical rated power, commutation mode and technique, switching components, power factor, harmonic content, efficiency at rated power)
- availability of standardized inverters designed on the basis of utility specifications or for special utility applications (e.g., roof tops) and their typical characteristics
- prices paid for specific shipments (NC/$W_p$ and US$/$W_p$)

■ Batteries
- list of manufacturers with a specific experience in the PV sector
- typical product characteristics
- prices paid for specific shipments (NC/$W_p$ and US$/$W_p$)

■ Battery charge controllers
- list of manufacturers with a specific experience in the PV sector
- typical product characteristics
- prices paid for specific shipments (NC/$W_p$ and US$/$W_p$)

■ DC switchgears
(circuit breakers, isolated switches)
- availability of components purposely designed for dc circuits (PV array) and their main characteristics

■ Supporting structures
- availability of standardized supporting structures and the characteristics and, if possible, prices (NC/$m^2$ and US$/$m^2$) of specific installations

### c) Systems

■ The information collected should include the following items:
- list of the main companies operating in the market of PV systems; for each company, it should be specified what kind of systems (stand-alone systems and/or grid-connected plants) are marketed and if some of the plant components (modules and/or BOS components) are custom made
- availability of standardized systems for special utility applications (grid support, roof tops, facades, isolated houses, etc.)
- availability of electric utility specifications for specific systems
- prices (NC/Wp and US$/$W_p$) paid for specific small (< 1 $kW_p$) and large grid-connected plants and for some typical stand-alone systems

## 2. Market and Business Today

### a) Overall PV System Market

- total installed power per country in $kW_p$ by 31/12/92 and 31/12/93
- value of the business in 1993 $ connected with this national market, based on a "turn key" price of the total energy system
- import of complete modules in $kW_p$ as an indicator for the share of foreign companies in the national PV market and the indicated business value in 1993 $
- export of complete modules in $kW_p$ as an indicator for the share of national companies in the international PV market and the indicated business value in 1993 $
- in the first Status Review, information about import and export will be collected just for modules; in the subsequent Status Reviews, similar information on systems will also be collected

### b) PV System Market Sectors

- installed power per country in $kW_p$ by 31/12/92 and by 31/12/93
- mean irradiation and/or estimated annual energy production (MWh/yr) for the following submarkets:

- non-domestic autonomous applications, divided into the following categories:
  - water pumping
  - professional (telecommunications, warning devices, aids to navigation)
  - cathodic protection
  - agricultural
  - other

- rural electrification (domestic), divided into the following categories:
  - recreational applications and holiday houses
  - single houses
  - other, including villages and islands

- small dispersed PV on buildings, divided into the following categories:
  - dwellings
  - commercial buildings-facades
  - commercial buildings-roofs

- medium and large scale grid-connected systems, divided into the following categories:
  - smaller than 100 $kW_p$
  - between 100 $kW_p$ and 1 $MW_p$
  - larger than 1 $MW_p$

## 3. Demonstration and Field Tests

### a) Main Demonstration Programs and Projects

List of main photovoltaic demonstration programs and projects and the associated promoters (such as national governments, government agencies, local authorities, electric utilities, industry)

For each program and project, a short description should be provided containing the following data:

- reasons for and expected goals from embarking on the demonstration program or project
- size (installed power capacity, $kW_p$) and main technical and economic data
- funding sources and cost sharing
- organization responsible for plant construction and management
- main accomplishments by the end of 1993 or end of operating period (energy produced, system efficiency. operating cost, etc.)
- problems encountered and lessons learned
- planned continuation of program and plans for new activities

Costs should be given in NC and 1993 US$.

### b) Provide a table summarizing the demonstration programs and projects in the country. Smaller installations may be lumped together or described by giving a typical example.

## 4. Non-technical Factors

### a) International Policies Affecting the Use of PV Power Systems

- environmental policies and treaties
- other

### b) National or Local Policies Affecting the Use of PV Power Systems

- national and/or regional plans to promote the diffusion of photovoltaic generation in general
- national and/or regional laws regulating non-utility production of electric energy

### c) Standards

- main technical regulations for PV plant construction and operation (dc working voltage, safety and control devices, harmonic distortion, power factor, supporting structures, etc.)
- availability of standards and grid interconnection rules for PV systems
- specific rule problems to be solved in order to facilitate PV plant diffusion

### d) non-electrical factors limiting PV applications

- building codes
- land use
- ownership/liability
- other

### e) Tariffs and Rates

- national and/or regional laws providing incentives for the construction of PV plants (public subsidies, fiscal incentives, and amounts collected)
- price regulations for the PV energy delivered to the grid
- identity class of subsidy recipient (customer, manufacturer, utility)

### f) Environment

- existence of specific environmental regulations which favor PV plants with respect to conventional plants
- availability of specific studies to evaluate hidden and social costs of the various energy sources
- existence of taxes on environmental pollution (carbon tax, etc.)

## g) Utility and Public Perceptions

Utility perceptions of photovoltaic should be presented taking into account the following points:

- public perception of PV
- research and development activities carried out by utilities
- pilot plants built and/or managed by utilities
- planned use of PV for demand or supply side applications (isolated/remote users, grid support, peak load production on consumer premises, etc.)

# APPENDIX C

## Terminology, Definitions and Abbreviations

The symbol "$" will always mean United States Dollars. For other countries using dollars for their currency, the "$" symbol will be presented with their country designation, e.g., CAN$.

The word "program" will be used throughout this report, including when reference is made to the IEA Photovoltaic Power Systems Programme. In that case, the word "program" will also be spelled as it is in the United States.

The term "off-grid" systems will be used in place of terms such as "stand-alone" systems and "autonomous" systems.

Throughout this report, the words "Europe", "Pacific Rim" and "North America" refer to those reporting countries in each region. Note that "Europe" lacks important data from Spain which is not a reporting country, the "Pacific Rim" only includes Japan and Korea, and that data from Mexico is not included in "North America".

The following currency conversion rates from the June 1, 1994 Washington Post were used:

| Country | Dollar in Foreign Currency |
|---|---|
| Austria | 11.58 |
| Canada | 1.38 |
| Denmark | 6.47 |
| European Union | 0.86 |
| Finland | 5.42 |
| France | 5.63 |
| Germany | 1.65 |
| Italy | 1,597.00 |
| Japan | 100.00 |
| Korea | 806.00 |
| Netherlands | 1.85 |
| Sweden | 7.78 |
| Switzerland | 1.40 |
| Turkey | 33,377.00 |
| United Kingdom | 0.66 |

# APPENDIX D

## National Input Reports

| | |
|---|---|
| AUSTRIA | Status Report on PV Power Applications In Austria |
| CANADA | Status Review of PV Applications in Canada |
| DENMARK | Danish Status Review of PV Power Applications |
| EUROPEAN UNION | Status Review of PV Power Activities Supported by the European Commission |
| FINLAND | Task 1 Status Report Finnish Contribution |
| FRANCE | Status Review of Photovoltaic Power System Applications In France |
| GERMANY | Status Review of PV Power Applications in Germany |
| ITALY | Status Review of PV Power Applications in Italy |
| JAPAN | Status Review of PV Applications in Japan |
| KOREA | Status Review of PV Power Applications in Korea |
| NETHERLANDS | Status Review of PV Power Applications in the Netherlands |
| PORTUGAL | Task 1 Status Report Portugal Contribution |
| SWEDEN | The Swedish Photovoltaic Technology Status Survey 1993 |
| SWITZERLAND | Status Review of PV Power Applications |
| TURKEY | PVPS Programme Status Report for Turkey |
| UNITED KINGDOM | Status Review of PV Power Applications In The United Kingdom |
| UNITED STATES | Status Review of US PV Power Applications |

# APPENDIX E

## Task 1 Participants

| | |
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