# European Photovoltaic Industry Association

# PHOTOVOLTAICS IN 2010

## Photovoltaics: Current Status and a Strategy for European Industrial and Market Development to the year 2010

## 1. INTRODUCTION

It is a European Union objective to stabilise Europe's carbon dioxide emissions at their 1990 levels by the year 2000 in order to counteract the threat of global warming. The European Union approved in 1993 the ALTENER Programme which aims to develop the use of renewable energy sources in Europe and increase trade in renewable energy products internationally.

ALTENER, which will run for five years, from 1993 to 1997 inclusive, with a total budget of around 40 MECU, will do this by: promoting the market for renewable energy and its integration into the internal energy market; financial and economic measures; training, information and outreach activities; and cooperation with countries beyond the Union.

The Programme's specific target is to effect a 180m tonne reduction in carbon dioxide emissions by:

- doubling the use of renewable energy sources, from 4% of total consumption in 1991 to 8% in 2005
- trebling production of electricity in Europe from renewable energy sources
- securing a biofuels market share of 5% of total vehicle fuel consumption

As well as environmental protection, ALTENER will contribute to the better use of local energy sources, ensure efficient allocation of public funds, play a part in the completion of the Union’s internal market and, importantly, reduce dependence on imported energy.

As part of the ALTENER Programme the European Commission Directorate for Energy (DGXVII) commissioned the European Photovoltaics Industry Association (EPIA) to undertake a study into the current status of photovoltaics (PV) in Europe and worldwide and to develop a strategy for the development of the European industry and market to the year 2010. The study was undertaken considering the targets for PV set by the ALTENER Programme of 500 MW of PV installed on European Union territory by 2005. EPIA contracted three of its members to undertake the background work for the study (IT Power Ltd - UK, LIFE - Italy and TEAM - Italy).

## 2. OBJECTIVES AND SCOPE

The objectives of the study are to recommend a framework for the sustainable growth of the European Photovoltaic Industry in partnership with the increased production of European electricity from a renewable energy source (photovoltaics) and to increase international trade in European PV products. The time frame considered is to the year 2010.

The study has been undertaken with due consideration of the ALTENER targets and also the conclusions and recommendations of other studies including The European Renewable Energy Study (TERES, DGXVII, 1993) and the conclusions of the 1994 Madrid conference *Action Plan for Renewable Energy Sources in Europe* (DGXII, XIII, XVII, European Parliament STOA Programme).

The recommendations have been developed after a general invitation to the European PV industry to propose and prioritise initiatives as well as the direct inputs of EPIA.

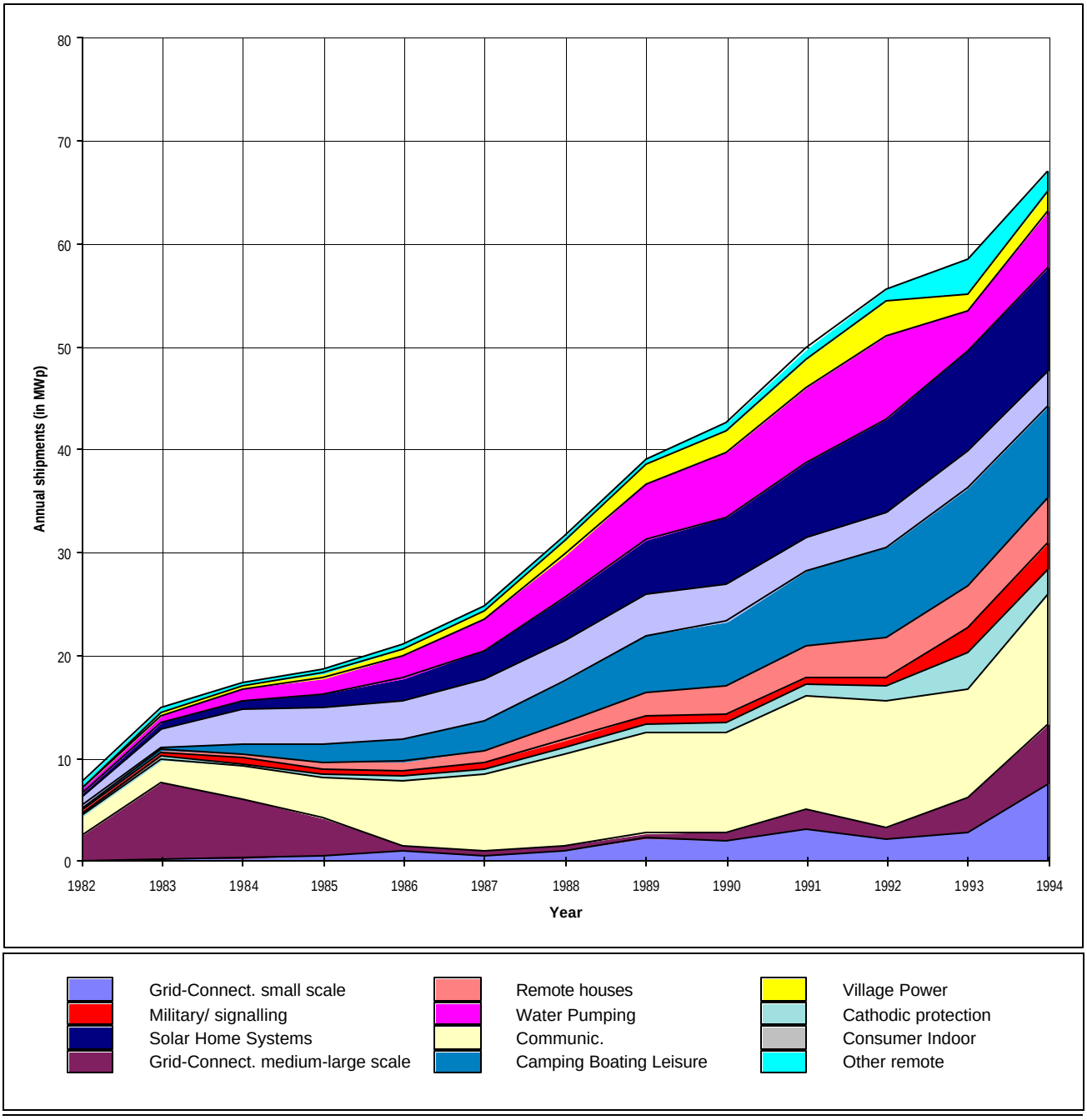
## 3. STATUS OF EUROPEAN PHOTOVOLTAICS

### 3.1. World market history

The year 1994 saw an upturn in the world market after the slower growth rates of the past 2 years. The overall total was estimated at 69.8 MWp in 1994, which was a record high, and showed 14 percent growth over last year's total of 61.2 MWp. Figure 3.1 shows the history of the world market from 1982 to the present day by application. It is estimated that in 1994 a cumulative total of 350 MWp of photovoltaics was installed worldwide 70 MWp of which was installed in Europe.

During the period 1988-91 world market growth rates were in the 15 to 20% range. However, the 1992 and 1993 growth rates were around 6-8%. The higher growth rate for 1994, and the mood of optimism within the industry are indicators that these slacker years were a temporary phenomenon and that the previous higher rates can be resumed (or in the correct conditions, exceeded) over the next decade.

Figure 3.1: Actual world photovoltaic market development (1982-1994)

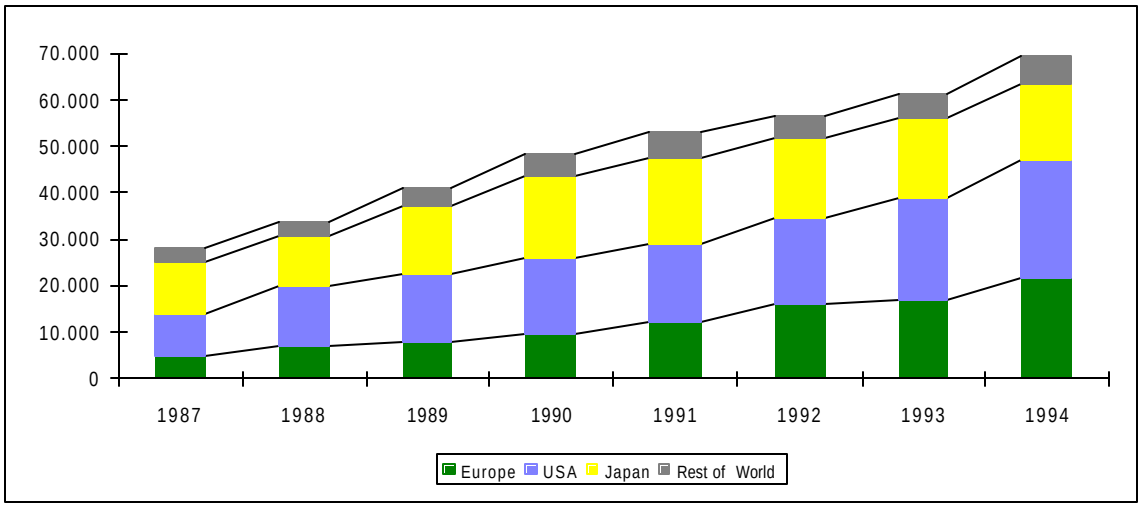


## 3.2 Europe within the world market: 1994

For the purposes of analysis the world PV production market is usually divided into four groups: Europe; US; Japan and the 'rest-of-the-world (ROW)'. Conventionally European module production has been considered as produced by European owned companies but excluding companies based in the USA. Figure 3.2 shows the contributions of the various regions cumulatively over recent years. Although Japan and the US have been market leaders over much of the history of the market, Europe has gained rapidly in recent years and now produces more than Japan, taking just over 30% of the share of the world market. The rest of the world category is comprised mostly of manufacturers in the developing countries of India, Brazil and China.

Table 3.1 shows the PV industry shipments by region since 1987 and the present production market breakdown in terms of MWp in 1994 and % share of the world market. The European PV industry is growing well with a 3-year average growth rate exceeding that of the USA or Japan. This years shipments from European companies stood at 21.7 MWp. This makes European companies the fastest growing and second only to the US in terms of annual production.

Figure 3.2: World PV Industry shipments




| *Geographical Area* | *Production Capacity of Cells Manufact.* | *Estimated annual Shipments in kWp* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Mwp/year* | *1987* | *1988* | *1989* | *1990* | *1991* | *1992* | *1993* | *1994* | *Cumulative 1987-1994* | |
| | | | | | | | | | | *kWp* | *%* |
| Europe | 31,7 | 4.700 | 7.100 | 7.900 | 9.800 | 12.100 | 16.000 | 16.900 | 21.700 | 96.200 | 24,6% |
| USA | 54,0 | 9.300 | 13.000 | 14.400 | 16.100 | 17.000 | 18.400 | 22.300 | 25.400 | 135.900 | 34,7% |
| Japan | 25,2 | 11.000 | 10.800 | 15.100 | 17.700 | 18.500 | 17.300 | 16.900 | 16.500 | 123.800 | 31,6% |
| Rest of World | 12,0 | 2.900 | 3.000 | 3.500 | 4.500 | 5.700 | 5.000 | 5.100 | 6.200 | 35.900 | 9,2% |
| **TOTAL** | **122,9** | **27.900** | **33.900** | **40.900** | **48.100** | **53.300** | **56.700** | **61.200** | **69.800** | **391.800** | |

Table 3.1: Annual PV shipments by region

## 3.3 The module destination market

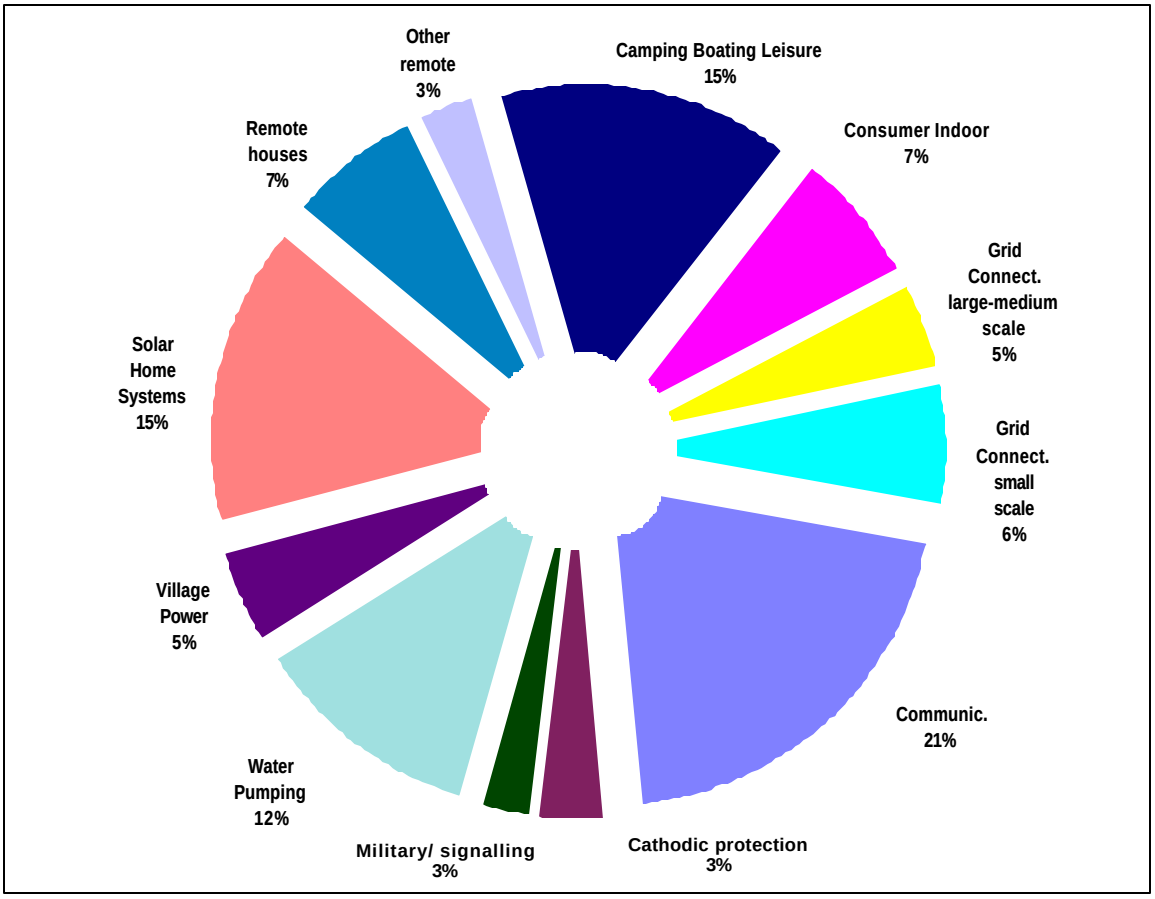
The market can also be analysed by the final application for which PV modules are used.

Figure 3.3 shows the PV industry application destination for the period 1990 to 1994. The largest markets at present are (in order of decreasing importance):

- Communications
- Leisure, boating and caravaning (mainly industrialised countries)
- Solar home systems with the major part in developing countries
- Water pumping (mainly livestock and village water supply in the developing world

The grid connected market represents only 10% of the overall market but in the industrialised countries, particularly in Europe, the market share is higher (22%) and represents one of the fastest growing markets.

Figure 3.3: World PV application market breakdown

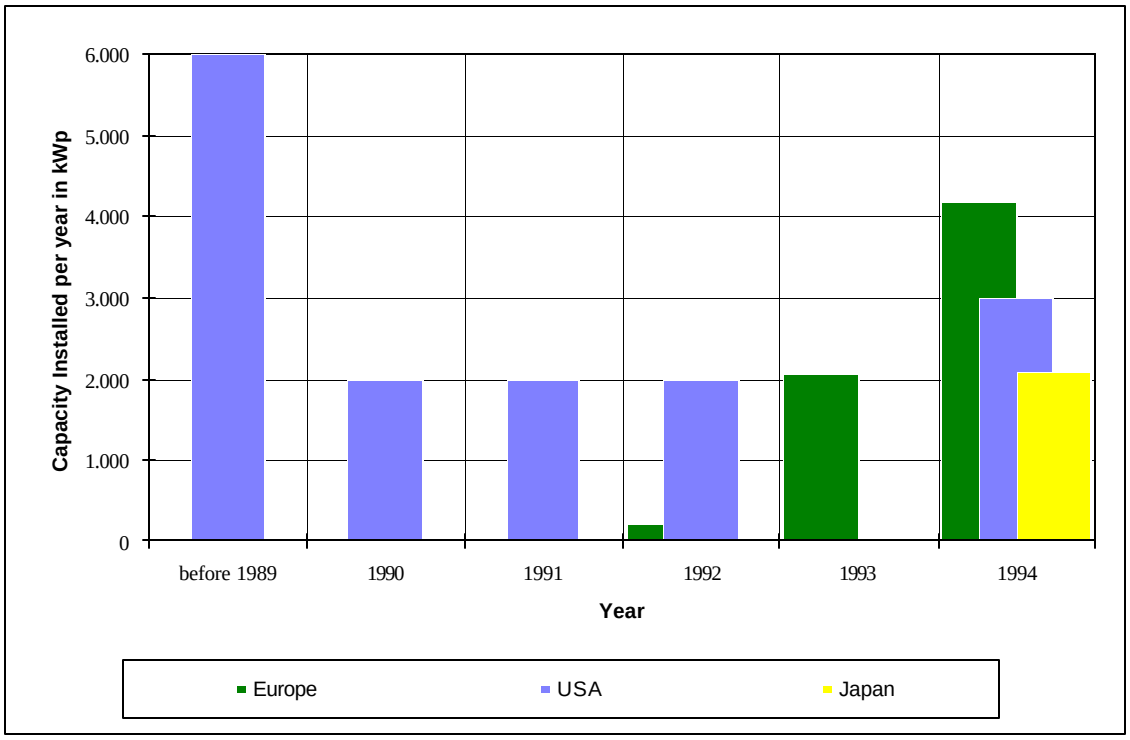


## 3.4 The Market for PV in Europe

In 1994 the European market was dominated by the stand-alone applications (rural habitation and remote industrial), which between them accounted for about 43% of PV use. Installation of medium & large scale plant was also high in 1994 at 5.9 MWp (installation work underway at the Serre plant, Italy and in Spain). The cumulative total of PV installed in Europe in 1994 was 70+MWp.

The roof and building facade grid connected market represents the fastest growing market in Europe. The European share of building mounted grid connected PV systems started each year since 1989 is shown in Figure 3.4.

Figure 3.4: Annual building mounted grid-connected PV system installations



## 3.5 The European PV industry

A survey has been conducted of all known players in the European PV industry, including manufacturers of cells (and/or) modules, systems suppliers, and production equipment manufacturers. These companies (66 in all) were asked to give information in a questionnaire format on their present status (i.e. shipments, capacities, technologies) and also on their future intentions. This was carried out together with the survey of industry views on strategy and policy suggestion that forms the basis of the strategic plan document (Volume 2) that accompanies this report.

In some cases the information that was requested was commercially sensitive, and therefore companies responding were given the choice of flagging certain information items as confidential: in these cases the data will not be shown explicitly, although it may be used in forming totals or aggregates. Of the 66 companies questioned most of the major producers responded. For those which did not respond, estimates have been made based on other industry sources and existing data.

Table 3.2 shows the main players in the European module production industry, ranked in approximate order of production volume. This ranking is derived from survey results, and other published estimates.

Table 3.2: Major players in the European PV module production industry

| Rank (according to production volume) | Company | Country | PV cell technology |
|---|---|---|---|
| 1 | BP SOLAR International | UK | mono/poly |
| 2 | EUROSOLARE | Italy | poly |
| 3 | ASE | Germany | x-Si & amorph |
| 4 | PHOTOWATT | France | poly |
| 5 | HELIOS | Italy | poly |
| 6 | SIEMENS | Germany | mono/amorph. |
| 7 | ISOFOTON | Spain | mono |
| 8 | NAPS | France | amorphous |
| 9 | KONCAR | Croatia | amorphous |
| 10 | R&S | Netherlands | poly |
| 11 | GALLIVARE | Sweden | poly |
| 12 | SOLEL | Denmark | x-Si |
| 13 | ENE | Belgium | poly/mono |
| 14 | INTERSOLAR | UK | amorphous |
| | WESTERN SILICON | Russia | |
| | INTERTECH | Russia | x-Si |

### 3.5.1 Capacity & technology

The manufacturing capacity of the European industry can be defined in different ways. All manufacturers were asked to give their current production capacity in MWp/year and also to specify the numbers of shifts to which this applies. This varies from one to three. Therefore to make a comparison, all capacities were normalised to represent the equivalent 2-shift capacity. Results are shown in Table 3.3. It can be seen that the total 2 shift installed PV module manufacturing capacity in 1994 was 31.7 MWp/yr. Actual shipments were 21.7 MWp in 1994.

The bulk of European production is still based heavily on crystalline silicon, although many of the smaller manufacturers are involved exclusively in amorphous module production. There is still a balance between poly- and mono-crystalline production, with some companies specialising in one only and others using both.

Despite many companies experimenting with thin-film (CIS, CdTe) production, none were in full production at the end of 1994 although some production was expected in 1995.

Table 3.3: European PV manufacturing capacity in 1994

| *Technology* | *Manufacturing Facilities* | |
|---|---|---|
| | *number* | *capacity MWp* |
| Crystall. silicon | 11 | 26,7 |
| Ribbon | | - |
| A-Si | 6 | 5,0 |
| CdTe | | - |
| CIS | 1 | - |
| Other | 1 | - |
| **TOTAL PRODUCTION LINES** | **19** | **31,7** |
| Only modules assembly | 4 | 4,1 |
| **TOTAL PRODUCERS** | **18** | |

### 3.5.2 Production status in 1994

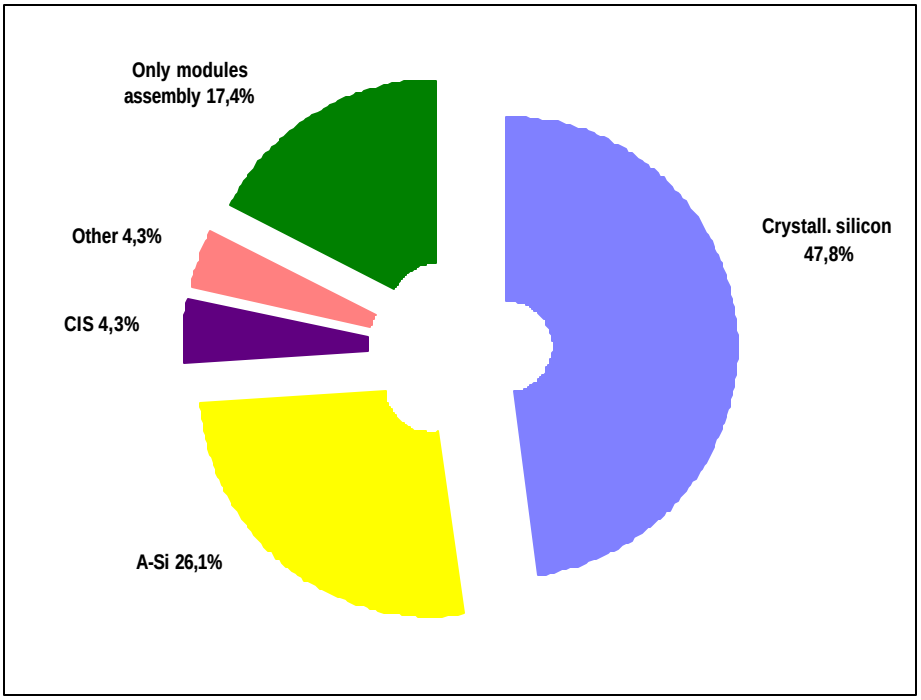
It has already been shown that the estimated PV shipments by European companies in 1994 were approximately 21.7MWp. This figure has been calculated from survey data, and from estimates for other companies that did not respond. The total corresponds closely with other industry estimates. The data includes that for non-European subsidiaries of European companies (i.e. BP Solar Australia etc) but does not include US production by Siemens Solar Industries. A summary is shown in Table 3.4. The companies have been grouped for commercial confidentiality.

The table also contains manufacturer's estimates for the percentage of their modules that were exported outside of Europe. Based on the information received it is estimated that overall around 50% to 70% of European production (11MWp) is exported outside Europe, and the remainder consumed internally.

Table 3.4: European production and exports: survey results

| Company | MWp shipped 1994 | % exported outside Europe |
|---|---|---|
| ASE + BP Solar + Eurosolare | 12 | 50 |
| Photowatt + Siemens + Helios + Isophoton | 5 | 60 |
| All others | 4.7 | 40 |
| **Total** | **21.7** | **50** |

Figure 3.5: Distribution of European PV module manufacturers by technology



### 3.5.3 Plans for expansion

All manufacturers were asked whether they had any plans for expansion. Of the companies that responded to the survey, all expressed an intent to install extra capacity. The responses indicate that the total production capacity of European PV manufacturers is expected to increase by 11MWp/year over the next two years. Within the next five years production is expected to increase by up to 20MWp/year.

### 3.5.4 Employment

All companies were asked the number of employees that they had in Europe and worldwide. Including estimates for companies which did not respond, the number of people employed in manufacturing, systems houses and equipment manufacturers is about 1680 within Europe and 2725 worldwide (including Europe).

Of course in addition to this must be added:

- customer maintenance personnel for installed systems
- photovoltaic research scientists at Universities and research organisations
- consultants
- PV related employment at balance of system suppliers

# 4. THE PHOTOVOLTAIC MARKET: DEMAND SIDE ASSESSMENT

## 4.1 The Existing Market

As reported in section 3 the world shipments of PV modules in 1994 was 70 MWp bringing the cumulative total of operating PV at the end of 1994 to more than 350 MWp. The recent history of module shipments for key applications is shown in Figure 4.1. A detailed analysis of the exisiting PV markets by technology and application are reported in Volume 3 of the reports of this study titled *The PV Market to 2010*.

The cumulative installed capacity of distributed, small-scale grid-connected, building mounted photovoltaics is shown in Figure 4.2 and for medium to large-scale PV power plant in Figure 4.3.

Whilst growth in the PV industry, particularly in Europe, picked up in 1994 the cumulative total of PV produced to date is insignificant with the perceived potential for the technology.

It is however the barriers to be overcome to realise the enormous potential that remains the key factor in the evolution of the PV market.

Figure 4.1: PV Module shipments by application (1990-1994)

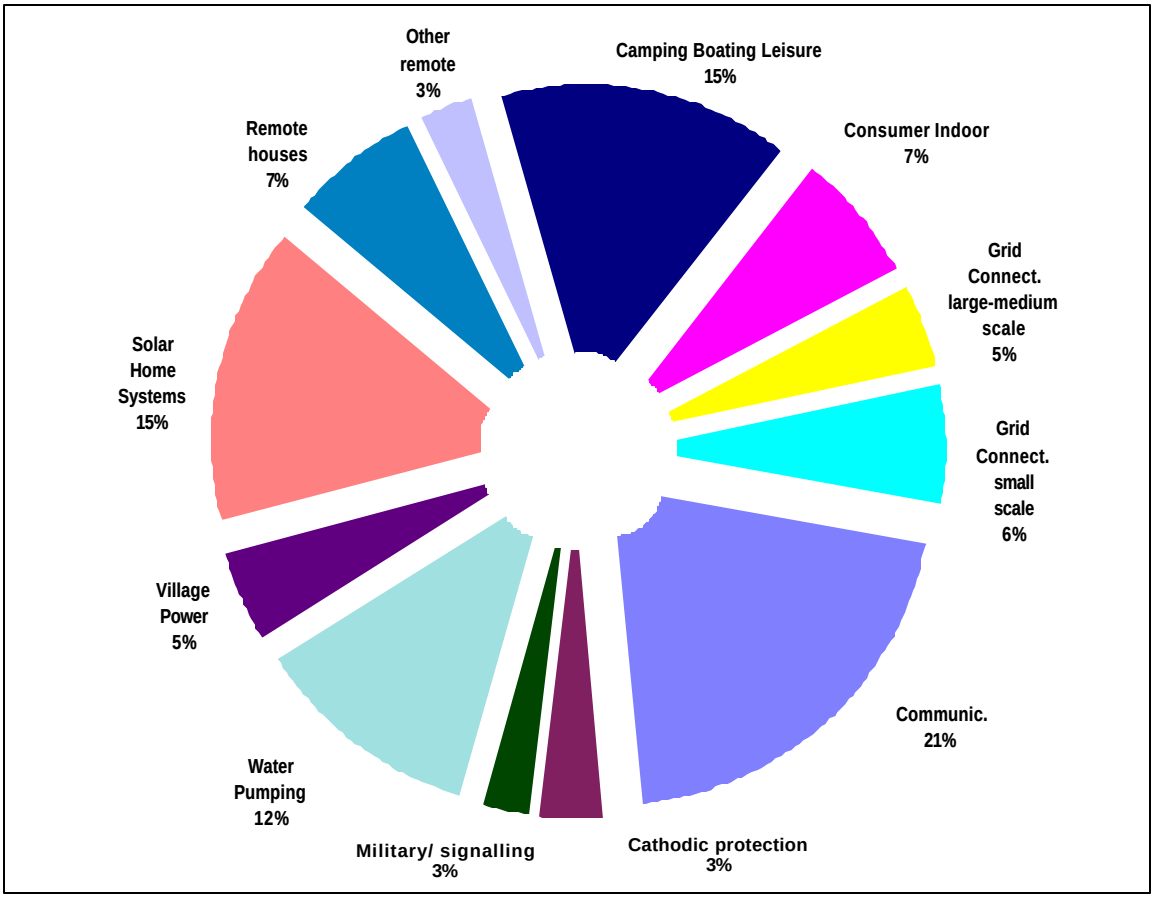


Figure 4.2: Cumulative installed capacity of small-scale grid connected PV

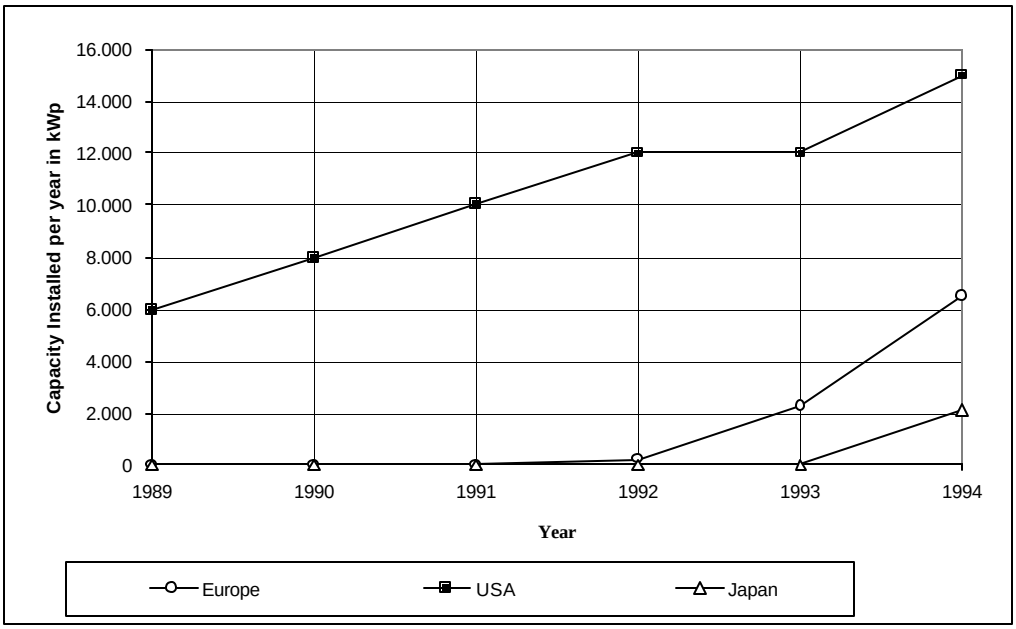
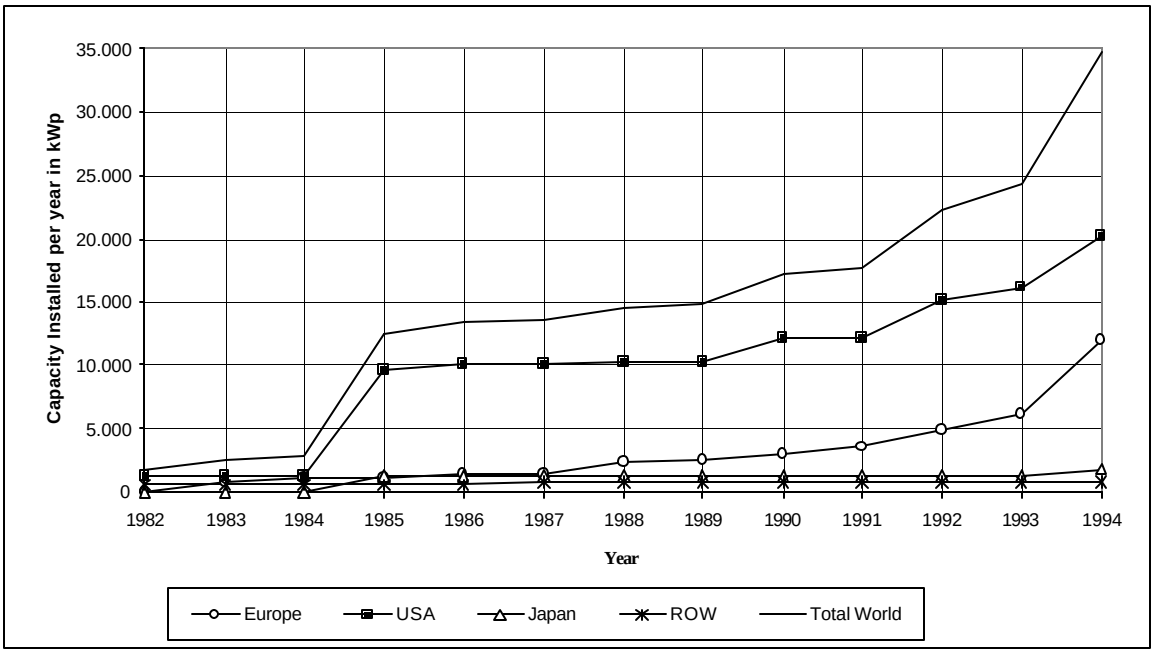



Figure 4.3: Cumulative installed capacity of large scale grid connected PV



## 4.2 The Potential Photovoltaic Market

### 4.2.1 The grid connected market

**Small-scale building mounted applications**

Economic analysis shows that as a result of the cost savings of roofing or building cladding displaced by a PV roof or facade, plus savings on distribution costs as a result of on-site power generation, building mounted PV represents the first entry point economically for grid connected PV. Estimates of the net roofing surfaces available for solar installations have been taken from several investigations. Taking into account the net utilisation factors of building surfaces (as a result of orientation. and obstacle restrictions) an estimate of the net available solar surface area has been determined as shown in Table 4.1 for OECD countries.

The estimated PV electricity potential from these surfaces has been calculated taking into consideration solar irradiation, PV efficiencies and balance of system efficiencies to determine an installable PV building mounted capacity as shown in Table 4.2 and Figure 4.4 for the year 2010. This estimate has taken into consideration improvements in cell efficiency (to 16.5% in 2010) and the evolution of net available solar surface area. It can be seen that some 618 GWp of PV is potentially installable on PV roofs in Europe and more than 1100 MWp in the rest of the OECD countries. The take up of this technology in the developing countries is considered likely to be relatively small. The annual electricity production from 618 GWp of PV in Europe could be 500 TWh but is limited by the ability of the grid to accept day time power.

Figure 4.4: Estimated building mounted PV potential energy contribution in comparison to electricity consumption and hydropower share

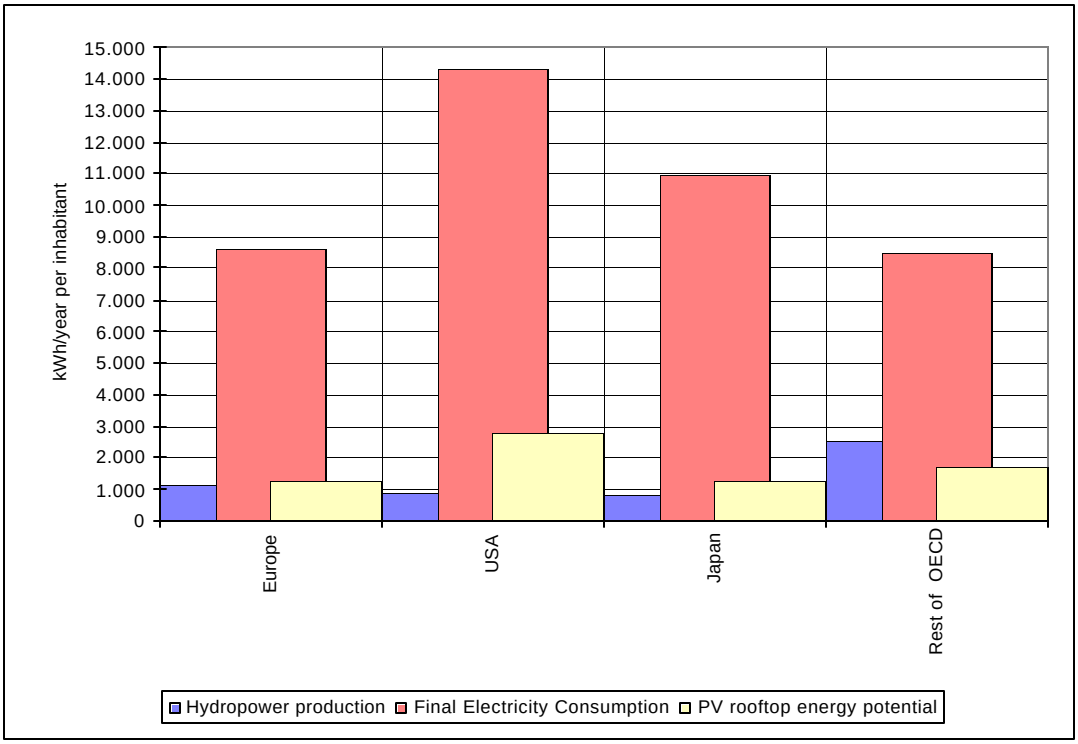


Table 4.1: Estimate of net solar building rooftop surfaces

| Countries | Irradiation kWh/ m2 year | Net Available Solar Surface | | | |
|---|---|---|---|---|---|
| | | houses km2 | offices & services km2 | industrial buildings km2 | TOTAL 1992 km2 |
| Austria | 1.200 | 50 | 15,0 | 13 | 78 |
| Belgium | 1.000 | 43 | 20,0 | 14 | 77 |
| Denmark | 1.000 | 34 | 11,0 | 6 | 51 |
| Finland | 900 | 45 | 11,0 | 8 | 64 |
| France | 1.200 | 362 | 122,0 | 85 | 569 |
| Germany | 1.000 | 532 | 214,0 | 242 | 988 |
| Greece | 1.500 | 64 | 11,0 | 6 | 81 |
| Iceland | 800 | 2 | 1,0 | 0 | 3 |
| Ireland | 1.000 | 16 | 5,0 | 4 | 25 |
| Italy | 1.300 | 336 | 120,0 | 86 | 542 |
| Luxembourg | 1.000 | 2 | 1,0 | 1 | 4 |
| Netherlands | 1.000 | 63 | 30,0 | 21 | 114 |
| Norway | 900 | 34 | 10,0 | 8 | 52 |
| Portugal | 1.700 | 54 | 11,0 | 11 | 76 |
| Spain | 1.600 | 145 | 60,0 | 51 | 256 |
| Sweden | 900 | 78 | 20,0 | 13 | 111 |
| Switzerland | 1.200 | 42 | 18,0 | 12 | 72 |
| United Kingdom | 1.000 | 248 | 123,0 | 96 | 467 |
| Japan | 1.300 | 486 | 289,0 | 264 | 1039 |
| Australia | 2.000 | 153 | 36,0 | 25 | 214 |
| Canada | 1.200 | 224 | 76,0 | 55 | 355 |
| New Zealand | 1.400 | 34 | 6,0 | 4 | 44 |
| Turkey | 1.700 | 324 | 37,0 | 33 | 394 |
| Alaska | 1.000 | 5 | 2 | 1 | 8 |
| USA - Rest | 1.600 | 1838 | 599 | 395 | 2832 |
| USA - South West | 2.100 | 491 | 167 | 110 | 768 |

Table 4.2: Forecast of year 2010 installable building rooftop mounted PV

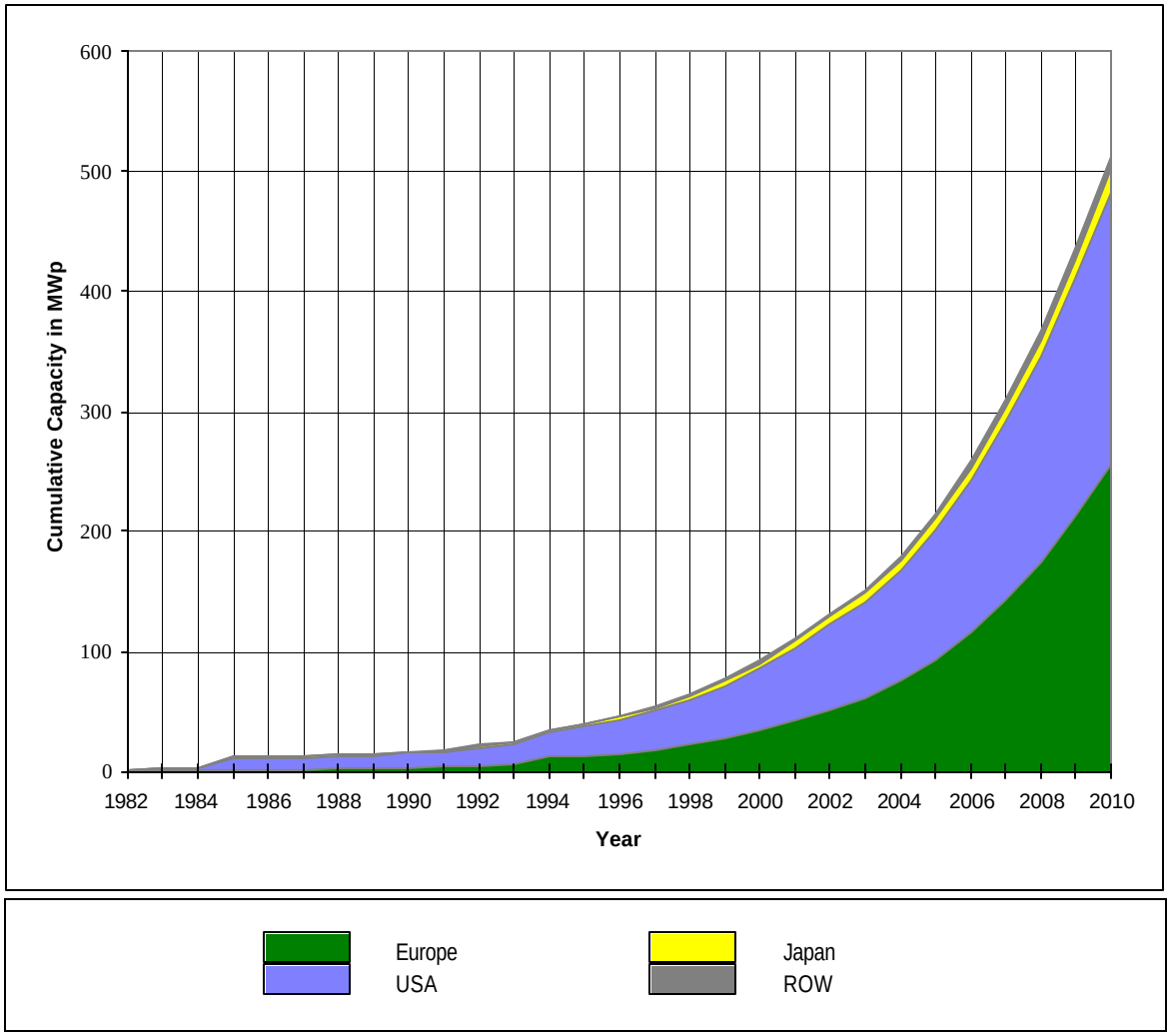
| **REGION** | **Installable PV GWp** | **Wp per Inhabitant** | **ELECTRICITY OUTPUT TWh/year** |
|---|---|---|---|
| EUROPE | 618 | 1584 | 494 |
| USA | 757 | 2344 | 903 |
| JAPAN | 174 | 1385 | 159 |
| REST OF OECD | 211 | 1564 | 230 |

**Medium to large size PV**

The supply side analysis (Volume 3 of the study reports) has shown that grid support applications (such as area grid support installed near a substation or radial line support along single feeders) represents the next entry point for grid connected photovoltaics because of the higher value of electricity at these points.

The limit to the potential of grid connected PV is thus how much of the grid requires PV support as it has been shown in the supporting document that large scale multi-megawatt PV is unlikely to compete economically with conventional power plant up to 2010. A forecast to the year 2010 of large to medium grid connected power plant assuming shipment growth of 15% is shown in Figure 4.5 and indicates a cumulative installed capacity in 2010 of 200 MWp in Europe.

Figure 4.5:. Large to medium grid-connected PV plant cumulative capacity forecast (15% growth)



### 4.2.2 The stand-alone rural development market.

**Developing countries**

The access of rural populations to basic services is summarised in Table 4.3 for the principal developing country regions. Each application of water pumping, health care, education, communications and household electricity has been considered by region and thus the total potential PV requirement calculated. This is shown in Table 4.4 and Figure 4.6.

Table 4.3: Access of rural populations to basic services

| *Geographical Area* | *DEMAND FOR SAFE DRINKING WATER % of Rural Population* | | | |
|---|---|---|---|---|
| | *Low Income Countries* | *Low-Middle Income Countries* | *Upper-Middle Income Countries* | *TOTAL* |
| Central America and Caribean | 63% | 56% | 22% | *40%* |
| Latin America | 29% | 48% | 44% | *46%* |
| North Africa | 14% | 56% | --- | *35%* |
| Saharian Africa | 76% | --- | --- | *76%* |
| Sub-Saharian Africa | 71% | 50% | 50% | *70%* |
| South Africa | 64% | 78% | 10% | *64%* |
| Middle East | 75% | 31% | 19% | *35%* |
| South Asia | 32% | --- | --- | *32%* |
| Central Asia | 32% | 42% | 24% | *32%* |
| East Asia | 57% | 21% | 34% | *47%* |
| Oceania | --- | 80% | --- | *80%* |
| **TOTAL** | **40%** | **38%** | **33%** | ***40%*** |

With a rural population without access to electricity of more than 1 billion people in the developing world the PV potential is more than 16 GWp. Some of the applications such as water pumping can be achieved by wind pumps but for household energy the solar home system remains the preferred option (with more than 10,000 already installed in Indonesia for example).

**Europe**

Within Europe it was estimated in 1987 that the total European (EU12) population that lives permanently or seasonally without electricity was approximately 1.2 million, mainly in the isolated Mediterranean areas, and that around 70,000 houses would be less expensively electrified with PV (totalling 50 MWp) than through grid extension.

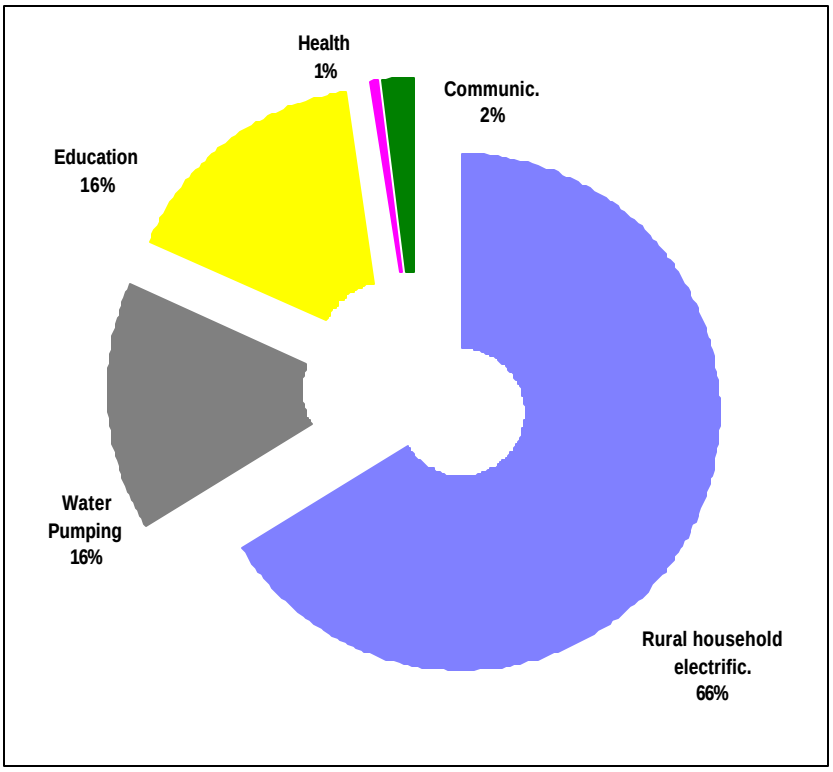
The electricity requirements of island communities in the Mediterranean area of Greece and Italy are particularly of interest for electrification with PV

Including the isolated dwellings and occasionally occupied buildings in Finland, Sweden and Austria a total European potential market of some 150 MWp of PV is estimated after consideration that many summer houses in Scandinavia are already using PV systems.

Table 4.4: Potential developing world stand alone PV power requirement.

| *Geographical Area* | *Potential PV Peak Power required in MWp* | | | | | |
|---|---|---|---|---|---|---|
| | *Rural household electrific.* | *Water Pumping* | *Education* | *Health* | *Communic.* | *TOTAL* |
| Central America and Caribean | 217 | 47 | 236 | 3 | 13 | 516 |
| Latin America | 443 | 72 | 296 | 28 | 22 | 861 |
| North Africa | 356 | 111 | 74 | 2 | 8 | 550 |
| Saharian Africa | 290 | 83 | 36 | 2 | 7 | 418 |
| Sub-Saharian Africa | 1.468 | 327 | 194 | 7 | 28 | 2.023 |
| South Africa | 427 | 106 | 50 | 2 | 8 | 593 |
| Middle East | 450 | 131 | 191 | 9 | 15 | 796 |
| South Asia | 3.272 | 530 | 749 | 44 | 107 | 4.702 |
| Central Asia | 2.267 | 942 | 519 | 9 | 73 | 3.810 |
| East Asia | 1.947 | 294 | 305 | 7 | 34 | 2.586 |
| Oceania | 13 | 2 | 6 | 0 | 1 | 22 |
| **TOTAL** | **11.151** | **2.643** | **2.657** | **112** | **314** | **16.877** |

Figure 4.6: Developing world stand alone PV market potential



## 4.3 Priority Markets

### 4.3.1 Europe

The recommended approach for Europe is that of significantly increasing the contribution of electricity generated from photovoltaics in Europe, in line with the ALTENER objectives, thereby creating a sustainable photovoltaic industry that can maintain its internationally competitive position.

The priority application areas for Europe are shown in Table 4.5. The realisation of these targets, coupled with the cumulative installation of 200 MWp of PV by 2010 for "specialist" applications, including military/signalling, cathodic protection and communications purposes, would guarantee a total of 2000 MWp of PV capacity installed in Europe by 2010.

Table 4.5: Priority markets for PV in Europe - EU15

| APPLICATION AREA | POTENTIAL (MWp) (Theoretical) | PROPOSED CUMULATIVE TARGET IN 2010 (MWp) |
|---|---|---|
| PV roofs | 620,000 | 900 |
| PV facades on commercial and institutional buildings | included in above | 400 |
| Other grid connect | - | 400 |
| Isolated buildings and island communities | 150 | 100 |

#### 4.3.1.1 PV Roofs

The generation of electricity by roof mounted photovoltaics is attractive because:

- generation is on-site thus reducing transmission losses and transmission costs
- there can be savings on avoided roofing tile costs
- there is no additional land usage for the power generation
- distributed PV has a more widespread and higher profile
- visual impact is limited (and sometimes enhances surroundings)
- some users are willing to pay extra as an environmental statement

The installable PV capacity on European roof tops has been estimated as 618 GWp or approximately 1.2 kWp per inhabitant. The potential European electricity production could thus be as high as 500 TWh per year.

There has been significant PV roof top experience within European member countries. In Germany the 1000 roof programme generated 60,000 enquiries which resulted in 2,250 installations (1-6 kWp) during 1990-1994. The total installed power is approximately 6 MWp. In Austria a 200 kWp PV rooftop programme was launched in 1992. In 1994 Japan launched a 70,000 PV roof programme.

#### 4.3.1.2 Commercial and institutional building facades

The benefits of distributed grid-connected photovoltaics on the facades of commercial and institutional buildings are similar to that of roof mounted PV with an additional benefit that often the building electricity demand profile is more closely matched with that of the solar energy resource (peak electricity demand is during office hours).

There have been several PV facades (also known as cladding or curtain walling) installed in Europe. The most recent of these are the 50kWp amorphous silicon facade at the Joint Research Centre, Ispra in Italy and the renovation of the University of Northumbria's computer building in Newcastle, UK where a 40 kWp PV facade was unveiled in January 1995.

The building facade market is considered a priority market for European PV electricity production because of:

- the ability to benignly integrate PV into building elements
- the potential savings on conventional facade material that would have been used (this could equate to as high as 60% of the PV cladding cost once products are standardised)
- the relatively high financial contribution the building users can make.
- many buildings are owned and operated by local and regional governments who may support the objectives of clean technology electricity generation
- it is an application of renewable energy in the urban built environment and can be applied in the renovation of large european cities (a specific area of interest of the EU 1994 Actions de Preparation, d'Accompagnement et de Support - APAS).

It should be noted that roof mounted systems are generally of greater interest in the lower latitudes of Europe whereas building facades (with the exception of PV sun-shades) are of greater interest in the higher latitudes (because of the lower solar altitude). The British Photovoltaic Association (PV-UK) recently proposed a 100 PV facade programme for the UK.

#### 4.3.1.3 Other Grid Connect

In addition to building mounted grid connected PV there remains significant potential for:

- photovoltaics mounted on motorway and railway sound barriers
- grid-support and non-building mounted distributed PV

In many European countries, where population densities are high and available land is scarce, it is often impractical or unfeasible to reserve prime areas of real estate for land-intensive applications such as central generating PV power plants. As has been demonstrated in the case of building integrated systems though, the modularity of PV makes it possible to combine or add PV systems into an existing support structure which already serves one purpose thereby effectively using the same space for two different functions.

Motorway and railway sound barriers are excellent examples of such structures: noise abatement has become a major issue in many communities as new high speed rail links are introduced. At least two European railway companies are investigating combining sound deflecting barriers with the installation of photovoltaics. Several schemes incorporating grid-connected PV systems into motorway barriers have already been successfully completed, such as the 100kWp pilot project on the N13 motorway near Chur in Switzerland, a 40kWp installation on the A1 motorway in Austria, and a 55kWp installation in the Netherlands.

There is considerable potential that similar schemes could be replicated throughout much of Europe. Estimates of the Swiss potential for using land surrounding highways for power generation purposes suggest that some 375 MWp could be generated from these areas, while Dutch calculations propose that an annual electrical output of some 18 billion kWh from road and railway verges in the Netherlands is technical feasible.

In the longer term, multi-megawatt power plants will be a viable option for large-scale electricity generation in southern European states. Already, Italy has one 3.3 MWp plant operated by ENEL at Serre, and there are plans for more than 10MWp of utility owned PV power plant by the end of 1995. In Toledo, Spain, a 1.1 MWp is helping to develop PV system components into a reliable cost-effective power station technology which would aid replication throughout Southern European states.

#### 4.3.1.4 Isolated buildings

It was estimated in 1987 that the total European (EU12) population that lives permanently or seasonally without electricity was approximately 1.2 million mainly in the isolated Mediterranean areas and that around 70,000 houses would be less expensively electrified with PV (totalling 50 MWp) than through grid extension.

With the isolated dwellings, occasionally occupied building in Finland, Sweden and Austria and island communities Europe wide a potential market of some 150 MWp of PV is estimated after consideration that many summer houses in Scandinavia are already using PV systems.

The European isolated building market is considered a priority area because:

- the use of PV is often economic even without consideration of external costs
- many of the dwellings are in regions designated for regional EU support

### 4.3.2 Global Markets

The analysis of the global markets has identified priority regions and applications. These are summarised in Table 4.6.

Table 4.6: Priority applications and markets for development outside of Europe

| APPLICATION | REGION | COMMENTS |
|---|---|---|
| Solar home systems | India | -very high recent growth<br>-international support<br>-60M ECU PV project underway |
| Solar home systems<br>Health care systems | Indonesia | -proven market<br>-World Bank GEF project initiated<br>-50 MW government target |
| Solar home systems<br>Industrial (telecomms, navaids etc.) | China | -high potential<br>-indigenous industry outdated<br>-World Bank projects under consideration |
| Solar home systems | Central Asia (CIS and Mongolia) | -high potential<br>-many Nomadic families<br>-international support developing<br>-CIS PV industry underdeveloped |
| Solar home systems<br>Health care systems<br>Solar pumps | South Africa | -high potential<br>-OPEC, US, EU support developing |
| Solar home systems<br>Health care systems<br>Solar pumps | Maghreb | - EU support<br>- past initiatives (PV Euromed) |
| Solar home systems<br>Solar pumps | Brazil/ Argentina and SouthAmerica | -high potential<br>-relatively high income in some rural areas<br>-strong competition from USA |
| PV roofs and facades | OECD | -urban development<br>-high potential<br>- higher awareness |

These markets have been given priority with respect to a European PV Industry plan because they are markets that are presently underdeveloped and thus where concerted and co-ordinated market development is required.

In comparison there are established markets for the European PV industry in telecommunications, navigational aids, cathodic protection etc. where the market is already free and competitive. Developed regions such as North America, Japan and Australia are already key markets for many European PV companies and thus already being monitored. Although the potential for PV applications in these regions is assumed to be greater than that in developing countries, these are not considered priority targets for public supported market development.

Note that the developing world solar home systems market includes large scale provision of solar electricity as an alternative to grid extension and can be utility organised as well as NGO and government sponsored.

## 4.4 Market Forecast To 2010

### 4.4.1 Business as usual scenario

Extensive extrapolations of different market scenarios to the year 2010 have been developed using a computer based model of the market. The business as usual scenario has been based on the same average 15% growth rate as experienced in the last decade. Accelerated scenarios have also been considered. It should be noted that other technologies such as personal computers and mobile cellular telephones have market growth rates of 25% to 50%.

The outcome of the business as usual forecast is shown for annual shipments and by year 2010 application in Figure 4.7 and Figure 4.8 respectively. Annual shipments are expected to reach 630 MWp in 2010 with the two largest markets:

- solar home systems in developing countries
- grid-connected mainly building mounted systems in industrialised countries

Figure 4.7: The Business as usual 2010 market forecast by application

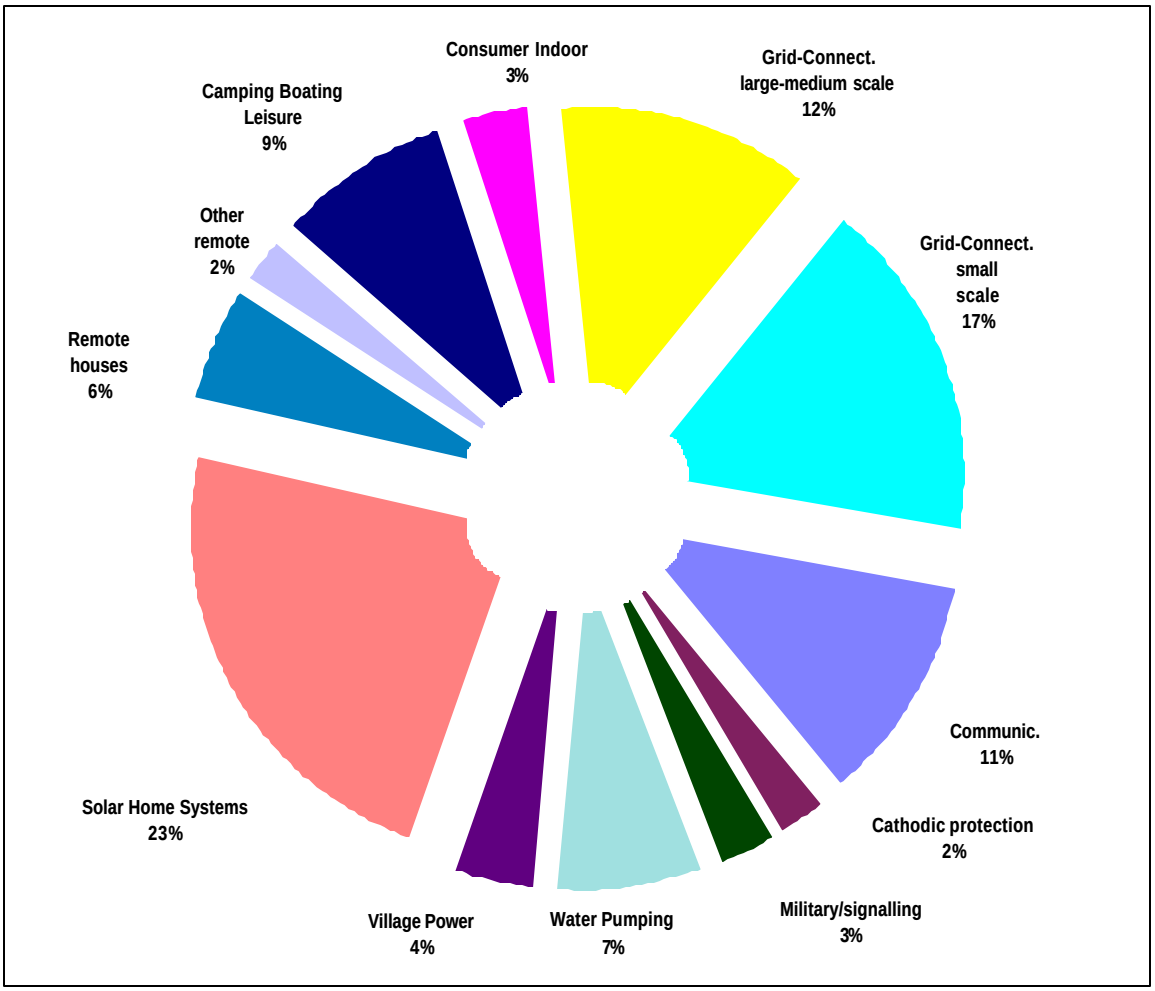
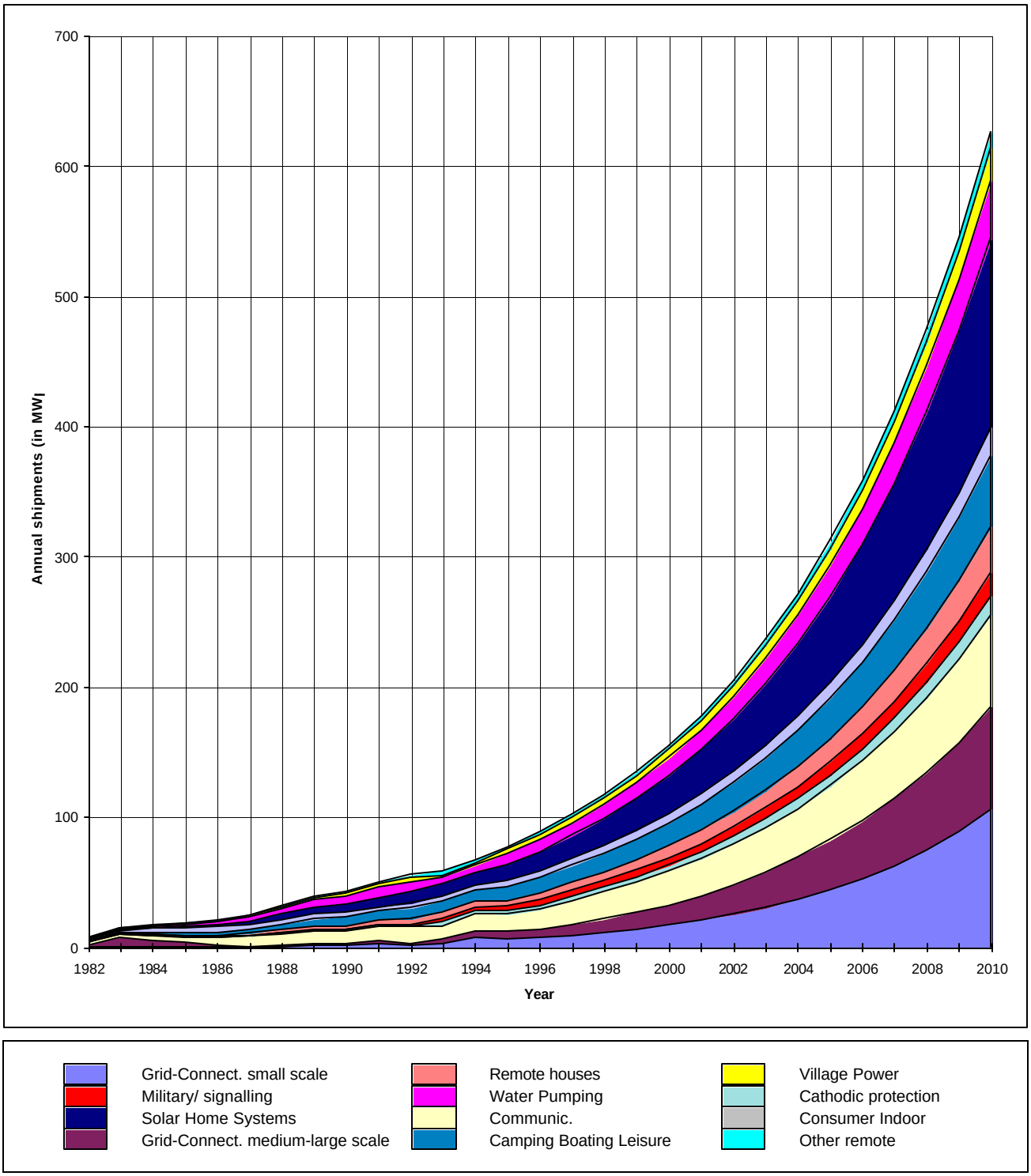


Figure 4.8: Business as usual world PV market forecast to 2010



### 4.4.2 Enhanced scenarios

Table 4.7 presents 5 enhanced market growth scenarios. In all cases the cumulative installed amount of PV in Europe is assumed equal to 32%. It should be noted that the 20% world market growth rate scenario would result in 2000 MWp installed in Europe in 2010 (and also reach an intermediate key stage of 500 MWp installed in 2005).

Table 4.7 also indicates the investment required annually (as a percentage of industry PV module annual sales value) and direct employment generated.

Table 4.7: Enhanced market growth scenarios to 2010

| **What is required** | | **to reach in year 2010 a whole world PV market scenario of:** | | | | **Europe (assuming 32% of capacity installed in EU)** | |
|---|---|---|---|---|---|---|---|
| World PV market growth rate | Investment for manufacturing capacity increase | Annual shipments | Cumulative installed capacity | PV sector Employement | Remarks | Cumulative installed capacity | PV sector Employment |
| % year | % of sales | MWp/year | MWp | Employed | | MWp | Employed |
| 15% | 7,2% | 630 | 3.900 | 152.000 | Business as usual, will develope spontaneously | 1.200 | 32.000 |
| 20% | 9,3% | 1.240 | 6.300 | 261.000 | Achievable by eliminating market barriers | 2.000 | 56.000 |
| 25% | 11,1% | 2.380 | 10.200 | 453.000 | Requires consistent market stimulation | 3.300 | 98.000 |
| 30% | 12,8% | 4.460 | 16.700 | 783.000 | Requires breakthrough in technology and costs | 5.300 | 170.000 |
| 35% | 14,4% | 8.160 | 27.300 | 1.345.000 | Extreme scenario | 8.700 | 294.000 |

# 5. THE PHOTOVOLTAIC MARKET: SUPPLY SIDE ASSESSMENT

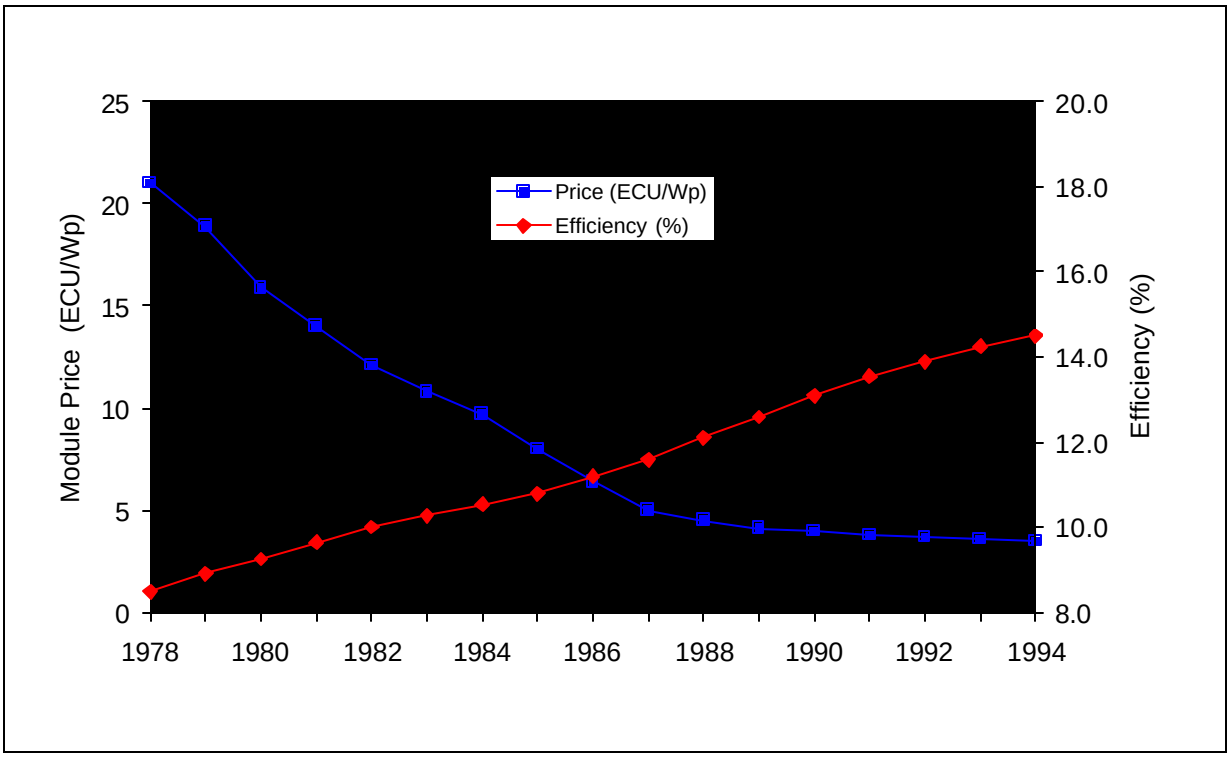
## 5.1` Technology Assessment

### 5.1.1 Background

The rate of advancement in PV module technology since the 1970's has been extremely rapid, both in the development of cell and materials technology, and in improved manufacturing methods. The industry has fought to keep pace in bringing these advances into the commercial market place. This has resulted in a dual trend of falling prices and rising efficiencies. Figure 5.1 illustrates the complementary trends of crystalline PV module price and achievable commercial efficiency from 1978 to 1994.

Of the modules available commercially, monocrystalline silicon continues to yield the highest efficiencies, and the best commercial modules presently have module efficiencies of 13.5 %.

Figure 5.1: Cost and efficiency of PV modules



Amorphous silicon remains the only thin-film technology in full commercial production. The two main rivals are cadmium telluride (CdTe) and copper indium diselenide ($CuIS_2$ ,CIS), both still under research or pilot production. Several companies have produced prototype CdTe modules, although none have yet embarked on full commercial production. The efficiencies of CdTe and CIS modules are greater than those of amorphous silicon - around 10% under laboratory conditions - and they do not suffer performance degradation.

This review of PV technology focuses on the 2 key features which govern its future prospects, namely efficiency and cost.

### 5.1.2. Theoretical and practical PV efficiencies

#### 5.1.2.1 Crystalline silicon

Crystalline silicon (either monocrystalline or polycrystalline) is still the mainstay of power modules for the professional and remote systems market. Silicon is not the ideal material for solar cells, but it has the benefit of being a widely available raw material which is the basis of the electronics industry. It is well understood and intensively researched and the same technology developed for the electronics industry is transferable to solar cells. Efficiencies of more than 20% have been obtained with silicon cells in the laboratory, but production cells are currently averaging 13-14% efficiency. The theoretical limit for crystalline modules approaches 30%.

#### 5.1.2.2 Thin-Films (a-Si, CdTe, CIS)

There are three types of thin film cell which are likely to be of commercial importance in the next few years. These are the amorphous silicon cell, most probably in a double junction structure, the copper indium diselenide/cadmium sulphide heterojunction cell (or variants of it) and the cadmium telluride/cadmium sulphide heterojunction cell. All of these cells have active layers in the thickness range 1-10 microns, and all are manufactured by processes which are capable of large volume, low cost production. There has been a major R&D effort to increase the efficiency of the cells and the reproducibility of the product.

**a-Si**

Amorphous silicon is the best developed thin-film cell. Its performance is still hindered by the fact that the optimum material for the top layer - which should be an optically transparent highly conductive p-type material - has not yet been discovered. The transparent conducting material used is usually tin oxide, which is n-type. The action of light absorption by one of the layers reduces the efficiency of the cells in time. Production single junction a-Si modules have a stabilised efficiency of around 5%, although more than 12% has been achieved in the laboratory and it is expected that commercial modules will have efficiencies of 8% by 2010.

**CdTe**

Cadmium Telluride has an ideal energy gap (1.45 eV) for a solar absorbing material and has been under research since the 1970s. BP Solar (Europe) and Photon Energy (USA) have both undertaken pilot production and are both planning to commence commercial module production. BP Solar have produced prototype small modules demonstrating efficiencies over 10%.

**CIS**

Copper indium diselenide exhibits the highest optical absorption of all PV materials. Although CIS can be used alone to form an appropriate p-n junction, the best devices have used cadmium sulphide (CdS) as the n-type material. The incorporation of Gallium into CIS (to become CIGS) also has a number of benefits, in particular it increases the energy gap, which at 1eV for CIS gives an inconveniently low voltage. No standard CIS power modules are available commercially as yet.

#### 5.1.2.3 Concentrator Cells

Concentrator cells focus light from a large area onto a small area of photovoltaic material. For this to make sense, an optical concentrator (such as a Fresnel lens) has to be used which costs less than PV cells of the same area. It then becomes possible to justify the use of small areas of sophisticated and expensive cells of very high efficiency, such as gallium arsenide. Gallium arsenide cells have achieved 27.5% in the laboratory, but are more efficient when used in a 2-layer structure with another semiconductor material. 32.6% has been achieved in this way, with hopes to raise this to 40% with a 3-layer cell. Silicon is also used for concentrator cells, with a recorded laboratory efficiency of 26.5% and prototype module efficiency of 20.3%. The two main drawbacks with concentrator systems are that they cannot make use of diffuse sunlight and must always be directed towards the sun with a tracking system.

### 5.1.3 Future prospects for module efficiency improvements

#### 5.1.3.1 Technology advances

A number of areas are being addressed in order to improve cell and module efficiencies. The largest losses arise from the fact that:

- Light is reflected from the module surface
- Light is reflected by the electrical contacts on the front of the cells
- Light can pass through the cell without being absorbed
- The output voltage is only two-thirds of the energy gap.
- Electrons and holes can recombine before crossing the p-n junction
- The semiconductor has electrical resistance which dissipates power
- The energy gap excludes light of lower energies and wastes a proportion of the light of higher energies.

#### 5.1.3.2 Crystalline Silicon

Recent work on crystalline silicon technology has focused upon improved anti-reflection coatings (ARC), front-electrode design and surface texturing to improve light capture.

Silicon reflects about 30% of the incident light and means are under investigation to try to reduce this to below 5%. This is being attempted by using an anti-reflection coating on the surface and by texturing the surface in the form of small pyramids.

Recent advances in silk-screen technology have enabled the printing of finer grid-lines which maintain a high thickness. Grid-lines have already been reduced by some manufacturers from 350 microns to 250 microns - adding almost 0.5% to module efficiencies - and further reductions to 150 microns are expected in the next few years.

Another recent innovation is the introduction of a *back surface field*. Impurities are added to the rear of the cell to create a heavily doped p-type region which sets up a positive electric field. The field acts to reflect free electrons back towards the p-n junction - which they must cross in order to contribute to the output of the cell. Experiments have demonstrated that a full 1% addition to the cell efficiency can be expected using a back-surface field, and this modification can be applied using existing equipment.

A recent innovation known as *laser grooved buried cell* technology has been to form grooves in the cell surface and to deposit the metal contacts into these grooves, effectively turning them on their side. The metal coverage on the surface is reduced in this way from about 5% to under 1%. With these techniques the total reflection can be reduced to around 2% although costs of manufacture are presently higher.

#### 5.1.3.3. Thin films

Efficiency is a critical factor in thin-film module production. At the moment, module costs per Wp are directly linked to efficiency because existing methods for improving efficiency are unlikely to add significantly to material or production costs. Whether this will apply in the longer term to the more complex multi-junction cells being proposed remains uncertain.

A module efficiency of 10% for initial production of CdTe modules for 1996 is estimated by the leading European CdTe module manufacturer, who anticipate a linear increase to 13% by 1999. A major research effort would be necessary to achieve efficiencies of CdTe beyond 13%.

There is scope for improved efficiencies and better stabilities of thin-film modules by the use of *multi-junction cells*. These consist of several (usually three) layers of amorphous silicon or germanium, with each layer tuned to absorb a different part of the solar spectrum. Experimental multi-junction cells have exhibited stable efficiencies of 10%.

#### 5.1.3.4 Future projections

Projections are made below which cover the likely efficiency improvements achievable by 2010, as anticipated by the PV industry. The projections are generally conservative, and assume a continuation of current trends without major technical breakthroughs or order of magnitude market expansion.

Figure 5.2: PV Module efficiencies - crystalline silicon

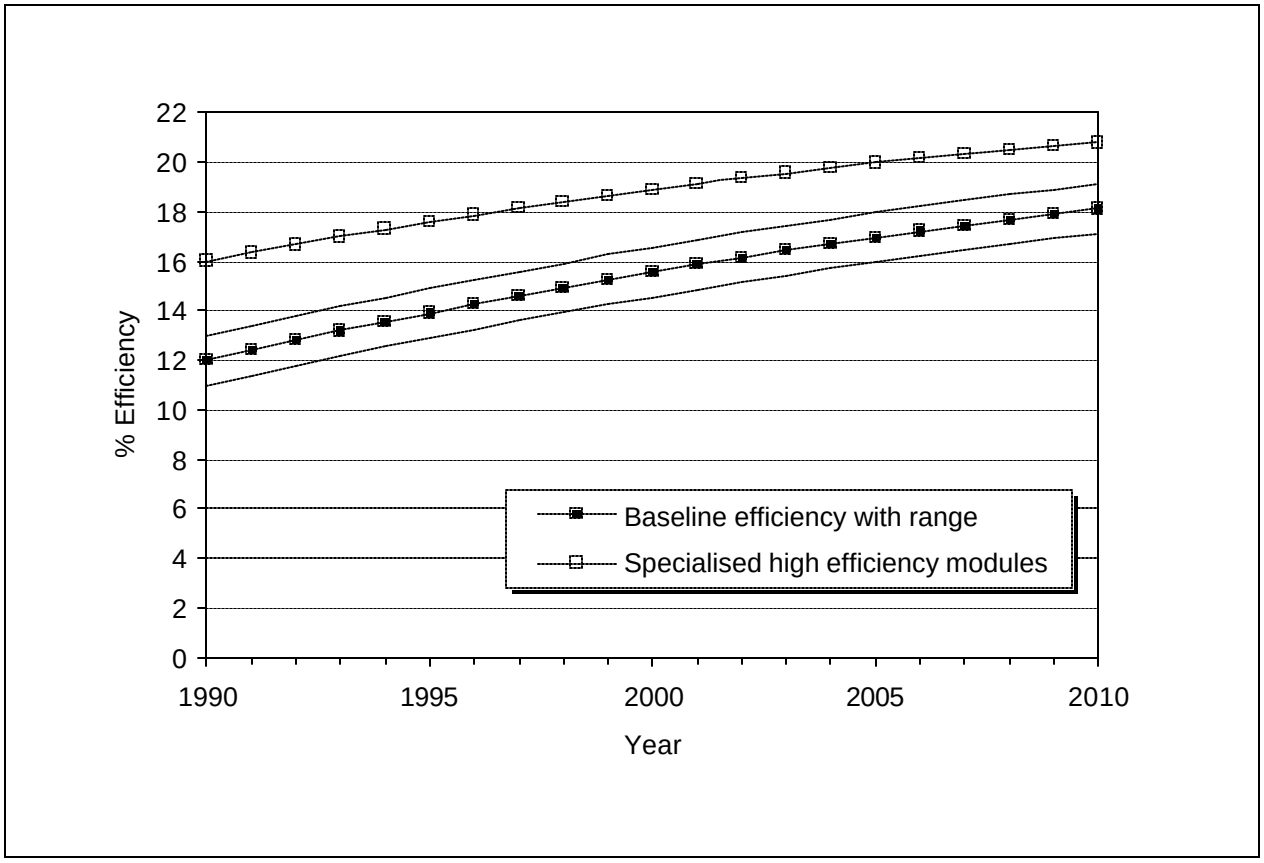
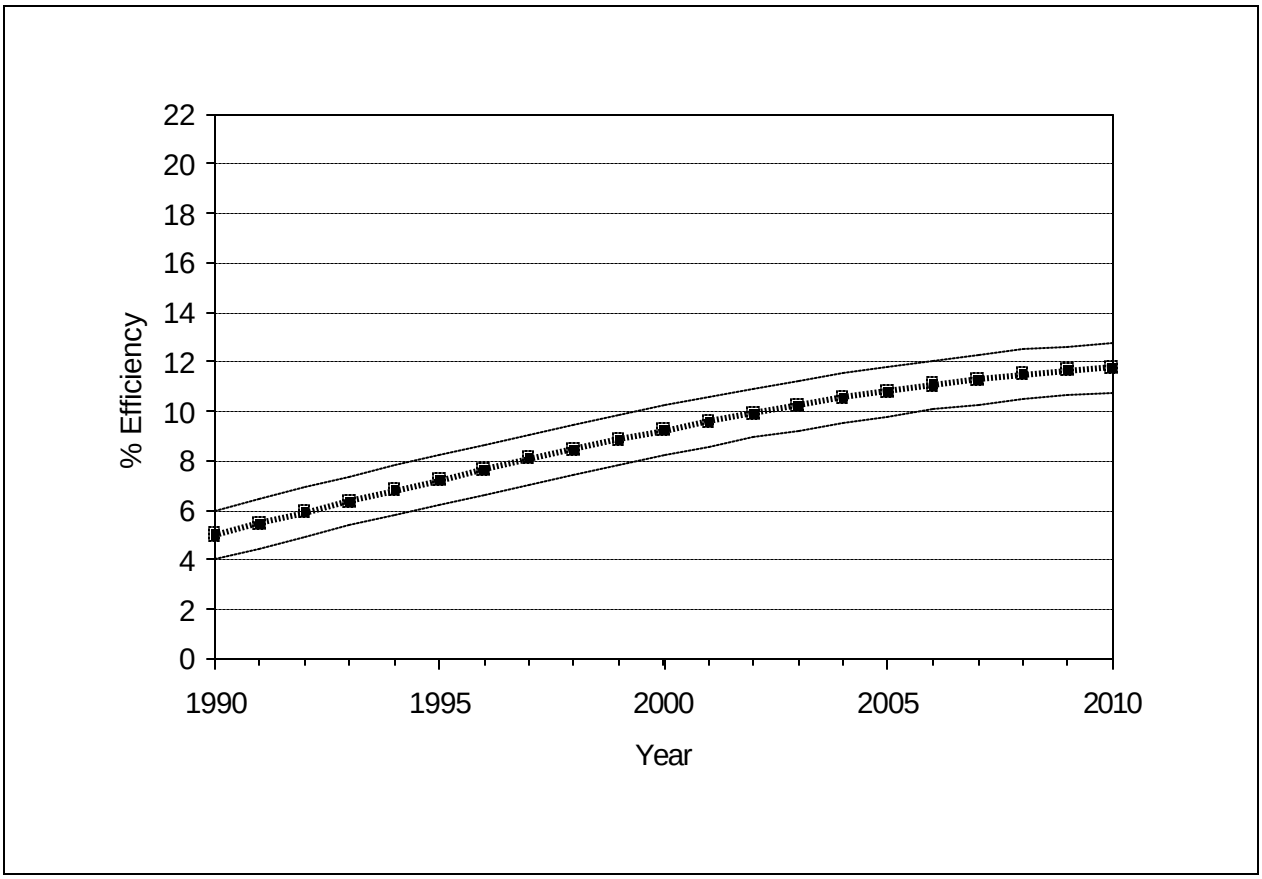


Figure 5.3: PV Module efficiencies: thin film



## 5.2 Power Module Evolution

Crystalline silicon will remain the key technology for power modules to the year 2010 and thus a scenario for power module evolution is described here based on data collected in 1994. It should be noted however that price data in particular varied considerably in the first few months of 1995 as a result of $/ECU and Yen/ECU exchange rate fluctuations. In addition a firming up of prices in early 1995 was noted.

The industrial cost (i.e. not price and thus excluding trading overheads and profit) per Wp for modules made of crystalline silicon based cells, was about 3.3 ECU/Wp in 1994 with significant variations up and down according to material sources and the ability of the various producers to remain within the process yields. The aim of photovoltaic R&D work supported by the European Commission is directed at a production cost level of 1 ECU/Wp for multimegawatt production levels.

A complete micro and macro economic analysis of the photovoltaic process is described in Volume 4 of the reports of this study. For each phase of the PV module process the effects which the various parameters have on the product cost have been analysed. The consumable materials costs are much higher than the other elements of cost. Therefore, the first aspect to be considered is the improvement of the process yield as secure improvements can be obtained investing in process engineering rather than on the research of higher conversion efficiencies. Table 5.1 summarises the possibilities for crystalline module cost reductions.

Table 5.1: A strategy for crystalline silicon PV module cost reduction

| | BASIC CASE | PROCESS YIELD IMPROV. | 156 $cm^2$ CELLS | 280 µm WAFER THICKNESS | 280 $cm^2$ CELLS | EFFICIENCY IMPROV. | EFFICIENCY IMPROV. | EFFICIENCY IMPROV. | EFFICIENCY IMPROV. |
|---|---|---|---|---|---|---|---|---|---|
| SOLAR CELLS ECU/$m^2$ (cell) | 210 | 188 | 165 | 158 | 148 | 148 | 148 | 148 | 148 |
| SOLAR CELLS ECU/$m^2$ (module) (Cell cost / 0.95 X 0.85/y) | 188 | 163 | 143 | 137 | 128 | 128 | 128 | 128 | 128 |
| MODULE MANUF. COST ECU/$m^2$ (modules) | 101 | 98 | 80 | 80 | 70 | 70 | 70 | 70 | 70 |
| MODULE COST ECU/$m^2$ | 289 | 261 | 223 | 217 | 198 | 198 | 198 | 198 | 198 |
| CELL EFFICIENCY | 13% | 13% | 13% | 13% | 13% | 13.5% | 14% | 14.5% | 15% |
| MODULE POWER DENSITY Watt/$m^2$ | 110 | 110 | 110 | 110 | 110 | 114 | 119 | 123 | 128 |
| Wp COST ECU/Wp | 2.60 | 2.40 | 2.00 | 1.90 | 1.80 | 1.70 | 1.65 | 1.60 | 1.50 |
| YEAR | 1995 | 1996 | 1997 | 1999 | 2001 | 2002 | 2003 | 2004 | 2005 |

### 5.2.1 Wafer Cost Reduction

The analysis has shown that with improved management and engineering the wafer process yield in material can be increased from 0.326 to 0.4 (ie. potentially the “waste” material of the ingot from which the wafers are cut could be reduced so that 40% of the ingot is made into wafers as opposed to the 32.6% which is commonly achieved today). This allows a cost decrease of 20% and therefore the polycrystalline silicon which in 1994 had a cost of 100 ECU/$m^2$ could reach the value of 80 ECU/$m^2$.

The wafer cost decreases when its area increases. This improvement is not great (-7%) but it has a great impact both on the cell cost and on the module cost. Moving to 12.5 cm x 12.5 cm cells and keeping the same process yield of 0.4, for the 156 $cm^2$, a wafer cost of 74 ECU/$m^2$ can be obtained.

It is still possible to decrease the wafer thickness but this change requires modifications in each phase from the cut to the modules. It is also necessary to ensure that there is not any worsening in the process yield as a result of decreasing wafer thickness and it is thus necessary to achieve an automatic process of wafer collection, washing and drying and improve cell handling. It is possible that, in a short time, the wafer thickness could decrease from 350 µm to 280 µm with 156 $cm^2$ wafers. This operation allows a decrease in the cost of about 8%.

Therefore the 156 $cm^2$ wafer 280 µm thick will have a cost of 68 ECU/$m^2$.

### 5.2.2 Solar Cells Cost Reduction

It is estimated that the wafer process yield presently around 90% could go up to 95% with process engineering improvements. With this yield the cell cost would reduce from 210 ECU/$m^2$ to 200 ECU/$m^2$. If instead the starting point is a wafer of 80 ECU/$m^2$ and that is with a wafer obtained with a 0.4 process yield a further cell cost decreases of 10% is possible.

Finally the accommodation of the machines and of the management in both departments makes it possible that the solar cell could cost 188 ECU/$m^2$. Considering an area of 156 $cm^2$ a decrease of 12% in relation to the "basic case" can be obtained and this takes the cost to 165 ECU/$m^2$. A further decrease of 4% can be obtained by reducing the wafer thickness from 350 µm to 280 µm, taking the wafer cost to 158 ECU/$m^2$.

Increasing cell area increases cell currents which inevitably induce a lower conversion efficiency. It is possible however to hypothesis further overall improvements to the solar cell production such that costs would be reduced to 148 ECU/$m^2$.

### 5.2.3 PV Module Cost Reduction

The modules process yield could easily increase to 0.98 with a few but effective actions. On the other hand the cost of the module decreases because of the decreased cost of the wafers and of the cells.

It must be noted that when the wafer area increases the normal 36 cell module increases its area and its power rate. This has a meaningful effect over the module cost because elements of the modules cost are divided over a greater area. The above considerations are synthetically shown in Table 5.1.

The first line of Table 5.1 gives the solar cell cost evolution which, because of the various actions described decrease to 148 ECU/$m^2$ from 210 ECU/$m^2$. The second line is the contribution of the solar cell cost in the module and therefore it is referred to the module area, considering a ratio cells area/module area = 0.85. Therefore carrying out all the actions above indicated, the production cost of the module decrease from 289 ECU/$m^2$ to 198 ECU/$m^2$.

The cell efficiency and the consequent module power rate density, remain constant at the present value of 13% until the actions on the various processes are not carried out. Afterward the efficiency increases up to 15%. The effects of the efficiency increase have therefore been separated from the previous ones because of editing reasons.

To obtain higher conversion efficiencies it is necessary to work on the quality of the polycrystalline material. The present quality could reach 15% efficiency but the efficiency distribution is quite wide and has an average of 13% at the module level. Experiments of "impurities gathering" by means of heavy diffusion of phosphorous and aluminium have been very effective in the improvement of the overall material performance, taking the average diffusion length of the lower carriers from 100 ÷ 120 μm to 150 ÷ 170 μm. With these values the average efficiency could reach 13.5%.

Further efficiency improvements could be obtained with actions to the cells process: superficial passivation with oxide deposition, increases of the thickness of the serigraphic metallization, introduction of layers p+ at the back of the cells, could be able to take the efficiency to 15%.

Nevertheless these actions often make the process more difficult and increase the costs. It would be deceiving to make precise calculations introducing processes not yet stabilized in their methods costs. It is better to consider that those other costs are marginal in relation to what has been considered above and in any case could be absorbed in the effect of other actions not described here, for example production volume increases.

For those reasons the effects of the efficiencies improvement have been taken very far in time, when the production volumes should be more than triple present day volumes.

Therefore, in the last line of Table 5.1, the chosen dates in which the various actions could be taken to a successful end have been indicated. These dates represent only one possible time

schedule, but other time frames could be chosen. Probably, for example, efficiency improvements could be obtained in a shorter time whereas the area increase up to 278 $cm^2$ may require a longer period.

The fact reamins that in a period of ten years, the PV modules industrial costs could be reduced close to 1.8 ECU/Wp. It is important to note that this is achieved with existing technologies not new technologies. To reach this aim there is not the need to foresee technological results which do not exist at present, but it is only necessary to do better what can already be done today. There is not therefore any need to invest in new production processes but it is necessary to invest to give a more rational assessment to those already existent.

## 5.3 Comparison of PV kWh Cost Vs Fossil Fuels kWh Cost

PV supplied electric energy has various applications each one with a specific cost. Frequently it is improper to speak of the PV-kWh cost because it is more interesting to know the use that the PV-kWh produces. For example, in the case of pumping, it is more useful to know the cost/$m^3$ of the water produced.

The economics of stand alone PV versus grid extension or stand alone diesel engines are well documented. Although site specific (relating to solar input, distance form grid, fuel transportation costs and maintenance costs) it is generally accepted that stand alone PV systems of up to 2 kWp are economic on a life cycle cost basis. Smaller systems such as solar lanterns or solar home systems for developing countries can be cost competitive on an initial capital cost basis when compared with connecting to the local grid or buying a generator set.

For grid connected electricity generation in Europe analysis has been undertaken for the area of EU countries around the 40° parallel with an average annual insolation on the horizontal surface of 1500 kWh/$m^2$/year. The analysis was undertaken assuming flat PV modules which face south and tilted 30° from the horizontal. The ground cost was not considered because state property or marginal grounds are generally used.

As an example in Italy for the 3.3 MWp ENEL plant in the Serre site, the total building costs were estimated to be around 40 MECU with a modules cost of 12 MECU and an estimated kWh cost of 0.4 ECU considering a plant life-time of 25 years.

If 1.5 ECU/Wp for PV modules is achieved with a positive trading margin of about 20% added the resulting module price will be 1.8 ECU/Wp. Under these conditions the same 3.3. MWp plant would produce electricity at a cost of 0.28 ECU/kWh. This demonstrates that the research action on the PV modules alone is not sufficient to make the PV-kWh cost competitive with the fossil fuels-kWh. Therefore an R & D parallel effort on Balance of System (B.O.S.) components is needed.

Recent photovoltaic power plant installed costs reviewed varied between 5 ECU/Wp and 7.1 ECU/Wp and this does not depend on the plant dimensions. On the B.O.S. cost there is even more variation with values between a minimum of 18% of the plant cost up to a maximum of 47%. Yearly maintenance cost of the plant is generally less than 2% of its initial cost.

The PV kWh cost strongly depends on the overall plant life-time. This is obvious because the photovoltaic systems are characterised by high initial investments and low running and maintenance costs. For the same reason the PV-kWh cost is strongly dependent on the way it is financed i.e. on the interest rate. The same plant whose life-time is 25 years will have a kWh cost ranging between 0.3 ECU and 0.72 ECU if the yearly interest rate ranges between 2% and 15%.

**This means that the PV kWh cost is also strongly dependent on the financial policy applied to these plants and therefore on the support policy which will be adopted by the European Governments towards the photovoltaic power generation.**

It is therefore necessary that PV plant life-time should be at least 25 years.

Conventional electric energy production cost is very variable depending on countries, generation and user sites, type of plant and fossil fuels, usage, etc. An analysis of those costs is not carried out here, it is only stressed that the cost of conventional electricity is around 0,05 ECU/kWh. This value is to be attributed to the electric energy generated by the main power plants. However if the PV plants are installed to sustain the grid in terminal sites, then the electricity can assume values up to 0.25 ECU/kWh.

With these considerations in mind it can be assumed that the photovoltaic electricity generation can have an effective use not only for the improvement of life using stand alone systems but also as a support to national electricity grids at terminal sites, and afterward as a demand support in the peak hours. A PV-kWh production cost of 0.25 ECU/kWh can be considered as the entrance threshold for the first case and for the second case 0.1 ECU/kWh seems to be the minimum possible value.

Electricity generation from PV is free of any type of acoustic or radioactive environmental pollution. It occurs without any gaseous emissions and does not therefore cause public health problems or damage to agriculture, and does not in any way affect the general and local climate.

It can be said that the main justification for the introduction of photovoltaics in Europe is the potential for reducing the gaseous emissions that are linked to the combustion of fossil fuels. Whilst it is not currently possible to establish the competitivity of PV in relation to the traditional generation in terms of the kWh cost alone, if gaseous emissions abatement is the main driving force, then the associated environmental and social benefits improve the viability of PV.

Furthermore, optimum electricity generation from photovoltaics corresponds to the period of greatest insolation which, in some regions, coincides with the period of greatest demand. During these hours the generation costs for fossil fueled plant can double compared to the average value as less efficient generating plant is called upon. The contribution from PV during peak-hours could reduce the need to upgrade the National Electric Grid to manage the peak-hour energy demand. The contribution of PV installed at the point of use should also be considered.

In addition to the "industrial" cost of the kWh from fossil fuels a "social" cost should be added to take into account all the environmental impact problems linked to the combustion.

It has been estimated that overall social costs including the results of global warming effect represents at least a factor 3, in relation to the initial cost per kWh.

On the negative side, the cost of photovoltaic generation is penalized by the uncertainty of production which is dependent on meteorological factors. This uncertainty forces utilities to invest, even if only partially, in peak power plants. Therefore photovoltaic plants contribute to a decrease in the management costs but not the investments on peak power plants. This consideration implies a negative factor for photovoltaics evaluated around 0,75.

When building mounted grid connected PV systems are considered it is necessary to consider the savings made form the cost of conventional cladding avoided. This saving could be considerable if the cost of building mounted modules approach conventional PV modules.

**Thus PV kWh cost with the fossil fuels kWh cost can now be compared in the following way:**

| | | ECU/kWh |
|---|---|---|
| 1) | **Basic fossil fuel plants** | |
| | Industrial cost | 0.05 |
| | "Negative cost" for emissions | 0.05 |
| | "Negative cost" for $CO_2$ (greenhouse effect) | 0.05 |
| | **Total cost** | **0.15** |
| 2) | **Peak plants** | |
| | Industrial cost | 0.13 |
| | "Negative cost" for emissions | 0.10 |
| | **Total cost** | **0.23** |
| 3) | **Grid support plants** | |
| | Industrial cost | 0.25 |
| | "Negative cost" for emissions | 0.10 |
| | **Total cost** | **0.35** |

It can therefore be found that the photovoltaic plants could be used as a support to the grid in terminal sites where the PV kWh cost will be around 0.26 ECU/kWh and this could happen around the year 2000.

The PV used to sustain the demand in the peak hours will be possible around 2005 where the cost will decrease below 0.17 ECU/kWh.

In the hypotheses above PV will never compete with "Bulk generation". The use of the PV in the main generation plants is also held back because of its discontinuous character.

However when building mounted photovoltaics is considered (with potential savings on avoided conventional cladding or roofing material) photovoltaics has the potential to be competitive with conventional power plant (if external and social costs are included) provided that PV tiles and cladding module costs approach that of conventional PV modules.

# 6. MARKET DEVELOPMENT ISSUES

## 6.1 Europe

The principal barriers to the more rapid dissemination of PV in Europe are summarised in Table 6.1 along with possible solutions to overcome these barriers.

Table 6.1: Barriers to the widespread use of photovoltaics in Europe

| BARRIER | SOLUTION |
|---|---|
| **Grid Connected** | |
| High PV cost | -Transitional support through levies |
| | -Support for large-scale production facilities |
| High unit energy costs relative to conventional power plant | -Support for large scale production to reduce costs |
| | -Include external costs of conventional power |
| | -R&D on efficiency improvement |
| User uncertainty | -Demonstration and promotion (ALTENER and THERMIE |
| Regulatory grid connection barriers | -Legislation |
| Utility constraints: | |
| Interconnection needs | -develop and standardise utility connection |
| lack of demonstrated performance | -Demonstration and promotion |
| unattractive buy back prices | -transitional price support |
| Legislation not supportive of PV | -Carbon taxes, transitional levies, non-fossil fuel obligations required |
| Lack of awareness | -Architects and planners information programmes (ALTENER) |
| Lack of standards, utility certification | -Standardisation and utility certification programme |
| **Stand Alone** | |
| High PV cost | -Support for large scale production |
| lack of awareness of potential | -Information programmes (ALTENER) |
| Consumer reluctance | -Guarantee of performance |
| | -Industry charter |
| | -Education programmes |
| Subsidised diesel fuelled electricity on some island communities | -remove subsidies |
| **Consumer Goods & OEM Market** | |
| lack of awareness of OEM's | -OEM seminars |
| lack of know-how & skills in OEM's | -OEM seminars and training programmes |

## 6.2 International Markets

In the international non-developing country markets the principal barriers to the development of the market for European photovoltaics are the same as for the European markets with two additional barriers. These additional barriers are the greater competition from the US and Japanese PV industry, particularly in their home markets and the high cost of seeking out projects and markets.

The US and Japanese PV industries are strongly supported by US ECRE and MITI respectively. The two organisations are government controlled and fund the development of export markets and partly cover industry's marketing costs.

A proposal to form a European Renewable Energy Export Council was launched by Mr. J.C. Bonda, Secretary General of EPIA with the full support of all the various European Renewable Energy Associations. The European Parliament and the EC are looking at the proposal but progress has so far been slow.

Table 6.2: Additional barriers in the non-EU, non-developing country markets

| BARRIER | SOLUTION |
|---|---|
| International competition from USA and Japan | -Improve competitiveness on price, performance and product range |
| High cost of identifying market | -Export promotion support |
| High cost of servicing market | -Distributed manufacture and support |

## 6.3 Developing World

The impact that photovoltaics can make on the developing world is potentially enormous. The proposed EU initiative *Power for The World: A Global Photovoltaic Action Plan* notes that there are more than 1 billion people in the developing world without electricity and that 10 Wp per capita is sufficient for survival, development and basic needs for lighting, water, health, education and social development. Analysis undertaken for this study has identified a total stand alone developing country PV market of more than 16 MWp (see Volume 3).

PV is acknowledged as the most practical and economic solution (on a life cycle and in some cases capital cost basis) to meet the energy requirements of the 1 billion people without electricity in the developing world. There remain however significant barriers to market development however as summarised in Table 6.3.

Table 6.3: Barriers to the widespread uptake of European photovoltaics in the developing world

| BARRIERS | SOLUTIONS |
|---|---|
| Lack of funds of many potential users | -International support |
| Lack of appropriate financing schemes | -Innovative finance schemes / credit |
| Price distortions | -Reduce subsidies on fossil fuels |
| Lack of awareness - decision makers | -Information programmes |
| Lack of awareness - users | -Information / advertising programmes |
| Lack of technical skills | -National / regional training programme |
| Lack of infrastructure support (eg. preventative maintenance, repair service) | -Ensure programmes are of critical mass to allow cost of infrastructure support<br>-Integrated programmes |
| Lack of standardised products and quality control | -Product standardisation and certification<br>-Product specification and monitoring |
| Institutional problems with project planning and implementation | -Facilitate longer term projects<br>-Define responsibilities of organisations<br>-Project management training |
| Import duties | -Lobbying |
| Government supported competition from US and Japanese PV industries | -EU supported programmes |

# 7. A STRATEGIC ACTION PLAN FOR EUROPE

A strategic action plan is proposed here for the development of the European PV Industry and Market. The plan calls for the following:

- Targets for installed PV in Europe by 2010
  - and resulting carbon dioxide saving contribution
- Target for European manufacturing capacity by 2010
  - and resulting employment generation
- Proposed programmes and recommended policies

## 7.1 The Year 2010 Target:

The proposed European photovoltaic targets for 2010 are summarised in Table 7.1.

Table 7.1: Proposed 2010 European photovoltaic targets

| PARAMETER | YEAR 2010 TARGET |
|---|---|
| Cumulative installed PV capacity in Europe | 2000 MW<br>- PV roofs 900 MW<br>- PV facades 400 MW<br>- PV grid plant 400 MW<br>- Isolated homes 100 MW<br>- Other 200 MW |
| Manufacturing capacity | 1000 MW/yr |
| European share of international PV trade | >40% |
| Solar homes supplied to the developing world | 20 million |

These targets are considered realistic and have been proposed taking into consideration the various barriers and proposed programmes and policies to overcome these barriers and the needs for a sustainable European PV industry.

For comparison targets and forecasts by other EU reports are presented in Table 7.2.

Table 7.2: European PV Targets

| PARAMETER<br>Year | 1994 | PV2010<br>2010 | ALTENER<br>2005 | TERES Existing 2010 | TERES Proposed 2010 | MADRID Plan 2010 |
|---|---|---|---|---|---|---|
| Installed PV in Europe (MWp) | 70 | 2,000 | 500 | 1,135 | 6,730 | 16,000 |
| PV Electricity (TWh/yr) | <0.05 | 2.0 | - | 1.25 | 7.4 | |
| Manufacturing Capacity (MW/yr) | 35 | 1000 | - | - | - | 2,000 |
| European share of international trade in PV | 30% 8MW | >40% | - | - | - | 500 MWp |
| CO2 savings mill. Tonnes/yr | <0.05 | 2 | | 1 | 7 | 15 |

TERES = The European Renewable Energy Study , 1993 (DGXVII)
Madrid = Action Plan for Renewable Energy Sources in Europe, 1994 (DGXII, DGXIII,DGXVII)

It should be noted that to achieve 2000 MWp installed in Europe by 2010 requires a consistent 20% annual growth in European PV installations. (An annual growth of 45% is required to achieve the Madrid plan)

A European PV manufacturing capacity of 1000 MWp/yr requires an investment of some 2,000 M ecu.

## 7.2 Proposed Programmes

### 7.2.1 European 500 MW grid connect programme

The benefits of PV as a source of electricity in Europe are more than sufficient to justify a major programme of public support, aimed at developing the market to the targeted 2000 MW installed by 2010 and a commercially sustainable market of around 350 MWp/yr.

To meet the overall target of 2000 MWp installed in Europe by 2010 a 10 year transitional (1995-2005) market enablement programme is proposed with the following key projects:

- 100,000 PV roof project
  (average size = 3 kWp, total = 300 MWp)
- 2,000 PV building facades project (average size = 50 kWp, total = 100 MWp
- large scale power plant
  (0.5-5 MWp range, total = 100 MWp)
  (including noise barriers)

This programme would result in a total of 500 MWp by the year 2005 (thereby meeting the existing Altener 2005 PV target and enabling 25% of the PV2010 goal to be reached. Continuation of the growth together with non publicly supported installations would account for the other 75% .

The proposed public funding support would be a relatively large component of the cost initially (49%) dropping off linearly to zero in 2006.

The proposed contribution from public funds would be at three levels:

- European 60%
- National 30%
- Local 10%

The scale of the programme is shown in Figure 7.1 and the system price predictions in Figure 7.2.

Figure 7.1: Annual installations of the proposed European 500 MW grid connect programme

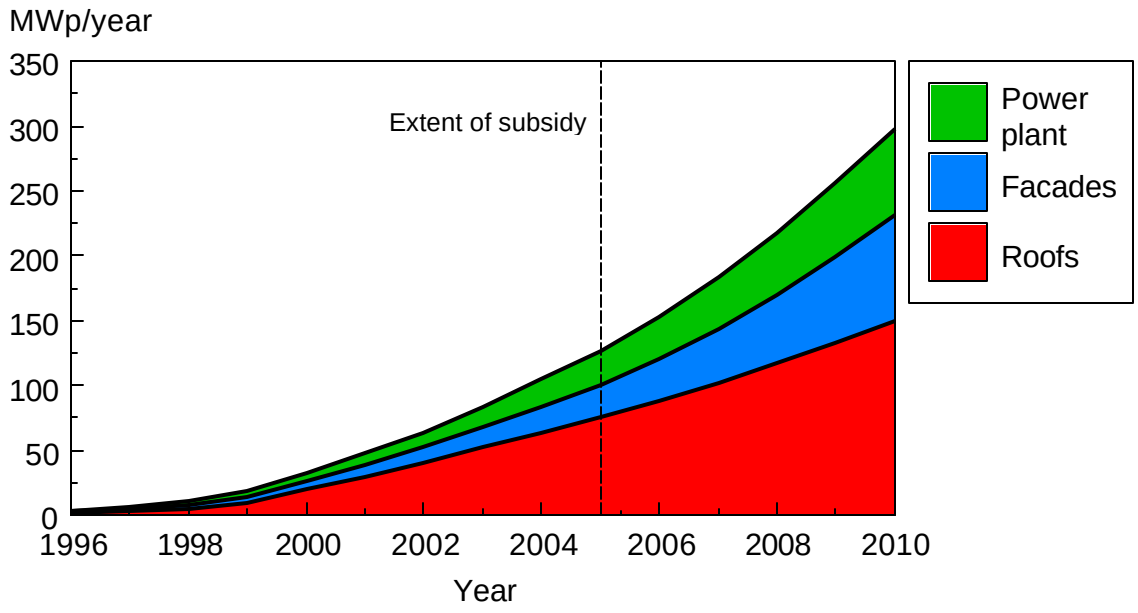
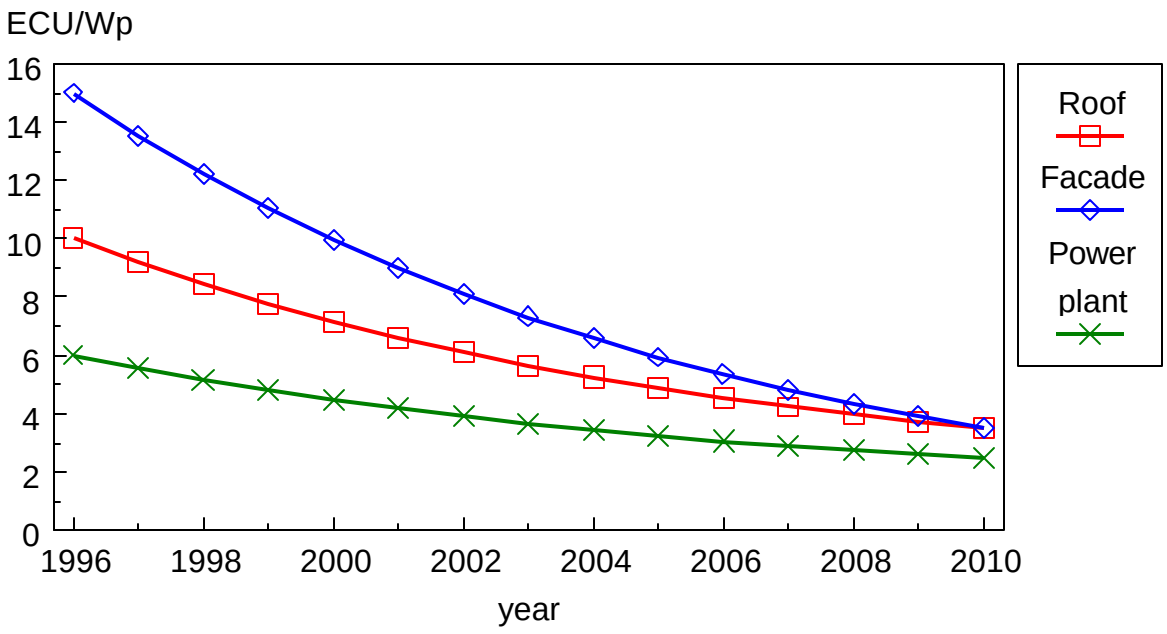
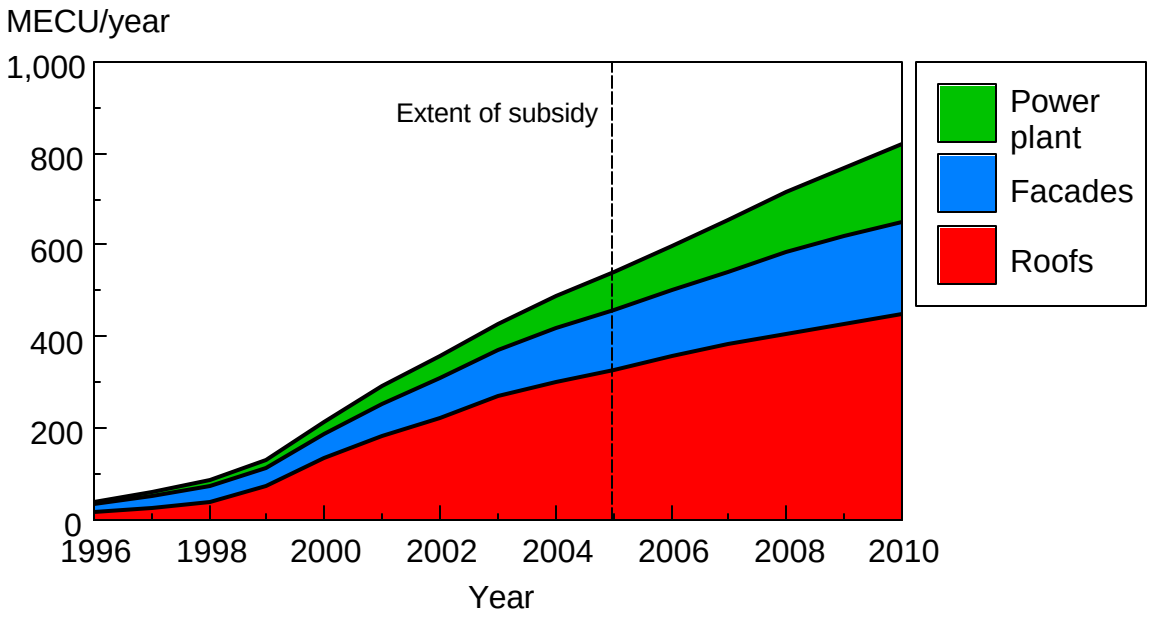


Figure 7.2: Price predictions for grid connect systems




The total cost of the programme is shown in Figure 7.3.

Figure 7.3: Overall cost of the EU 500 MW grid connect project



The public funding required for transitional support over the proposed 10 year programme is shown in Figure 7.4 where it is assumed the support falls linearly from 49% in 1996 to zero in 2006. This is summarised in Table 7.3.

Figure 7.4: Transitional support contributions to the proposed EU 500 MW grid connect project.

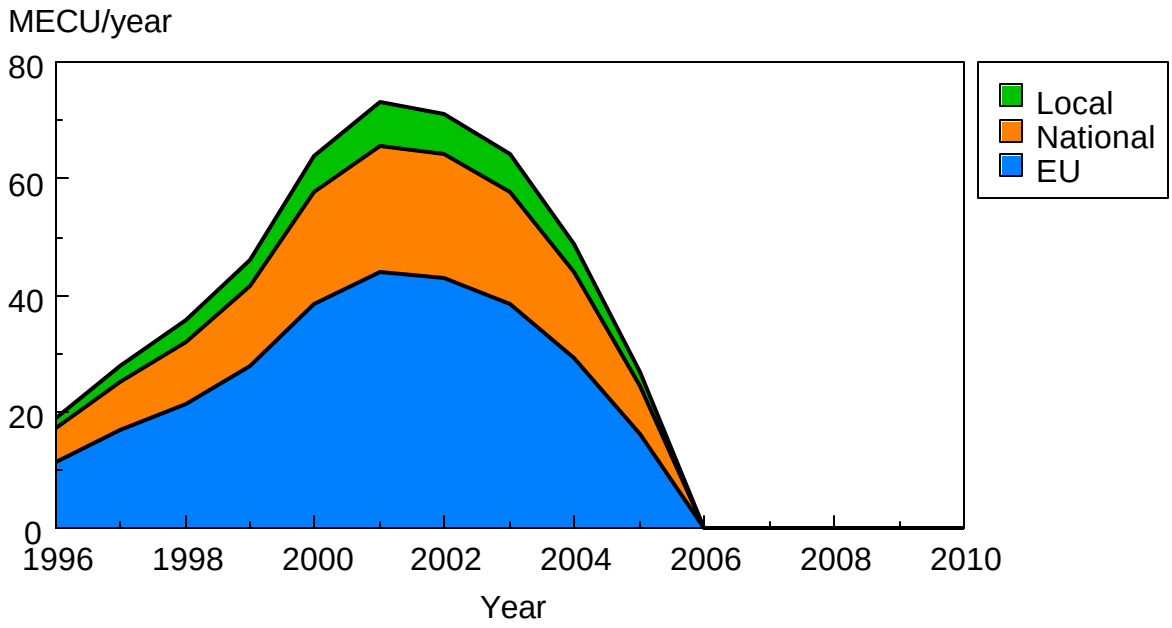
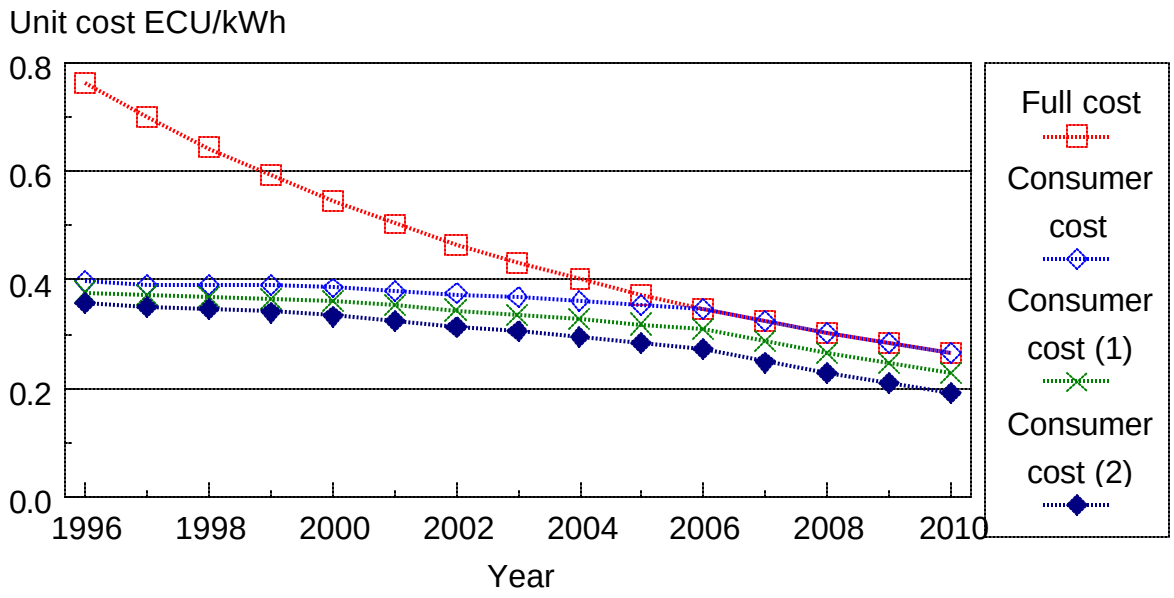



Table 7.3: Costs of the 500 MW grid connect programme

| | MILLION ECU |
|---|---|
| Total costs PV roofs | 3600 |
| Total costs PV facades | 1550 |
| Total costs other grid connect | 1050 |
| Total programme costs | 6200 |
| Local contribution | 50 |
| National contribution | 150 |
| EU contribution | 300 |

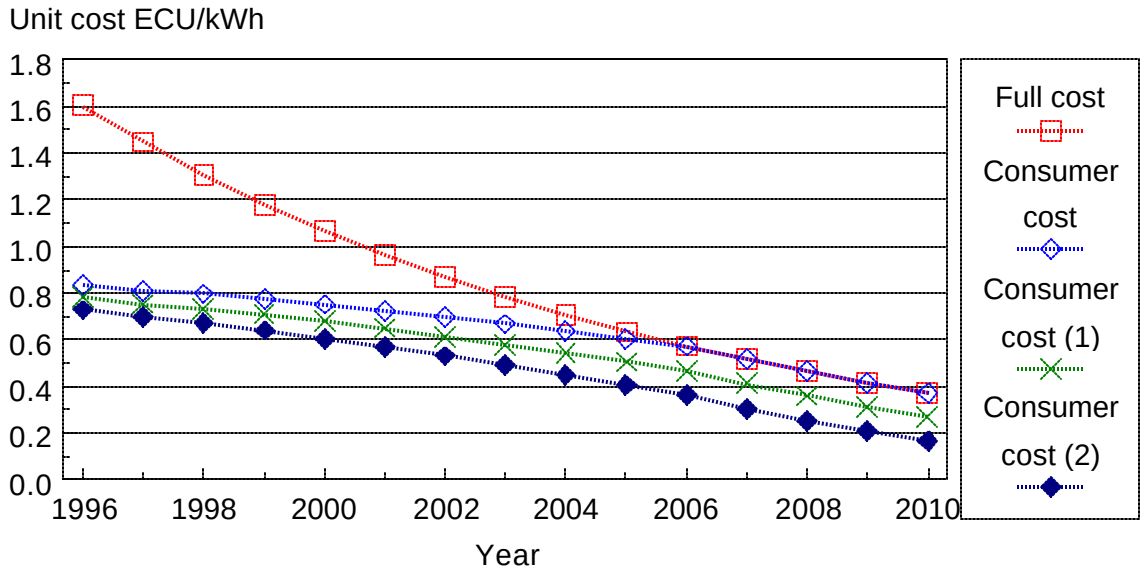
Figure 7.5 and Figure 7.6 illustrates the unit energy costs from roof mounted grid connected PV systems in southern Europe and facade systems in central Europe. The beneficial effect of the transitional support for the consumer is clear. The final resulting unit energy costs in the year 2010 are competitive with conventional energy costs if external environmental and social costs are taken into consideration for conventional fossil fuelled electricity.

Figure 7.5: Unit Energy Costs: roof integrated systems in southern Europe




Note: (1) Avoided roofing costs at 50 ECU/m2
(2) Avoided roofing costs at 100 ECU/m2

Figure 7.6: Unit energy costs: building facades in central Europe




Note: (1) Avoided cladding costs at 100 ECU/m2
(2) Avoided cladding costs at 200 ECU/m2

It is proposed that many of the building mounted installations would be high profile buildings and innovative installations attracting public attention and support and encompassing urban development and renovation.

It is proposed that the 500 MW grid-connect project also be supported by a programme of enabling and market development measures notably:

**for building mounted grid connected systems**

- country by country review and recommendations on utility legal constraints
- promotion to architects and planners (which is already being done as part of the ALTENER in some countries
- provide product development support (continuation of JOULE programmes in this area)
- guarantee of performance for customer
- guarantee of electricity buy-back at selling price
- tax incentives (such as accelerated depreciation)

**for grid-connected PV plant generally**

- a non fossil fuel obligation on utilities to generate a proportion of output with specified new renewable energies
- standardisation and certification of utility connected equipment
- a levy on fossil fuel electricity as currently applied by some regions in Europe

### 7.2.2 European 100,000 Isolated building project

One area of activity in the EU APAS programme is a survey of non-electrified houses in Southern Europe. It is proposed that this activity be followed with a target electrification with PV of 100,000 isolated buildings throughout the EU but mainly in Southern Europe.

The barriers to widespread dissemination of stand alone PV in Europe have been outlined earlier in this report. To counter these barriers it is proposed that a series of enablement measures be introduced under Altener or regional EU programmes.

The proposed measures are:

- Promotion of PV to potential users
- financial incentives at the regional or national level

In addition it is proposed that the PV industry seek to establish methods of guaranteeing the performance of systems to build up user confidence in the systems.

### 7.2.3 Developing World Programme

The EU *Power for the World* Initiative, the *Solar Energy Initiative* of the World Bank and Global Environment Facility (GEF) programmes in India and Zimbabwe demonstrate the growing support for the use of PV in developing countries to meet basic and development needs.

EPIA fully supports these initiatives and recommends that a 2010 target of 20 million European enabled (supplied or funded) solar lanterns or solar home systems are installed by 2010 with an approximate installed PV capacity of 1000 MWp.

The key elements recommended for the developing world programme are:

- co-operation between the EU, World Bank, UN, GEF, ADB and others in financing and implementing the major development programmes
- Establishment of regional revolving funds and appropriate financing schemes supported by industry, NGO's and international development agencies to operate in co-operation with developing country organisations. An EPIA lead organisation to develop projects should be considered
- The European industry should play a more active role in formulating World Bank, ADB, UNDP, GEF PV developing country projects by providing advice and seconding personnel to major programmes
- Enhanced infrastructure support to PV programmes in developing countries (training, project management, support centres)

The European PV industry is experiencing aggressive competition at present in the developing world market, particularly from the US PV industry. The US industry has established close links with USAID and US DoE to develop the market in key areas such as India, Indonesia, Mexico and Southern Africa. The US DoE has also sponsored seconded positions in World Bank departments.

A temporary transitional support programme is thus recommended to counter the US industry market initiatives as summarised in Table 7.4.

Table 7.4: Elements of the proposed developing world market development programme

| ACTIVITIES RECOMMENDED |
|---|
| Establishment of a European Renewable Energies Export Council to facilitate export promotion missions |
| Support and secondments to GEF, World Bank, ADB, IADB |
| Project identification missions |

### 7.2.4 Low cost manufacturing partnership investment programme

The study team supports the proposal of the Madrid Conference for a partnership investment programme for new large scale manufacturing plant. This should be achieved as follows:

- a CEC invitation to the PV industry, electricity utilities, and European investment funds to participate in the development of large 50 MWp+) PV manufacturing plant
- long term contracts from the utilities for PV at agreed prices and quantities
- guaranteed number of PV procurements for developing world projects
- 
- committed enhanced support for ALTENER, THERMIE, ERDF, Cohesion Fund, and other EU programmes to support the introduction of PV
- incentives for the industry for existing production processes which could for example be linked to achievements in developing the process and overcoming bottlenecks
- incentives for balance of system suppliers for improved equipment
- support for companies to provide all necessary assistance to potential users

### 7.2.5 Increased R&D support for new PV technologies

The benefits of JOULE programmes in the development of new PV technologies such as PV cladding and new manufacturing techniques are well recognised. It is recommended that such support should be continued and enhanced up to the year 2005 and prioritise on:

- new low cost manufacturing techniques

- standardisation and certification of products for
  - utility connection
  - isolated dwellings
  - developing country solar home systems

## 7.3 Benefits To The European Union Of The Proposed Programmes

### 7.3.1 Employment

The employment generated by the PV sector has been estimated separately for the areas of origin of PV equipment (PV+BOS manufacturing, services and wholesales) and for the areas of destination (local retailers, installation, maintenance) and, assuming the *Business as Usual* Scenario, will total in year 2010 more than 150.000 employed (of which 32.000 in Europe).

If the proposed programmes are supported and the target of 2000 MWp of PV installed in Europe is achieved it is estimated that a minimum 58,000 additional jobs would be created in Europe.

### 7.3.2 $CO_2$ Emissions Reductions

The savings in carbon dioxide emissions resulting from the displacement of coal fired electricity generation plant with an energy technology that does not emit $CO_2$ during the generation process would be approximately 2 million tonnes per year. Even assuming that PV was displacing power plant representative of the average European electricity generating plant with associated $CO_2$ emissions of 0.55 tonnes/MWh, (rather than dirty coal power plant), annual savings in $CO_2$ would amount to approximately 1.1 million tonnes per year.

### 7.3.3 Security of Supply

One of the important objectives of the ALTENER Programme is to reduce Europe's dependence on imported energy. Energy dependence is undesirable as supplies from external sources are vulnerable to major disruption, whether this be caused by war or political upheaval, as the recent gulf crises demonstrated, or embargoes, as the two oil crises of the 1970s highlighted. Energy dependence can also contribute to national debt and has implications for trade balances with many nations struggling to pay for imported energy.

Photovoltaics and other renewable energy technologies, by allowing countries to utilise their sustainable indigenous energy sources, provide energy independence, thereby avoiding the potential for supply disruption and reducing the likelihood of associated conflicts.

### 7.3.4 Rural Water Supply, Health Care and Education

PV can make a significant contribution to improving the quality of life of innumerable small communities especially in rural areas by helping to meet basic potable water needs which leaves local inhabitants free to tend crops or establish small business for trading.

Health care and education needs can be similarly enhanced. PV provides the opportunity to meet essential lighting, water pumping, refrigeration and communications requirements. This can have a significant impact on the success of education schemes and regional health care programmes.

--ooOoo--