Solar photovoltaics development. Status and perspectives

Fenhann, Jørgen Villy

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Solar Photovoltaics development

- Status and perspectives

Jørgen Fenhann

Risø National Laboratory, Roskilde
September 1998

Summary

This is the final report on the status and long-term perspectives for the development of solar photovoltaics, contributing to the Macro Task E1 on production cost for fusion and alternative technologies, part of the programme for Socio-Economic Research on Fusion.

After a short introduction about the most promising PV technologies the report concentrates on the present market trends showing that the PV sales has been growing 16% over the last 9 years, 28% over the last 3 years and expanded by 43% last year to a global total of 126.7 MWp 1n 1997. The annual shipment is largest in the U.S. with 53 MWp followed by Japan and EU.

Until now off-grid installation have dominated the solar PV market, since they are already economically competitive. However, often the financial mechanisms and necessary organisational set-up are missing. At the moment many big PV manufacturers are working to get good successful reference cases in developing countries. But now the on-grid installations in developed countries are beginning to increase. The main growth area in on-grid domestic installations, where there are big programs running in Japan (5000 MWp installed in 2010), U.S. (3000 MWp in 2010) and the Netherlands (1450 MWp in 2020).

Looking at the perspectives a continuation of the high growth in solar PV production will continue supported by the United Nations Framework Convention on Climate Change and the Kyoto Protocol. The PV industry has already announced increases in production capacity large enough for a continuation of last year high growth.

The report shows status and perspectives for production costs for solar PV until 2050. The routes to PV module cost of 1$/Wp are clear. The growth of the market to an annual shipment of over 2 GWp (reached in 2010 with a 25% annual growth) will lead to production plants of the scale needed to achieve these cost. It is expected that the PV industry will make decisive investment of this size in the period 2005-2010.

A substantial cut in solar PV cost per kWh can be expected within the next 10-50 years. Before 2010 it will be reduced by a factor of five and somewhere between 2010 and 2050 solar photovoltaics will be fully competitive to conventional fossil fuel based electricity production.

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CONTENT

Preface

This is the final report on the status and long-term perspectives for the development of solar photovoltaics, contributing to the Macro Task E1 on production cost for fusion and alternative technologies, part of the programme for Socio-Economic Research on Fusion

The programme for Socio-Economic Research on Fusion (SERF) was started in the autumn of 1997 following an initiative from the EU-commission. The programme includes a number of different tasks and subtasks – all related to the long-term development of fusion. These tasks include the development of long term energy/economy scenarios, status and perspectives for the technical development of fusion and alternative technologies, and the evaluation of externalities related to these technologies. Finally, a number of sociology related topics are treated in the programme.

This report concentrates on the market trends and the development of the production costs for solar photovoltaic power. The report shows status and perspectives for production costs for wind turbines until the year 2050.

Senior scientist Jørgen Fenhann has prepared the report in the summer of 1998.

Risø, September 1998

1 Introduction

Photovoltaics, developed in its modern form in 1953-1954, has been used to power satellites in space since 1958; remote telecommunications, cathodic protection, and signalling systems since the mid-1960s; remote residential and commercial systems since the 1970s; and grid connected residential and commercial systems since the 1980s. Today, with the price of the technology coming down and the price (financial and environmental) of conventional fuels rising, PVs is entering a new era of international growth.

The amount of solar energy, which arrives to the surface of the earth, depends on the latitude and the atmospheric conditions. The highest annual solar energy flow in the world is in Saudi Arabia (2500 kWh/m^2/year). Values for other regions can be found in Table 1.

Table 1. Average annual surface insolation

Area	kWh/m2/year
Denmark	1000
Southern Europe	1500-1800
Japan	1500
U.S.	1500-2200
South America	1500-2200
Africa	1800-2200
Saudi Arabia	2500

Source: Map from Metéorologie Nationale, France.

Chapter 2 describes the present state of the different solar photovoltaic technologies, the efficiencies reached and their present state of cost. Chapter 3 gives an overview of the development of the market for PVs until now and in Chapter 4 the future trends for the costs and installed capacities globally is discussed.

2 PV TECHNOLOGIES

PV comes in many flavours, though the bulk of the material in use today is silicon-based. In general, PV materials are categorised as either thick crystalline (sliced from castings, or grown ribbons) or thin film (deposited in thin layers on a substrate) polycrystalline or amorphous.

2.1 Thick Crystalline Materials

Single-crystal silicon--Sliced from single-crystal castings of grown silicon, these wafers/cells are now cut as thin as 200 microns. In stead of cutting the silicon in slices, nearly single-crystal silicon cells can be made from thin ribbons, which are grown from a crucible of molten silicon, drawn by capillary action between the faces of a graphite die. Research cells have reached nearly 24-percent efficiency, with commercial modules of single-crystal cells exceeding 16.5-percent. Mass-produced solar cells are normally about 13% efficient.

Multicrystalline silicon--Sliced from blocks of cast silicon, these wafers/cells are both less expensive to manufacture and less efficient than single-crystal silicon cells. Research cells approach 18-percent efficiency, and commercial modules approach 14-percent efficiency.

Gallium Arsenide (GaAs) - A III-V semiconductor material from which high-efficiency photovoltaic cells are made, often used in concentrator systems and space power systems. Research cell efficiencies greater than 25 percent under 1-sun conditions, and nearly 28 percent under concentrated sunlight. Multijunction cells based on GaAs and related III-V alloys have exceeded 30-percent efficiency.

Concentrator systems—The performance of a PV array can be improved by employing concentrating optics, which use lenses or reflectors to focus sunlight onto the solar cells or modules. Lenses, with concentration ratios of 10x to 500x, typically Fresnel linear-focus or point-focus lenses, are most often made of an inexpensive plastic material engineered with refracting features that direct the sunlight onto a small or narrow area of cells. The cells are usually made of Silicium. GaAs cells and other materials have higher conversion efficiencies, and can operate at higher temperatures, but they are often substantially more expensive. Module efficiency can range upwards from 17%, and concentrator cells have been designed with conversion efficiencies in excess of 30%.
Reflectors can be used to augment power output, increasing the intensity of light on modules, or to extend the time that sufficient light falls on the modules.
Concentrator system lenses are unable to focus scattered light, limiting their use to areas, like desert areas, with a substantial number of cloudless days on an annual basis.

2.2 Thin-Film Materials

All three types of commercial thin film materials mentioned below are produced as modules with integrally interconnected cells. This is a technique well suited to large-scale, low-cost production, as the entire module area is coated with the film. Thin-film research and development continues to show great promise in the United States, Europe and Japan.

Improvements in performance and efficiency are making it more competitive with single and polycrystalline silicon.

Amorphous Silicon (a-Si)

a-Si is a non-crystalline form of silicon, first used in photovoltaic materials in 1974. In 1996, amorphous silicon constituted about 12 percent of the worldwide PV production (see

Table 4). Small experimental a-Si modules have exceeded 10-percent efficiency, with commercial modules in the 5-7-percent range. Used mostly in consumer products, a-Si technology holds great promise in building-integrated systems, replacing tinted glass with semi-transparent modules.

The a-Si cells have not yet solved their weakness with long-time efficiency stability. Concerning material consumption, energy consumption and techniques for production, a-Si cells will be superior when this problem is solved.

Cadmium Telluride (CdTe)

A thin-film polycrystalline material deposited by electrodeposition, spraying, and high-rate evaporation, holds the promise of low-cost production. At present module efficiencies are around 8% and show no degradation like for a-Si. Except for “indoor” applications CdTe has not been commercial available. But now BP Solar is building a 10MWp per annum plant in California, which is due to ship products at the end of 1998. Another similar plant is scheduled for completion in 1999 in Germany

Copper Indium Diselenide ($CuInSe_2$, or CIS)

A thin-film polycrystalline material, which has reached a research efficiency of 17.7 percent, in 1996, with a prototype power module reaching 10.2 percent. The average efficiency of commercial modules are likely to be around 8%. The difficulty in taking this technology to a production level lies in the difficulty in avoiding the formation of defects during deposition that prevent the formation of uniform layers.

2.3 PV costs

Although this depends greatly on the application, some general guidelines can be given. Since 1980, the price of solar cells has fallen 80 percent from the 1980 level of 23 $/Wp, as the technology matured. In the past decade, the industry’s advance has slowed, due to low oil prices, a lack of sufficient government support in many countries, and a reluctance of manufacturers to commit the resources needed to bring down costs. As a result, module prices have temporarily stabilised in the last decade and only dropped about 1 $Wp (World Watch, 1998).

The cost of the PV modules is typically 4-6 $/Wp. On the 2nd Solar World Conference in Vienna in July 1998, an average price of 4.2 $/Wp was mentioned. The Balance of System cost (BOS) is all costs besides the PV modules. In an off grid installation the BOS cost is typically 60% of the total installation cost while in a on-grid installation the BOS cost goes down to 40% (no batteries etc.). A standard 50W off-grid installation thus typically cost 450-800 $.

The present cost of PV- generated energy generally ranges from 0.30$ to 1.00$/kWh (a cost projection is shown in Table 8). This cost generally limits the current application of PV to areas which are not served by an existing utility grid, although low-power applications may be cost-effective close to (sometimes only a few feet from) a power line.

3 The present market trends

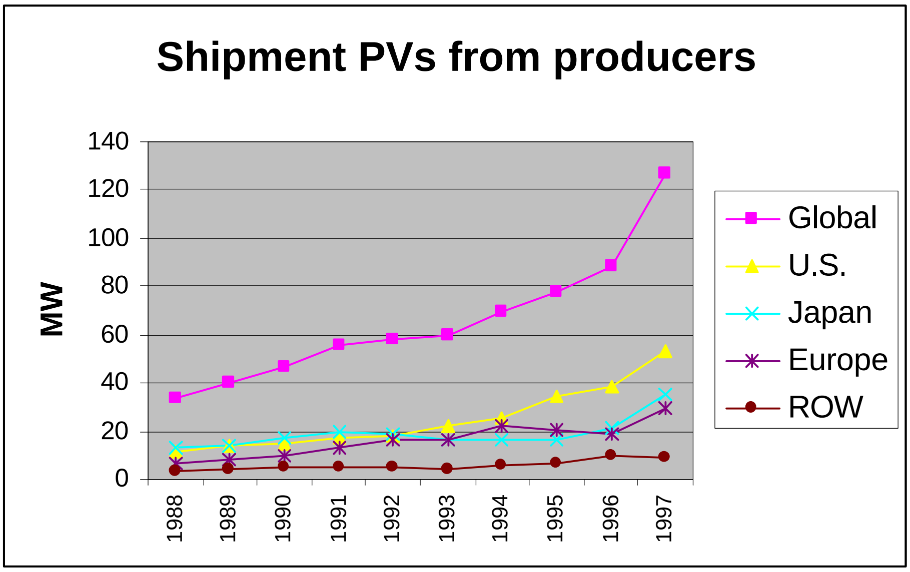
The tables in this chapter showing information on the global production of photovoltaic cells (called shipment) are based on the information published in Solar Letter (latest 13.02.1998) collected by Paul Maycock, PV Energy Systems.

Table 2. Global sales (shipment) of Solar PVs

MWp	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Global	33.6	40.2	46.5	55.4	57.9	60.1	69.4	77.6	88.6	126.7
U.S.	11.1	14.1	14.8	17.1	18.1	22.4	25.6	34.8	38.9	53.0
Japan	12.8	14.2	16.8	19.9	18.8	16.7	16.5	16.4	21.2	35.0
Europe	6.7	7.9	10.2	13.4	16.4	16.6	21.7	20.1	18.8	29.3
ROW	3.0	4.0	4.7	5.0	4.6	4.4	5.6	6.4	9.8	9.4

Figure 1 and Table 2 show that the sales of PV cells are growing fast and that the growth rate is increasing. The PV sales has been growing 16% over the last 9 years, 28% over the last 3 years and expanded by 43% last year to a global total of 126.7 MWp. The annual shipment is largest in the U.S. with 53 MWp followed by Japan and EU, where the production are of the same order.

Figure 1. Global sales (shipment) of Solar PVs



The 9.4 MWp produced in the Rest of the World (ROW) in 1997 was produced in India (5.2 MW), Taiwan (2.5 MW), China (1.5 MW) and others (0.2 MW). This means that all the larger PV producers are based in the U.S. , Japan and Europe. The 10 largest producers of solar cells are shown in Table 3. They are based in all three regions. Siemens Solar Industries' is the largest producer, its shipment increased 7 MWp or 41.2% last year, the largest increase of any company and a boost equal to the company's total shipment in 1990, where Siemens also had the largest shipment. BP is number four on the list showing the companies interest in diversifying. The head of BP Solar is quoted in BP's The Shield Magazine, issue 1997, for saying: "One day the solar industry will be as big as oil". In January 1998 BP opened its new 10MWp solar factory in Fairfield California. Over the next decade BP plan to invest $1 billion in solar energy. In October 1997 Shell announced a new division, Shell International Renewable. Shell will invest $500 million in this division the next five years and want to capture 10% of the global solar PV market before 2005, it has teamed with Pilkinton Solar International to build a 25 MW polycrystalline factory in Germany, the world largest so far. The race for the solar share, even among oil companies, has begun.

Table 3. The largest PV producing companies

1997	MW
Siemens Solar (U.S.)	24.0
Kyocera (Japan)	15.4
Solarex (U.S.)	14.8
BP Solar (EU)	11.3
Sharp (Japan)	10.6
Photowatt (France)	5.7
Sanyo (Japan)	4.7
Astropower (U.S.)	4.3
Solar International (U.S.)	4.0
ASE Americas (U.S.)	4.0
Total	98.8

Table 4 shows that almost all PV cells today (99%) are produced from Silicium (Si). Crystalline silicon remained the king of PV materials with 49.6% coming from single-crystal silicon and another 33.9% from polycrystalline silicon. Amorphous silicon increased in production from 11.7 MW in 1996 to 15 MW in 1997, but its market share actually decreased from 13 to 11.8 percent. About half of the amorphous Si (7.1 MWp) is used for "indoor" applications like calculators, watches and toys. Most of the small amount of Cadmium Telluride solar cells is also used for indoor applications. Indoor applications for PV could be approaching saturation levels since their shipment since 1991 has been on the same level compared to the large increase for other applications.

Table 4. Shipment breakdown by technology

1997	MW	Share
Single-crystal Si	62.8	49.6%
Polycrystal Si	43.0	33.9%
Amorphous Si	15.0	11.8%
Crystal Si concen.	0.2	0.2%
Ribbon Si	4.0	3.2%
Si on low cost substrate	0.5	0.4%
Cadmium Telluride	1.2	0.9%
Total	126.7	100.0%

3.1 Current markets applications

Based on the information in Table 2 (+ earlier years) the global installed PV capacity can be estimated to be about 800 MW. Almost no global statistics about installed PV power exist. However, the current boom in solar energy is being driven by a previous neglected small-scale application: Providing power for individual households. The big PV producing companies are working to show successful demonstration project in developing countries.

Table 5 (IEA, 1997) shows the PV power installed in the IEA countries in 1995. The 176 MW listed in the table do not agree with the sales figure above – at the beginning of 1995 about 500 MW was shipped globally and it sound unreasonable that 2/3 of this was shipped to non-IEA countries. However, Table 5 shows

Table 5. PV power installed in the IEA countries

MW	Total installed Power in 1995	Power added in 1995
USA	74.8	12.5
Japan	26.0	6.7
Germany	17.8	5.4
Italy	15.8	1.7
Australia	12.7	2.0
Switzerland	8.1	0.9
Spain	6.6	0.9
France	2.9	0.5
Netherlands	2.5	0.5
Korea	1.8	0.1
Canada	1.8	0.3
Sweden	1.6	0.3
Finland	1.3	0.1
Austria	1.3	0.3
United Kingdom	0.4	0.03
Portugal	0.2	0.02
Denmark	0.2	0.04
IEA total	175.8	32.3

The market consists of two parts: Off-grid systems and on-grid systems. Table 6 shows that the share of off-grid installations in the total PV market is falling, but still the most important. In the IEA countries it dropped from 93% in 1990 to 71% in 1995 (IEA, 1997). About half of installed power is for non-domestic application and the other half for domestic applications.

Table 6. PV systems installed by application in IEA countries.

New PV system	1990	1995
Off-grid	93%	71%
On-grid Distributed	5%	20%
On-grid Centralised	3%	9%
Total	100%	100%

3.2 Off-grid systems

Terrestrial PV systems have traditionally been used as a high cost power source for off-grid non-domestic professional applications. However in the past 20 years costs have steadily decreased and the use of PV in remote areas has increasingly proved to be a commercial attractive application also for domestic applications. Off-grid domestic installations are typically already economically competitive but often the financial mechanisms and necessary organisational set-up are missing

Typical *off-grid non-domestic applications* are: Telecommunications and signals; consumer systems for homes, farms, boats, campers; water pumping, small lighting systems and lantern systems for the developing world. Space applications now only take a small amount of the annual shipments of PVs. Assuming the about 20 satellites are launched annually each requiring between 1 kW and 15 kW gives an demand of around 0.2 MW (SunWorld Vol. 22 No.3, Sept 1998).

Off-grid domestic systems:
In addition to the PV module a typical Solar PV home system consists of a battery storage system a converter form dc to ac and a regulator. A typical 50 Wp system can cover the demand from a house with 3 lamps, a radio and a black and white TV.
The World Bank/Global Environment Facility has since 1997 supported a program in Indonesia to install Solar PV home systems in 200,000 in 4 regional markets.
In 125 villages in Burkina Faso, among them the province capitals, public buildings will be supplied with solar PVs, funded by Spain. In the new electrification plan for the country more than half of the town/villages is planned to have electricity from solar PVs.

3.3 On-grid systems

On-grid systems consist of distributed systems on buildings and centralised systems. A number of centralised grid-connected PV plants are in operation in e.g. U.S., Italy, Spain and Switzerland but at present the market for centralised PV power generation is not a real market but consists mainly of demonstration plants funded from national or international programmes.

The main increase at the moment is in on-grid distributed installations (see Table 6) on buildings, noise protection walls, parking spaces etc. Before 1990, PV systems were scarcely used in housing or utility construction. Now architects around the world are beginning to integrate a large selection of building integrated PV (BIPV) products into their designs: BIPV modules, integral roof modules, roofing tiles, modules for wall facades etc. There are at present several national initiatives in this area:

The Million Solar Roofs Initiative in the U.S. The initiative shall enable businesses and communities to install solar PVs on one million rooftops across the United States by 2010. The total installed power is anticipated to be about 3 GW. A 15% tax credit of the cost of a new system is planned

The EU Commission has formally proposed a 500,000 solar homes program in Europe and 500,000 in the developing world by 2010 (EU, 1997), totalling about 3 GW.

In *the Netherlands* the Ministry of Economic Affairs aim at 10% renewable energy in the year 2020. To achieve this objective, a plan was made for solar energy aiming to have installed 8 MWp by 2000 and 1450 MWp by 2020.
The Nieuwland 1 MW PV System. In the Netherlands the Regional Distribution Company of Utrecht (REMU), is currently constructing PVs on 500 existing houses in Nieuwland, Amersfoort's new housing area (10% of all houses in the area). The Government of the Netherlands plans to support the construction of 3000 solar homes by 2000, 100,000 by 2010 and 500,000 by 2020 (NOVEM, 1997).

The Japanese Government has a target to install solar power systems in 70,000 homes by the year 2000 (~400 MW) and 4600 MW in 2010. After the Kyoto meeting the target was raised to 5000 MW (WWF, 1998). The utilities are required to purchase any extra electricity produced at the same price they charge producers - a price that is currently more than 20 c/kWh. The transaction is determined by "net-metering", meaning that the rooftops' output is subtracted from the consumer's use of power from the grid. Some 9,400 solar home systems (~37 MW) were installed under this arrangement in 1997 and 13,800 are expected in 1998 (World Watch, 1998).

Industry is increasingly designing products to fit particular applications (like architectural elements) and packaging equipment with end-use appliances (water pumping, off-grid home power, emergency systems, etc.) to increase customer value. At the same time, these packages are tending towards greater standardisation so that the overall energy service and reliability is enhanced.

4 Future trends

The PV industry has announced a large increase in their production capacity in the coming years. Table 7 shows that until year 2000 the capacity will be large enough for a continuation of an annual production increase of 43%. It is interesting to see the large expected increase in thin-film PVs from both a-Si and others. During 1998 three new plants with a total capacity of 25 MW a-Si modules has come in operation: United

Solar's 5 MW plant in Michigan, Solarex's 10 MW plant in Virginia and Canon's 10 MW plant in Japan.

Table 7. PV capacity increases announced by producers

MW	1998	1999	2000
C-Si	216	297	337
a-Si	49	68	90
CdTe,CuInSe2	20	41	65
Total	285	406	491

Since this paper is a "pure PV" paper it has not been considered how large a fraction of the base load could be supplied from PV's.

Much like the automobile industry at the turn of the century, the PV industry today lacks a cohesive market chain – from manufacturer, to market, to after-sales service and support. At the moment the development is uncoordinated but the PV industry is beginning to incorporate practices and infrastructure components of a sustainable technology business.

At a market of 10-20 MW annually, the PV industry was barely able to keep up with the subsidised markets of the developed countries and the purchases supported by development agencies in developing countries. But the competition is getting stronger with the present shipment around 200 MW annually and a strong growth mainly driven by off-grid domestic applications in developing countries, where the big manufacturers are competing to get successful demonstration project, and on-grid systems in urban areas in developed countries.

Though PVs will continue to do well in remote markets and in subsidised BIPV markets, ultimate success in broader markets will depend on getting the cost per watt low enough to compete with other alternatives.

According to the Massachusetts-based Spire Corporation, which makes equipment for manufacturing solar modules, its latest equipment allows large factories to produce modules selling as low as 2 $/Wp (World Watch, 1998).

The routes to PV module cost of 1$/Wp are clear. The growth of the market to an annual shipment of over 2 GWp (reached in 2010 with a 25% annual growth, see Table 8) will lead to production plants of the scale needed to achieve these cost without the need for any technical breakthroughs. This is documented in a BP study (Bruton, 1997) that with an investment of 550 Million US$ into a 500 MW solar photovoltaic factory, the production cost can be reduced by 80%. It is expected that the PV industry will make decisive investments of the size in the period 2005-2010.

In projections, taking into account further actions needed to implement the Kyoto Protocol, an annual market four times business as usual in 2010 equal to an annual shipment of 4 GWp (Greenpeace, 1998) is forecasted.

The technologies needed to make it possible to achieve costs of 0.5$/Wp are coming into sight. Of course a lot of product development is needed, but in order to mature a market with a large scale of production is required. If thin films of polycrystalline silicon can be deposited on modules-sized substrates, in integrally-interconnected structures, then it may be possible to achieve the cost/unit area or thin film modules with the efficiency of wafer silicon modules, and costs below 0.5$/Wp will be possible (Hill, 1998). One way of reaching this goal is to create the islands of crystalline by melting a film of amorphous silicon by a special laser technique (Science, 1998) and letting the atoms rearrange themselves into a crystalline form.

The Second Assessment Report (IPCC, 1996) from the Intergovernmental Panel on Climate Change refers to a projection from the National Renewable Energy Laboratory in the U.S where the costs also reach 1$/Wp in 2010 and ultimately 0.6 $/Wp.

The cost projection for solar PVs mentioned above is shown in Table 8. At the moment only 0.03% of the global power capacity is covered by solar cells. However assuming that the annual shipment will continue to increase with about 25% annually the production capacity will reach about 2 GW in 2010 (and the total accumulated installed capacity about 10 GW) or a size necessary to reduce the price to 1 $/Wp. After 2010 it is assumed that the annual growth will be reduced to 20% and global solar capacity will have reached around 1% of the total in 2020. After that it is assumed that the annual growth will fall to 10% annually and the solar capacity will increase to 30% of the total global capacity in 50 years from now. It must be remembered that this is the fraction of the total capacity, and since the capacity factor for solar PVs are one third to one half of the capacity factor for fossil fuels, the share of the energy consumption from solar PVs should be multiplicated with the same fraction.
For comparison it can be mentioned that the present level of the global installed capacity for wind power is around 6 GW and the growth for the global capacity of wind power is about 20% (Morthorst, 1998).

The solar penetration mentioned above in 2050 agrees with the values reported in IIASA’s global forecasts for the World Energy Council (IIASA, 1995): In their High Growth Scenario solar reaches a 15% share of electricity produced and in their Ecological Driven Scenario 25% of the electricity generation is cover by solar in 2050.

Shell expect the global energy consumption to triple over the next 50 years, 50% of this demand will be met by alternative energy. Photovoltaic power is expected to have a 10% share or somewhat lower than estimated in Table 8.

Table 8, PVs share of future global power capacity

	1997	2010	2020	2050
Accum. GW-PVs	0.8	10.9	75.5	2400
% of total	0.03%	0.3%	1.5%	27%
Cost $/Wp	4.2	1.0	0.8	0.5
Efficiency	12%	14%	16%	18%
Cost c/kWh	32.5	6.6	4.6	2.6

The assumptions behind the calculations in Table 8 are the following: a discount rate of 5%, a lifetime of 20 years, an insolation of 1600 kWh/m^2/year. It is assumed that 100 Wp covers 1 m^2. Finally the electricity production from the solar cells is reduced with 10%, since they are not always under ideal conditions (1000 W/m^2 and 25 degrees Celcius)

Both in the present cost and in the future it is assumed that for on-grid installations the Balance of systems (BOS) cost will decrease in parallel will the cost of the modules and stay at 40% of the total costs (Maycock, 1998).

5 Conclusions

With in the last year's solar photovoltaics has experienced a very rapid growth. The global installed capacity has increased from 34 MW in 1988 to 127 MW in 1997 with an increasing growth in the shipments: 16% over the last 9 years, 28% over the last 3 years and an expansion of 43% last year. There are now 10 producing companies with an annual shipment of over 4 MWp.

The two main drivers are the domestic off-grid installations in developing countries and the domestic on-grid installations in developed countries. Until now off-grid installation have dominated the solar PV market, since they are already economically competitive. However, often the financial mechanisms and necessary organisational set-up are missing. At the moment many big PV manufacturers are working to get good successful reference cases in developing countries. But now the on-grid installations in developed countries are beginning to increase. Of the new PV systems installed in the IEA countries, on-grid distributed systems rose from 5% in 1990 to 20% in 1995 and had a very sharp increase last year. The main growth area in on-grid domestic installations, where there are big programs running in Japan (5000 MWp installed in 2010), U.S. (3000 MWp in 2010) and the Netherlands (1450 MWp in 2020).

Looking at the perspectives a continuation of the high growth in solar PV production will continue supported by the United Nations Framework Convention on Climate Change and the Kyoto Protocol. The PV industry has already announced increases in production capacity large enough for a continuation of last year high growth.

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A substantial cut in solar PV cost per kWh can be expected within the next 10-50 years. Before 2010 it will be reduced by a factor of five and somewhere between 2010 and 2050 solar photovoltaics will be fully competitive to conventional fossil fuel based electricity production.

6 References

Bruton, T., 1997. A study of the manufacture of 500 MW p.a. of crystalline silicon photovoltacis modules. BP Solar International et al. 14th European Photovoltaic Conference. Barcelona.

European Commission, 1997. Energy for the future: Renewable sources of energy: White Paper for a Community Strategy and Action Plan. Communication from the Commission, December 1997.

Hill, R., 1998. PV cells and modules. Renewable Energy World, Vol 1 No. 1, July 1998.

IEA, 1997. Photovoltaic power systems in selected IEA member countries. Task 1, Report IEA PVPS Ex.CO.\Tl 1997:1.

IIASA, 1995. Global Energy Perspectives to 2050 and beyond. IIASA.

IPCC, 1996. Climate Change 1995, Impacts, Adaptations and Mitigation of Climate Change, Chapter 19.2, IPCC Working Group II..

NOVEM, 1997. The PV Programme 1997-2000 in the Netherlands, European Solar PV Conference. Barcelona, June 1997.

Maycock, P. Private communication, 31 August 1998.

Morthorst, P.E., 1998. Wind Power development – Status and Perspectives. Risø, 1998.

Science. Bringing order to Amorphous Silicon. Vol.29. February 27, 1998.

World Watch, 1998. Solar Power Markets Boom, September/October 1998.

Worldwide PV Shipment. The Solar Letter, page 52-53, February 13 1998.

WWF & FEU, 1998. Solar Photovoltaic Power – The Power Supply of Tomorrow, A conference to follow-up on the Climate Summit in Kyoto. Copenhagen, 31 August – 1. September 1998. WWF and Forum for Energy and Development.