IEA INTERNATIONAL ENERGY AGENCY



Added Values of Photovoltaic Power Systems



PHOTOVOLTAIC POWER SYSTEMS PROGRAMME



The cover photographs show two examples of photovoltaics integrated into the building so as to enhance building quality. Photovoltaic modules on the walls of the Nippon Telephone and Telegram (NTT) Masushino R&D Center match with the modern style of the building. The night time photograph of photovoltaic modules on the J House captures the modern Japanese feeling of this house which was designed by Mr Jiro Ohno for his own residence. He is a leading Japanese architect and an expert member of Task 7 - PV in the Built Environment.

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Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organisation for Economic Co-operation and Development (OECD) which carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA Photovoltaic Power Systems (PVPS) Programme is one of the collaborative R & D agreements established within the IEA. Since 1993, a variety of joint projects have been conducted in the applications of photovoltaic conversion of solar energy into electricity. The Programme, whose mission is "to enhance the international collaboration efforts through which photovoltaic solar energy becomes a significant renewable energy source in the near future", is divided into nine Tasks which address specific aspects of photovoltaic technology development and implementation. Further details about the Programme are available on the PVPS website www.iea-pvps.org.

This report has been prepared as a special information activity within PVPS Task 1, which facilitates the exchange and dissemination of information on the technical, economic, environmental and social aspects of photovoltaic power systems. Participating members are: Australia (AUS), Austria (AUT), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Mexico (MEX), The Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE),

Switzerland (CHE), the United Kingdom (GBR), the United States of America (USA), as well as the European Commission. It has also had input from Task 7, which aims to enhance the architectural quality, the technical quality and the economic viability of photovoltaic power systems in the built environment and to assess and remove non-technical barriers for their introduction as an energy-significant option.

The special information activity "Added Values of Photovoltaic Power Systems" has involved two international workshops and exchange of information between interested parties, with Japan as lead country supported by Australia, The Netherlands, Switzerland and the United Kingdom.

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with the assistance of Tony Schoen, IEA-PVPS Task 7 and under the supervision of PVPS Task 1 members. It incorporates the deliberations of two workshops on Added Value, held in Sapporo, Japan in September, 1999 and in Glasgow, Scotland in May, 2000.

Abstract

The structure, ownership and operation of electricity systems around the world are changing in response to industry restructuring, the availability of new technologies and increasing environmental awareness. At the same time, many countries have yet to provide basic energy services for their populations, particularly in areas not served by the electricity grid. Large scale, central power generation and distribution which characterized the electricity industry for much of the 20th century is being challenged by new technologies, which are cleaner, faster to deploy and better matched to local requirements. Higher values are being placed on ancillary services, such as power system reliability and voltage stability, so that a simple comparison of energy cost is no longer appropriate as a measure of competitiveness. Solar photovoltaic electricity is unique

amongst the new energy sources for the wide range of energy and non-energy benefits which can be provided, while the use of photovoltaic power systems as an integral part of a building provides the greatest opportunity for exploiting non-energy benefits and for adding value to the photovoltaic power system.

This report documents the potential added values or nonenergy benefits photovoltaic power systems can provide, the current state of market development and the key barriers faced by renewable energy technologies generally and photovoltaic power systems in particular. Means by which non-energy benefits may be used to overcome barriers to the use of photovoltaic power systems are then discussed, with specific attention to the use of building integrated photovoltaics.



Keywords

Ancillary services, building integrated photovoltaics, capacity credit, competitive markets, distributed generation, externalities, green power, micropower, peak lopping,

photovoltaic power systems, power factor correction, renewable energy, restructured utilities, solar photovoltaic electricity, sustainable development.

Glossary

Ancillary services: resources used to maintain power supply quality, such as reliability, voltage and frequency stability and waveform purity.

Cogeneration: the simultaneous production of electricity and heat, usually for commercial or industrial use.

Clean Development Mechanisms (CDMs): intended to help industrialized countries achieve their Kyoto Protocol emissions reduction targets while helping developing countries achieve their sustainable development goals. Emissions reductions resulting from CDM projects within developing countries will be available, at least partially, to the project funders.

Distributed resources: small scale generating, storage or demand management plant, sometimes referred to as micropower, and typically connected into the electricity distribution, rather than transmission, network. These can include photovoltaic power systems, wind generators, batteries or other storage devices and appliances, such as solar water heaters, which reduce electrical load on the distribution network.

Emissions trading: a mechanism to control the increase in greenhouse gas emissions by setting emission limits, allocating permits and allowing emitters to trade permits amongst themselves as a means of achieving the lowest cost emission reductions overall.

Fossil fuels: energy sources derived from ancient plant and animal matter trapped on the earth's surface over geological time. These include coal, oil and natural gas, all of which are non-renewable over any human timeframe.

Greenhouse gas emissions: emissions of gases which collect in the atmosphere and contribute to the Earth's "greenhouse" effect. Increasing concentrations of gases, such as carbon dioxide, methane and nitrous oxide are currently producing an enhanced greenhouse effect, because they are accumulating at a rate faster than they can be dispersed. The combustion of fossil fuels is thought to be a major cause of this enhanced effect, which in turn is expected to contribute to higher average global temperatures over the next century.

Photovoltaic power system: a system including photovoltaic modules, inverters, batteries (if applicable), and all associated installation and control components, for the purpose of producing solar photovoltaic electricity - also commonly referred to as PV or photovoltaics.

PV or photovoltaics: see above.

Renewable energy: energy sources derived directly or indirectly from the energy of the sun, the earth's core or from lunar and solar gravitational forces and which are therefore renewable over time. These include solar, wind, biomass, tidal, wave, hydro and geothermal energy.

Sequestration: removal of greenhouse gases from the atmosphere by the use of plants, storage devices or other technological means.

Vertically integrated utilities: whereby generation and transmission and sometimes also distribution and retailing of electricity are combined in a single organisation.

Watt peak (Wp): the peak power of a PV module or system under standard test conditions of 1000 Wm⁻² irradiance, 25 °C junction temperature and solar reference spectrum AM 1.5.

Acknowledgments

This report was conceived and guided by the Japanese IEA-PVPS members and experts from NEDO and PVTEC. It is based on presentations made and discussions held at workshops organized by IEA-PVPS Task 1 in 1999 and 2000.

It also has input from the work of Task 7. Greg Watt, the IEA-PVPS Task 1 Operating Agent, provided valuable assistance in developing the structure of the report and in eliciting key resource documents.

Executive Summary

While solar photovoltaic electricity, particularly in off-grid applications, is an important market for photovoltaic power systems in developing countries, this report focuses more closely on market development for grid-connected photovoltaic power systems in the IEA-PVPS member countries. However many of the issues which need to be addressed, particularly those relating to the electricity industry and energy policy, are the same for both industrialized and developing countries.

Many renewable energy and energy efficiency technologies meet the definition of "distributed resources" which can be strategically located within electricity distribution networks to reduce the need for external energy supplies, while also providing a range of electrical system, environmental, architectural and socio-economic benefits. Solar photovoltaic electricity is unique amongst the new energy sources for the wide range of energy and non-energy benefits which can be provided, while the use of a photovoltaic power system (often referred to as PV or photovoltaics) as an integral part of a building provides the greatest opportunity for exploiting non-energy benefits and for adding value to the photovoltaic power system.

Photovoltaic power systems installed on the surfaces of buildings allow the possibilities of combining energy production with other functions of the building envelope, including structural support, weatherproofing, shading or solar thermal collection. Cost savings through these combined functions can be substantial. Additionally, no high-value land is required, no separate support structure is necessary and electricity is generated at the point of use. The latter contributes directly to the building occupant's electricity requirements while also avoiding transmission and distribution losses and reducing capital

and maintenance costs for utilities. The integration of the photovoltaic power system into the architectural design offers more than cost benefits. It also allows the designer to create environmentally benign and energy efficient buildings without sacrificing comfort, aesthetics or economy, and offers a new and versatile building material.

A number of projects around the world show an emerging market for grid-connected building integrated photovoltaic power systems, despite the fact that solar photovoltaic electricity is still more expensive than grid power. The market for grid-connected photovoltaic power systems in IEA member countries is therefore growing rapidly and now accounts for more than 50% of installed capacity.

This report shows that solar photovoltaic electricity can contribute significantly to reductions in greenhouse gas emissions from the electricity sector. Lifetime CO₂ emissions with current photovoltaic power system technologies are 85 to 94% less than those from coal fired power stations and will be 95 to 97% less with new technologies. Solar powered manufacturing plants can operate as "solar breeders" ensuring a sustainable technology in the long-term.

Solar photovoltaic electricity can contribute to improvements in air quality. When it displaces coal fired generation, the NO_x emissions are typically reduced by 50% and SO_x emissions by 90%, making solar photovoltaic electricity a valuable addition to clean air policies. For improving urban air quality, photovoltaic power systems can play a role in facilitating the introduction of electric vehicles, either by powering the vehicle directly or by providing power to recharging stations.

Solar photovoltaic electricity can assist in securing energy supplies in both the long-term and short-term. With fossil fuel resources expected to be depleted this century, photovoltaic power systems provide a means of maintaining electricity supplies in industrialized countries and providing electricity to the developing world without concern for fuel supply security. Dispersed photovoltaic power systems feeding into electricity distribution networks, or operating independently, can provide more reliable electricity supplies during power outages caused by summer peaks or emergency situations.

The production of photovoltaic power systems is a high technology industry which can create new jobs in manufacturing, distribution, installation and maintenance. Dispersed application means that employment is created in regional areas, as well as in industrial centres. Direct employment in the PV industry world-wide is expected to be between 250 000 and 300 000 by 2010.

The modularity of photovoltaic power systems provides benefits to electricity utilities by allowing for generation to be expanded, or reduced, to match demand more easily than with large central generation plant. Lead-times are also shorter, exposure to fuel price volatility is reduced and grid augmentation can be avoided. Hence financial costs and risks are reduced. On-site or local generation also reduces transmission and distribution losses. Dispersed generation reduces the likelihood

and impact of large scale power outages while smoothing output fluctuations from individual power systems. It can be especially valuable in dealing with summer peak loads, where the effective load carrying capacity, or firm power output, can exceed 80% of the PV rated output.

For customers, the photovoltaic power system offers a range of benefits which can significantly increase its value. These include providing aesthetically pleasing, non-intrusive, multi-function building elements, ensuring supply reliability, reducing energy and peak demand charges and contributing to environmental protection. For society as a whole, photovoltaic power systems provide a means of delivering more sustainable energy systems for both rural and urban developments.

Nevertheless photovoltaic power systems face a number of barriers to their entry into the mainstream energy and building markets. These include high capital costs and associated financing problems; immature products and service delivery chains; a lack of information, expertise, standards and demonstration systems; electricity industries that still favour the central generation paradigm; and electricity markets that do not yet account for environmental externalities. Some of these barriers can be overcome by assessing both the energy and non-energy benefits which can be provided by a photovoltaic power system, thus making it a cost effective option even with current costs and energy prices.



Introduction

At the start of the 21st century, the structure and composition of many electricity systems around the world are changing Industry restructuring, which commenced in the 1990's, is beginning to challenge the "natural monopolies" of large scale, central power generation and distribution which characterized the industry for much of the 20th century. New technologies, which are cleaner, faster to deploy and better matched to local requirements are attracting the interest of industry, investors and local communities. At the same time, an increasingly digitized world is placing higher value on power system reliability and voltage stability [Dunn, 2000], so that a simple comparison of electricity cost is no longer appropriate as the only measure of competitiveness. Rather, technologies will increasingly be measured by their ability to meet new market needs [Bower & Christensen, 1995]. Many renewable energy and energy efficiency technologies meet the definition of "distributed resources", which can be strategically located within electricity distribution networks to reduce the need for external energy supplies, while also providing a range of electrical system, environmental, architectural and socio-economic benefits. Photovoltaic power systems (often abbreviated to PV or photovoltaics) are unique amongst the new energy technologies for the wide range of energy and non-energy benefits which can be provided, while the use of photovoltaics as an integral part of a building provides the greatest opportunity for exploiting non-energy benefits and for adding value to the photovoltaic power system.

Photovoltaic power systems are already widely used as a cost effective option for small scale power supplies in remote areas. Here the difficulties and costs associated with fuel transport or with maintenance support are high and well recognized, making photovoltaic power systems an attractive option. Despite this, large scale centralized power supplies continue to be supported over distributed options by utilities and governments in rural areas of both industrialized and developing countries.

For grid-connected photovoltaic power systems, comparisons continue to be made almost entirely on the basis of electricity cost which, despite consistent cost reductions over the past three decades, typically remain higher than those available from centralized, fossil fuel or nuclear plants. However, even in grid supplied areas, values other than kWh energy cost are important. For utilities these include ancillary services, such as power quality and reliability, and capacity values. For customers and society they include power quality, reliability, environmental impact, convenience, security and employment. Nevertheless, present arrangements for ancillary services and network augmentation or extension in electricity markets continue to focus on the larger participants in the electricity market, and distributed options such as photovoltaics do not yet receive equal consideration. In addition, regulation of the electricity industry with respect to climate change is still in its infancy, so that no value is yet placed on emission free generation.

Although many of the benefits cited in the report are recognized, they are rarely attributed a value which could, for instance, be applied to project cost/benefit assessments. In fact, it is easier to attribute value to some of the benefits than to others. This report is a first step at documenting the "added values" of photovoltaic power systems. This will help the non-energy benefits to be more readily quantified and incorporated into project evaluations, and also help identify aspects of existing energy policies which require modification so that the full potential of photovoltaic power systems and other renewable and distributed generation technologies can be realized.

Although solar photovoltaic electricity in developing countries, particularly in off-grid applications, is a major market for photovoltaic power systems, this report focuses more closely on market development for grid-connected photovoltaic power systems in the IEA-PVPS member countries, especially building applications. However, many of the issues which need to be addressed, particularly those relating to electricity industry and energy policy, are the same for both industrialized and developing countries. As an example of international recognition of the issues facing renewable energy introduction in both industrialized and developing countries, a recent meeting of the G8 countries, which comprises the US, UK, Japan, Italy, Canada, Germany, France and Russia, set up a renewable energy task force [www.renewabletaskforce.org] to examine:

- Barriers to renewable energy diffusion and opportunities for overcoming them
- Examples of successful market development and initiatives the G8 countries might take
- The relevance of commercial versus non-commercial markets for renewable energy service provision to the poorest countries and communities
- Priorities and potential for renewable energy capacity building, market development and trade in developing countries, taking account of local political, institutional and investment conditions
- The role of subsidies, green certificate trading and export credits in renewable energy trade and development
- The role of renewable energy R&D
- The importance of renewable energy advances in industrialized countries for accelerating diffusion in developing countries
- How public/private partnerships, or other useful mechanisms, can be promoted
- The role and relative importance of renewable energy service provision to urban and rural populations.



The subject of this report provides information specific to photovoltaic power systems which addresses many of the questions posed by the G8 task force.

This report is based on the outcomes of workshops organized by IEA-PVPS Task 1 which were held in 1999 and 2000. It also has input from Task 7, the IEA-PVPS Task which deals specifically with photovoltaics in the built environment. The report is structured as follows:

- Chapter 1 of the report defines "added value" and outlines key drivers for renewables;
- Chapter 2 provides background material on the current status of photovoltaic power system manufacture and use;

- Chapter 3 outlines the added values or non-energy benefits that photovoltaic power systems can provide, and provides case studies which quantify various added values in different market sectors and different countries;
- Chapter 4 documents the key barriers faced by renewable energy technologies generally and photovoltaic power systems in particular;
- Chapter 5 summarizes the means by which nonenergy benefits may be used to overcome barriers to the use of photovoltaic power systems.

1 Renewable Energy and Added Value

1.1 Definition of Added Value

As with most assessments of value, the value which can be attributed to a photovoltaic power system (PV or photovoltaics) depends on the perspective from which it is being viewed. Hence the electricity industry will value electrical output and network benefits, the building industry will value building function and aesthetics, while governments and the community will value environmental benefits, employment creation and energy self-sufficiency. At present, few of the non-energy benefits of PV or other renewable energy technologies are quantified in a way which would

reflect their value to the different interest groups. Quantifying both energy and non-energy values is critical to illustrating the cost effectiveness of PV and hence to facilitating its entry into the mainstream energy market. Figure 1.1 illustrates the process of developing cost-effective PV systems, from the current stage where incentives are used to buy down the effective cost, through increasing acceptance and quantification of the added values PV can offer, which serve to reduce the net cost of PV generated electricity and eventually lead to situations where PV is more attractive than conventional energy sources.

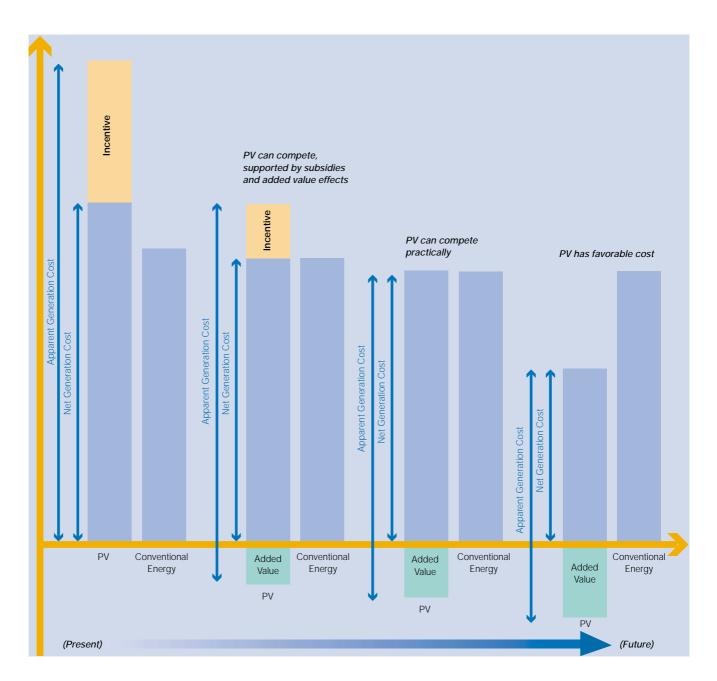


Figure 1.1: The Impact of Non-Energy Values on Apparent PV Generation Costs [Konno, 1999]

1.2 Drivers for Renewables

Documenting and quantifying added values can provide links to key government, utility and industry drivers and will become increasingly important in addressing customer preferences in competitive energy markets. There are a number of key drivers which are impacting at various levels on renewable energy development and use around the world. These include internationally coordinated greenhouse gas reduction policies and clean air policies generally, the introduction of competitive energy markets, the need to create employment and new types of industrial development and the need to maintain or achieve energy supply security, as discussed below.

Photovoltaic power systems offer electricity supply with **low environmental impact** relative to almost all other electricity options, hence fitting well with many environmentally driven programmes or objectives at the international, national, regional or individual level. Greenhouse gas and other air and water emissions are low, land use and visual impacts, particularly for building integrated systems, are low, noise levels are low, resource depletion is minimal and a high proportion of components can be recycled.

Greenhouse gas reduction strategies are beginning to be a key driver for renewables. Over this century energy efficiency and renewables are set to become essential parts of the energy supply and demand mix, with the costs of renewables falling due to technology development and scale-up of manufacture. Most countries include some renewable energy programmes in their greenhouse gas reduction strategies. The emphasis on renewables varies, with some countries seeing major industry development and export opportunities, in addition to internal emissions reductions.

Clean air programmes are another key driver for renewables in many countries, usually on a regional basis and aimed at reducing local air pollution. Acid rain and $\mathrm{NO_x}$ have been targets in the past. However, government policy in many countries is increasingly being focussed on greenhouse gas reduction and, although solar photovoltaic electricity may play only a minor role in the short-term, renewable energy programmes are included in most government climate change strategies.

The **job creation potential** of renewables has been identified as an important benefit and a key objective in many countries, with renewables typically providing a range of new employment opportunities dispersed over a wide geographical area. Employment is a key driver for governments, with location and skill levels being important parameters. Large incentive packages are offered by some governments in order to attract PV manufacturing facilities [Engler, 2000].

Energy security is a driver for both governments and industry. Renewables can contribute to energy supply security by increasing the use of indigenous resources and diversifying fuel sources. Short-term security of supply was a major driver both for national governments and for international organizations during the 1970s and early 1980s, resulting, for example, in the Japanese Sunshine Project, the formation of the International Energy Agency, and driving research into alternative sources of energy and energy efficiency [ATLAS Project, 1999]. Short-term supply security, to avoid black-out or extreme electricity prices in periods of high demand or adverse weather conditions, is of increasing concern in many parts of the US and Australia and has long been a concern in developing countries. Long-term security of supply is now becoming an important driver, with the prospects of fossil fuel resource depletion this century, concerns about environmental impacts of energy systems and price increases associated with both issues.

Competitive electricity markets are being introduced in many countries and utilities are increasingly aware of the attractiveness of a green image to contestable customers [IEA-PVPS,1998]. This has been a useful driver for PV, with many utility funded systems now installed around the world, despite relatively high electricity costs. The short lead time required for project development and completion, the relative ease of siting and the high local presence possibly all favour PV over many other renewable energy technologies. Low levels of emissions, noise and visual intrusion reinforce PV's environmental credentials. For utilities, ancillary network service values, such as reliability, voltage stability and management of peak demand can be strong drivers, as can the desire to defer expenditure on network augmentation. These values can be difficult to quantify. However, documentation of case studies, such as those contained in this report, which illustrate site specific benefits gained, will assist in building up a database of the range of values which can be expected.

Function and design are drivers for architects and developers. The potential of PV products to perform a variety of building functions, in addition to energy generation, gives them a significant advantage over other energy technologies and will therefore become more important as the grid-connected PV market is developed. For this market, high value is also placed on convenience and aesthetics, as well as the ease of installation, modularity and low maintenance offered by PV systems.

This report aims to summarize the added values PV can offer and to match these against the key international drivers, so that the values can be better recognized, quantified and used to overcome current barriers to increased renewable energy use.



2 The Status of PV Applications

PV production levels have been growing steadily over the last 30 years, but escalated rapidly over the last decade, as shown in Figure 2.1. Production is expected to reach 380 MWp by 2005 and 940 MWp by 2010 [Allied Business Intelligence, 2000].



Figure 2.1 World PV production during the 1990s [based on figures reported in Photovoltaics Intelligence Report and Solar Flare, 1991-99]

2.1 Market Size and Growth Rates in IEA Countries

By the end of 1999, 516 MWp of PV power had been installed in the twenty countries participating in the IEA Photovoltaic Power Systems Programme. The increase in installed capacity between 1992 and 1999 is shown in Figure 2.2, broken down into primary applications [IEA-PVPS, 2000/2 - www.iea-pvps.org]. Although the worldwide installed power is significantly higher than this, it is indicative of the global trend.

Between 1992 and 1998 the total installed capacity grew by 20-28% per annum. This increased to 31% between 1998 and 1999, with 60% of 1999 installations occurring in Japan. Collectively Japan, the USA and Germany accounted for 87% of the 121 MWp installed in 1999, although Switzerland remains the country with the highest installed power per capita [ibid].

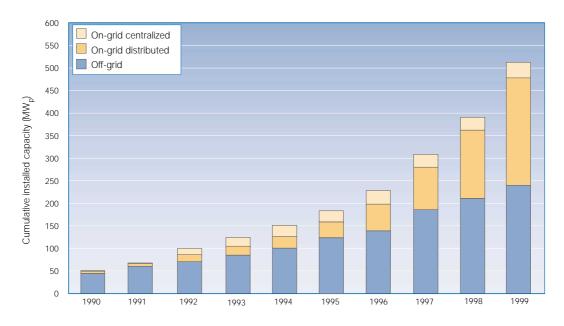


Figure 2.2 Cumulative installed PV power by application in IEA-PVPS member countries

Figure 2.2 shows that traditionally most PV systems were for off-grid applications. This is still true in the majority of the reporting countries and in Australia, Canada, Finland, France, Israel, Korea, Mexico, Norway, Portugal and Sweden over 90% of the total installed capacity is off-grid.

This encompasses a wide range of applications: in Canada, Finland, Norway and Sweden, the majority of off-grid PV systems are used for seasonal/recreational buildings and remote cabins. In France, Israel and Mexico, PV is used as a strategy for rural electrification. In Australia, Korea and Japan most off-grid systems are non-domestic - providing power for pumps, agriculture, traffic signals and, in particular, telecommunications. For remote areas, PV provides a commercial alternative to diesel and central grid supplies.

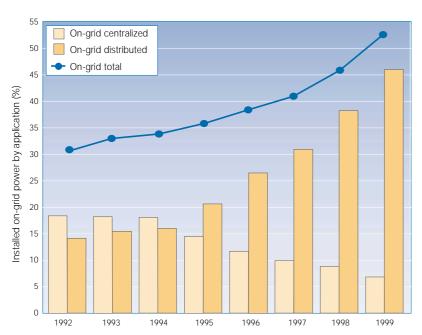


Figure 2.3 Trends in centralized and distributed grid-connected PV power in IEA-PVPS member countries (% of total installations)

However the overall trend, as shown in Figure 2.2 and more explicitly in Figure 2.3, is a steady increase in the proportion of PV power that is grid-connected. In 1992 only 29% of the installed capacity was connected to the grid, by the end of 1999 this had reached 53%. This is due almost entirely to a proliferation of on-grid distributed systems [ibid].

The rise in on-grid distributed applications is driven mainly by the large government subsidy programmes in Japan, Germany, the USA and the Netherlands, which focus on PV in the urban environment. Although not yet significant in absolute terms, it is worth noting that the on-grid distributed market is actually expanding most rapidly in Denmark and the UK (countries with a relatively small PV market at present) and in countries such as Australia and France where, traditionally, PV has been used for off-grid applications.

2.2 Applications in the Built Environment

Increasing cell efficiency and reducing installed cost have been the primary focus of research efforts aimed at improving the economics of PV. However, effective cost reductions can also be achieved through the integration of photovoltaics into the built environment (building integrated PV or BIPV), thereby displacing conventional building materials and providing a range of other values. PV installed on the surfaces of buildings allows the possibility of combining energy production with other functions of the building envelope, including structural support, weatherproofing, shading or solar thermal collection [Schoen, 1996].

Cost savings through these combined functions can be substantial. For instance, conventional cladding costs for expensive facade systems may equal or exceed the cost of PV modules. Additionally, no high-value land is required, no separate support structure is necessary and electricity is generated at the point of use. The latter contributes directly to the building occupant's electricity requirements while also avoiding transmission and distribution losses and reducing capital and maintenance costs for utilities. The integration of PV into the architectural design offers more than cost benefits. It also allows the designer to create environmentally benign and energy efficient buildings, without sacrificing comfort, aesthetics or economy, and offers a new and versatile building material [ibid].

A number of projects around the world show an emerging market for grid-connected PV systems, despite the fact that electricity from PV still is more expensive than grid power. Pioneers in this field are beginning to install PV for energy-efficiency and ecological reasons as well as for reasons of aesthetics and prestige. On the other hand, electric utilities view building integrated PV as a decentralized power source with a large potential for the future and are correspondingly starting to construct and operate building integrated PV systems.

Creative partnerships between PV manufacturers and building material suppliers are beginning to emerge [Siemens, 2000], with the aim of developing products for this potentially large new market. The challenge is to meet market expectations and to develop photovoltaics into a cost-effective and clean power source, available to the utility companies and the building owners of the 21st century. The interest of the photovoltaics research and development community and the PV industry, together with architects, the building industry and property developers, is required in order to take up this challenge effectively on national and international levels.

3 Added Values Offered by PV

The diverse benefits offered by PV have different values in different sectors. There is obvious overlap, nevertheless, key values are discussed below from the perspective of governments and planners, utilities, building designers, end use customers, the environment and the education sector. Examples of work undertaken in IEA-PVPS member countries on the diverse benefits of PV are also given. They serve to quantify values and to illustrate their relative importance in different parts of the world.

3.1 Values for Governments and Policy Makers

3.1.1 Net energy benefits and greenhouse gas emission reductions

Greenhouse gas reduction strategies are becoming key energy policy drivers in industrialized countries.

Although increased use of PV is not necessarily the lowest cost greenhouse gas reduction option in the short-term, in the longer-term PV is one of the most attractive and versatile emissions free electricity technology options. Hence, most countries have included some PV programmes in their greenhouse gas reduction strategies as a means of fostering development of the technology and the market.

The emissions reduction benefits offered by PV depend on the technologies used and the energy sources being displaced. Estimates of the time required for PV to "pay back" the energy used in its manufacture range from less than 2 years for standard unframed thin film modules to 10 years for standard framed crystalline silicon modules [Nieuwlaar & Alsema, 1997]. For systems specifically designed for rooftops, but still using existing technology,

Alsema [1998] narrows this down to between 3 and 8 years. New production processes and increased production volumes are expected to reduce payback times to less than 1 year for modules and less than 2 years for complete systems [ibid]. Alsema [1998] calculates life cycle carbon dioxide emissions from PV generators to be only 6-15% of those from coal fired power stations and 11-26% of the average EU generation mix, as shown in Figure 3.1. He expects them to drop to 2-3% of coal and 3-5% of the average within a decade.

Kazuhiko Kato of the Electrotechnical Laboratory, MITI, Japan has evaluated the primary energy requirements (PER) and carbon dioxide emissions from the manufacture of different PV technologies and used this to assess the net energy benefits and the greenhouse gas reduction potential of rooftop PV systems in Japan [Kato, 2000].

Three PV technologies were studied: thin film cadmium telluride (CdS/CdTe), flat plate polycrystalline silicon (poly-Si) and thin film amorphous silicon (a-Si) at three different levels of production: 10, 30 and 100 MW per year. The total primary energy requirement for poly-Si modules ranges from 15.7 MJ (100 MW/yr) to 25.4 MJ (10 MW/yr) per Watt of production; for a-Si the range is 10.3 MJ to 21.6 MJ per W and for CdS/CdTe 10.2 MJ to 17.5 MJ per W. For poly-Si, half the total PER can be attributed to cell and wafer production. Based on these figures, PV is calculated to generate between 29 and 73 g CO₂ per kWh. Hence, a 3 kW rooftop PV system in Japan, including balance of system PERs, can be expected to pay back the energy used for its manufacture in 1.1 to 1.7 years for production levels of 100 MW per year and 1.6 to 2.4 years for 30 MW per year. Over a 20 year life, it can save approximately 26 t of CO₂ emissions, based on displacing current Japanese electricity which has a CO₂ intensity of 418 g CO₂ per kWh.

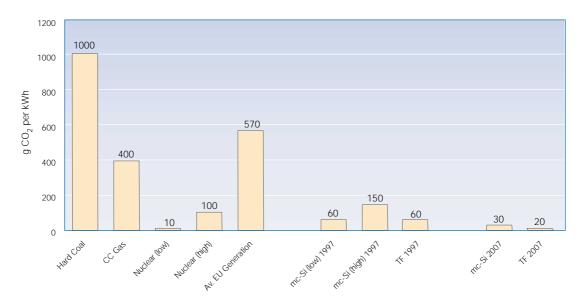


Figure 3.1 Life cycle CO₂ Emissions for Grid-Connected Rooftop PV Systems (under 1700 kWh/m²/yr) and for Conventional Power Systems [Alsema, 1998]

In Australia PV is calculated to release around 104 g/kWh produced, compared with 932 g per kWh for existing black coal fired electricity plants and 439 g from combined cycle gas plants [BHP, 2000], representing CO₂ emissions reductions of 89% and 76% respectively. Hence 1 kWp of grid-connected PV in Australia at present, with predominantly coal fired power, would save 45 t CO₂ over a 30 year life.

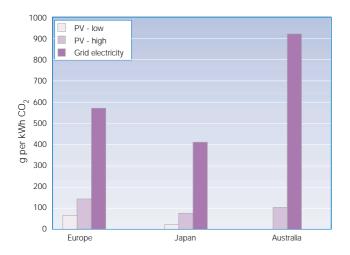


Figure 3.2 Comparison of CO_2 emissions from PV and grid electricity in Europe [Alsema, 1999], Japan [Kato, 2000] and Australia [BHP, 2000].

Hence, with existing technology, PV systems can be expected to generate at least 3 times, and most probably more than 10 times, the energy required for their manufacture over their lifetime of operation. Carbon dioxide emissions are reduced by 85% or more compared to coal fired generation, making PV an important technology to include in plans for long-term, sustainable energy systems. Expected reductions in PV manufacturing energy requirements will reduce energy payback periods to less than 2 years. Hence, if PV is used to power PV component factories, it can operate as a "solar breeder" technology, with a sustainable long-term future.

From the viewpoint of PV as a building material, Ruyssevelt [2000] argues that PV is the only building component required to show an energy payback time. Atria, glass facades or marble cladding are routinely used, even when they reduce thermal comfort levels in a building, or require additional heating, cooling or lighting. If PV is included in the building or renovation brief from the start, he argues that payback time should not be an issue. PV should be treated like any other building component, with added benefits of electricity output, PR value, sustainability and, at present, the opportunity for funding assistance [ibid].

3.1.2 Clean air targets

Clean air programmes have been put into place in many countries, usually on a regional basis and aimed at local air pollution. Programmes typically target local emissions from vehicles, and combustion of coal, natural gas, oil and biomass.

More recent clean air policy proposals acknowledge global issues and incorporate greenhouse gas reduction strategies. For instance, the US Clean Air Partnership Fund has broadened the reach of clean air programmes to include support for reductions in greenhouse gases and other air pollutants. In Australia, the NSW air quality management plan deals with local, regional and global issues. Clean air policies can be an especially strong driver to promote renewable electric transport systems. In California, where clean air policies are directed at transport systems, PV powered recharging stations for electric vehicles are being installed [Trends in Renewable Energies, 1999], free charging from renewable sources, up to 5000 miles per year, is being offered by one utility [TenderLand, 2000] and a manufacturer of electric bikes offers PV recharging kits [Zero Air Pollution, 1999].

 ${
m NO}_{\rm x}$ and ${
m SO}_{\rm x}$ trading is already being used as part of clean air policies in some countries and offers opportunities for PV to play a role. Where PV generation displaces coal fired power generation, life cycle ${
m NO}_{\rm x}$ emissions are halved and ${
m SO}_{\rm x}$ emissions are reduced by 90% [BHP, 2000]. In future it may be administratively useful to establish standard emissions trading procedures which can be applied to the full range of pollutants - ${
m NO}_{\rm x}$, ${
m SO}_{\rm x}$, ${
m CO}_{\rm 2}$ and others - with clear links between clean air and PV policies. Clean air policies are already beginning to impact on standby generation plant and plans for increased use of distributed generation [Trends in Renewable Energies, 2000]. Clean air policies in Texas may restrict the use of distributed generation plants using diesel or waste fuel [ibid] and provide more opportunities for photovoltaics and other low emission options.

3.1.3 Energy supply security

Traditionally, most government and utility planning has been directed at short-term security of supply, or "keeping the lights on" [ATLAS Project, 1999]. Priorities are thus to ensure smooth day-to-day operation of the national power and fuel supply systems, and cope with short-term disruptions such as unexpectedly cold weather, international price fluctuations or industrial action in the fuel supply industry. These concerns have been addressed by measures such as ensuring stockpiles of fuel, ensuring over-capacity of plant or entering into long-term supply contracts. By contrast, long-term security of supply is concerned with looking ahead to the future depletion of fossil fuel resources and responding to environmental impacts that may seriously curtail their use libid].

For countries or regions dependent on imports of fossil fuels, PV offers the prospect of local electricity supply security both in the short-term and in the long-term. In the short-term, the installation of photovoltaics on household, commercial and light industrial buildings can reduce peak electricity demand and improve energy supply security. PV can contribute to long-term energy supply security by reducing reliance on depleting fossil fuels, by increasing the use of indigenous resources and by diversifying fuel sources.

The importance of security of supply as a driver for energy research and development changes over time. When there are significant oil price rises, short-term security of supply is a major driver both for national governments and for international organizations. In the 1970s, this resulted in the formation of the International Energy Agency and drove research into alternative sources of energy and energy efficiency. In periods of low energy prices and increased production of oil and gas, security of supply recedes as an issue for many countries, although it is still important for countries such as Japan with few indigenous fossil fuel resources. Nevertheless, for socio-economic reasons, the use of indigenous resources is important in all countries.

In countries such as Australia, with high levels of local coal use and export and high per capita greenhouse gas emission levels, the challenge of reducing emissions and diversifying away from fossil fuels is an important long-term supply security issue.

3.1.4 Industry development and employment growth

The job creation potential of renewables has been identified as an important benefit and a key objective in many countries, with renewable energy industries providing major new job creation prospects [Singh, 1999; Renner et al, 2000]. Some countries see major industry development and export opportunities, in addition to internal emissions reductions. Canada's Action Plan 2000 [Government of Canada, 2000] aims to reduce greenhouse gases as well as transforming the country into a world leader in sustainable development. Several governments have linked emissions reduction and employment creation by using taxes on fossil fuels to assist industry development and job creation in areas with high unemployment [Environmental Science & Technology, 1998]. Some European countries and US States are actively pursuing the establishment of renewable energy manufacturing facilities, for instance, by the use of tax incentives, offers of land, purchase guarantees and other means [Interstate Renewable Energy Council, 1999]. Despite negative perceptions of the employment consequences of sustainable energy development, linked mainly to reduced employment in fossil fuel industries, the overall impacts are positive for most countries [Renner et al, 2000]. In the future, the potential employment benefits of renewable energy technologies may become an increasingly important factor influencing government policy.

Although still relatively small, the PV industry is growing fast. The European Commission anticipates world-wide employment of 261 000 by 2010, if the PV market continues to grow at 20% per annum [European Commission, 1996] and if current market barriers are removed. The European PV Industry Association estimates PV could directly employ 294 000 people by 2010 for production, installation and maintenance [Eurosolar, 1999]. In the US, the PV industry already employs 20 000 people directly and estimates that 3800 jobs are created for each \$100 million of PV sales [Solar Energy Industries Association, 1999]. Installed PV capacity is expected to grow at 19.4% and be the fastest growing source of electricity generation in the US over the next 20 years [US EIA, 2000].

For both developed and developing countries, one of the important aspects of the job creation potential of PV is the diversity both of skills required and job locations. The scope for PV use is widespread, in both urban and rural areas and thus there are opportunities for new manufacturing and service industry development and associated professional and trade level employment creation in urban and regional areas. A shift from centralized supply to distributed resource use would also favour the use of PV and demand side options. Hence, even if the labour intensity of PV manufacture reduces with capacity increases and automation, there will be regional development benefits in the locations in which they are used.

3.1.5 Examples of government programmes driven by added values

The European Union has developed an Energy Strategy and Action Plan which aims to double renewable energy contributions from 6% to 12% of Europe's energy supply by 2010 based on a combination of expected added values [Scowcroft, 2000]:

- Environmental benefits: to assist in meeting its Kyoto target of an 8% reduction in greenhouse gas emissions by 2010 compared with 1990 levels.
 CO₂ reductions of 402 million tonnes per year by 2010 are expected.
- Economic and employment benefits: strengthening Europe's competitive edge in the global renewables market, thereby capturing employment and manufacturing niches, plus associated education opportunities. This is supported by investment subsidies, tax credits and market incentives offered by EU member countries. Renewable energy business is expected to be worth 17 billion EUR by 2010, creating 350 000 extra jobs.
- Security of supply: reducing fuel imports by 17.4% between 1997-2010 (21 billion EUR savings).

The Netherlands has run a staged PV development programme for a decade and is looking to a new "PV Covenant" for the next 10 years. The programme aims have been to reduce costs by development of supportive infrastructure, gaining experience and increasing the market for PV, especially as a building product [Schoen, T, 2000]. PV use is supported because it will increase the country's energy self sufficiency, reduce greenhouse gases and provide a new industry with potentially large internal and export markets. The density of development in the Netherlands makes PV an attractive choice for installation on buildings and other structures, such as highway noise barriers.

The initial phase of the programme was to establish R&D infrastructure and to gain experience with PV installation and use. The second phase continued support for R&D, but also aimed at increasing public acceptance of the technology, developing easy to use BIPV and stand-alone PV products and reducing non-technical barriers by increasing PV expertise amongst utilities, planners, architects and builders.

Demonstration system sizes and density have been gradually increased from several kWp to 1 MWp and plans now include a target of 250 MWp installed capacity around the country by 2010 [ibid].

The Australian Government has launched a comprehensive package of renewable energy programmes as part of its greenhouse gas reduction strategy [Walsh, 2000]. The greenhouse strategy is supported by funding of AUD 1 billion over 5 years and includes the establishment of an Australian Greenhouse Office, which links to government portfolios of industry, science and resources, environment and heritage, agriculture, fisheries and forestry, transport and foreign affairs.

Renewables programmes are aimed at industry and export market development as well as greenhouse gas reduction. They include:

- · a mandatory target for renewable electricity
- · renewable energy "showcase" demonstration projects
- venture capital for new companies
- · commercialization funds
- rebates for displacement of diesel fuel in remote area power systems
- · rebates for building integrated PV systems
- a renewable energy action agenda and
- a comprehensive renewable energy web site.

The Japanese Government has targeted both the development of new BIPV products as well as an increase in installed BIPV capacity. The main impetus behind BIPV research has come from the New Energy Development and Industrial Technology Organization's (NEDO) New Sunshine Programme, which focuses on sustainable economic growth and the resolution of energy and environmental problems. Extensive research on electricity network issues related to distributed PV systems has also been conducted at the Rokko Island research facility.

The development of specific BIPV products is considered a high priority in reducing costs and increasing consumer acceptance of PV. R&D projects funded by NEDO to investigate BIPV building elements typically involve a PV manufacturer, a construction materials company and a construction company. Projects include development of exchangeable shingles, prefabricated roof panels, heat insulated roof panels, glass curtain walls, metal curtain walls and flexible roofing sheets. A second phase of the R&D focuses on improving costs, performance and design. Innovative concepts being examined include durability, colour, flexibility, fire resistance, strength, light weight and integration with building components [Yamaguchi, 2000]. Fire resistance has been of particular importance in Japan and is incorporated in many of the new BIPV products. An interesting product which illustrates durability and strength is a semi-transparent PV decking material, which can be

walked on, and is illuminated from below at night, providing a useful and attractive material for public areas, as well as for residential use [Ito, 2000].

The Ministry of International Trade and Industry (MITI) subsidizes individual residential BIPV installations and aimed to have 70 000 systems installed by 2001. This scheme is administered by the New Energy Foundation (NEF) with users eligible for a 30-50% rebate on installation costs. This scheme has been very popular and often over subscribed. NEF also provides grants under its Field Test (FT) programme for installations of 10 kWp or more on public or industrial sites, on the basis that performance information is made public. Low interest loans are also available to corporations wishing to install systems. In addition to subsidies for system installation, net metering (with buy back rate same as selling rate) has been legislated since 1992, with encouragement given for utilities to pay a 10% premium for renewable energy.

As a result of these programmes, the typical cost of a 3 kWp residential PV system had decreased to 3 million Yen by 1998, between one third and one quarter of the cost 5 years previously [Yamaguchi, 2000]. PV production capacity increased from less than 15 MWp to 50 MWp in the decade 1988 to 1998; installed capacity is now over 130 MWp and is expected to reach 5000 MWp by 2010. Over 76% of 1998 sales were for residential systems [ibid], with 30 000 systems already installed and 10 000 being added each year [Ohno, 2000]. The FT programme has resulted in 2 MWp installed on 73 systems, again showing significant cost decreases in the first 5 years of operation [Ito, 2000].

The US Government's Million Solar Roofs Initiative was announced in 1997 and is aimed at installing a million solar water heaters and PV systems on US rooftops by 2010. The Initiative expects to achieve reduced greenhouse gas emissions, high technology job creation and a competitive US solar energy industry. By October 2000 more than 100 000 roofs had been installed, almost double the 51 000 target set for 2000 [US DoE, 2000/2].

The target for federal government buildings is 20 000 solar roofs by 2010. The government is using its own sites for demonstration, to showcase the technology and to develop construction methods on which future systems can be based. A 2800 module, 100 kWp system recently installed at the Maryland Federal Center near Washington DC also includes an educational kiosk and will be open for public tours [ibid].

Both Federal and some State governments in the US use their buying power to offer low interest loans for renewable energy systems [US DoE, 1999], in order to reduce the risks and the lifetime costs.

Spain already has an active PV industry, with 3 manufacturers and a large export market. **The Spanish Government** has begun a comprehensive programme of renewable energy development which will assist PV further. It is aimed at reducing fuel imports, improving the efficiency of energy use,

improving environmental quality and providing jobs and social development [Chivelet, 2000]. The programme includes:

- a Royal Decree which requires utilities to pay an additional 0.36 EUR per kWh for renewable electricity from grid-connected systems less than 5 kWp and 0.18 EUR for systems between 5 kWp and 50 MWp;
- laws for grid interconnection, which include technical requirements, and waiver of taxes and legal approvals;
- a renewable energy target of 12% of electricity by 2010, with associated work on analyses, identification of barriers and development of procedures and incentives.

3.2 Values for Utilities

Over the past half century, central generation has been seen as the most efficient way of delivering electricity to large numbers of consumers. This resulted from the economies of scale offered by large fossil fuel and nuclear generators, combined with the availability of low cost fuels and government support for infrastructure development.

However, for PV, the lower energy density of the solar resource results in optimal sizes being smaller than for fossil fuel or nuclear systems, while economies of scale are achieved by increases in production volumes rather than installation size. Smaller scale generation, connected into the electricity distribution, rather than the transmission, network is referred to as distributed generation and includes building integrated PV systems. Table 3.1 summarizes some of the benefits offered by distributed generation, termed "micro-power" by Lovins and Lehmann [2000].

3.2.1 Reduced infrastructure costs and network losses

Distributed generation can offer reduced costs for infrastructure, such as line capacity and peak load generation facilities, as well as reduced network operating and maintenance costs. It can also serve to delay or eliminate the need for network augmentation. With network costs accounting for up to 50% of electricity bills, where retail competition has not been introduced, this is an important benefit, particularly where networks span large distances, where high load growth in some areas is leading to grid constraints or where lines are reaching the end of their expected life [Outhred & Watt, 1999]. Generation close to load centres also reduces network losses, which can be as high as 25% of electricity distributed through long rural lines.

Table 3.1 Eight Hidden Benefits of Micropower [Lovins & Lehmann, 2000]

Benefit	Description		
Modularity	By adding or removing units, micropower system size can be adjusted to match demand.		
Short lead time	Small-scale power can be planned, sited, and built more quickly than larger systems, reducing the risks of overshooting demand, longer construction periods, and technological obsolescence.		
Fuel diversity and reduced price volatility	Micropower is a more diverse, renewables-based mix of energy sources lessens exposure to fossil fuel price fluctuations		
"Load-growth insurance" and load matching	Some types of small-scale power, such as cogeneration and end-use efficiency, expand with growing loads; the flow of other resources like solar and wind, can correlate closely with electricity demand		
Reliability and resilience	Small plants are unlikely to all fail simultaneously; they have shorter outages, are easier to repair, and are more geographically dispersed		
Avoided plant and grid construction, and losses	Small-scale power can displace construction of new plants, reduce grid losses, and delay or avoid adding new grid capacity or connections		
Local and community choice and control	Micropower provides local choice and control and the option of relying on local fuels and spurring community economic development		
Avoided emissions and environmental impacts	Small-scale power generally emits lower amounts* of particulates, sulfur dioxide and other nitrogen oxides, heavy metals and carbon dioxide, and has a lower cumulative environmental impact on land and water supply and quality		

^{*} because of the technology often employed e.g. photovoltaics, wind, small hydro etc.

3.2.2 Reduced financial risk

Another key advantage of decentralized PV systems over traditional centralized supplies is the lower risk it offers in upgrading capacity. The ability to follow load growth more closely by adding incrementally to supply reduces the period of over-capacity which inevitably follows the installation of a large system, and hence also the period of low prices experienced until load growth catches up. In periods of uncertainty, the risks associated with under-utilized assets may add considerably to the costs. Excess new capacity can also lead to premature retirement of older plant and hence reduce the returns on previous investments. PV systems offer further risk reductions: few management overheads related to ongoing fuel contracting or legal costs and no fuel price risks [Awerbuch, 2000]. Despite these acknowledged risks, PV systems continue to be assessed from an engineering economics perspective, whereas the use of capital asset pricing models, already used as the basis for "lean" manufacturing, would provide values for the reduced risks and uncertainty, as well as for the planning flexibility, reversibility and modularity offered by PV [ibid].

There is some utility recognition of the potential cost benefits of increasing network support through distributed generation in current planning processes or in their longer-term strategic thinking. As competition, and perhaps privatization, occurs in the electricity industry, the advantages of distributed generation may be more widely recognized. In the interim, regulatory processes must ensure that distributed resources are given equal access to the network and that central generation is not favoured simply because it is the existing paradigm.

3.2.3 Capacity credit and peak lopping

Compared to central PV stations, decentralized systems smooth output fluctuations and provide a better match to loads, therefore providing a higher capacity value from the utility point of view. This has been verified by studies undertaken in Japan [Ohtani, 1999] which show that regional output becomes more important for decentralized systems than the output from individual systems. More work is needed to determine optimum sizes and distribution of PV systems to gain maximum network benefit, however, short-term fluctuations due to moving cloud cover could be compensated for within a 10 km radius. The impact on effective capacity over larger areas, including entire interconnected networks, needs to be assessed. Improved weather forecasting is expected to allow better forecasts of PV output and hence higher reliability of output for utility planners.

For commercial and industrial customers, the capacity value that can be placed on a PV system is as important as its energy value, since billing has a strong demand component. From a utility perspective, it is difficult to attribute capacity credit to a PV system, because of the stochastic nature of the output and hence the relatively uncertain correlation with peak demand. However, on average, solar radiation levels are very reliable, so that, where air conditioning loads

contribute significantly to peak demand a positive correlation would be expected with PV output. The value of PV could therefore be higher for utilities in areas with a summer peaking load.

From the customer's perspective, the effective load carrying capacity (ELCC) of PV can be especially high for commercial customers, with typically good matching between peak PV output and daytime air conditioning load. This correlation is not as high for residential customers in countries where peak loads are typically later in the day, but may be high for some residential customers with daytime peak loads.

Studies in Japan [Nanahara, 1999] show that PV output between 2pm and 3pm in summer averages 31% of rated PV capacity and for peak summer days output averages 39% of rated capacity. Correlation levels between PV output and peak demand vary over the country, however PV output on peak summer days is consistently higher than for average summer days in all except the northern most part of Japan [ibid].

Studies in the U.S. have shown that the correlation between summer to winter peak load and effective load carrying capacity is higher than that between average irradiance levels and ELCC [US DoE, 1996]. The ELCC can exceed 80% of PV rated output when the ratio of summer to winter peak load is greater than 1.5 [ibid]. Hence a 1 kWp PV system could be considered to have a dispatchable rating of 800 Wp. Using this approach, the US DoE has published a map showing the different PV ELCC across the US [ibid]. This map allows planners to target areas where PV would have a high value. These areas are not necessarily those with high solar radiation levels.

Perez et al [1999] have shown that the ELCC can be increased further by simple load control strategies aimed at optimizing load and PV output. They found that improvements of 10-25% are possible for photovoltaic power systems sized at 10% of the building load, resulting in an added value of USD 100 to 500 per kWp, depending on location, with a U.S. average of USD 300 per kWp for commercial buildings.

3.2.4 New business opportunities

Utilities are generally keen to take advantage of the positive customer image of utility reliability and the public interest in environmentally friendly energy sources in their development of PV businesses. Such perceptions, combined with the greater ability, compared with independent operators, to offer a variety of financial packages, and with the history of monopoly service, provides utilities with a competitive advantage in the market. Utilities have explored business opportunities in stand-alone PV systems, rooftop PV and Green Power products. Some utilities are specializing in providing renewable energy projects as a service to other utilities, to cater for green power markets or mandatory renewable energy targets. Green Power provides utilities with an opportunity to market a premium product, rather than just a commodity.

3.2.5 Image

Corporate positioning and image are important strategic factors for many utilities involved in competitive markets. An involvement in PV is being used by some utilities to demonstrate a commitment to the environment and as a sign that the organisation is dynamic and innovative. This is demonstrated by the large number of PV images now used in the advertising or marketing materials of utilities operating in a competitive market. In a fully competitive market customers can compare utility programmes and seek justification for claims made. The initial introduction of retail competition in the US has seen a significant level of customer interest in green products. Even in countries such as Australia, where full retail competition has yet to be introduced, almost all electricity retailers now offer green products. Although PV is not the cheapest technology for utilities, most still include some PV in their portfolios because even systems as small as 1 kWp can be installed in high visibility locations, close to customers, and provide a high technology, green image.

3.2.6 Examples of utility programmes

In Switzerland a "stock exchange" model has been used successfully to promote PV installation and solar photovoltaic electricity use [Nowak, 2000]. A Solar Stock Exchange was established in Zurich in 1995, whereby PV system owners sign long-term contracts with utilities for solar photovoltaic electricity, which is in turn sold to customers (see Figure 3.3). By early 2000, 42 systems with 1.62 MWp capacity had been installed; 5700 customers had subscribed, representing 2.9% of the target population and purchasing 1.2 GWh per year of solar photovoltaic electricity. A subsequent national programme, "Energy 2000", has resulted in 90 Swiss utilities offering solar products to 3 million customers. By early 2000, 21 000 customers had subscribed for 3.5 GWh per annum at tariffs of EUR 0.6 to 0.9 per kWh and 3.4 MWp has been installed. A mix of products, marketing and models were used, with nearly 50% using the stock exchange model.

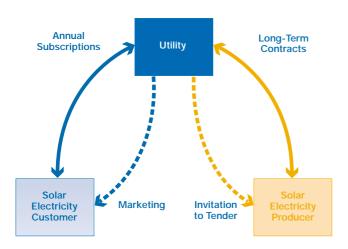


Figure 3.3 The Solar Stock Exchange Model [Nowak, 2000].

Green Power products have emerged as one means for utilities to offer differentiated products to domestic and business customers, with the intention of gaining new customers or increasing customer loyalty. Many utilities around the world now offer some form of Green Power, however, there is considerable variation between the schemes on offer and they are often offered to both contestable and franchise customers.

The growth in Green Power around the world reflects the increased focus placed on customer preferences as a result of restructuring. In many instances, the potential mobility of customers has forced utilities to look more closely at the attitudes and perceptions of customers, and to develop products and marketing approaches in response. However, Green Power can only work as a real marketing tool when customers have choice of retail supplier. Where such competition exists, Green Power programmes are proving to be an important element in customer choice and, in some US states, utilities have chosen to use State subsidies for renewables to lower the price for Green Power, sometimes to below the standard electricity tariff [Green-e Renewable Electricity Program, 1999].

To ensure customer confidence in the programmes, the Green-e programme in the US provides independent certification for Green Power schemes, publishing details and ensuring that utility claims are not fraudulent.

Australian schemes are certified and now require labeling to distinguish levels of greenhouse gas reduction.

The reliance on Green Power and solar stock exchange models as means of increasing renewable energy use does, however, place the burden of environmental action on customers and individuals [IEA-PVPS, 1999], without necessarily changing the structure and operation of the energy sector. Government and community acceptance of a need for a transition to sustainable energy systems is necessary before renewables can play a significant role.

Minimum buy-back rates have been introduced in some European countries and US States for renewables based electricity generally or PV specifically feeding into the grid from small generators. Typically these rates are higher than standard bulk rates which would otherwise be paid, and have been effective in stimulating the PV market, particularly when the rates are guaranteed for long enough to achieve acceptable returns on investment [Goldstein et al, 1999]. Even if they are not much higher, the availability of standard rates removes uncertainty during the feasibility phase of new projects and reduces the time and cost otherwise associated with tariff negotiations.

In an effort to stimulate local PV and other renewable energy industries and drive down costs, some areas have introduced rates that are higher than retail tariffs. In particular, so called "rate based incentives" up to 10 times the retail tariff are being used in areas of Austria, Switzerland and Germany,

usually as a result of consumer demand. The rates are funded from across-the-board levies and have time or capacity limits. Compared to Green Power schemes, the investment burden is shifted from the utility to the customer. However, tariff incentives are seen by some as more sustainable means of market development than one-off capital subsidies. In particular, with returns based on electricity generated, there is a high incentive to choose low cost and high efficiency systems, while capital cost subsidies typically apply to installed capacity without regard to performance.

Net metering can be a practical way to provide transitional support for small-scale grid-connected PV generators. A single meter is used to measure both the export of electricity to the grid and the import of electricity from the grid. This eases problems of market access for PV by reducing administrative costs and metering complexity. In addition to the simplicity and low cost of this arrangement, customers receive the retail rate for electricity exported to the grid until their exports exceed their imports. This in turn encourages appropriate sizing of PV installations and efficient energy use. Net metering is particularly useful once the performance of a technology is reasonably well understood, since the single meter removes the monitoring function that would otherwise be provided by a separate meter.

Typically, a cap is placed on installations qualifying for net metering, based on peak capacity installed or a percentage of electricity generated in the area. There is a move to encourage standard application procedures, as a further means of easing access, rather than using a system of individual contracts [State of Vermont Public Service Board, 1999].

Net metering is being encouraged by a resolution to the US Congress [NARUC, 1998] and has been regulated for in thirty US states [IREC, 1999]. For many utilities, net metering is seen as good marketing strategy, with minimal financial risk and the possible added value of distributed generation in grid constrained areas. It could also be a very cost effective means of reducing the need to purchase power during summer peaks, when spot prices have been as high as USD 50 per kWh. However, utilities can still apply high connection or supply charges as a disincentive.

3.3 Values for Architects and Building Developers

Enhancement of the building integrated PV market requires acceptance of PV by builders, architects and users. The physical characteristics of PV products for integration into buildings must therefore meet architectural requirements for colour, size, and materials. The challenge for the PV R&D community, together with architects and builders is to develop and demonstrate high-quality integration concepts that meet the industry's objectives as well as the architectural needs of buildings [Schoen, 1999].

3.3.1 Design features

The building envelope has several functions, each of which is an architectural concern. These functions include: sustaining the interior environment, protecting the building structure from the environment, structural requirements, exterior and interior aesthetics, and community planning requirements [Sick & Erge, 1996]. These functions are performed within certain economic and environmental constraints. PV offers a new and attractive building material which can be used to create new building designs which fit into an increasingly important architectural aim of demonstrating environmental sustainability. Architects are now beginning to explore the design possibilities of PV, integrating it into their buildings as day-lighting, shading and façade features. Aspects of BIPV elements which are important to these functions include the colour, shape and transparency of the PV module, although it must be remembered that custom designs will result in higher cost PV modules, while in general, product standardization is necessary for cost reduction.

Colour: There are several ways to alter the colour of PV building elements. One method is to colour the front of the PV encapsulation or the visible backing layers of the laminate. The appearance of the element is then a combination of the colouring and the PV cells themselves. Any transmitted light will also be coloured. Altering the tint and surface conditions of the front encapsulation can also provide different textures, similar to stone or metal. The alternative is to colour the PV cells themselves by means of thin film interference using antireflection (AR) coatings. Some PV cell manufacturers have already begun to develop coloured cells. The successful leasing of the ÖKOTEC3 building in Berlin, in an environment of office space oversupply, has been partly attributed to the highly attractive "iridescent blue" PV facade elements manufactured by Flachglas [Chehab et al, 1995].

Shape: Since many of the BIPV installations to date have been retrofits to existing buildings, or have been designed to fit into existing architectural styles, the predominant shapes and sizes of BIPV elements have been determined by the building elements they have displaced. Thus most BIPV elements are rectangular, like roof tiles and spandrel units. Economies of scale of manufacture favour the development of standard products, although this is not necessarily straightforward, given the diverse range of building styles found worldwide.

Transparency: Transparency of a BIPV element potentially affects both the exterior appearance and the interior environment of the building. Transparency in elements using crystalline cells is determined by the spacing of the cells. The transparency of an amorphous PV cell deposited on glass is achieved by the presence of pin-holes in the cell. The degree of transparency is set by the density and size of the pin-holes. Semi-transparent PV modules provide an attractive opportunity for architects to select the amount of light entering a glassed area while creating interesting shade patterns which change over the day. Acoustic and thermal insulation properties can be incorporated by adding appropriate layers of glass to the rear of the modules.

3.3.2 Roofing elements

The most common and readily accessible site on a building for installation of a PV system is often the roof. New PV roofing materials shaped to fit in with conventional roof tiles or sheeting can save materials and installation costs, without changing the look of the building. Similarly, transparent or semi-transparent PV modules can readily replace standard skylights, providing one of the most cost effective BIPV applications. Even standard PV modules installed over an existing roof can provide significant electricity output and a range of additional values offered by distributed generation, which are discussed below.

3.3.3 Load management

PV output is generally well matched to commercial building electricity usage patterns, thus providing potential value for load management. Net metering is not as important an issue as it is for residential customers, since net export would not usually be expected. PV systems on commercial premises can often qualify for business related investment and tax allowances, which add to energy and capacity values to influence the break-even costs.

The U.S. Department of Energy [DoE, 1998] has mapped the breakeven cost of PV for commercial premises across the country, taking into account the local solar resource, capacity values, tax allowances and tariffs. Several areas show breakeven costs above USD 6,000 per kWp, with some as high as USD 11,000 per kWp. However, commercial building developers are also interested in the net investment cost (cost less energy benefit) of a PV product compared to that of a standard façade or building element [Schoen, 1999, DoE, 1998], which may be in the range of USD 60 to 200 per m². Hence the building element value can be added to the breakeven costs, potentially raising even vertical structures from low breakeven costs of around USD 2000 per kWp to reasonably competitive levels of USD 5000 per kWp or more [DoE, 1998, Perez et al, 1999]. Further, the development of attractive and easy to install multi-purpose PV building products adds even more value to PV for commercial building customers. Energy savings up to 25% of the PV output are possible through improved insulation and shading [Perez et al, 1999].

3.3.4 Improved thermal performance

Insulation: PV can serve as an insulating element to improve thermal comfort levels. Studies on roofs of a railway station in Japan [Tanaka, 1999] have shown that the Predicated Percentage Dissatisfied level (PPD) dropped from 91% to 70% when PV was added. The average temperature under the roof dropped from 40 °C to 30 °C.

Theoretical calculations subsequently made for a gymnasium, where the average surface temperature under the roof is 43 °C, and another railway station, where the temperature is 38 °C, shows that thermal radiation would be reduced by 35% and 31% respectively if PV were added [ibid].

Heating: Infra red radiation is largely transmitted by PV cells and contributes to heating the module and whatever is behind it. Heat generated by PV modules can be extracted to satisfy low grade heat demands, such as space or water heating, in a hybrid electric/thermal (PV/T) system. This can increase the energy efficiency and the cost effectiveness of the overall installation. Leender et al, [2000] have undertaken a review of currently available PV/T systems, finding them promising, but yet to be optimized.

The production of heat in PV/T systems will coincide with PV power production. Thus the availability of warm air would be highest in summer, when space heating is not required. If the heat is to be retained, thermal mass storage can be incorporated. Such a system has been installed in Switzerland [Posnansky & Eckmanns, 1995]. It provides 53 kWp of electrical and 115 kW of thermal energy. In conjunction with 9 kWp from a separate PV facade, the system provides approximately 70% of the electrothermal energy requirements of the factory. Thermal energy is extracted by passing air behind the PV panels and is used to heat the factory or can be stored for short periods in concrete slabs and underground for seasonal storage. Combined heat and power units using a-Si glass laminates are also under development. The PV layer effectively reduces the solar radiation available to the solar thermal system by around 10%. Since a-Si is not as temperature sensitive as crystalline Si, the PV cooling function is not critical.

Ventilation: In cases where building ventilation is important, passive ventilation can be achieved by the "stack effect" where warm air becomes buoyant and rises, thus creating an upward flow of air. The stack effect can be employed to ventilate the space adjacent to the column of moving warm air by extracting air through louvres or windows. The extraction of heat from the PV modules also helps to lower the PV operating temperature, which results in higher operating efficiencies for crystalline technologies.

Atlantis Energie has installed ventilated PV shingle roofs [Posnansky & Eckmanns, 1995]. Air enters a channel beneath the roof shingle through the eaves and rises to the ridge as it absorbs heat from the roof. During the heating months this warm air is drawn into the building while in warmer months it is vented to the exterior through vents in the ridge of the roof.

The Mataró Public Library in Spain has been equipped with a multifunctional PV façade, based on 6m high PV elements forming the southern wall of the building. Elements consist of laminates of spaced poly-Silicon cells, so that 15% of the incident light enters the building. An air gap separates this laminate from a second layer of clear glass. During the heating months air flowing up through this gap is preheated before passing to a conventional gas heater for the building. During the warmer parts of the year the hot air is ventilated in order to cool the PV and reduce heat gain into the building.

3.3.5 Sound proofing

The use of PV for sound proofing in buildings and highway barriers has been widely exploited in Europe, where dense urban development makes this a premium value. A 100 kW PV sound barrier was first installed in Switzerland in 1989. A variety of designs have since been developed and installed around Switzerland and Germany, some as a result of an international design competition [Frölich, 1999]. Conventional sound barrier materials cost between USD 250 to 485 per m² in Germany [ibid], which provides an indication of the material substitutional value available. Innovative designs are now using bi-facial PV cells, which allow the use of light from north and south facing surfaces, thus increasing the annual electricity output.

3.3.6 Shading

Shading elements are typically secured to the outside of the building envelope to limit the amount of daylight and heat entering through a window. They may be permanently fixed or moveable to track the sun over the day or year. Shading elements are well suited to accommodate PV laminates, as they are oriented towards the sun, often have a flat surface and allow rear ventilation. They can also be automatically controlled to track the sun. PV covered window blinds for use inside the building, behind the window glass, have also been suggested [Sala et al, 1996]. Shading devices are increasingly needed because of the trend to larger window sizes and the use of curtain walls in commercial buildings.

Seven kWp of PV window shades installed at the University of Texas are expected to generate 10,000 kWh of electricity a year, as well as to reduce the air conditioning load by 2600 kWh [Applied Power, 2000]. The system will also contribute towards the Texas 1999 mandate for 2000 MW of new renewable energy generation by 2009.

PV covered shading for car parks is also of interest in areas with hot summers. In some cases, the PV power is available for charging electric vehicle batteries. The value of a PV shaded car park can be assessed in terms of the electricity and the parking revenue generated. An example in the US estimates the value of a PV covered parking space as USD 1600 per annum from the solar photovoltaic electricity plus parking revenue of USD 8212 per annum, resulting in a total value of USD 9812 and a 10 year payback period with respect to the initial investment [Eiffert, 2000].

3.3.7 IEA activities

In order to encourage and assist architects to explore the use of PV the IEA-PVPS Task 7, PV in the built environment, has listed (Table 3.2) the criteria it would apply in evaluating BIPV systems [Schoen *et al*, 2000].

Task 7 has also collated case studies of high profile and interesting BIPV demonstration projects, developed computer based design tools and organized design workshops. In 2000, Task 7 organized an international BIPV design competition, aimed at stimulating the interest of architects,

Table 3.2 Overview of IEA-PVPS Task 7 Architectural Criteria [Schoen et al, 2000]

1 NATURALLY INTEGRATED

The PV system is a natural part of the building. Without PV, the building would be lacking something - the PV system completes the building.

2 ARCHITECTURALLY PLEASING

Based on a good design, the PV system should add eye-catching features to the design.

3 GOOD COMPOSITION

The colour and texture of the PV system should be in harmony with the other materials. Often, also a specific design of the PV system can be aimed at (e.g. frameless vs. framed modules).

4 GRID, HARMONY AND COMPOSITION

The sizing of the PV system matches the sizing and grid of the building.

5 CONTEXTUALITY

The total image of a building should be in harmony with the PV system. On an historic building, tiles or slates will probably fit better than large glass modules.

6 WELL-ENGINEERED

This does not concern the watertightness of PV roof, but more the elegance of design details. Have details been well-conceived? Has the amount of materials been minimized? Are details convincing?

7 INNOVATIVE NEW DESIGN

PV is an innovative technology, asking for innovative, creative, thinking by architects. New ideas can enhance the PV market and add value to buildings.

Table 3.3 Judging Criteria for IEA-PVPS Task 7 Design Competition for PV in the Built Environment [IEA-PVPS, 2000]

Judging Criteria

Visually attractive

Integration into the built environment. The product should fit well in the context for which it is intended.

Functional - the product should meet whatever function the type of product is expected to provide

There must be an identifiable market for the product (it is not the size of the market that counts)

The product should be innovative in some respect. This may involve innovative components, the assembly of the components or the application

The product should be reasonably simple to install, maintain and operate, where applicable

The performance/efficiency of the product is important. Thermal outputs can be considered as well as electrical outputs where appropriate. Demonstrate issues such as ventilation and shading have been considered to maximize output from the chosen PV technology

Practical and cost effective manufacturing method

Environmental issues. Demonstrate that environmental issues have been considered, including minimizing the energy payback of the system and the use of materials harmful to the environment

Flexibility/versatility of the design (able to use in various locations/orientations/markets, etc.)

building developers and students in developing innovative and practical uses of PV in the built environment. The judging criteria for assessing the entries are given in Table 3.3. Prizes were awarded in the categories of: Overall Winner; Exhibition Prize; Roofing Products; Facades; Other Building Products (sunshades, blinds, windows, louvres); Non-Building Structures (street lights); and New PV Products.

The overall winner was Robert Webb of Robert Webb Associates, UK, for his design for PV panels as a ventilated rainscreen system over a lightweight stressed-skin timber construction. The judges admired the overall concept for the building and its consideration for environmental and passive solar issues in addition to electrical generation. Careful consideration had been given to the manner in which the different energy systems interact. While not being a category winner this entry had a holistic approach spanning a number of categories.

3.3.8 Commercial products

A range of specially designed BIPV products are now beginning to be available in some countries [Munro, Ruyssevelt & Knight, 2000]. These include:

- PV roof tile products, which can be readily integrated with conventional tiles.
- PV module support structures for both sloping and flat roofs, which are easy to install on new or existing roofs and onto which a range of PV modules can be attached.
- Total integrated roofing systems for sloping or flat roofs, incorporating supports and modules.
- Transparent and semi-transparent PV products for use in façades, windows and skylights.

 Fixed and tracking PV shades for awning and window shading.

There is an awareness of the need for the BIPV products to be seen as environmentally benign, with an emphasis on low energy and recycled materials. There is also a growing interest in purpose built multi-function building elements, providing daylighting, passive heating, insulation or other benefits. Combined systems offer architectural and aesthetic benefits and should allow for lower overall costs by avoiding duplication of collector area and support structures. Of particular interest are photovoltaic/thermal collectors (PV/T), which combine electricity production with water or space heating. Several are now available commercially. Extraction of the heat behind crystalline silicon PV modules has the added benefit of reducing module operating temperature, and hence improving efficiency. However, optimizing thermal and electrical output requires careful design.

In the United States, the PV:BONUS (Building Opportunities in the U.S. for Photovoltaics) programme, supported by the US Department of Energy aims to develop technologies and to foster business arrangements that cost-effectively integrate photovoltaics or hybrid products into buildings. Cost-effectiveness of the products developed is achieved through design, integration (i.e. components, system or building integration), dedicated end-use applications, and technology bundling (e.g. PV/thermal hybrids) [Hayter, 1999]. The Department of Energy is interested in products that can replace commercial building products and can be installed without the need for specialized training. The ultimate goal of the PV:BONUS programme is market demonstrations of commercially viable products that lead to manufacturer commitments to pursue production and sales. Building designers are, in general, extremely interested in using the new products, especially when they are easy to integrate into the building envelope and/or with building systems.

The partnerships developed between DOE, private industries and public institutions ensure that buildings-related issues are addressed, thus increasing the likelihood of success for all emerging BIPV products. With the building sector using one third of all energy and two thirds of all electricity produced in the US each year [ibid], the market for BIPV is significant.

3.4 Values for Customers

The benefits offered by PV to utilities, architects and developers also flow on to customers. Improved thermal comfort and soundproofing, reduced energy demand charges and interesting building design features are all of importance to customers. In addition, customer surveys around the world increasingly show an interest in the impacts of energy systems on the environment and on quality of life. Some customers are also interested in increasing their own energy self-reliance, others in portraying a clean image. The perceived benefits of PV depend to some extent on the perspective from which it is viewed. For instance [Watt et al, 1999]:

- a building owner may be interested in offset building costs, enhanced property value and improved rental prospects, compared to the investment made;
- a building occupier may attribute value to visual appeal and green image, as well as to reduced power bills, increased self reliance and reliability of supply;
- to the community, the value may be determined by visual amenity, enhanced property values, local employment, reduced power outages or brown-outs, safety and reduced local and global pollution levels;
- for the nation, the value may be determined by employment creation, pollution reduction, energy self reliance and impacts on fossil fuel requirements.

Some of these values are based on perceptions or preferences which are difficult to define or quantify. However, they are a key component of energy system choice and are particularly important when introducing new technologies into the marketplace. For BIPV products, market analysis is even more difficult than it is for conventional power system products, as building values are far less tangible. Recent surveys in the Netherlands [Schoen, 1999] of customers living in houses with PV indicate that PV was not a factor in deciding to purchase the house. However, customers expressed support for PV use generally, an interest in receiving more information about PV and in receiving a direct benefit from their systems (the latter from residents where PV ownership and hence benefits rests with the utility). General environmental awareness and concern was a factor in customer decision making. However, customers indicated a clear preference for PV products which offer additional benefits, such as architectural or aesthetic features.

3.4.1 Electricity supply costs

For remote customers, the option of stand-alone PV based power systems may save considerable costs otherwise

associated with grid extension or with fuel delivery for gas or diesel based power systems. Low maintenance requirements are also an important factor for remote locations. In Canada alone, there are an estimated 12 000 homes which could potentially use PV systems. In Australia there are similar numbers, as well as up to 60 000 off-grid holiday homes. Summer holiday homes are also a potentially large market in Scandinavia and elsewhere in Europe.

Studies in the U.S. [Herig *et al*, 1999] indicate that the breakeven cost (when lifetime customer benefits balance costs) for PV in 15 US States is now over USD 4 per Wp, and above USD 7 per Wp in five States, taking into account the various tax regimes and incentives on offer, plus environmental costs, interest rates and capacity factors. Current PV system prices are between USD 4.5 and 7.5 per Wp. Hence, the combination of values attributed to PV from the various market sectors - utility, state government, regional development, environment etc. - combine to provide a tangible financial value which makes PV a competitive option in many areas.

3.4.2 Non-intrusive qualities

Compared to almost all other electricity generators, PV is noiseless, produces no on-site emissions, is relatively maintenance free and can be installed in a wide range of locations. Combined with its modularity, these characteristics make PV attractive for household, community or urban use, particularly as a replacement for diesel or petrol generators, but increasingly as a non-intrusive supplement or replacement for grid power.

3.4.3 Image

For commercial customers especially, but also for residential customers, on-site PV generation creates a strong green and high-tech image. This makes PV attractive for use in corporate buildings, housing developments at the high end of the market and for any person or group wishing to demonstrate environmental credentials. The Ökotech building in Berlin uses an expensive PV glass and granite façade to add class to the building, as well as to demonstrate environmental credentials and reduce electricity purchases [Hagemann, 2000].

3.4.4 Energy independence

PV obviously offers the opportunity for increased or total energy self reliance. In addition, the use of distributed PV systems can conceivably mitigate the onset and/or the effect of power outages caused by high summer demand or severe weather [Perez et al, 1997; Perez, 1998]. Recent electricity shortages and price fluctuations in areas of the US have led to a significant increase in customers investing in PV and wind systems for total or partial electricity self-reliance. This emergency value of PV can begin to be gauged by premium reductions or incentives offered by insurance companies for improved power reliability [Perez et al, 1999]. The authors conservatively estimate this at 10% of the insurance premium, which translates to a value of around USD 440 per kWp for a small commercial building.

It should be noted that grid connection guidelines in many areas require the PV system to disconnect when grid power fails. This removes the emergency benefit for both the customer and the utility. After the Kobe earthquake, guidelines in Japan were changed to allow self-operation of photovoltaic power systems when the grid fails, with a manual inverter switch-over.

The value of PV for general energy independence and in emergency situations is increased when storage is included in the system. However, storage increases the system cost and complexity. Work is needed to assess the cost-benefits of different levels of storage required to influence PV values from the customer and the utility perspectives. Nevertheless, many commercial, institutional and industrial buildings already include battery storage uninterruptible power supply (UPS) systems for emergency power supply. Studies carried out at a Swiss bank building [Kröni, 2000] show that connection of the building's PV system to the UPS battery system can extend emergency power availability significantly over the summer months. Standby time was increased by 200% for 20 or more days in June and July and between 5 to 15 days in March, April, May and August. An 80 kWp building integrated photovoltaic power system currently being installed in a new commercial building in Brisbane, Australia, will provide added value by feeding its output through a UPS system which supports the building's computer equipment [Wren & Barram, 2000].

Transportable PV systems are increasingly being used for temporary power supply in emergency zones, for medical services, water purification and communications. Interest in this market for PV is evidenced by the running of workshops on the topic [www.fsec.ucf.edu/PVT/].

3.4.5 Environmental merits

Environmental awareness is increasing worldwide, with surveys in many countries consistently showing community support for increased use of renewable energy sources. In the US, green power programmes introduced after electricity industry restructuring have often been oversubscribed, with a significant portion of customers who changed retailer doing so for purchase of a green power product. In both Japan and Australia, government grants for BIPV systems have had to be modified following overwhelming customer demand. Customer surveys in Switzerland indicate that environmental, ecological and sustainability issues are a high priority, so that the type of electricity product purchased was very important [Nowak, 2000]. Non-nuclear options were important, as were the adoption of new technologies and associated employment. For customers already purchasing a solar product, the provider, the price and the type of promotion were of medium importance, but for non-subscribers price was the most important factor.

3.4.6 Customer preferences

Marketing of the first generation of houses with PV has, perhaps understandably, been undertaken in a low key way. In Australia, PV systems on houses in the Solar Village near the Sydney Olympic site were placed so as not to be

generally visible. In the Netherlands, ownership of the PV system was retained by the utility in early PV estates in Amsterdam. For the next generation of BIPV product, it would seem that customers require attractive, multifunctional PV products and that marketers must provide substantially more information on all aspects of their systems, so that customers can appreciate all features. Nevertheless, there is a need to identify more clearly what customers are looking for and what would make PV more attractive to them. In tandem with this is a requirement for rapid improvements in the development of codes and standards, permit procedures, interconnection guidelines and liability insurance issues which would make it easier for customers interested in PV to go ahead with a purchase [Herig et al, 1999].

Marketing strategies used in Switzerland to promote solar photovoltaic electricity products have found it important to offer choice of product, a clear description of benefits, not merely kWh produced, and an initial annual subscription, with the opportunity for renewal [Nowak, 2000]. Regular communication on the product, as well as general environmental information was essential, both with existing and potential new customers, using a variety of media, including mailouts, the internet and site visits [ibid].

3.5 Benefits for the Environment

Environmental costs can begin to be valued by referring to the current costs of emissions control and the cost of environmental damage caused by $SO_{x'}$, NO_x and CO_2 . Studies in the U.S. indicate that emission control values lie in the range of USD 0.75 to 11 per tonne of $SO_{x'}$: USD 0.82 to 15 for NO_x and USD 9 to 22 for CO_2 [Herig *et al*, 1999]. The US Department of Interior, National Park Service [Denver Service Center Guideline 82-1] uses much higher environmental costs in evaluating electricity sources: SO_x - USD 1,650 per tonne, NO_x - USD 7,480 per tonne and CO_2 - USD 8.8 per tonne.

Since PV systems generate few emissions over their life cycle, if they are used to displace electricity from high emission sources, a small component can be added to the total PV break-even costs [ibid]. Values up to USD 0.035 per kWh have been estimated [Buchanan et al, 1991]. Perez et al [1999] use a value of USD 0.027 for their calculations of externality value for commercial building PV systems, but note that this does not include a value for fossil fuel resource depletion. On average over the US this adds USD 800 per kWp to the breakeven cost [ibid].

3.5.1 Sustainable development

Environmental goals need to be added to economic and social goals, to achieve the "triple bottom line" of sustainable development [Twinn, C, 2000]. Twinn illustrates the operation of the triple bottom line approach in a zero fossil fuel energy development (ZED) in Beddington, UK, where the use of PV is integrated with an overall aim of sustainability. The developers aimed to achieve an affordable product and a desirable lifestyle, at the same time as:

- reconciling density with amenity and creating a sense of community in urban areas
- tying new developments into the needs of existing communities
- coping with increasing numbers of single parent families
- · using existing stocks of brownfield sites
- encouraging bio-diversity back into urban areas
- reducing water consumption and stopping pollution of rivers & streams
- building using materials with low environmental impact, maximum durability and yet allowing for eventual recycling
- minimizing embodied energy in construction
- reducing the volume of waste produced by a household
- maximizing renewable energy harvesting in urban areas
- · reducing the need for travel to work and for food
- reducing fossil fuel powered car use, encouraging walking, cycling & public transport.

The ZED houses reduce energy requirements for heating and hot water by 75% and for private car use by 90% [ibid]. Reducing energy demand allowed the relative contribution which could be made by PV to be significant.

The Solar Office at Doxford, UK, is another example of integrated planning for sustainable development [Lloyd Jones, 2000]. Careful design has allowed conventional office activity to be undertaken with an energy requirement of 85 kWh per m² per year, compared with 400 kWh per m² used in a standard office block. A 73 kWp inclined, semi-transparent PV facade provides between one quarter and one third of electricity requirements, while providing light and heat to the atrium behind it.

The building designers had to make some compromises to optimize PV output and to achieve the low energy building aims of:

- · Controllable cross ventilation
- Glare free daylighting and solar control through windows
- Minimum winter heat loss through the building envelope
- Knowledgeable and sensitive building controls and management.

The importance of holistic design is illustrated by the designers' use of a wind trough along the façade to use winds at the exposed building site to assist with ventilation and cooling behind the PV system. Heat from behind the PV system is used for space heating in winter and to assist air

flow through the building in summer. Compared with an equivalent standard office building, the Solar Office cost GBP 940 per m² rather than GBP 750 per m², but will save GBP 55 000 per year in energy costs and 375.6 tonnes per year of CO₂. The PV component comprised around 50% of the façade cost.

Environmental criteria are now used by the Asian Development Bank for energy project evaluations [Rao, 2000]. The likely project effects evaluated are those on:

- human health
- flora and fauna, especially due to habitat disturbance
- · soils, buildings, art works,
- social assets, including visual pollution, climate change, recreational activities.

The process followed is to:

- · Determine emissions and resource usage
- · Assess the changes in environmental quality
- · Estimate the impacts of environmental change
- Assess the value of the impacts, including changes in well-being
- Aggregate the changes across effects, individuals and time.

In Poland, the environmental benefits offered by renewables are evident by the use of environmental funds to develop renewable energy projects [Pietruszko, 2000]. New energy legislation requiring energy enterprises to purchase from renewable generators, combined with a requirement to license small generators is providing opportunities for PV. Funds are available from a variety of sources, including:

- Ecofund, the "foreign debt for environment swap", which has priorities of:
 - abatement of the emission of gases causing global climate changes,
 - limiting cross-border sulphur dioxide and nitrogen oxides transportation,
 - reduction of the Baltic Sea pollution,
 - Poland's biological diversity protection.
- The Environment Protection Bank, which provides up to 7 years of credit for renewable energy projects;
- The National Fund of Environment Protection and Water Supplies Management, which provides loans and subsidies for:
 - environmental education, pilot projects regarding the implementation of technological advancement and new technologies with high level of risk or of an experimental nature
 - special provision for local or municipal authorities, units connected with health care, social aid, education.
- The Fund for Thermomodernisation of existing buildings, which includes installation of RE technologies.

3.6 Educational Opportunities

An educated population and a skilled workforce are considered a high priority in both industrialized and developing countries. Personnel trained in new technology areas such as photovoltaics are in high demand worldwide. In many countries, solar energy topics are being added to curricula so as to raise the awareness and interest of pupils from an early age. The UN Food and Agriculture Organization [FAO, 2000] cites the need for training, information and education on PV installation, operation, maintenance and repair services for agricultural applications in developing countries, including information aimed at women.

Many schools, technical colleges and universities around the world are now beginning to offer renewable energy courses, often available on the web or by distance learning. The Sandia National Laboratories has begun a listing of PV courses available in the US [www.sandia.gov/pv/training.htm].

3.6.1 Demonstration and training sites

An example of a comprehensive educational activity is in the ancient town of Nitzana in Israel, an educational settlement where some 15 000 pupils are exposed to the various educational programmes during the year. A new programme is now underway, called "BE'IKVOT HA'SHEMESH", the

Hebrew saying for "Following the Sun", which has two modes of activity: teaching a solar curriculum and building a solar demonstration park.

For the solar energy curriculum, pupils learn about solar energy, the science and technology behind its exploitation, its merits, and the prospects for its further use in Israel and abroad. During their course the pupils visit the Sede-Boqer campus where they watch ongoing experiments aimed at module assessments, long-term monitoring of solar irradiation quality and intensity, and see the newly installed 400 square meter solar concentrating dish. They visit the solarium, housing a library and students' accommodation, and meet the architects who design passive solar houses and desert-adapted buildings.

At the 10 000 square meter Solar Demonstration Park, pupils and other visitors gain hands-on experience with solar technology through various solar energy systems and facilities, tools and an exhibition of balance of system equipment. Product manufacturers and suppliers anticipate an increase in orders coming from the solar-aware public.

3.7 Summary of Added Values

Table 3.4 provides a summary of the values which can be attributed to PV systems.

Table 3.4 Summary of Non-Energy Benefits Which Can Add Value to PV Systems [IEA-PVPS, 2000/4]

Category	Potential Values
Electrical	KWh generated; kW capacity value; peak generation and load matching value; reduction in demand for utility electricity; power in times of emergency; grid support for rural lines; reduced transmission and distribution losses; improved grid reliability and resilience; voltage control; smoothing load fluctuations; filtering harmonics and reactive power compensation.
Environmental	Significant net energy generator over its lifetime; reduced air emissions of particulates, heavy metals, CO_2 , $NO_{x'}$, SO_x - resulting in lower greenhouse gases, reduced acid rain and lower smog levels; reduced power station land and water use; reduced impact of urban development; reduced tree clearing for fuel; reduced nuclear safety risks
Architectural	Substitute building component; multi-function potential for insulation, water proofing, fire protection, wind protection, acoustic control, daylighting, shading, thermal collection and dissipation; aesthetic appeal through colour, transparency, non-reflective surfaces; reduced embodied energy of the building; reflection of electromagnetic waves; reduced building maintenance and roof replacements.
Socio- Economic	New industries, products and markets; local employment for installation and servicing; local choice, resource use and control; potential for solar breeders; short construction lead-times; modularity improves demand matching; resource diversification; reduced fuel imports; reduced price volatility; deferment of large capital outlays for central generating plant or transmission and distribution line upgrades; urban renewal; rural development; lower externalities (environmental impact, social dislocation, infrastructure requirements) than fossil fuels and nuclear; reduced fuel transport costs and pollution from fossil fuel use in rural areas; reduced risk of nuclear accidents; symbol for sustainable development and associated education; potential for international cooperation, collaboration and long-term aid to developing countries.

4 Key Barriers to the Implementation of Photovoltaic Power Systems

The main barriers facing the PV industry in increasing its market share, are summarized below under the general headings of cost, electricity industry and information issues. It should be noted that the barriers cited do not apply uniformly in all countries. The IEA-PVPS Task 7 has also prepared a report specifically on non-technical barriers to PV use in buildings [IEA-PVPS, 1999].

4.1 Cost and Price Issues

4.1.1 High capital cost/low operating costs

PV is a cost effective alternative to fossil fuels for many off-grid power supply applications. Nevertheless, compared to supply based on fuels such as diesel, kerosene or petrol, PV systems still suffer a disadvantage when seeking finance because of the relatively high initial capital costs, project development costs and transaction costs [Rao, 2000]. Hence, even though running costs are much lower, PV purchasers must pay significant up front costs, which typically require third party financing. In addition, it may be difficult to guarantee cash flows and financing agencies may view renewables projects as having limited marketability compared to conventional power projects [ibid]. In developing countries particularly, credit facilities for individuals are either non-existent or unregulated and customers are faced with significant financial risks. Even in developed countries it is not necessarily straightforward for individuals or companies to raise finance for independent power supply systems. In recent years, the Grameen Bank has provided useful finance in developing countries, while the advent of "Green Mortgages" [US DoE, 1999] and the interest of some utilities in supplying off-grid power [IEA-PVPS, 1998] may assist purchasers in developed countries. The Solar Bank [www.solarbank.com] (Figure 4.1) illustrates the impact of financing, compared with system efficiency improvements and cost reductions. Providing appropriate financing is therefore a critical component of successful PV marketing.

4.1.2 Difficulties with project assessment

Straightforward and consistent procedures for assessing the financial viability of BIPV systems will assist architects and project developers to market the technology. Following from a survey of US architects, where project assessments were found to be difficult, Eiffert [2000] recommends the following approach:

- Net benefits or life-cycle cost methods for designing and sizing BIPV systems. When net benefits increase and life-cycle costs decrease as system size or cost increases, the larger or more expensive system can be chosen. Savings-toinvestment and adjusted rate of return methods are also suitable, provided incremental costs only are assessed.
- Savings-to-investment ratio and adjusted internal rate of return methods - for ranking investment alternatives. Best returns will result from choosing projects in descending order.
 Overall optimization can be achieved by combining assessments of design and cost with ranking methods.

In addition to the method of assessment, the relevant perspective of the building owner to future energy costs and to availability and cost of capital is important. As a guide, Eiffert [ibid] recommends defining a project as cost effective when the savings-to-cost ratio is greater than one; when the annual internal rate of return is greater than the discount rate; when the sum of all time adjusted costs over the required time period is lower than for competing energy systems; or when the simple payback period is less than the life of the PV system.

Of course, in making investment decisions, the direct energy savings, the indirect energy system benefits, as well as the non-energy benefits of PV systems, must be included in the analyses wherever possible. Awerbuch [2000] suggests the

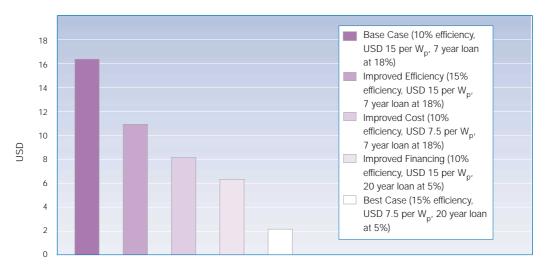


Figure 4.1 The impacts on monthly repayments for 50Wp household PV systems of improvements in system efficiency, capital cost and financing arrangements [www.solarbank.com].



use of capital asset pricing models (CAPM), rather than engineering economic models for PV system assessment, as a means of including the values of risk reduction associated with known (up-front) costs, low operating costs, reliability and technical flexibility.

The International Performance Measurement & Verification Protocol (IPMVP) offers standardized procedures for project development and financial evaluation, which can assist in reducing up-front project establishment costs (www.ipmvp.org/). The IPMVP is a document which discusses procedures that, when implemented, allow owners, energy service companies (ESCOs), and financiers of energy projects to quantify energy conservation measures performance and energy savings. The IPMVP provides an overview of current best practice techniques available for verifying savings from both traditionally- and third-party-financed energy and water efficiency projects. The purpose of the IPMVP is to reduce major barriers to the expansion of the energy and water efficiency industries by helping to:

- · Increase certainty, reliability and level of savings;
- Reduce transaction costs by providing an international, industry consensus approach and methodologies;
- Reduce financing costs by providing project measurement and verification standardization, thereby allowing project bundling and pooled project financing;
- Provide a basis for demonstrating emission reduction and delivering enhanced environmental quality;
- Provide a basis for negotiating the contractual terms which ensure that an energy project achieves or exceeds its goals of saving money and improving the building's operating environment.

4.1.3 Protracted approvals and installation procedures

Lack of familiarity with PV and with coordination of the PV installation with the building process, non-standard components and systems, as well as generic rather than buildings application specific PV products increases these costs for PV systems at present. The latter also contribute to poor or incorrect installation which can increase long-term maintenance costs. With limited long-term field experience, there is in any case little general knowledge regarding the likely system maintenance costs. Nevertheless some provision for maintenance, as well as an estimate of cost must be included in the economic analysis of a system.

With electricity utilities still uncertain about PV and about distributed generation more generally, procedures and costs for grid interconnection can be lengthy and high. They can include interconnection fees, metering calibration charges, engineering design and study fees, liability insurance, property easements, legal indemnities, monitoring and additional protection equipment. While these costs may represent a very small component of the overall cost of a large central generating plant, for small systems they can

result in the project becoming non-viable. These issues are discussed further in Section 4.2, but point to the need for standardized procedures and interconnect guidelines. From the building side, another set of permits and fees can apply, which add further to system costs. These can include construction permits, electrical permits, and inspection fees. Again, lack of familiarity with BIPV often results in lengthy delays and high costs.

Uncertainty about procedures and requirements also impacts on ownership and responsibility and liability, which in turn impacts on legal costs and access to finance.

Standard procedures, power supply agreements and maintenance contracts would reduce this uncertainty.

4.1.4 Low system efficiencies

Typical efficiencies for commercially available power system modules based on crystalline silicon are now around 12-15%, while for thin film products the range is 5-10%. Concentrator systems can have efficiencies up to 35%, but their use is more restricted. R&D continues on improving efficiencies by a range of methods, including reducing reflection and internal cell losses, using layers of different semi-conductors to capture a wider spectral range and incorporating reflectors, concentrators and ventilators into PV systems. Nevertheless, when losses through balance of systems components are included, especially non-optimal inverter operation, wiring and battery losses, many systems operate at relatively low efficiency. In addition, shading, PV module mismatches, accumulation of dirt or snow and non-optimal orientation also cause systems to operate at lower efficiencies.

The impact of improved efficiency on the customer price of PV electricity is illustrated in Figure 4.1. For each kWp of system capacity, a higher PV system efficiency reduces the surface area required, thus reducing both the material requirements for the PV cell, as well as for the module and the balance of system components, such as wiring. Hence, at module efficiencies of 20%, a target price of 0.2 USD per kWh and 1 000 USD per kWp can be achieved at area related system costs of 200 USD per m², but costs would need to be as low as 50 USD per m² if the efficiency is 5% [Kiess, 1997]. Based on material costs, a realistic lower limit to the area related cost of modules is around USD 100 per m², so that efficiency improvements remain an important component of cost reduction [ibid].

4.1.5 High production costs

PV prices have dropped consistently over the past 30 years, with an 18% price reduction for each doubling of sales [IEA-PVPS, 2000/2] and PV electricity can now be generated at less than USD 0.6 per kWh, which is cost competitive in many off-grid applications. However, it remains higher than central grid supplies. Hence, PV is locked in a critical "chicken-and-egg" situation between price and economy of volume. The prices are too high to generate a substantial market and a market is needed to generate economy of scale [IEA-PVPS, 1999].

While financing is important, PV system costs must continue to fall, if PV is to enter mainstream electricity markets. Cost reductions will depend largely on research and innovation, increased markets and production levels and increased experience with system design & installation.

Production cost for PV cells and systems are dictated by the technology and materials used, as well as by the production process. Over 80% of PV production is currently based on crystalline silicon cells, using silicon wafers of around 350 microns thickness. These wafers remain the most significant cost component of the PV cell. In addition, much of the existing PV capacity around the world is based on relatively small plant (5-20 MW), with low levels of automation. Hence there are opportunities for cost reductions by reducing wafer thickness, removing the wafer stage and ultimately moving to thin films (< 50 microns) of semi-conductor material, by increasing the scale of production and, for production in developed countries, by increasing automation. Studies by Bruton et al, 1997, found that it was feasible for the production lines of crystalline silicon cells to be scaled up to 500 MW per annum and that production costs would be reduced to below USD 1.25 per Wp. Similarly, for thin films [Woodcock et al, 1997] this cost could be reached at production levels of 60 MW per annum. It is difficult to generalize current costs of production, due to the different technologies, plant ages and financing arrangements, however current PV module prices have been quoted as averaging USD 6.25-6.5 per Wp for crystalline product and USD 5.5 for amorphous silicon [IEA-PVPS, 2000/3]. Long-term or bulk purchases (say 20 to 100kWp), combined with government or utility subsidies, can achieve prices of USD 3 per Wp.

Even though PV module costs have been decreasing consistently over the past 3 decades, total system costs have not necessarily fallen at the same rate. These "balance of system" or BOS costs can include construction and grid interconnect permits, system design, mounting frames, inverters, batteries, wiring, lightning protection, labour and transport for installation and on-going maintenance costs. They typically account for 50% or more of the total system cost, but can be less than 50% for grid-connected systems, if products and procedures are streamlined.

4.1.6 Lack of integrated PV systems and products

Most PV systems are still designed individually and constructed on site. This means there is a limit to the cost reductions possible through standardized systems and specifically designed products. The first generation of building integrated PV systems has relied on conventional PV modules and used a variety of support structures to facilitate installation onto the building. For the end user, however, innovative PV products, designed to replace standard building components and to meet specific building needs are required. To open up potentially large new PV markets, products must improve on current performance, reduce installation costs and be both attractive and desirable. Hence innovation is needed at several stages: PV cell development and production, module design and production, system design and integration and end-use marketing.

4.1.7 Poor service delivery

The PV market is developing rapidly, with the demand for product overtaking the available pool of trained system designers and installers. In addition, for the non-utility market in particular, there is a severe lack of basic infrastructure, such as supplier networks and maintenance facilities, as well as the support structures such as regulations and standards which would ensure industry credibility and build customer confidence [IEA-PVPS, 1999]. Hence a significant problem for PV is to increase sales without sacrificing the quality of products, installation and back-up. Many of the field problems reported for PV systems are associated with a failure in service delivery, rather than intrinsic technical problems [Lloyd *et al*,2000, Fraunhofer Institute, 1997]. Adequate service delivery would include:

- appropriate customer advice at the outset concerning the cost, the likely performance and the maintenance requirements of a system;
- proper design, component and material selection to ensure customer needs are met and that problems such as corroding connectors are avoided;
- correct installation to avoid shading, maximize PV output at the required time and facilitate ready access for maintenance;
- customer education on basic system operation and maintenance;
- service back-up for general inquiries, routine and emergency maintenance and spare parts.

4.2 Electricity Industry Issues

4.2.1 Impacts of industry restructuring

Many countries are now restructuring their electricity industries, usually with the stated objectives of introducing competition into the market and allowing greater customer choice, although there are often other objectives as well, such as obtaining government revenue through privatization and achieving changes in conditions of employment. For developing countries, energy sector restructuring can play a key role in alleviating poverty and improving health and education outcomes, particularly for the rural sector, where current energy supply systems have not proven to be effective. Restructuring can be used to introduce much needed regulatory reform, including environmental regulations. It can also allow competitive markets, and perhaps private investment, to improve local participation in decision making and in finding more cost effective and appropriate options for energy supply. PV can play a key role in these markets.

The process of electricity industry restructuring, the introduction of competitive markets and the redefinition of roles and business aims which are often associated with them, cause a high degree of upheaval. In this context, the maintenance or development of initiatives to promote PV and other renewables can easily be overlooked. In addition,

some previously successful programmes may no longer be appropriate in the regulatory environment of a competitive market, while changes to expert departments, or the re-allocation of responsibilities which accompanies restructuring, often has a deleterious impact on renewable energy development [IEA-PVPS, 1998]. In addition, when associated with privatization of assets, environmental legislation, such as the imposition of targets or least cost planning mechanisms may be considered by governments to reduce the market value of these assets. Thus a conflict in political objectives may arise.

At least in the early period following the introduction of competition, offering lower electricity prices is regarded by electricity retailers as the key strategy in achieving increased market share. This has been most notable where there is an excess of supply capacity. In the longer-term, however, electricity prices which are too low lead to under-investment in new capacity and hence problems in peak periods. This has been most evident in the US over recent summers. Distributed generation technologies, such as photovoltaics, are recognized as offering a solution [US DoE, 2000], are quick to deploy and are well suited to summer peaking loads. Nevertheless, it is too early to see whether the electricity industry is confident enough in the new technologies to include them in their planning processes or to undertake extensive deployment [California Energy Commission, 2000].

4.2.2 Low conventional electricity prices

As an example of relative prices, solar photovoltaic electricity prices in the US can be as low as USD 0.13 per kWh, with long-term contracts and subsidies [IEA-PVPS, 2000/3]. However, USD 0.25 to 0.30 per kWh for grid-connected photovoltaic power systems and USD 0.5 to 0.75 for stand-alone systems are the more typical situations, while conventional grid electricity prices average USD 0.08 to 0.12 per kWh [ibid]. The high prices of PV electricity are caused by the relative immaturity of the industry and its products, and hence the volume of production, as discussed previously. However, the difference between PV and conventional electricity prices is increased by the large price decreases which have accompanied energy sector restructuring in many countries (although retail electricity prices can also increase dramatically as has occurred in California), as well as an inability to access cross subsidies which are available to the established energy industry. Falling energy prices have kept renewables from becoming cost competitive over the last 2 decades, even though most technologies have met or exceeded projected cost reduction targets [McVeigh et al, 1999].

4.2.3 Network price issues

Few developing countries have introduced transparency or competition into their energy markets. An estimated US \$100 billion per year is spent on fossil fuel subsidies and monopoly industries are protected, yet only a relatively small portion of the population receives the benefits of adequate energy supply [World Bank, 2000]. However, even in industrialized countries where the electricity industry has been restructured, the market does not yet provide a 'level playing field' with respect to renewable energy.

To illustrate the extent of the cross subsidies provided via uniform tariff regulations, it has been estimated that potential revenue losses from rural residents in the State of Victoria, Australia amount to AUD 30 million per year. This works as an effective barrier to the use of PV or other renewables by artificially maintaining low electricity prices and by removing any locational price signals from the network.

Network costs can account for 50% of a customers' electricity bill, yet renewables are rarely considered as an option which might delay or eliminate the need for conventional line upgrading or extension. In addition, network prices are highly averaged and the values of distributing ancillary services have yet to be recognized. Ancillary services are resources used to maintain quality of supply, in particular voltage, frequency and waveform purity. The present arrangements for ancillary services in many electricity markets focus on large participants, and distributed options for ancillary services do not yet receive equal consideration. Arrangements for ancillary services are important for PV because investment decisions in network augmentation are often taken on the basis of quality of supply considerations. Excessive investment in network capacity can result when distributed ancillary service options, such as PV, are not given appropriate consideration. At present, pricing arrangements tend to favour incumbent large generators [Australian Cogeneration Association, 2000], with PV and other distributed generators facing problems caused by:

- Transmission cost savings resulting from the operation of a distributed generator not able to be captured by the generator. This puts the distributed generator at a competitive cost disadvantage compared with distant generators.
- Highly averaged distribution loss factors that do not reward distributed generators for the losses they save by producing power that is consumed locally.
 In addition, there are often restrictions placed on how distributed generators can sell their power.
- Inefficient maximum demand charges that do not reflect the actual time of maximum demand, which penalize electricity customers who self-generate.

4.2.4 Network access issues

As previously vertically integrated utilities are split up into functional units, network costs should become more transparent and provide an incentive to examine the cost-benefits of distributed generation, as an alternative to grid augmentation or extension, particularly if decision making is decentralized. However, one of the unresolved aspects of electricity industry restructuring is the extent to which the so-called 'wires businesses' of transmission and distribution can be made contestable, either by other wires businesses or by distributed resources. The experience in countries such as Australia and in sections of the US, where the formal monopoly on wires business has been removed, but not the regulated franchises, is that network prices are still not fully cost-reflective or are highly averaged and are therefore in reality not providing a powerful driver. This has created a number of additional barriers for PV to

overcome, which are included in the following list of general barriers that have been identified for all distributed resources [Australian Cogeneration Association, 2000]:

- Without access to planning, load and network constraint information, it is extremely difficult for distributed generation proponents to negotiate efficient connection agreements. It is also extremely difficult for proponents of demand side management and local generation to develop competing proposals to network augmentation.
- Information for new market entrants, including distributed generators, which outlines their rights and obligations when connecting to the network and the options available to them is not easily accessible.
- Market registration provisions are restrictive and participation fees are excessive for smaller generators.
- Costs charged by the network provider for project definition, design approval, site supervision, facility commissioning and connection works for distributed generators can be made prohibitively high.
- The lack of information and effective negotiation frameworks has led to delays and frustration for parties negotiating connection agreements.
 When a contract has been negotiated, the supplier of distributed generation has faced higher costs and greater risks than necessary.
- New generators are required to meet more onerous technical standards than existing generators.
- Distributed generators are sometimes expected to pay for deep (firm access) transmission augmentation while transmission connected generators are not.
- The lack of effective separation of electricity network and retail businesses can compound the problems while providing less scope to share the benefits with the retailer and thus makes contracting with distributed generators less attractive to other retailers.

Chivelet [2000] cites many of the above as barriers to PV use in Spain and adds problems due to lack of coordination between government agencies, rigidity in applying subsidies, lack of legislation, regulations and standards for components, installation, grid connection and building integration and limited local government involvement.

Specific regulations covering grid access for distributed PV systems have recently been introduced in the US States of California, Texas and New York, while the interconnection regulations recently introduced in Spain remove legal barriers [Chivelet, 2000], and are important steps in removing access barriers to PV and other distributed resources.

4.2.5 Environmental externalities

Although there has been some progress in industrialized nations, usually via legislation, towards reducing the direct environmental costs associated with fossil fuel use, such as sulphur dioxide, particulates and nitrous oxide emissions,

in general environmental costs and benefits are not taken into account by energy market participants and regulators. Hence, the costs of environmental damage caused by fossil fuels and nuclear energy are borne by the community generally and are not reflected in the costs of energy services based on those sources. Until recently, the environmental impacts discussed have been those noticeable at the local or regional level. However, as the evidence increases that global warming is being caused by fossil fuel use, worldwide environmental impacts are beginning to be considered. With no inclusion of these costs in energy markets and decision making, low emission and low environmental impact energy options, such as PV, are not able to be appropriately valued. Clear annunciation of policy aims to support the transition to sustainable energy systems would provide confidence for investors. It would also facilitate the introduction of supportive regulations, such as solar access provisions, which in turn would provide customer confidence in the long-term viability of PV systems.

In addition, electricity customers are poorly informed with regard to the environmental impact or carbon intensity of electricity supply so that, even where choice of electricity retailer is available, customers are not able to make informed decisions about their energy supply, nor to influence government or energy industry planning processes. Provision of information to customers is a prerequisite for an efficiently working market. Utility disclosure to customers of the fuel mixes used to generate electricity is a means of increasing the efficiency of competitive markets. In addition to electricity sources, disclosure of greenhouse emissions and other environmental indices would provide important information in enabling consumer choice.

4.3 Lack of Information, Market Knowledge and Training

The final, but often the most critical barrier to PV at present is a general lack of awareness and information on what is available or where to source it. Access to customers, to the grid, to energy planning information and to investment capital is also more difficult for PV than it is for established fossil fuel industries. There is a widespread misuse of "commercial-inconfidence" provisions within the newly corporatized energy industries, as a means of restricting information on the electricity system which was previously in the public domain. Access to information such as solar energy resource data, network loads, maintenance costs and upgrading plans would save considerable lead time and expense to PV system proponents. For building integrated systems, a US survey of architects indicates that assembling and presenting technical and financial analyses to clients is a major barrier to implementation [Eiffert, 2000]. Some of these issues overlap with barriers cited previously. Others are discussed below.

4.3.1 Lack of certification, standards and guarantees

Some countries have recently introduced guidelines and standards for grid interconnection of PV systems (for instance

the IEEE "interconnection standard for utility-intertied photovoltaic systems", IEEE Std 929-2000, the Australian "guidelines for grid connection of energy systems via inverters" and the UK's Engineering Recommendation G77 2000 - "Connection of photovoltaic generation to the distribution network - single phase PV systems up to 5kVA"), while PV modules can be rated against accepted performance standards. Nevertheless, to date there has been a severe lack of basic industry support structures such as regulations and installation standards which would ensure industry credibility, reduce costs and build customer confidence. A lack of standards can result in over engineering, low installer confidence, extensive one-off site testing, commissioning of dangerous technology and hence significant cost increases, eroded user confidence and unreliable systems, prone to failure [Spooner, 2000].

However, with such a rapidly growing industry sector and such a wide range of disciplines involved, the development of PV system standards is difficult and time consuming [ibid]. In addition, for grid-connected systems, connection of large numbers of small distributed generation systems into a network designed for a few large scale central generating plants poses new technical and institutional problems. The priority area for standards development is safety - for the dc wiring and the grid interface [ibid]. Nevertheless, standards for building integration and other aspects of system design and operation are also needed [Chivelet, 2000].

Warranties can provide some level of confidence for the customer, and most PV manufacturers offer module warranties of 10 to 25 years. However, the range of possible applications limit their effectiveness, unless total system warranties can also be given. Other than module over-rating, few of the faults found in the German "1000 Rooftop Programme" were attributable to PV module defects. Most were caused by inverters, unsuitable wiring, fuses or switches, or installation faults, while significant system losses were also caused by shading and soiling of the panels [Laukamp *et al*, 2000]. Hence testing and certification of components used in PV systems is required, as is certification of system installers.

While standards will undoubtedly assist the implementation of PV, it is important to remember that that this is a new and rapidly evolving industry and that stringent standards could stifle innovation and technology development. Hence for some issues, it may be appropriate to develop and use a series of guidelines, which can be readily updated, before progressing to formal standards. The IEA-PVPS Task 5 has summarized grid interconnection guidelines and standards applying around the world [IEA-PVPS Task 5-2-01, 1997].

4.3.2 Lack of expertise and demonstrations

With such a rapidly growing industry and one developing from such a small and technically specialized base, it is not surprising that it has been difficult to keep up with training requirements at all levels from manufacturing through system design, installation and maintenance. When ranked against all factors considered important in the success of PV system introduction [Groenendaal et al, 2000], the status of specialist knowledge was lowest in all areas. Lack of expertise is an important component of reliable and cost effective system design, with poor installation practices and inadequate training for ongoing system maintenance being routinely cited as reasons for system breakdown or poor performance.

The availability of and access to a variety of installed systems is an important element of education and training. Worldwide there are fine examples of building integrated PV, sometimes with actual costs and monitored performance data available. However, for most individuals, architects or developers potentially interested in using PV in a building, there are few local examples to view. Even where they exist, systems installed by utilities or private companies are not always accessible, nor are costs or performance published. Before BIPV can become accepted and desirable for clients, there must be a range of accessible demonstration systems available which illustrate different applications, styles and possibilities.

Demonstration systems are also required in developing countries, especially for promotion of PV use in agricultural applications and cottage industries [FAO, 2000]. Demonstration projects should include all stakeholders and results should be made public [ibid].

4.4 Summary of Key Barriers

In summary the key barriers facing the increased use of photovoltaic power systems include:

- High production costs and electricity prices relative to conventional energy sources
- Lack of familiarity with and procedures for financial analyses, compounded by limited financing options
- Lack of procedures for project assessment, approvals and installation, leading to delays and higher costs
- Lack of standard designs and optimized PV products and systems
- Poor back-up service delivery in many areas
- Restructuring in the electricity industry, with impacts on PV programmes, electricity prices and network
- Lack of consideration of environmental externalities in the energy sector
- Lack of long-term energy policy guidelines regarding the transition to sustainable options, which would provide confidence for investors
- Lack of information for customers and investors
- Lack of standards, training and certification.

5 Overcoming Barriers to the Implementation of Photovoltaic Power Systems

Energy markets are still heavily biased towards centralized supply and existing participants. In order to achieve a level playing field for PV and other distributed resources, there must be co-ordination of energy industry, greenhouse gas and renewables policies and more proactive stances on least cost planning and the availability of system information. Industry policies, taxation, pollution standards and other measures may need to be rewritten to ensure that they do not favour fossil fuels or nuclear options, while market regulations must be seen to avoid discrimination against distributed, small scale or variable resources.

Documentation and quantification of non-energy values of PV can be used to overcome the barriers facing its use in the built environment. The responsibilities for action fall to different spheres of government, utilities, PV manufacturers and the building industry and can be categorized under the general headings of gaining market access, reducing prices, improving technology and increasing market acceptance through information and education. Many of these actions apply to renewable energy deployment generally, some are specific to PV, others to BIPV. They could therefore be useful to groups such as the G8 Renewable Energy Taskforce, government policy advisors, the UN Food and Agriculture Organisation, as well as to the PV and electricity industries.

IEA-PVPS Task 7 is carrying out a detailed evaluation of the market potential, the barriers affecting implementation and the strategies to remove these barriers for photovoltaic power systems in the built environment. An IEA-PVPS Executive Summary report on non-technical barriers incorporating this work will be published in the near future. Following is an introduction to the problem of overcoming the barriers to the implementation of photovoltaic power systems more generally.

5.1 Market Access

The Australian Cogeneration Association [2000] summarized some of the actions it considers are required in order to deliver a level playing field for PV and other distributed generation options. These include providing fair network access and connection arrangements, fair transmission access contributions and ensuring disclosure of planning information by distribution network businesses. Cost reflective network pricing and fair demand charges would also allow the benefits of distributed PV generation to be rewarded, while incorporating environmental sustainability into the objectives of electricity markets and making it mandatory to disclose greenhouse intensity on customer accounts would reward more environmentally sustainable electricity supply options.

For building integrated PV specifically, at least for systems up to a certain size, standard procedures and requirements must be developed for grid connection and incorporation into buildings. This will minimize the costs and time required for project evaluation and approval. These procedures and requirements must be transparent, so that the existing energy industry does not have an unfair market advantage.

Readily accessible databases of regional information should be developed which cover solar resources, nodal electricity prices, trends in load growth, plans for infrastructure developments, finance available and other market information. This will make the process of site selection, project feasibility studies and economic assessment much faster and more reliable, thereby reducing the costs and the risks for new projects. Further, the use of life cycle cost calculations must be encouraged in public sector energy decision making and reflected in funding allocations to capital expenditure and running costs. The use of capital asset pricing, rather than engineering economics models for project evaluation should also be examined, as a means of reflecting the added values of lower risk and flexibility in calculating project viability.

Supply chains need to be established which can provide information, prices and trained personnel for installation and maintenance of PV systems. Customers are used to having this level of support infrastructure for their energy services and without it they will not have the confidence to try new technologies. Industry credibility will also be enhanced by the availability of standards and regulations, although these need to be flexible enough to incorporate new developments.

5.2 Price

Price, particularly initial capital cost, is the most visible barrier to PV. Continued R&D on new technologies and production processes is necessary, including assessments of possible economies of scale in manufacture and use. Options for lower cost products should also be examined, even at some expense to efficiency, if this would enable a market to be developed.

The technologies currently available for the integration of PV into buildings are, in general, too expensive for large scale introduction. Cost reductions are thus still essential. They can be achieved by carefully redesigning the PV support structure, but also by integrating the PV system into known building components, by developing multi-function systems and by standardization and prefabrication so that economies of manufacturing volume can be reached and installation costs reduced.

Government and utility investment can be actively used to provide viable market sizes for PV, while options to pool their purchasing power to achieve cost reductions, which could be passed on to smaller users, should be examined. Governments should continue to examine the need for targeted long-term subsidies for market stimulation in

particular areas or for particular products. Standard finance packages for certified systems can also assist purchasers. Standard net metering guidelines should be available for small scale installations, up to an agreed percentage of electricity sales, to reduce up front costs and boost the economic viability of PV in the short-term. For larger systems, on-cost assistance and standard procedures for feasibility studies, project development and approval processes would lower up front costs and reduce risk.

Emission taxes on fossil fuels would ensure that their prices more correctly reflect true costs, hence reducing price differentials with PV. Regulatory processes can also be used to ensure transparent pricing of energy supplies, with clear indications of cross subsidies, to allow PV to be targeted to those areas where it is most cost effective.

5.3 Quality Enhancement

If PV is to become a well-accepted technology readily available for use by the energy sector, agricultural enterprises, architects, the building industry, property owners, villages and individuals, the total PV system and products must be customer friendly: well designed for the end-use, reasonably priced, reliable, aesthetically pleasing with innovative designs, non-intrusive, easy to install and maintain and demonstrably environmentally friendly.

For BIPV, integration concepts will have to meet regular building quality standards. This can be achieved by fully integrating the PV system into building materials and by integrating the construction process of BIPV systems into the building construction process. On the other hand, the physical characteristics of PV products for integration in buildings must meet architectural requirements of color, size and material type, which will sometimes require PV performance and hence economic compromises. This is a challenge for both the architect and the PV module manufacturer.

5.4 Market Acceptance

Market acceptance of PV is very low at present, despite a high level of community support for its development and use. Significant effort is needed to raise levels of awareness and credibility. Information on PV must be made readily available to the general public, for household applications and for trades, professions, investors, insurers and planning agencies for all applications. Certification procedures and standards must be developed to enhance credibility and performance. For BIPV, enhanced market acceptance would be assisted by a holistic approach to the design of the entire PV building, including overall energy efficiency and sustainability of building materials used.

Market acceptance by property developers, utilities, development and financing agencies is also required. Added values, other than avoided electricity costs, should

be made clear to potential customers in these sectors. The operator of the PV system, the financing institution and, for BIPV, the owner of the building, must have long-term confidence in the performance of the PV system, both as an electricity source and, for BIPV, as a building material. For grid-connected systems, if the utility is not the owner of the PV system, long-term agreements for grid-interconnection and buyback tariffs are required. Similarly, standard procedures for project approval, contracts for maintenance and clear guidelines for responsibility and liability are needed to facilitate project development and to encourage investment in PV.

Customers are often surprised by the low level of renewables in existing electricity supplies and have generally been supportive of Green Power and other renewables support schemes when given the choice. Disclosure of fuel mix details on electricity accounts should be mandatory under competitive market electricity sector regulations, to facilitate customer choice. Nevertheless, there is a need for credible and independent information and advice which would allow customers to make informed choices.

Well documented and monitored demonstration of technical and non-technical aspects of PV projects is critically necessary - information on design, installation requirements and procedures, performance, costs or financing arrangements should be published for all publicly funded projects. In many countries, few such examples are available while misinformation on net energy requirements for PV and confusion with solar thermal systems persist.

Government investment in and use of PV could provide the basis for demonstration systems, as well as to increase public knowledge and confidence.

Information on general field performance is also needed for all PV applications. Systematic monitoring and standardized reporting formats must be developed, as well as a coordinated system of user feedback. The latter would be particularly useful in the short-term as a means of ensuring that any scale up of production to meet demand growth has taken into account problems with existing systems.

The diversity of PV applications has made it difficult for the different industry groups involved to achieve market presence and to provide adequate product support. Until each sector reaches maturity, there would be benefits in forming partnerships between PV industries, governments, utilities and other industries or groups which can pool resources to provide information, component supplies and installation, operation and maintenance services. This has been successfully achieved in some countries.

The diversity of PV applications also provides for a diversity of opportunities. There is a need to develop a portfolio of products and applications, so that the long-term benefits of complementary use of a diverse mix can be realized. At the current stage of market development, successful implementation of any system has a positive impact on others. Conversely, projects or applications that are perceived as unsuccessful have a negative impact on all.

Generic policy initiatives, such as renewable energy targets or trading schemes will also assist. However, there is a danger that the allocations will be taken up by a few large projects. If the measures are aimed at the development of robust renewable energy industries, as well as greenhouse gas reduction, the regulations should encourage selection of a range of technologies, best suited to local conditions. In general, energy policies at all levels should begin to reflect the need for a transition to sustainable energy systems. This will provide the long-term signals necessary for investor and public confidence.

5.5 Education and Training

A range of educational programmes is necessary, as is targeted promotion and training for trades and decision makers. Education needs range from those aimed at increasing awareness of applications and costs to wider information on environmental impacts of energy use and the added values offered by PV. Such education should begin in schools and be followed through with more detail in trade and professional courses. Certification for designers and

installers will improve system performance and costeffectiveness and reduce the number of faulty or inappropriate installations. In the short-term, bridging or short courses may be needed to retrain practising trade and professional people in the agriculture, electricity and building industries on the characteristics, performance and requirements of PV systems.

For customer products, there is a need for community education generally and the availability of information, advice and trained system designers and installers. This information should be in a form readily understood by the customer. PV has a history of being treated as an electricity supply technology, so that current material is largely technical. Architects need material on PV system operation and use which is presented in a form they can understand and apply. Similarly, material for householders or community groups needs to allow ready understanding of the general concept and requirements, as well as comparison with other options.

Demonstration systems, illustrating a range of PV concepts, are needed for educational purposes, as well as for awareness raising and inspection by potential customers.

6 Summary and Conclusions

Many renewable energy and energy efficiency technologies meet the definition of "distributed resources", which can be strategically located within electricity distribution networks to reduce the need for external energy supplies, while also providing a range of electrical system, environmental, architectural and socio-economic benefits. Photovoltaics is unique amongst the new energy technologies for the wide range of energy and non-energy benefits which can be combined, while the use of PV as an integral part of a building provides the greatest opportunity for exploiting non-energy benefits and for adding value to the PV system.

PV installed on the surfaces of buildings, allows the possibility of combining energy production with other functions of the building envelope, including structural support, weatherproofing, shading or solar thermal collection. Cost savings through these combined functions can be substantial. Additionally, no high-value land is required, no separate support structure is necessary and electricity is generated at the point of use. The latter contributes directly to the building occupant's electricity requirements while also avoiding transmission and distribution losses

and reducing capital and maintenance costs for utilities. The integration of PV into the architectural design offers more than cost benefits, however. It also allows the designer to create environmentally benign and energy efficient buildings, without sacrificing comfort, aesthetics or economy, and offers a new and versatile building material.

A number of projects around the world show an emerging market for grid-connected building integrated PV systems, despite the fact that electricity from PV is still more expensive than grid power. The market for grid-connected PV in IEA member countries is therefore growing rapidly and now accounts for more than 50% of installed capacity.

This report has shown that PV can contribute significantly to reductions in greenhouse gas emissions from the electricity sector: Lifetime CO₂ emissions with current PV technologies are 85 to 94% less than those from coal fired power stations and will be 95 to 97% less with new technologies. Solar powered manufacturing plants can operate as "solar breeders" ensuring a sustainable technology in the long-term.

PV can contribute to improvements in air quality. When PV displaces coal fired generation, ${\rm NO_x}$ emissions are typically reduced by 50% and ${\rm SO_x}$ emissions by 90%, making PV use a valuable adjunct to clean air policies. For improving urban air quality, PV can play a role in facilitating the introduction of electric vehicles, either by powering the vehicle directly or by providing power to recharging stations.

PV can assist in securing energy supplies in both the long-term and short-term. With fossil fuel resources expected to be depleted this century, PV provides a means of maintaining electricity supplies in industrialized countries and providing electricity to the developing world without concern for fuel supply security. Dispersed PV generators feeding into electricity distribution networks, or operating independently, can provide more reliable electricity supplies during power outages caused by summer peaks or emergency situations.

PV is a high technology industry which can create new jobs in manufacturing, distribution, installation and maintenance. Dispersed application means that employment is created in regional areas, as well as in industrial centres. Direct employment in the PV industry world-wide is expected to be between 250 000 and 300 000 by 2010.

The modularity of PV provides benefits to electricity utilities by allowing for generation to be expanded, or reduced, to match demand more easily than for large central generation plant.

Lead-times are also shorter, exposure to fuel price volatility is reduced and grid augmentation can be avoided. Hence financial costs and risks are reduced. On-site or local generation also reduces transmission and distribution losses. Dispersed generation reduces the likelihood and impact of large scale outages while smoothing output fluctuations from individual systems. It can be especially valuable in dealing with summer peak loads, where the effective load carrying capacity can exceed 80% of the PV rated output.

For customers, PV offers a range of benefits which can significantly increase its value. These include providing aesthetically pleasing, non-intrusive, multi-function building elements, ensuring supply

reliability, reducing energy and peak demand charges and contributing to environmental protection. For society as a whole, PV provides a means of delivering more sustainable energy systems for both rural and urban developments.

Nevertheless PV systems face a number of barriers to their entry into the mainstream energy and building markets. These include high capital costs and associated financing problems; immature products and service delivery chains; a lack of information, expertise, standards and demonstration systems; electricity industries that still favour the central generation paradigm; and electricity markets that do not yet account for environmental externalities. Some of these barriers can be overcome by assessing both the energy and non-energy benefits which can accrue from a PV system, thus making PV a cost effective option even with current costs and energy prices.

With the structure, ownership and operation of electricity supply industries changing rapidly around the world, the added values offered by PV ensure that it will be one of the most significant of the new energy technologies deployed over this century. However, to make the transition from existing to new and sustainable energy systems, work must be done to transform existing electricity systems from being reliant on central generation to systems which embrace the range of technologies and energy service delivery options offered by new, distributed resources. Governments and regulators must also ensure that energy markets account for environmental externalities in selecting network structures, technologies and energy sources and that citizens are well informed about the energy choices they make. The PV industry must continue its technology development by improving efficiencies, increasing production levels, reducing costs and providing reliable, easy to install and aesthetically pleasing products. Finally, a range of educational programmes is necessary, aimed at increasing the awareness and understanding of customers, planners, regulators, electricity industry personnel and the building industry. This needs to be complemented by targeted promotion and training for trades, professions and decision makers, as well as by a range of accessible demonstration systems in key market areas.

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