

New Markets for Solar Photovoltaic Power Systems

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Abstract. Over the past five years solar photovoltaic (PV) power supply systems have matured and are now being deployed on a much larger scale. The traditional small-scale remote area power supply systems are still important and village electrification is also a large and growing market but large scale, grid-connected systems and building integrated systems are now being deployed in many countries. This growth has been aided by imaginative government policies in several countries and the overall result is a growth rate of over 40% per annum in the sales of PV systems. Optimistic forecasts are being made about the future of PV power as a major source of sustainable energy. Plans are now being formulated by the IEA for very large-scale PV installations of more than 100 MW peak output. The Australian Government has announced a subsidy for a large solar photovoltaic power station of 154 MW in Victoria, based on the concentrator technology developed in Australia. In Western Australia a proposal has been submitted to the State Government for a 2 MW photovoltaic power system to provide fringe of grid support at Perenjori. This paper outlines the technologies, designs, management and policies that underpin these exciting developments in solar PV power.

Key words: Solar Photovoltaic, Power Projects, Perenjori Solar Power, Large-Scale Photovoltaics

1. INTRODUCTION

In a world growing in population and with the impacts of climate change upon us, the primary energy sources we have become accustomed to (*viz.* fossil fuels) have ceased to be the “easy” answers to our insatiable need for electric power. Combustion of fossil fuels releases oxides of nitrogen and sulfur, mercury and other toxic metals into our atmosphere, directly causing increasing incidence of respiratory disease, polluting our land and waters, damaging flora and fauna and contaminating our food supply.

Of the five major available energy sources, *viz.* energy from fossil fuels, nuclear energy, solar energy in its various forms, geothermal energy and tidal energy, only PV systems have traditionally found widespread use in niche markets such as remote area power supplies. Today, as a result of the declining costs, millions of PV systems have been installed in cities the world over. Low cost PV systems could easily provide for much of the world’s electricity in a carbon-constrained world and as a result, the renewable energy industry in general and the global PV industry are

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booming. Not only has growth been sustained since the industry was established, but also the global annual growth rate in the PV industry is increasing, with exponential growth as shown in Figure 1 below [1].

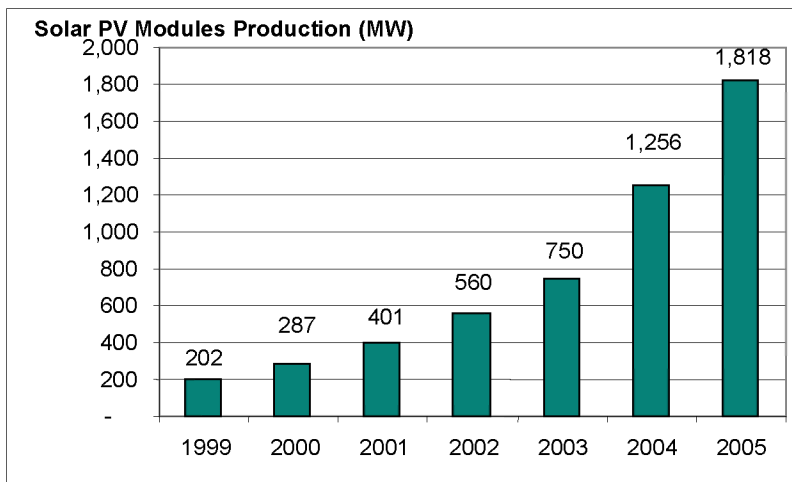


FIGURE 1. Production of Solar Cells [1].

2. CHANGING MARKETS FOR PV

Of the four main market segments for PV solar electricity, viz. off-grid industrial, off-grid rural, consumer applications, and grid connected, the first three market segments are already competitive and have had a typical growth rate of approximately 18% per year, whereas the grid-connected market is increasing at a surprising 63% per year [2]. Government policies such as the feed in tariffs in Germany, Spain, Italy, France, Portugal, etc and investment subsidies provided in Japan, the United States, and other countries have resulted in a net increase in the contribution of grid-connected systems to the total solar PV electricity market from about 25% six years ago to more than 75% today.

Until recently, large-scale grid-connected PV arrays were not a major part of the market. With most development taking place in the OECD countries, today this segment of the PV industry is the engine of the PV boom. Notable examples of market stimulation programs include the 100,000 roofs initiative in Germany, the current Renewable Energy Law in Germany, and the million solar roofs program in the United States. While in 1994 only 20% of new capacity was grid-connected, this had grown to over 70% by 2003 [3].

The ten largest photovoltaic systems in the world range from 4 to 12 MW, with eight of them being located in Germany and the other two in Japan and United States of America.

TABLE 1. World's Ten Large Solar PV Systems [4].

Sr.	Location	Country	Capacity MW
1.	Erlasee/Arnstein	Germany	12
2.	Pocking	Germany	10
3.	Mühlhausen	Germany	6.3
4.	Miegersbach	Germany	5.27
5.	Kameyama	Japan	5.21
6.	Bürstadt	Germany	5
6.	Espenhain	Germany	5
7.	Tucson	U.S.A.	4.59
8.	Sembach	Germany	4
9.	Geiseltalsee, Merseburg	Germany	4
10.	Göttelborn	Germany	4

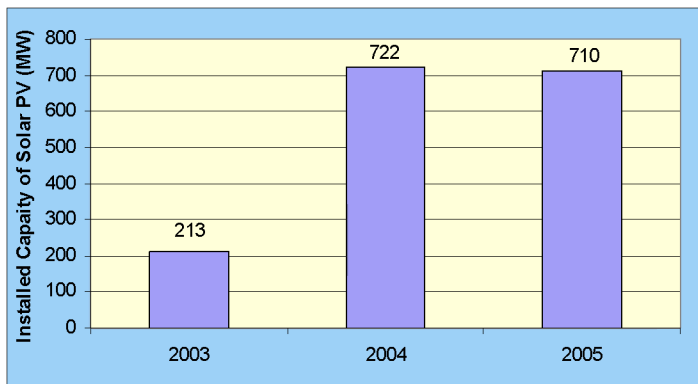


FIGURE 2. Solar PV Systems Installed in Germany [4].

In 2006, New Mexico State Land Office had allocated land to build a 300 MW system, the largest solar energy plant in the world. Juwi Solar GmbH has announced plans to set up a 70 MW system at Brandis airfield near Leipzig, Germany. Currently, there are numerous large solar PV projects under construction in Germany, Spain and Portugal, with capacities ranging from 5 to 30 MW.

Even in the Building Integrated PV systems market, the ten largest systems are found in Europe, with 9 of them being located in Germany, with the largest system being a 5 MW system [4].

Figure 2 shows the total installation of solar PV systems capacity from 2003-2005 in Germany. It should be noted that most of the capacity is added through the installation of large-scale PV systems [4]. There are more than 300 MW of solar PV projects at different stages from planning to installation in Spain, while it is estimated that the total installation in Italy will be 86.2 MW in 2007.

The IEA estimates [5] that by 2030 the PV industry will be producing 300 GW of modules per year made up of three main segments.

- Off-Grid Industrial 70 GW pa
- Rural Electrification 60 GW pa
- Consumer Products 20 GW pa
- On-Grid 150 GW pa

The largest component of this is clearly the grid-connected, large scale PV systems that are beginning to appear in Western Europe, where favourable Government policies are fostering their development. This is especially true in Germany where more than 40 PV systems of 1MW and larger have been installed or are currently under construction.

3. PROSPECTS FOR VERY LARGE-SCALE PV

A very large-scale PV system is defined as a PV system ranging from 10 MW up to several GW (covering 0.1-20 km²) consisting of one plant or an aggregation of units operating in harmony and distributed in the same district [6]. The objective of IEA PVPS Task VIII was to examine and evaluate the feasibility of Very Large-Scale Photovoltaic Power Generation (VLS-PV) Systems in desert areas in each of the continents. It was suggested that with existing technology, VLS-PV could directly compete with fossil fuels as the principal source of electricity for any country that has desert areas, though the exact economics would vary from region to region.

Task VIII found that there were ideal conditions for large scale PV systems in the Gobi, Sahara, Great Sandy and Arabian Deserts. Covering the Gobi Desert, which spans an area of 1.3 million km², (which is less than 10% of the world's desert area) with PV panels, could produce 10¹⁴ kWh of electricity pa or 384 EJ per annum which is more than 60% of world primary energy supply in 2005. [6]

Africa has by far the highest PV potential from its deserts (1,300,000 TWh/pa) as shown in Figure 3. The Sahara Desert covers 8.6 million km² and could produce more than six times as much as the electricity produced from the Gobi desert.

Current world electricity consumption is approximately 15,223 TWh/pa. In comparison the potential electricity production from the world's deserts is 2,357,840 TWh/pa or 150 times current demand. Therefore less than 1% of the surface area of the world's deserts would be required to supply all of the world's current electricity needs. Considering that current PV panels are about 15% efficient all of the world's

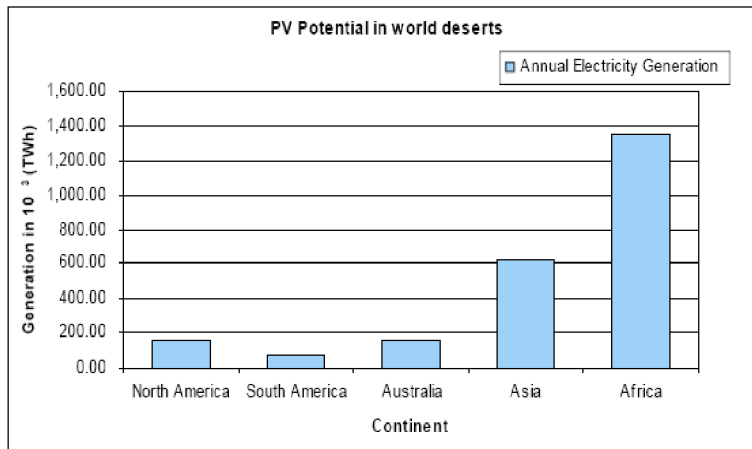


FIGURE 3. PV potential in the world's deserts [6].

current primary energy needs could be supplied by covering less than 10% of the deserts with PV panels.[5]

One of the targeted places for an 8 MW large scale photovoltaic power generation system is the Gobi Desert at Qiliying. The 8 MW VLS-PV system will be divided into eight substations of 1 MW each. The generated electricity from each 1 MW substation will feed to a high voltage grid (35 kV) through a 1,000 kVA transformer. The annual output is calculated to be 13 761 MWh/year, assuming a system efficiency of 0.77 and the annual in-plane irradiation facing south with a 40° tilted angle.[6]

The proposed 8 MW VLS-PV plant in Dunhuang City is considered the first pilot project in China within the Great Desert Solar PV program. In addition, a proposed 30 GW of solar PV power generation capacity could be developed by 2020 if government incentive policies are in place [7].

4. PROSPECTS FOR LARGE-SCALE PV SYSTEMS DEPLOYMENT IN AUSTRALIA

Australia produced 35.5 MWp of crystalline silicon cells in 2005 using imported wafers. Most of these were for the export market. 50% of a total of 6.7 MWp of modules made locally were exported, with imported modules making up an increasing share of local sales. 0.4 MWp of concentrating PV systems were also manufactured and installed in 2005 [8].

Australia produces the highest per capita greenhouse gas emissions in OECD countries [8]. Figure 4 below shows greenhouse gas emissions of the national electricity mix in OECD countries.

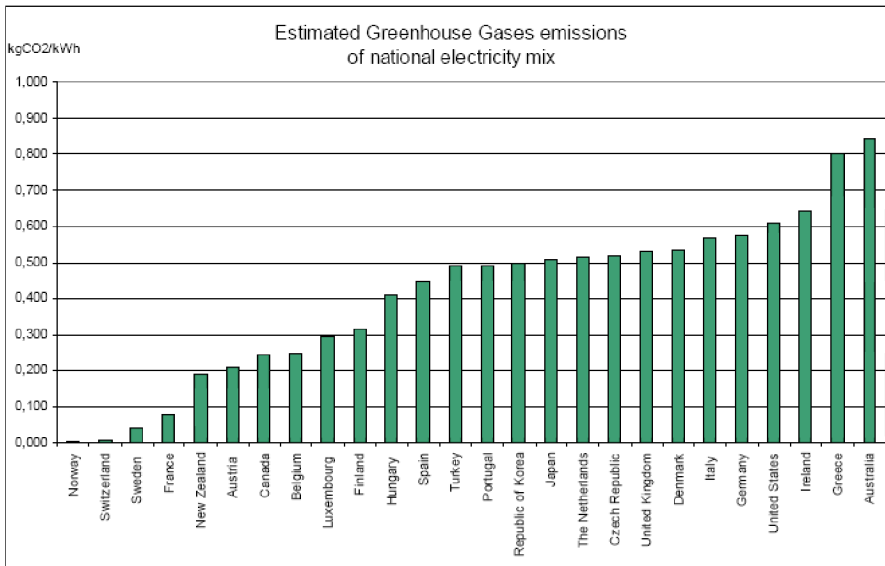


FIGURE 4. Estimated Greenhouse Gas Emissions of National Electricity Mix [8].

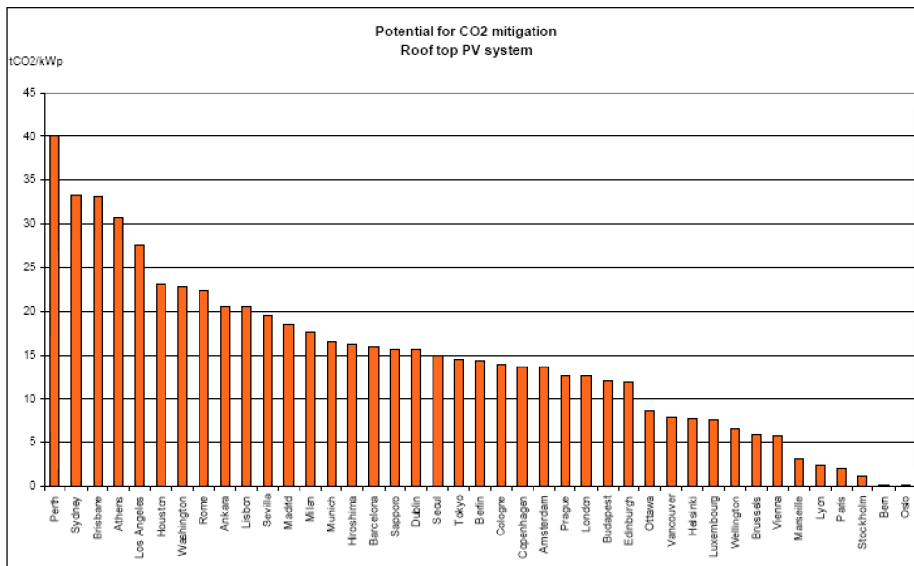


FIGURE 5. Potential for CO₂ Mitigation in Major Cities in OECD Countries [9].

On the other hand, Australia has the highest potential to mitigate greenhouse emissions as it has abundant solar radiation to produce electricity from pollution free solar PV systems. Figure 5 below compares the potential of CO₂ mitigation from the roof-top PV systems in major cities of Australia (Perth, Sydney and Brisbane) with other major cities in OECD countries.

As shown in Figure 5, Perth, or Western Australia as a whole has the highest potential to mitigate greenhouse gas emissions via rooftop PV. However, work done to promote the solar industry in Western Australia has been negligible so far.

However, as an outcome of the visit of International Energy Agency Task VIII to Perth in 2004, a significant solar PV power project has been planned in Perenjori. A consortium of the Shire of Perenjori, Prime Solar Pty Ltd and Murdoch University has been involved in developing this solar PV project. [9]

Perenjori, a small township located approximately 350 km north-east of Perth in is the site for a proposed VLS-PV system. The overall economy of setting up the project and generation costs will be less at Perenjori than in the Great Sandy Desert, due to the close proximity of the load and the availability of the local grid,. The proposed size of the VLS-PV system is 2 MW. This project is intended to provide grid support to Perenjori Shire which is currently on the fringe of the grid and suffers constantly from low line voltage and poor power quality. The estimated project cost of a 2 MW solar PV power generation project at Perenjori will be approximately AUS\$20 million [9]. A local company Prime Solar Power Pty Ltd has made an application for a grant from the Sustainable Energy Development Office in Perth, to support this project.

Perenjori has the potential to support a gigawatt size solar PV system. Solar PV systems of different capacities could be installed near to the load points in a cluster of several PV systems aggregating to a gigawatt capacity. The roadmap on Very Large-Scale Photovoltaic Systems for Perenjori provides the details [9].

Further, a rainwater collection mechanism could be developed to harness the rainwater falling on the large solar collector area as there is an average of 300mm/annum of rainfall at Perenjori. The water could be sold as premium bottled water to generate additional income from the solar PV systems [9].

5. REGIONAL DEVELOPMENTS

Regional and international commitments to combat the effects of climate change, have resulted in a number of countries giving their support to an emerging solar market by supporting its development through both research and market support. More importantly, they are also proactively educating their communities on the important social and environmental benefits that can be captured via the use of solar technology.

The development of the PV market is expected to vary from region to region around the world. While the OECD countries, especially the USA, Japan and Europe, will continue to dominate the global market up to 2010, much faster development is expected to take place in other regions, especially South Asia and Africa post-2010 as shown in Figures 6 and 7.

Presently, approximately 1.7 billion people around the world live without access to basic energy services. The development of solar villages in rural areas has the potential to meet the electricity requirements of rural communities in the developing world. It is a very important way of meeting part of the projected increase in global electricity demand, which is expected to rise from 16,000TWh in 2001 to 36,000TWh

in 2040, according to the International Energy Agency [10]. Half of the new energy needs of the developing world will be in decentralized rural applications, due to economic constraints of their population. Albeit several rural development programs have been initiated in developing countries, the impact has thus far been relatively small as the initial capital cost of the system has often been the stumbling block to the implementation of such systems for subsistence level communities.

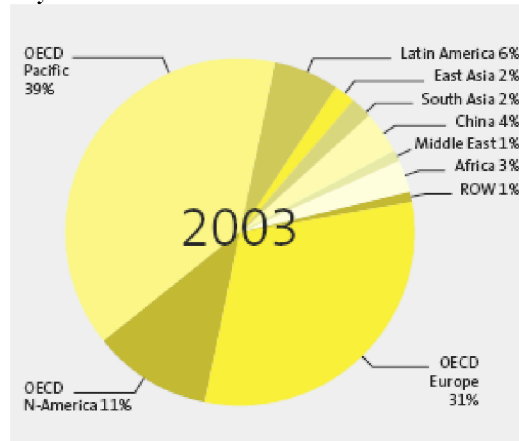


FIGURE 6. World solar power market by region 2003[11].

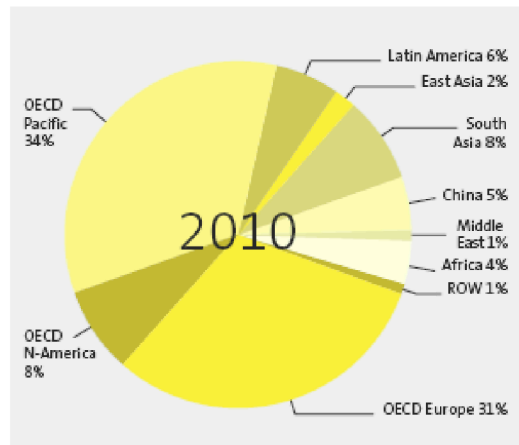


FIGURE 7. World solar power market by region predicted for 2010[11].

6. PROSPECTS FOR THE AUSTRALIAN PV INDUSTRY

In the 1980s Australia led the world both in research and development and installed PV capacity. Due to a lack of federal and state government funding and the absence of a supportive policy framework, this position has been lost.

TABLE 2. Cumulative Installed PV Systems in Australia by Sub-Market [12].

Sub-market/ application	31 Dec. 1992 kWp	31 Dec. 1993 kWp	31 Dec. 1994 kWp	31 Dec. 1995 kWp	31 Dec. 1996 kWp	31 Dec. 1997 kWp	31 Dec. 1998 kWp	31 Dec. 1999 kWp	31 Dec. 2000 kWp	31 Dec. 2001 kWp	31 Dec. 2002 kWp	31 Dec. 2003 kWp	31 Dec. 2004 kWp	31 Dec. 2005 kWp
off-grid domestic including recreational market	1 560	2 030	2 600	3 270	4 080	4 860	5 960	6 820	9 110	10 960	12 140	13 590	15 900	18 768
off-grid non- domestic	5 760	6 865	8 080	9 380	11 520	13 320	15 080	16 360	17 060	19 170	22 740	26 060	29 640	33 073
grid- connected distributed		5	20	30	80	200	850	1 490	2 390	2 800	3 400	4 630	5 410	6 860
grid- connected centralized				20	20	320	630	650	650	650	850	1 350	1 350	1 880
TOTAL	7 300	8 900	10 700	12 700	15 700	18 700	22 520	25 320	29 210	33 580	39 130	45 630	52 300	60 580

Despite this, the use of PV systems in Australia continues to grow at 15% per annum with total installed capacity reaching 60.58 MWp in 2005. Off-grid industrial and agricultural applications continue to dominate Australia's installed capacity (57%). In addition, off-grid residential applications also continue to grow strongly, accounting for 35% of 2005 installations and 30% of installed capacity. Total off-grid cumulative installed capacity accounts for 87% of PV installed in Australia. Grid connected PV has grown from zero to 13% of installed capacity over the past decade, with most of this (10%) being PV on residential and community buildings [12].

In August 2004 the Australian PV industry released its own PV Road Map, which includes targets and strategies for the different PV market sectors and with overall targets for 2010 and 2020 in terms of installed capacity, employment, market value and CO₂ abatement. [13]

Currently, the three main market development programs provided by the government for PV in Australia are the Renewable Remote Power Generation Program (RRPGP), the Photovoltaic Rebate Program (PVRP) and the Mandatory Renewable Energy Target (MRET). New initiatives implemented include the Solar Cities program announced in June 2004, the Renewable Energy Development Initiative (REDI) (for providing grants of up to 50% of the cost for R & D projects, announced in October 2005), Low Emissions Technology and Abatement (LETA) initiative and the Advanced Electricity Storage Technologies initiative.

7. THE ASIAN MARKET FOR PV

The solar market in South Asia is dominated by India, which is the only country in Asia with a government department solely devoted to the promotion and support of renewable energy. India's national energy policy is to achieve a 10% share of electricity from renewables by 2012. The high level of demand for electricity in regions which are not connected to the grid, a flourishing domestic PV industry and favourable operating conditions, offer tremendous opportunities to tap the vast solar electricity potential. Various PV incentives have been introduced, including up to

90% capital subsidy for solar home systems in unelectrified villages and subsidies of 50% and 67% respectively for isolated and grid-connected solar power projects which do not exceed a capital cost of \$5.50/Wp. A solar lantern subsidy is also available of up to \$42 [14]. However, the lack of adequate financing schemes for the installation of PV systems in rural communities, where per capita income is very low, is still the primary barrier.

The East Asian market, by comparison is currently quite small. However it is expected to be one of the key markets over the coming decades, with Thailand becoming an important player in this region. The Thai Government actively supports the development of renewable energy through its Energy Conservation Program. Financial incentives are provided through subsidy schemes, including a 50% grant towards the capital cost of rooftop PV systems during a pilot phase. The National Energy Policy Office and the Department of Energy Development and Promotion are also in the process of preparing a National Renewable Energy Policy which should specify priorities and further support measures. [15]

The total PV power installed in Korea during the year 2004 was 2,553 kW. With a PV implementation plan consisting of 100,000 residential roof-tops and 70,000 commercial and industrial buildings, it is hoped that the total capacity would increase to 1.3 GW by the year 2012. Three different sizes of systems will be developed such as 3 kWp for residential homes, 10 kWp for public buildings, and 20 kWp for industrial buildings [15].

As a major fossil fuel consumer, China has made a serious commitment towards exploiting its renewable energy resources. Over 70% of the Chinese population lives in rural areas, with approximately 30 million people having no access to electricity. The Chinese government announced the linking of three state agencies involved in renewable energy in 1998, viz. the Ministry of Science and Technology, the State Development and Planning Commission and the State Economic and Trade Commission - to work together on a program for New and Renewable Energy Development in China up to 2010. In addition, a World Bank renewable energy development program is scheduled to support the installation of 200,000 solar home systems with a total capacity of 10 MW [15].

The photovoltaic cells and modules market in Japan, estimated to be 640 MW in capacity, will rapidly grow to 2,350 MW in fiscal 2008 by recording an average growth of 30 to 40% each year. In the overview of the Japanese PV Roadmap Towards 2030, the report notes that this period to 2030 will be a critical formation stage in the creation of a full-scale market for PV systems. A cumulative capacity of 100 GW of photovoltaics in Japan is seen as achievable by 2030, by which time PV could meet 50% of residential power needs, or 10% of Japan's entire electricity supply [16].

8. CONCLUSIONS

The rapid increase in the price of crude oil and its subsequent effect on the domestic and industrial sectors worldwide has once again highlighted the urgent need to find a new equilibrium in the energy mix for both industrialized and developing economies. Higher energy prices are here to stay and in order to grow world

economies will have to adjust to meet this challenge. The national feed-in tariff for solar electricity which offers customers an attractive price for selling their PV electricity to the utility grid has been the primary reason for rapid uptake of solar electricity in Germany. A vital element of the feed-in law in Germany and other European countries is the fact that the tariff is set at the point of connection to the grid and this level is guaranteed for 20 years, which ensures planning security for customers. The fact that, the cost of the feed-in-tariff is financed by a small surcharge on all electricity users, rather than by a government subsidy is another critical reason for the success of the feed-in tariff. If PV is to have a promising future as a major energy source it must build on the experiences of those countries which have already led the way in stimulating the solar energy market.

In Australia, the Federal Government should promote solar PV technology by introducing an attractive feed-in-tariff and a grant scheme to develop a local industry base. Instead of promoting nuclear power, the Australian Government should focus its attention on developing its renewable energy industry, especially solar PV, which is able to meet the peak electricity demand in large areas of the country and support the grid around its fringes.

No form of energy production is 100% environmentally friendly. Some modes of energy production cause less damage to the environment by producing less toxic and damaging waste by-products than others. Although VLS-PV technology may seem like a very promising technology, if it is to become truly sustainable, we urgently need to carry out a full life cycle analysis of it. An LCA study will provide indications of measures that must be taken to minimize the adverse impacts of this technology over its entire lifecycle, thereby ensuring that it is more sustainable. We should not repeat the errors of the past by ignoring long term impacts otherwise, when these projects reach their end of their life, we may again be faced with similar problems that confront us today with disused power stations and nuclear reactors.

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