NEW ZEALAND MINISTRY OF ECONOMIC DEVELOPMENT

Assessment of the Future Costs and Performance of Solar Photovoltaic Technologies in New Zealand

by

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and

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EXECUTIVE SUMMARY

The Global Scene

Solar electricity is a key component of a sustainable energy mix. Solar electricity via photovoltaics (PV) is unique in its potential for significant cost reductions, its modularity, ease and speed of installation, suitability for a wide range of applications and sites, including integration into new or existing buildings, and its ability to generate electricity with no ongoing fuel costs. PV therefore has the potential to provide reliable, low emissions electricity for the future.

The world PV market has been growing at rates of more than 35% per year for the past decade, driven largely by support programs for grid connected installations in Europe and Japan. Installations in 2007 exceeded 3 gigawatts (GW) and the 2010 market is expected to be between 8 - 12 GW (Koot, 2008) (Hirshman, 2008). The PV industry generated US$17.2 billion in global revenues in 2007 (Marketbuzz, 2008). With a large increase in manufacturing capacity and continued improvements in efficiency and production costs, PV electricity prices are expected to begin to reach grid prices ('grid parity') in many markets from 2010 (Koon, 2008). This will gradually transform the market from one dependent on government support policies to one driven by customers seeking long-term electricity price certainty.

The International Energy Agency's *Scenarios and Strategies to 2050* identifies PV as a significant player in the longer term, should strong greenhouse gas reduction targets be set, with the Blue Map scenario including 1400 GW of PV generating 3000 Terrawatt hours of electricity by 2050, about 300 times the current production volume (IEA, 2008). The European PV Industries Association is claiming that 12% of Europe's electricity demand in 2020 could be met by PV electricity, if grid parity is reached in all European countries over the period from 2010 to 2020 (European PV Association, 2008).

The global industry is maturing fast, with strong competition and the likelihood of price reductions and industry consolidation over coming years, as supply from the many new manufacturing facilities begins to outstrip demand. At present there are more than 100 cell manufacturers, 300 module manufacturers and 80 thin film manufacturers around the world (Koot, 2008) (Hirshman, 2008), with a growing number in the Asia-Pacific region, including China, India, Korea, Taiwan, Philippines, Malaysia and Singapore. Plant sizes are increasing from the present norm of around 50 Megawatts per year to plans for 0.5 – 1 GW/yr plants by 2010 (Koot, 2008). Thin film products are finally beginning to make market inroads and are expected to increase both market share and price pressure from now on, while there is a growing use of concentrator and tracking systems to improve output. Energy payback times are now between 1 and 3 years for commercial technology and will continue to fall as the material intensity of PV product declines.

The New Zealand PV Industry

Electricity use in New Zealand has been growing and is expected to continue to grow to 2040, with the increase expected to be met by gas, hydro, various other renewables, demand-side responses, or CCS enabled coal in later years (Electricity Commission of New Zealand, 2008).

In the past PV module supply in New Zealand has been through a local wholesaler who purchases from an Australasian distributor. There are now a number of local distributors purchasing direct from overseas manufacturers, resulting in more competitive PV module prices. At least 15 PV brands are available in reasonable quantity, as well as a range of inverters, controllers and batteries. There is currently limited local manufacture. However, there is a range of research and development underway which could result in New Zealand product in the medium to long term.

New Zealand companies involved in the PV sector are generally small and diverse, with the majority working in the implementation or supply of imported products. Over 100 organisations currently have reasonable activity in the photovoltaic industry, with employment of around 225. Others are involved on a less regular basis.

Installation of PV systems involving voltages greater than 120VDC or 50VAC requires a registered electrician. More than 50% of installers are not believed to be registered electrical workers and as such are capable of working only on the extra low voltage (ELV) component of Stand Alone Power Systems. Electricians, while well qualified for the installation of electrical systems generally, have limited exposure during training to the specific requirements of photovoltaics, battery installations, ELV/DC wiring practice and safety aspects including working at heights (many PV arrays are installed on the roof of dwellings). Many of those working in the industry are therefore self-taught, with some training acquired through suppliers of equipment. There is only limited knowledge and application of the relevant design and installation standards and, as a result, a varied level of work quality and system performance. There are few courses run in New Zealand for the design and installation of photovoltaic systems. SEANZ recently announced a competency based training and accreditation scheme for installers and designers of small scale renewable energy systems. The Electrical Worker Registration Board (EWRB) is currently proposing a category of limited registration as an Electrical Service Technician for the installation of renewable energy systems.

PV Potential in New Zealand

The PV market in New Zealand has been growing slowly, built largely on off-grid sales but with a recent increase in grid-connected installations. The solar schools program and the Auckland Airport installation are examples of recent interest in the grid market.

The opportunities for PV deployment in New Zealand fall into four general categories: Large central generating plant or “Solar Farms”, medium scale installations on commercial and light industrial premises for daytime load reduction, small residential grid-connected systems, providing distributed generation, and off-grid systems displacing diesel (or petrol) generators or replacing uneconomic remote lines. There is also a growing market in PV products for garden lights, caravans, boats, computer charging, electric fences and other consumer products, which falls outside the power system market. In addition, as New Zealand makes the transition to a smarter grid and implements strategies to meet its target to be one of the first countries to widely adopt electric cars, the distributed nature of PV, as well as its daytime profile, may provide a useful complementary source of electricity.

PV deployment in Solar Farms is increasing rapidly worldwide, supported by high electricity buy-back rates (Feed-in Tariffs), tax benefits, renewable energy targets for electricity utilities and other mechanisms. Without such support, and if wholesale electricity prices increase by 2% per year to 2020 and 1% thereafter, Solar Farms are not expected to be cost effective in New Zealand in the period 2009-2035. However, thin film PV may begin to be cost effective after 2030, if wholesale prices rise at a slightly higher rate of 3% per year.

The international commercial and light industrial PV market has been key to achieving economies of scale in installation costs, and in creating the market volumes necessary for economies of scale in manufacture. It represents a significant portion of installations in countries with large PV deployment and usually provides a good match between PV output and load, thus adding value to the owner by displacing high cost daytime electricity, and to the network by reducing peak daytime loads. There is also a market for PV building products, including smart windows, window shades, roofing and wall panels, where the dual function can provide added value. Although it is difficult to generalize value via displaced electricity costs, since these are individually negotiated, in general, this market is expected to begin to be cost effective in New Zealand from around 2020.

The residential household PV market is one which can reach grid parity sooner than other markets, because of higher retail electricity prices. Even though costs per kilowatt can remain higher than for larger systems because of the system size, economies of scale can be achieved by volumes of systems installed, particularly if standardization can be achieved. In the short term, PV installations in this market are likely to be dominated by modules on roofs. In the longer term, PV roofing products are likely to dominate and bring costs down, especially for new homes. At current projections of retail electricity price rises, PV is expected to begin to become cost effective in this market in New Zealand from 2020, after which time the market could expand rapidly.

The off-grid market for PV displacing diesel generation or replacing remote lines is already cost effective in many locations and the former is the mainstay of the current New Zealand PV industry. There is increased interest in the use of PV in diesel grids on islands and other remote townships. Even at moderate diesel fuel price increases of 3% per year, PV becomes cost effective almost everywhere in New Zealand by 2021.

In summary, the medium to long term potential for PV in New Zealand is little different to that in other developed economies. The New Zealand solar resource is comparable to or better that many areas of Europe. Although PV currently has a higher cost in $/W or c/kWh than other options being examined for New Zealand, including greater use of hydro, geothermal, wind and biomass, it is relatively fast and easy to deploy and can be used in a wide range of sizes and end-use applications. Its output, though weather dependent on an hourly or daily basis, is well predicable over longer periods and is also well matched to loads in the rapidly developing commercial and light industrial areas of the North Island. For these reasons, the potential value of PV is often higher than its cost alone would indicate.

The private market for PV is likely to grow rapidly once grid parity begins to be reached around 2020. This indicates a need to develop robust regulation around distributed generation and build strong local capability in order to achieve the best outcomes for New Zealand. Inclusion of PV in the future energy projections for New Zealand would be worthwhile, as would be further examination of options to link PV and electric vehicle deployment.

Solar Photovoltaics (PV) is not modeled in either the Electricity Commission's Statement of Opportunities or in the New Zealand Energy Strategy. This report is intended to provide background information that will allow the potential contribution of PV to be assessed in future. It covers international PV technology and market trends, current New Zealand applications and costs, and potential future markets.

1. BACKGROUND

1.1 New Zealand Energy Use and Projections

Electricity use in New Zealand has been growing and is expected to continue to grow to 2040, with the increase met by gas, hydro, other renewables, demand-side responses, or CCS enabled coal in later years (Electricity Commission of New Zealand, 2008). The Sustainable Path scenario shown in Figure 1.1 involves higher renewables uptake. This scenario could see emissions reduced from current levels of 7 million tonnes CO2 equivalent per year to around 3 million tonnes, while other scenarios result in emissions increasing to as high as 19 million tonnes (ibid). Oil use for transport energy could also grow by 35% and emissions by 50% under business as usual projections, even with energy efficiency measures (New Zealand Ministry of Economic Development, 2006), although a high uptake of electric and hybrid vehicles and of biofuels could reduce this (Electricity Commission of New Zealand, 2008).

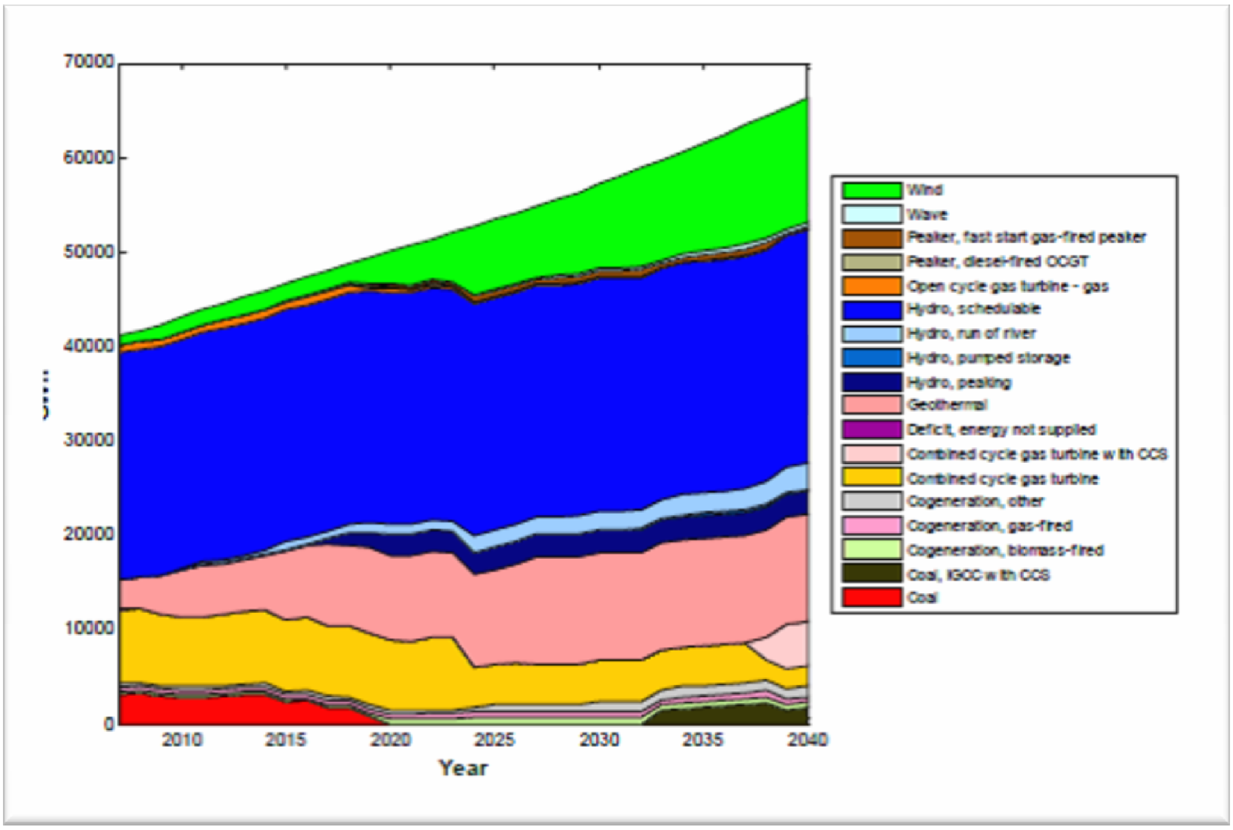

Figure 1.1: Possible electricity use trend New Zealand 2005-2040, under a Sustainable Path scenario in which high carbon and gas prices result in increased use of renewables (Electricity Commission of New Zealand, 2008)

Although New Zealand has historically had a high percentage of renewable electricity generation, recent drought, combined with demand increases have led to an increased use of coal and gas. In 2008, 65% of electricity was generated from renewables (Ministry of Economic Development, 2009). The longer term renewable energy percentages possible under the different electricity scenarios described above range from 62-95% (Electricity Commission of New Zealand, 2008).

The New Zealand Energy Strategy (NZES) aims to "deliver a reliable and resilient system delivering New Zealand sustainable, low emissions energy services" (Government of New Zealand, 2007). It includes a target of 90% of electricity from renewable sources by 2025 and energy efficiency measures, as illustrated in Figure 1.2.

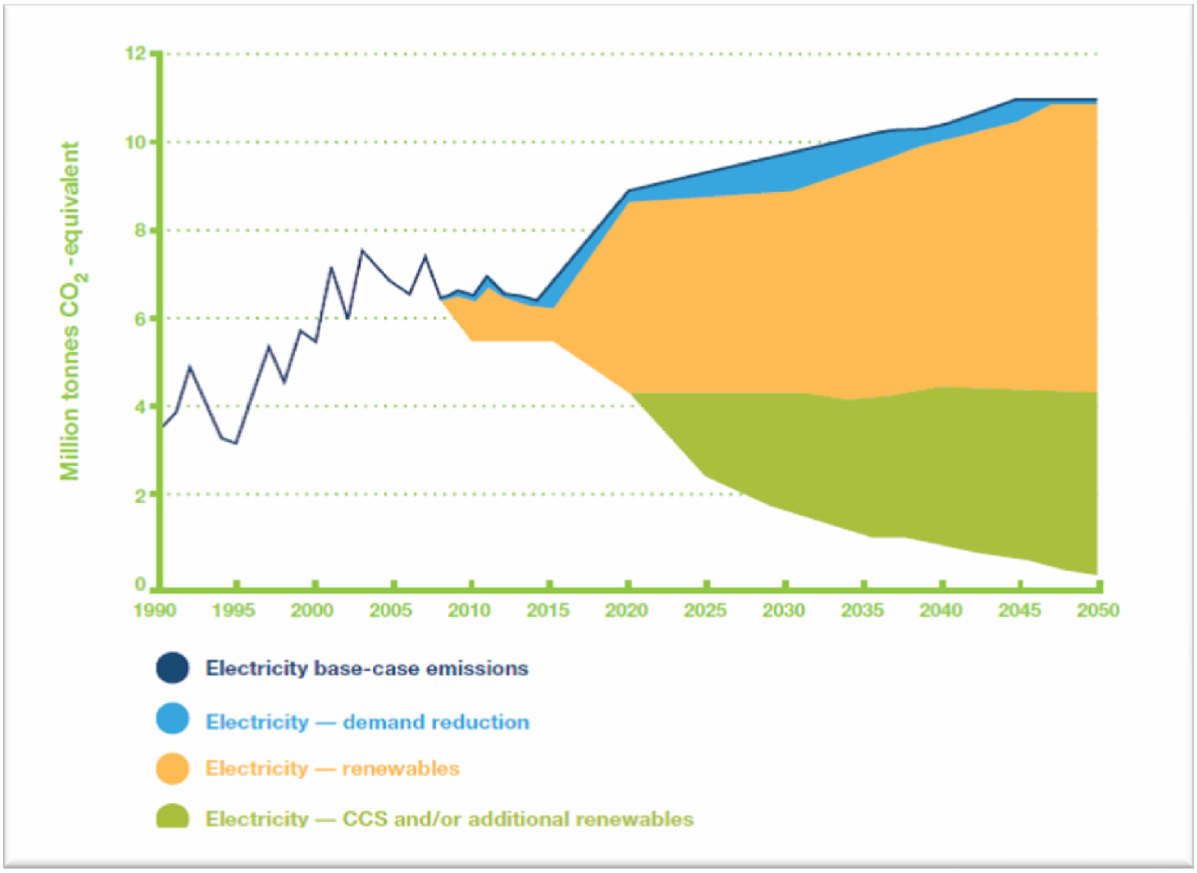

Figure 1.2: Emission Reduction Opportunities in the Electricity Sector (Government of New Zealand, 2007)

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2. REVIEW OF CURRENT PV TECHNOLOGY STATUS AND DEVELOPMENTS

Most photovoltaic devices, or solar cells, are manufactured from semiconductors, which can conduct electricity when electrons are freed from their atoms using the energy from photons of sunlight: the *photovoltaic effect*. Cells are connected to an external circuit to allow current flow. Since the voltage and current of a single cell is low, cells are usually connected together to create solar 'modules' or 'panels' with the desired voltage and current. Similarly, modules are connected together to form systems.

2.1 Crystalline or 1st Generation PV Cells

At present most solar cells use semiconductor silicon, which has a bandgap in the visible spectrum, i.e. can use photons with energy from sunlight to release electrons. Cells can be sliced from a single large crystal (c-Si), or from a cast of multi-crystalline silicon (mc-Si) material. Cells made from single crystal silicon have a higher efficiency then multi-crystalline cells, because there are no grain boundaries to block electron flows or to provide recombination sites. However, multi-crystalline silicon is cheaper and less energy intensive to produce and so has become increasingly popular.

The silicon purification and wafering processes are energy intensive and one of the main cost components of crystalline Silicon solar cells. In the past, wafers for solar cells were produced from semiconductor industry off-cuts. With the rapid increase in the solar market, dedicated solar silicon plants have been built which aim to reduce costs.

The cells are coated to minimise reflection of light or etched to increase reflection of scattered light back into the cell and to hence to maximise conversion of incoming light to electricity. Cells can be made 'bi-facial', allowing light to enter from both surfaces or they can have rear surface treatment to encourage internal reflection of light and hence enhance light capture. Metallic grids on the surface of the cells carry the current to the external circuit. The grids can be buried into a laser cut groove to minimise shading of the surface.

Terminology:

Photovoltaic modules and systems are usually described by their rated capacity, i.e. their output under Standard Test Conditions of 25 ºC, 1.5 Air Mass and 1000 W/m^2 of sunlight. This is referred to as the "peak rating" and is written as Watts (peak) or Wp. Hence, in order to estimate how much electricity to expect from a module, the average number of peak sun hours at the site is also required.

2.1.1 Ribbon and Dipped Silicon

To avoid the costly wafer process, thin sheets of crystalline silicon can be pulled from the silicon melt. Production costs are lower than for wafer based cells, while quality and hence efficiency can be as high as multi-crystalline product.

2.1.2 Crystalline Silicon Research Focus

Research on crystalline silicon cells focuses on improving efficiency, reducing wafer thickness, to reduce the use of high cost silicon, improving lifetimes and improving the manufacturing process.

Table 2.1 shows current production, efficiency and cost of different types of solar cells, while Figure 2.1 shows the impact of PV lifetime on the cost of electricity produced.

Table 2.1: Typical Production, Cost and Efficiency of Commercial Photovoltaic Cell Types in 2007.

Cell Type	Production MW[1]	Module Production Cost US $/Wp	Module Efficiency %	Market Share % [2]
Single Crystal Silicon	1020	3 – 4	12-18	42.2
Multi-Crystal Silicon	1639	2 – 3	12-14	45.2
Ribbon Silicon	93	2 – 3	13-14	2.2
Amorphous Silicon	124	1.50-2.50	5-8	5.2
Cadmium Telluride	186	1.00-1.50	8-11	4.7
Copper Indium Diselenide	31	2	5-11	0.5
Other – Dye, Organic			5%	0.1

Sources: 1: Mints, 2008; 2: Hirshman, 2008.

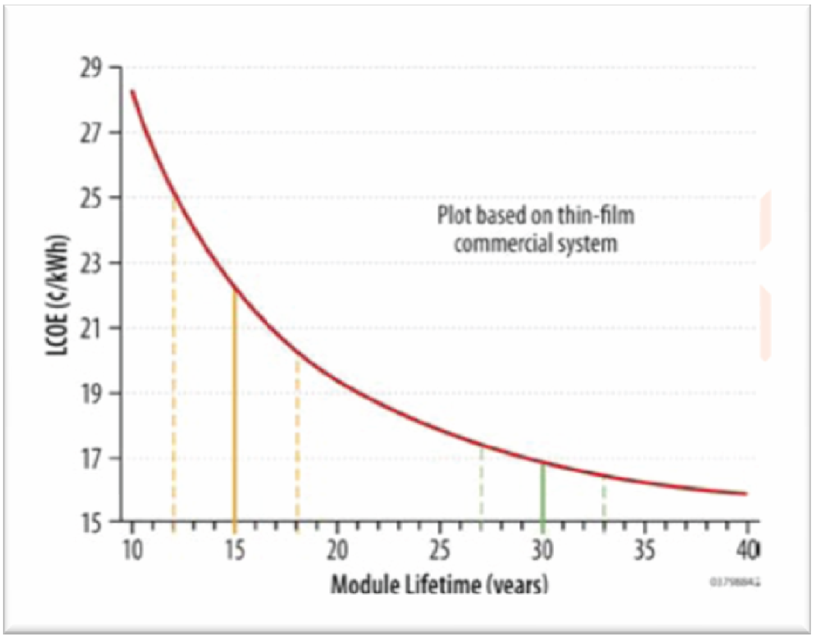

Figure 2.1: The impact of module lifetime on the levelised cost of electricity from PV systems (US DoE, 2004)

2.2 Thin Film or 2nd Generation PV Cells

In order to reduce silicon usage further, and remove the expensive ingot and wafer processes, various methods are used to deposit semiconductor layers as 'thin films' directly onto useable substrates such as glass, metals, such as roofing sheets, and plastics of various types, including flexible sheets. Production costs are lower than for crystalline products, however, manufacturing scale-up has posed problems in the past. Nevertheless, from 2007, the production of thin films exceeded that of crystalline modules in the US (von Roedern, 2008), which may indicate that thin films will finally begin to capture significant market share. The IEA "Blue Map" Scenario for PV (IEA, 2008) expects thin films to comprise 40% of the PV market by 2030, up from 10% at present, and 35% by 2050, when 3rd Generation products begin to take over.

2.2.1 Amorphous Silicon (a-Si:H)

To date the most successful of the thin film technologies is that of amorphous silicon, a disordered, non-crystalline allotrope of silicon, which can be deposited on a wide range of substrates in low temperature, continuous processes. Amorphous silicon cells are widely used in small consumer products, such as calculators and watches. In general, they have not yet achieved the efficiency and stability levels of crystalline silicon modules, but are finding a growing market in photovoltaic building products and other special purpose applications, as well as in large-scale solar power stations or 'solar farms' where their lower cost is an advantage, as it is for other thin film products. The output from a-Si cells does not drop off as sharply as temperatures rise as occurs with crystalline silicon cells, which again is an advantage in building applications.

Multi-junction a-Si products, using layers of other materials, including Germanium, silicon carbide and nano crystalline silicon, are often used as means of increasing efficiency and stability.

2.2.2 Cadmium Telluride (CdTe)

CdTe has an ideal bandgap for capturing sunlight and a theoretical efficiency of 29.7%, making it ideal for single junction solar cells. It can also be produced using relatively inexpensive processes and therefore has been one of the main non-silicon thin film technologies so far pursued.

The technology has been the first to reach a production cost of 1 US$/W, a breakthrough which is allowing companies such as First Solar to offer large scale solar farm systems under power purchase agreements of US$0.12 – 0.15 per kWh (First Solar, 2008). The company aims to reduce module costs to US$0.65-0.70/Wp, system costs to US$2/Wp and efficiencies to 12% by 2012, which will result in an electricity cost of US$0.075/kWh in good sites (ibid).

There have been some concerns regarding the use of Cadmium, which is highly toxic. However, there is very little chance of Cd leaching into the environment from the double glass PV modules and companies such as First Solar have implemented a full recycling program for their modules. Life cycle studies have shown that cadmium emissions from CdTe PV modules are 90-300 times lower for the same kWh output than from coal fired power plants (Fthenakis, 2008). Of more concern in the longer term is availability of Tellurium (Watt, 1995).

2.2.3 Copper Indium (Gallium) Diselenide (CIS or CIGS)

Copper Indium Diselenide cells are the most efficient of the current commercially available thin films, at about 11%, with efficiencies as high as 19.9% achieved in the laboratory (http://www.nrel.gov/pv/thin_film/). The cells can be made with varying amounts of Indium and Gallium.

Only a few companies currently supply commercial modules. These include Wurth Solar, Global Solar Energy and Honda Soltec. Availability of Indium may be an issue for large scale production in the longer term (Watt, 1995).

2.2.4 Thin film Research and Development

The focus of thin film research is on improved efficiency, stability and lifetime, use of multiple layers of different materials, improved deposition and continuous processing techniques, as well as on scale manufacture to reduce costs.

2.3 Novel or 3rd Generation PV Cells

A range of novel concepts are under investigation and are expected to capture an increasing share of the PV market over time. Some of these, such as nano silicon cells, aim to combine the high efficiencies of crystalline products with the low manufacturing cost of thin films. Others, such as organic cells use entirely different processes and may form the basis of very low cost PV products, even if efficiencies remain relatively low. These technologies may compete with the 'power modules' of generation 1 and 2, or provide a new range of PV applications, built into consumer products, clothing or building materials and replacing batteries in a wide range of appliances. Hence, the emphasis may be on integration, aesthetics and low cost more than on efficiency and long life. The IEA (International Energy Agency, 2008) expects 3rd generation PV to account for half the market by 2050. Some of the many promising new technologies are described below. New Zealand research in this area is summarised in Table 5.6.

2.3.1 Dye sensitised solar cells (DSC)

DSC solar cells use photosynthetic principles to capture light and redox based cell structures to produce electricity. They are also referred to as Graetzel cells, after the original developer, Michael Graetzel. Small area modules are already being used for specific purpose applications, including mobile phone and other battery chargers, sometimes integrated into clothing, otherwise coated onto flexible and lightweight substrates for mobile use. The ability to operate in low light conditions, even indoors, and to be made in a range of colours, provides opportunities for new applications.

Laboratory efficiencies of 11 % have been achieved, and the potential for very low cost and low energy manufacture has seen a significant increase in R&D. Further development of this technology is focussing on different dyes, improved sealing or the use of solid electrolytes to overcome sealing issues, concentrating systems, improving stability and durability (Marsh, 2008).

2.3.2 Organic Cells

This new area of development aims to use organic, rather than inorganic materials to absorb sunlight and convert it to electricity. A range of conductive polymers, carbon fullerenes and other materials are being examined, which it is hoped will enable continuous, low cost production processes to be established. Hybrid organic and inorganic cells are also being investigated. Research programs aim to explore new materials, improve efficiency and stability, as well as developing processes that can be used for commercial production.

2.3.3 Nano-technology

Nano layers, between 0.1 and 100 nanometres, of semiconductor material can be structured so as to optimise light absorption over a range of different frequencies. These layers can be deposited onto a-Si, c-Si, conductive polymers or other substrates to increase the bandgap of light capture and hence the cell efficiency. Efficiencies as high as 60% are theoretically possible (Green, 2002). Nano structures made from silicon have the same stable properties as c-Si, but use far less material and can potentially be deposited more cheaply onto the substrate. Hence, in the short term, tandem or multi-layered structures built onto 1st or 2nd generation cells are likely to be used. A range of different structures, including carbon nanotubes and quantum dots are being investigated.

2.4 PV Life Cycle Inputs

The most common myth about PV is "that PV does not pay back the energy used to create it". While this may have been an accurate statement during the first years of terrestrial PV, it has not been the case for the last three decades.

The most commonly used parameter to quantify the life cycle performance of PV is the energy payback time (EPT), defined as the time (in years) in which the energy input during the module life-cycle is compensated by electricity generated by the PV module. The EPT depends on several factors, including cell technology, PV system application, irradiation, the sources of energy used in its manufacturing processes and the energy the PV will displace.

One important quantity which is not included in an EPT calculation is the lifetime of the PV module, which can be an important distinguishing factor between different types of modules. The energy yield ratio (EYR) is defined as "how many times the energy invested is returned or paid back by the system in its entire life" (Pick, 2002). Hence an energy product with an EYR of greater than unity generates more energy over its lifetime than was required to fabricate it. EPT and EYR results for various aluminium framed modules and a 2 kWp rooftop PV system are shown in Table 2.2. Payback times for current modules range from 3 to 6.6 years under low insolation conditions while the energy used for manufacture is paid back between 3.1 and 6.8 times over a 20 year module life. For a typical 2 kWp rooftop system, the energy payback time is 4.9 years using multi-crystalline modules and more than 4 times the energy used in its manufacture is generated over a 20 year life.

As previously discussed, manufacturing processes are changing rapidly and material and energy intensity is being reduced. Hence recent analyses in Southern Europe (1700 kWh/m2/yr – equivalent to a tilted array in the far north of NZ) show EPTs of ribbon-Si (11.5%), multi-crystalline Si (13.2%), monocrystalline Si (14%) and thin-film CdTe (9%) photovoltaic rooftop installations of 1.7, 2.2, 2.7, and 1.1 years (Fthenakis, 2008).

Table 2.2: PV Module and System Energy Payback Time (EPT) and Energy Yield Ratios (EYR) for 20 and 30 year lifetimes(Richards, 2007)

	Efficiency	High Insolation			Low Insolation		
		(1825 kWh/m^2/y)			(1000 kWh/m^2/y)		
		EPT (years)	EYR_{20}	EYR_{30}	EPT (years)	EYR_{20}	EYR_{30}
Photovoltaic Modules (aluminium frames)							
Present mc-Si	13	2.2	9.3	13.9	3.9	5.1	7.6
Present c-Si	14	3.6	5.6	8.4	6.6	3.1	4.6
Present a-Si	7	1.6	12.4	18.5	3	6.8	10.2
Future mc-Si	15	1.9	10.7	16	3.4	5.9	8.8
Future thin film	10	1.1	17.7	26.5	2.1	9.7	14.5
Photovoltaic Systems (m-Si and aluminium frames)							
2 kW_p grid-connected rooftop	13	2.7	7.5	11.2	4.9	4.1	6.2

2.5 Concentrator PV Systems (CPV)

Higher efficiencies and lower costs can be achieved by concentrating sunlight, using low cost reflectors or mirrors onto small areas of photovoltaic cells. Such systems are described by their concentration compared to 'one sun' or 1000 W/ m^2. Concentrations of up to 500 suns have been achieved. Special purpose PV cells are used due to the high temperatures and the need to collect and transfer larger amounts of electricity per unit area. Both high efficiency silicon and III-V cells, including Gallium Arsenide and Indium Gallium Phosphide (usually used for space applications) are used, typically in multi-junction configurations.

Concentrator PV systems (CPV) require clear sky solar conditions to allow focussing and generally perform better in dry desert areas. Concentrator systems also require the use of trackers, and hence introduce a mechanical component into the PV system. Recent developments in tracker technology (see below), which have improved performance, cost and reliability, have made concentrator systems an attractive option for large scale PV arrays. They are now widely used in Spain and southern Italy, as well as in inland areas of Australia. A recent survey of concentrator system manufacturers by Photon International (Hering, 2008) shows potential for over 900 MW of CPV installed by 2010, and an anticipated installation of 200 MW.

2.5.1 Parabolic trough concentrators

Parabolic trough technology has been in operation in solar thermal systems for more than 20 years and provides one of the lowest cost concentrator options. For PV applications, they comprise rows of parabolic reflectors which focus onto a line of PV cells. They can operate as combined heat and power systems, with water or other circulating fluid used to collect heat and keep the cells cool (see for instance http://solar.anu.edu.au/research/linearconc.php). They require single axis trackers.

2.5.2 Dish Concentrators

Mirrored dish concentrators focus the sun onto cells at the focal point. Cooling and double axis tracking is also required. Efficiencies of 25-35% are typically achieved, depending on the cell technology used. Although modular, individual dish sizes are potentially restricted by weight and wind loading constraints, so that dish technologies are currently used mainly in smaller grid arrays or for diesel grids. For larger versions using the same concept, heliostat technology is used (see below).

A variation of this technology is to use mini dishes around each cell in an array, thus significantly reducing the amount of high cost solar cell material required for a given output. See for instance SolFocus (www.solfocus.com).

2.5.3 Fresnel Mirrors and Lenses

Flat or slightly curved mirrors can be arranged so as to provide the equivalent of trough concentrators, but potentially with more streamlined manufacturing costs. An array of independently tracking mirrors focus onto a central receiver. To date the technology has mainly been used for solar thermal applications.

At a panel level, Fresnel lenses can be placed over PV cells in individual mirrored containers, so that concentrating arrays can be made up. See for instance:
http://www1.eere.energy.gov/solar/concentrator_systems.html**).**

2.5.4 Heliostats

Arrays of mirrors can be used to focus the sun onto a central tower receiver where one or more solar cells are placed. This method is potentially cheaper and more efficient than trough and dish systems (Wolff, 2008), however, experience is more limited. Concentrator company Solar Systems is constructing a 154 MW heliostat system in Australia.

2.6 Tracking Systems

With the relatively high cost of flat plate PV systems to date, methods to improve output from each array have been of interest. Tracking systems allow the PV panel to follow the sun across the sky, thus allowing the panel to operate at higher output levels for more hours each day. Trackers can operate on a single axis, following the sun from east to west, or on two axes, thus allowing for seasonal variation in the sun's position as well. Tracking systems add a mechanical component and extra installation costs to a technology which otherwise relies on no moving parts. Additional land area is also required, compared to static arrays, to prevent shading of adjacent panels while careful consideration of wind loading is also necessary. Nevertheless, output can be increased by 25-35% for single axis trackers and 35-45% for dual axis tracking systems, so that trackers can be justified in high sun locations and where renewable energy buy-back tariffs are high. A wide variety of tracking systems has been developed (see for instance Siemer, 2008).

Figure 2.2 shows the yield that can be achieved for various tracking regimes in Nelson, which is one of the high sun locations in New Zealand.

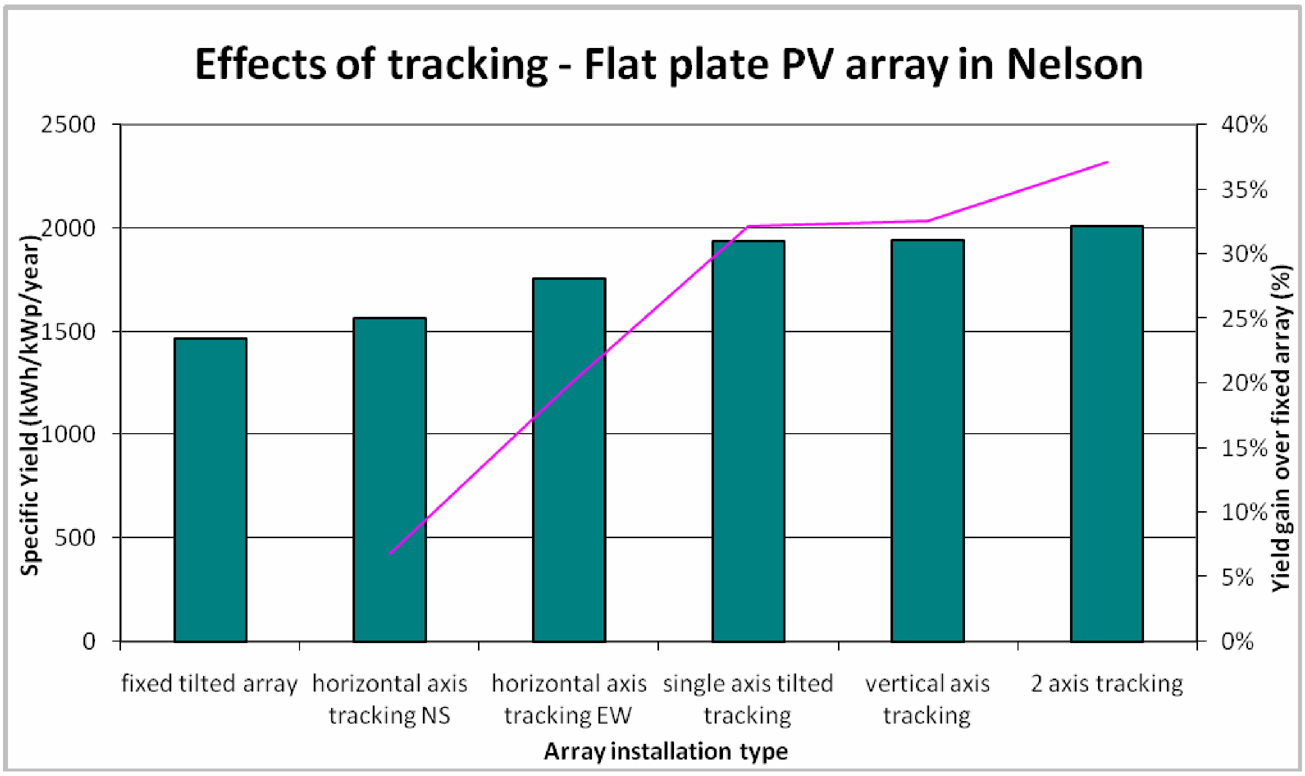

Figure 2.2: Specific yield gain as a result of array tracking (based on PVsyst simulations for Nelson). The pink line shows the percentage gain over a fixed array.

2.7 Factors affecting energy yield

For a grid connected solar PV array, energy yield varies with many factors. Comparisons of energy yield for PV technologies and systems are usually made using specific energy yield: kWh/kWp of rated capacity. For a grid connected system, comparisons are made on an annual basis. For off-grid systems, seasonal variations are significant, because they determine battery capacity and/or back-up generator requirements.

2.7.1 PV technology type

There are two important factors that differentiate the performance of PV technologies.

1. The output of silicon PV modules reduces as temperature increases. Amorphous Silicon PV modules have a lower temperature co-efficient than crystalline products, resulting in less output degradation and therefore relatively greater energy yields at higher temperatures. The

temperature of a PV module can be kept as low as possible by ensuring that the mounting method allows adequate ventilation at the rear of the module. This is more of an issue for roof-top and building integrated PV than it is for field arrays, since the former have more restricted rear ventilation.

2. Amorphous silicon and other thin film products have a different spectral response to that of crystalline silicon products, some performing better in cloudy conditions where more energy is present in the blue wavelengths between 400 and 500nm.

Even within each technology type there is significant variation in specific energy yield, as demonstrated by tests completed by Photon in 2007/2008 (Photon International, 2008) and shown in Figure 2.3. These tests show a 10% variation in specific yield between the best and worst crystalline PV module samples tested under uniform conditions. This variation may mask temperature or spectral yield gains.

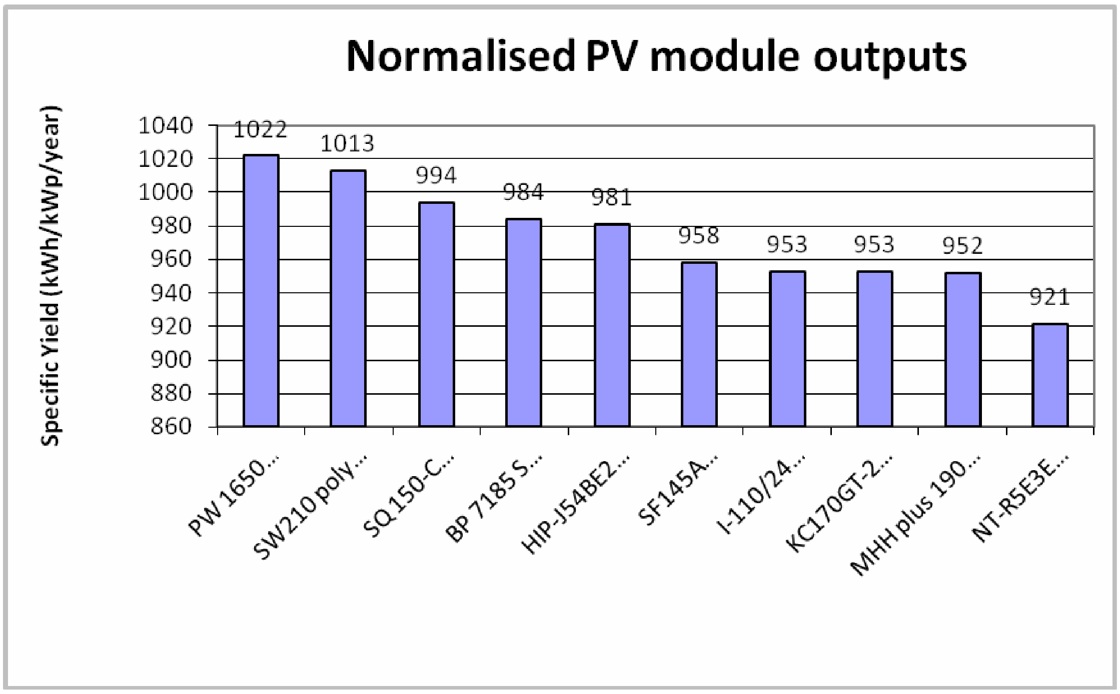

Figure 2.3: Variation of specific yield by product – Germany
(Photon International, 2008)

Hence module rated efficiency is not necessarily the best indicator of performance at a particular site. Nevertheless, efficiency impacts yield, as well as the area required for an array. Some of the new PV technologies are low efficiency but cheaper to manufacture, with the overall effect being a reduction of $/kWh. If the price is low enough, the increased framing costs (if required) and installation costs for low efficiency PV products can be compensated for.

2.7.2 Module power tolerance

Solar PV module power tolerance variation affects the performance of arrays. For a series string of PV modules, array output will be limited by the lowest module's power. Module power tolerance varies between +/-10% to –0%/+2.5%. For this reason, some effort is put into categorising modules so as to string those with similar characteristics together. The same issue arises in selecting cells for a module and again, cells with similar characteristics are strung together to maximise output from each module.

2.7.3 PV array orientation

Solar PV array orientation has the largest effect on energy yield. Typically, fixed PV arrays are oriented for maximum annual yield, with the array inclination favouring the summer period where radiation levels are higher. For off-grid installations, inclination is usually set to maximum winter yield when solar radiation is at a minimum, so as to provide as consistent an output as possible over the year. Figure 2.4 shows the percentage of maximum yield that can be achieved for various fixed arrays relative to an optimal inclination and azimuth of 30° facing north. A fixed PV array may also be oriented to maximum yield at one point during the day when electricity demand is highest or spot market prices are at a peak (e.g. early afternoon in places such as California).

In a small number of installations, particularly off-grid, ground mounted systems, the array mounting has the ability to be manually adjusted for inclination (a simple, seasonal tracking method) to achieve a relatively better yield across the year.

		Azimuth						
		-90°	-60°	-30°	0°	30°	60°	90°
Inclination	0°	90%	90%	90%	90%	90%	90%	90%
	15°	88%	93%	96%	98%	96%	93%	88%
	30°	83%	92%	98%	100%	98%	92%	83%
	45°	77%	88%	95%	97%	95%	88%	77%
	60°	69%	80%	87%	90%	87%	80%	69%
	75°	60%	70%	77%	78%	77%	70%	60%
	90°	51%	59%	63%	63%	63%	59%	51%

Figure 2.4: Effect of Azimuth (orientation) and Inclination on the annual yield of a fixed grid-connected array

2.7.4 Inverters

The PV array maximum power point (MPP) will vary with the level of insolation. Inverters with maximum efficiency throughout the MPP operating range will achieve the highest energy yields. For arrays that regularly operate at low insolation levels, yield will be maximised though the use of an inverter with a low start up voltage and high efficiency at low MPP voltage.

Inverter efficiency has been increasing year on year, with average efficiencies now around 95.5% and the best inverters 98.5%. Transformerless inverters are not yet common, however, their efficiencies are generally higher than those with transformers, averaging 96.5% (Kreutzmann, 2008).

2.7.5 Energy yield for off-grid arrays

Specific yield from an off grid system with battery storage, when compared to a system with unlimited load, such as a grid connected system, will be reduced according to the system's ability to store collected energy. Once a battery is full, any collected energy will be wasted unless the demand can be adjusted to use this energy. This is particularly the case for systems designed without backup energy generation, where specific energy yield can be reduced by as much 30-40%. Remote power systems that use a high level of back up generation or use solar PV to supplement another energy source (e.g. diesel generation) can achieve optimum specific yield in the same manner as a grid tied system.

Off-grid PV arrays are usually inclined to achieve maximum energy yield during the winter when the least amount of solar radiation is available, even though this reduces the potential maximum yield during the summer months. If summer demand is higher than winter demand, seasonal adjustment of the PV array inclination can be used to improve year-round energy yield.

Further system inefficiencies of between 10 – 15% result from battery charging and discharging, thus also reducing the available energy from the solar array.

2.8 The Role of Batteries in PV Systems

2.8.1 For grid use

On-grid battery storage can reduce the peak of a customer's energy load, as it is seen by the distribution system. This can improve utilization of assets on the electrical grid and manages customer energy demand so it is based on average instead of peak load, resulting in reduced maximum demand charges. The utility load factor is improved.

Figure 2.5 shows an example of how batteries can add value to a grid via a typical load profile for a given sub-station area. A steady ramp up is seen in the early morning as people wake up and start the day's activities such as cooking, showering etc. Meanwhile industry is starting or ramping up for the day. Around mid-morning the load profile reaches a more steady level, with a higher level in the later afternoon, if the weather is hotter and more air-conditioning load comes on. Late afternoon sees another peak develop as industry still runs and people start returning home, cooking evening meals and turning on home air-conditioners. The load then drops off in the late evening.

If the load is predominately residential / hotel and very little industrial, the load profile often shows two distinct main peaks, in the morning and in the early evening.

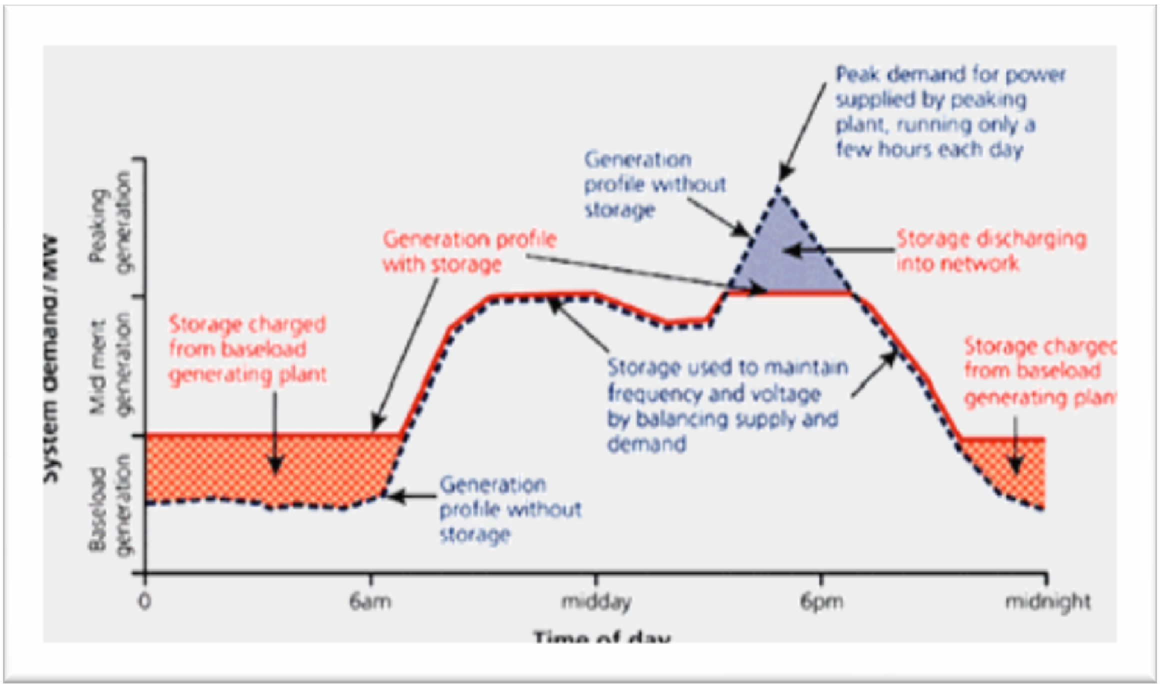

Figure 2.5: The role of grid connected storage (Electricity Storage Association, 2008)

Standard practise is to plan the variation of the output of large power plants to try and match the load profile, starting with the lowest cost generators, gradually adding higher cost generators as the load increases and fast reacting power plants to help with the peaks. Load dumping, typically via pumped storage hydro or defined off-peak loads, such as water heating, takes place over night when the load is low. Batteries associated with PV systems can be used in the same way, making use of solar energy during the day or the cheap overnight energy to fully charge, and allowing the grid to draw on this stored energy during the peak periods of the day. Grid PV systems with batteries can thus be used to minimise on-site peaks as well as to enhance supply security on parts of the grid which may be reaching capacity or otherwise prone to blackouts.

A system in Puerto Rico uses grid connected storage with a capacity of 20 megawatts for 15 minutes to stabilize the frequency of electric power produced on the island. A similar system in Anchorage, Alaska, uses a 27 megawatt 15 minute nickel-cadmium battery bank to stabilize voltage at the end of a long transmission line (Electricity Storage Association, 2008).

As energy sources such as wind and solar are intermittent, or non-dispatchable, they rely on the load following capability of other generating units. At low penetration levels (below 30% on a large grid with diversified generation) this presents few, if any, problems. However, at higher penetration levels, grid energy storage becomes more useful, both to absorb the solar and wind outputs when they exceed load demand and to provide power when the intermittent resource is not available. This presents further opportunities for grid-connected batteries to add value to the grid. In the same way that batteries allow peak load to be met, they can absorb the output from the intermittent resources for later use. This in effect makes wind and solar a dispatchable energy resource.

2.8.2 Issues

Battery storage systems are generally expensive, have high maintenance and limited operational life. Hence their use needs to be carefully considered and compared with other options, including additional generating capacity. Arrangements must also be in place for battery replacement and recycling, as most types of batteries contain toxic elements.

2.8.3 Types of batteries used on grid

- Large-scale batteries for grid connection are being developed on a number of fronts.
- Sodium-sulphur batteries have been used for grid storage in Japan and in the United States.
- Vanadium redox batteries (VRB) and other types of flow batteries are also beginning to be used for energy storage, including for the averaging of generation from wind turbines. VRB storage has relatively high efficiency, as high as 90% or better.
- Carbon Block and other resistive type batteries

The current applications of different types of batteries on the grid are illustrated in Figure 2.6.

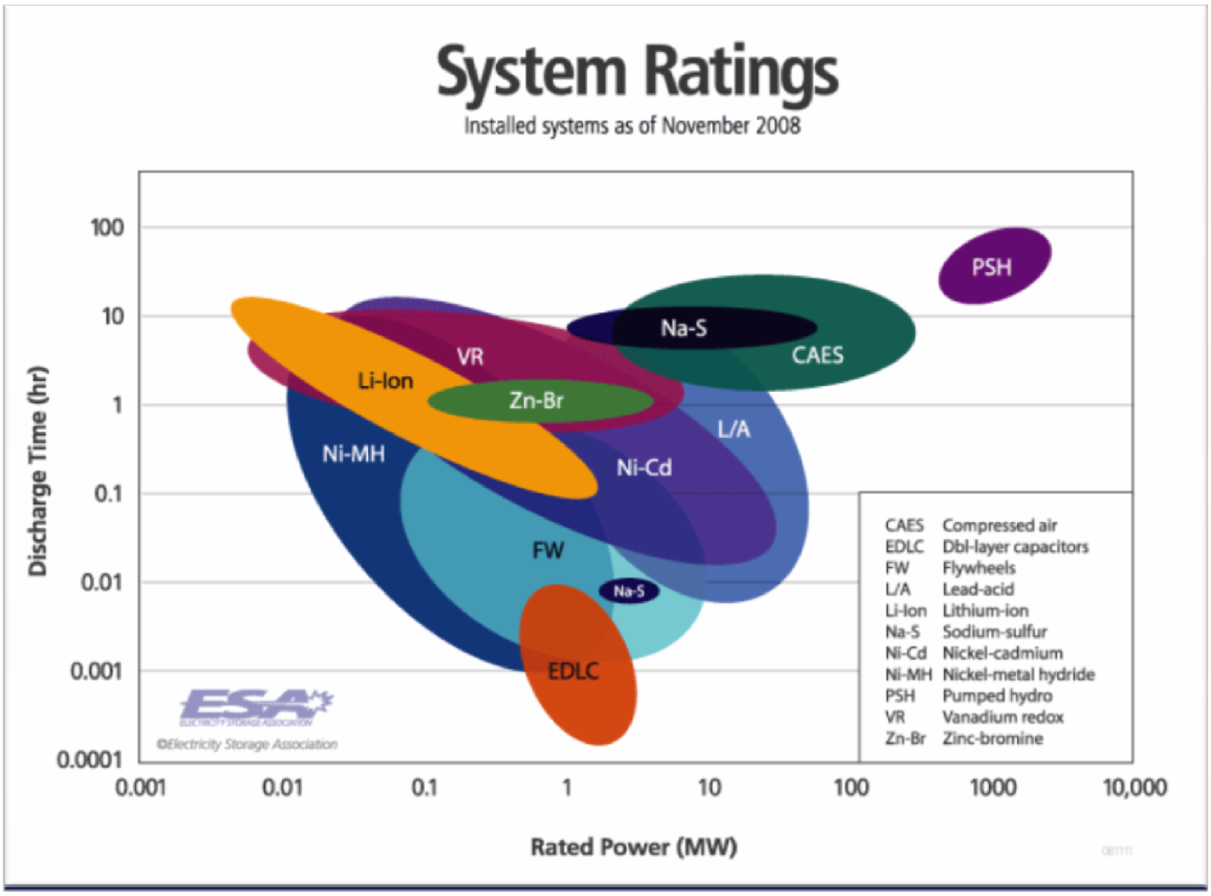

Figure 2.6: Application range of different types of batteries (Electricity Storage Association, 2008)

2.8.4 Electric vehicles

When plug-in hybrid and/or electric cars make up a greater percentage of the vehicle fleet, their 'mobile batteries' could be utilized for energy storage capabilities. Vehicle-to-grid (V2G) technology can be employed, turning each vehicle into a distributed load-balancing device or emergency power source. The link between electric vehicles and PV is discussed further in Sections 7.3 and 8.2.1. A V2G trial is currently underway in Delaware, USA (Boyle, 2009).

2.8.5 Batteries for off-grid use

Non-sealed lead-acid batteries dominate the off-grid market, as these systems are invariably owned / operated by self reliant people (farmers, remote businesses, self sufficiency types) who can cope with the maintenance requirements. Lead-acid gives the best returns for systems that are regularly and continually deeply cycled.

Sealed lead-acid batteries are often preferred for unmanned off-grid use, such as telecommunication towers etc, since they can operate for long periods without maintenance.

3. INTERNATIONAL TRENDS IN PV PRODUCTION, COSTS AND APPLICATIONS

3.1 Cell Production

Solar cell production is distributed widely across the world. There has been a rapid increase in Asian production over the past two years, a trend which looks likely to continue at least in the short term. 2007 production by region is shown in Figure 3.1.

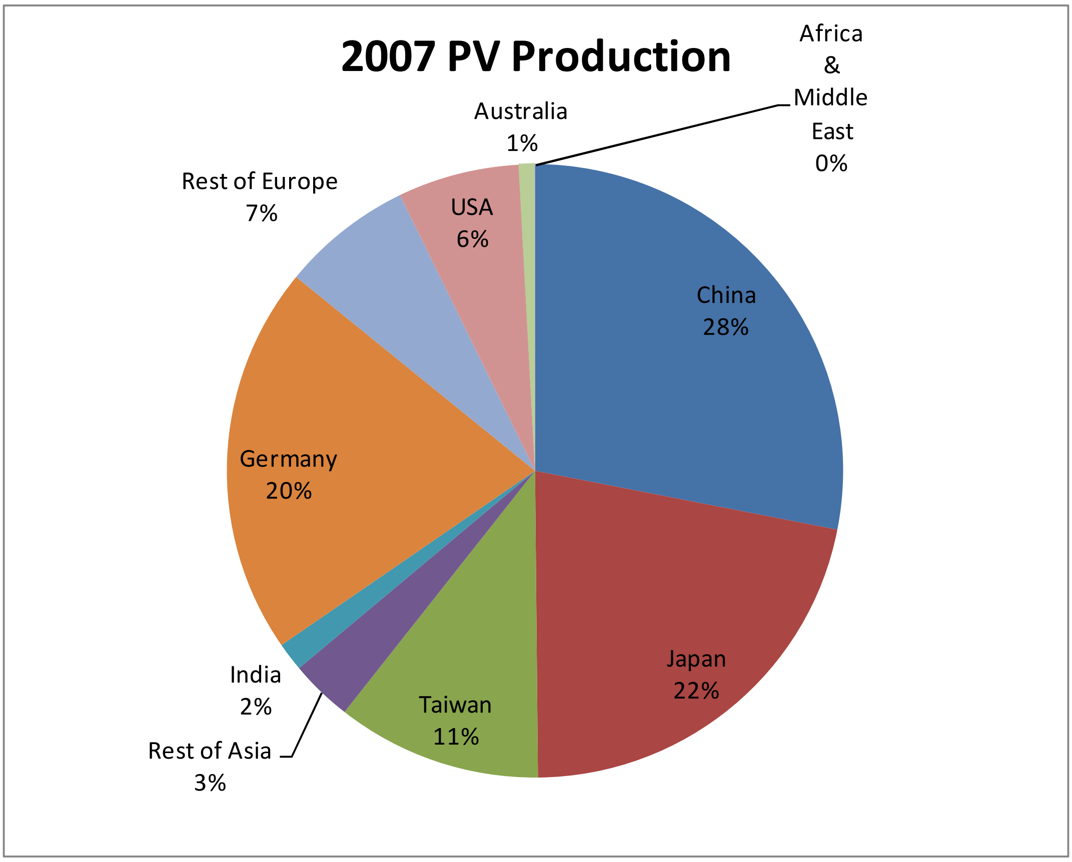

Figure 3.1: 2007 PV Production by Region (Hirshman, 2008)

Production in 2008 is forecast to be 8.5 GW, in 2009 between 10-15 GW, and in 2010 23 GW, up from 4.3 GW in 2007(Hirshman, 2008). This high growth in supply, combined with the impacts of the financial crisis, which are expected to make finance more difficult to secure and keep fossil fuel prices low, could see installation rates remain lower than previously forecast. The revised installation rates are (Karnick, 2008) 2008: 4.5 GW, 2009: 5.4 GW and 2010 8.3 GW. These trends are illustrated in Figure 3.2. Hence, anticipated production may not be brought on line as rapidly as previously planned. Nevertheless, investments in renewables remain relatively strong, with some investment sectors viewing renewables as a lower risk energy investment, given the greater certainty of electricity price after installation, especially in regions with guaranteed feed-in tariffs. The alternative view is to see renewables as more risky because of their continued reliance on government policy support (Jager-Waldau, 2008).

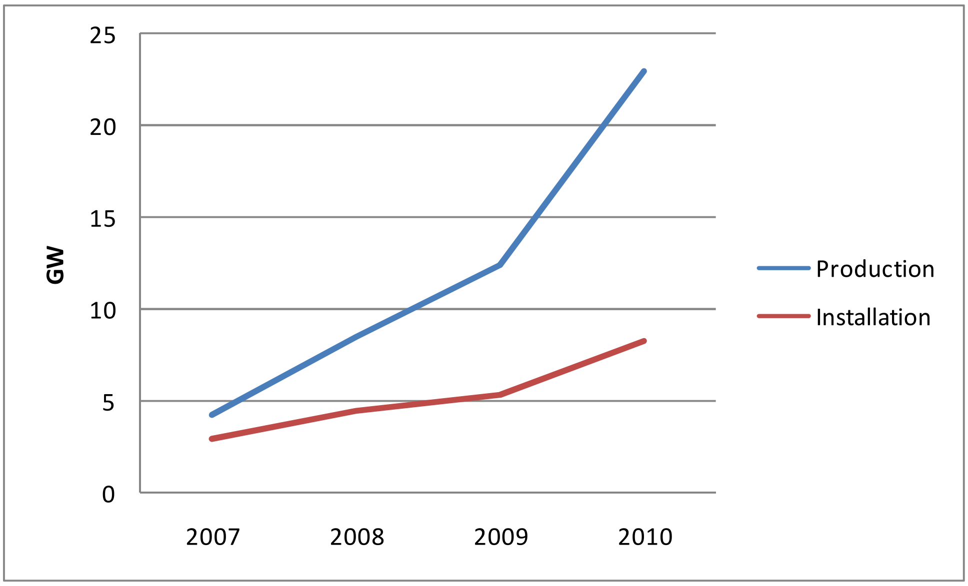

Figure 3.2: Anticipated trends in production and installation of PV 2007-2010 (Jager-Waldau, 2008); (Karnick, 2008)

Table 3.1: Expected Efficiencies and Market Share of Different PV Technologies by 2010-2030

Cell Type	2015 Cell Efficiency %	2020 Module Efficiency[1] %	2030 Module Efficiency[2]	2030 Market Share %[2]
Single Crystal Silicon	15-21	22	25-28	35
Multi-Crystal Silicon		20		
Ribbon Silicon		19		
Amorphous Silicon	10-13	15	18	37
Cadmium Telluride	12-13 (2012-2015)	15	18	
Copper Indium Di-Selenide	10-15	15	22	
Other, including Organics		10	15	28

Sources: 1: (Greenpeace and EPIA, 2008); 2: (International Energy Agency, 2008)

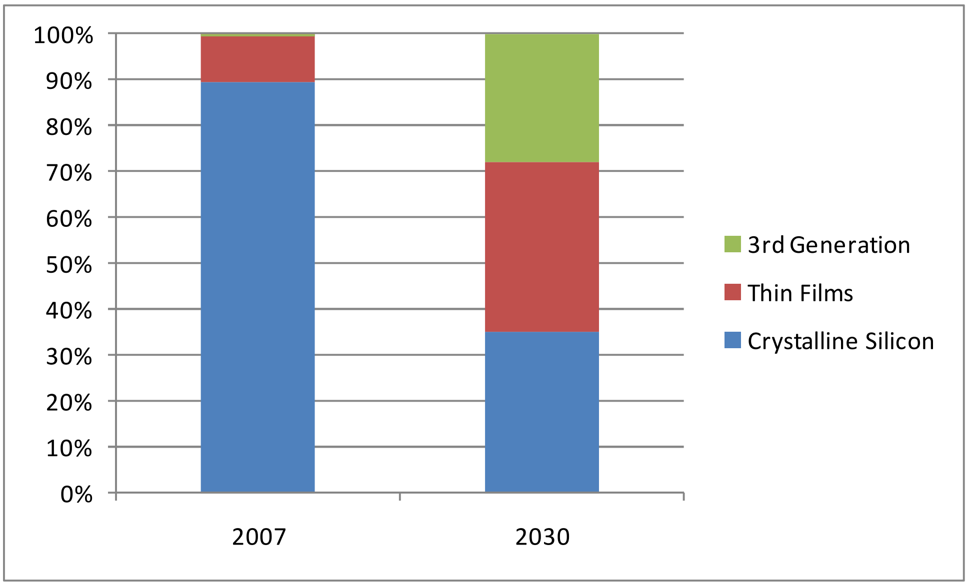

Figure 3.3: Relative market shares for 1st, 2nd and 3rd generation PV 2007 and 2030 ((Hirshman, 2008); (International Energy Agency, 2008))

Table 3.2: 2007 Module and System Costs in Selected Countries ((IEA-PVPS, 2008)

	US$/Wp		
Country	**Modules**	**Off-Grid Systems > 1 kWp**	**Grid Systems < 10 kWp**
Australia	5.80-6.70	15.00-19.20	8.30-10.00
Canada	4.20	7.20	7.90
Germany	4.10-6.80		6.00-7.10
Spain	4.10-6.20	20.50-27.40	9.60-12.30
France	4.10-5.50	18.00-21.00	7.50-9.00
UK	6.00-7.60	10.00-22.00	6.80-18.60
Japan	3.70		5.90
Portugal	3.80-4.80	11.00-13.70	6.80-8.20
USA	3.75	10.00-20.00	7.00-9.00

3.2 International PV Support Programs

3.2.1 European Union

The European Union has a renewable energy target of 20% by 2020. Photovoltaics had been expected to take up only 2-3% of this target until recently. The EU PV Industry Association (EPIA) recently announced a 12% PV target for the EU by 2020, on the basis of recent capacity increases and associated cost decreases resulting in increasing grid parity from 2010 (European PV Association, 2008). According to EPIA this will require appropriate Feed-in Tariffs, grid access, streamlined administration and implementation of the EU Strategic Energy Technology plan. The latter seeks cooperative R&D, strategic planning and deployment strategies to overcome current barriers to renewables.

Table 3.3: Expected Module Production Costs and System Prices 2010-2030

Cell Type	Module Production Cost 2010-2015 US $/Wp	System Price 2010-2015	System Price 2030
Crystalline Silicon	1-1.60	3.75-4.40	1.9[1]
Amorphous Silicon	0.45-0.7 (2015)		
Cadmium Telluride	0.65-0.7 (2012-2015)	1.5-2.1 (2012)	
Copper Indium Di-Selenide	1 (2015)	3 (2015)	
Other, including Organics			

1. Weighted average across all PV technologies (International Energy Agency, 2008)

3.2.2 Germany

The German market is currently the world's largest, with Germany having the highest installed capacity as well as the highest new capacity added in 2007 (Greenpeace and EPIA, 2008). It has developed rapidly over the past decade, as shown in Figure 3.4, as a result of strategic and long term market support programs, beginning with low interest loans and grants and now focussed on feed-in tariffs. The 1000 rooftop program operated from 1990-1999, with low interest loans. This was extended to the 100,000 rooftop program, which operated from 1999-2003, with a low interest rate of 1.91% until installed capacity reached 300MWp. From 2000, enhanced feed-in tariffs were also offered, starting at around €0.50 and increasing in 2004 to the levels shown in Table 3.4, after the soft loans ceased. Rates are available for a period of 20 years, vary with system size and type and decrease by a predetermined percentage each year.

The high demand created for PV by the German feed-in tariffs, has led to revisions. The program will see tariffs decrease faster (8-10% per annum) than previously (5%), as a means of reducing prices, although these rates can be adjusted if installations fall above or below defined targets. Higher tariffs for facades will cease. The new tariffs and degression rates are shown in Table 3.4 and Table 3.5. Although likely to be impacted by the current financial crisis, the market remains strong and Germany is expected to continue to dominate for the next few years.

3.2.2.1 Drivers and economic impacts

Support for PV in Germany was driven by environmental concerns, but is now maintained by economic ones. The Feed-in Tariff was accompanied by valuable manufacturing support programs and Germany now leads the world in both production and deployment of PV, with an installed capacity of over 4 GW, more than 1,500 businesses and more than 42,000 people employed in the field (Koot, 2008; PVPS, 2008). The PV FiT costs German households an average of €6.3 per year (Frondel et al, 2008) and turnover in 2007 was US$7.8 billion (IEA-PVPS, 2008).

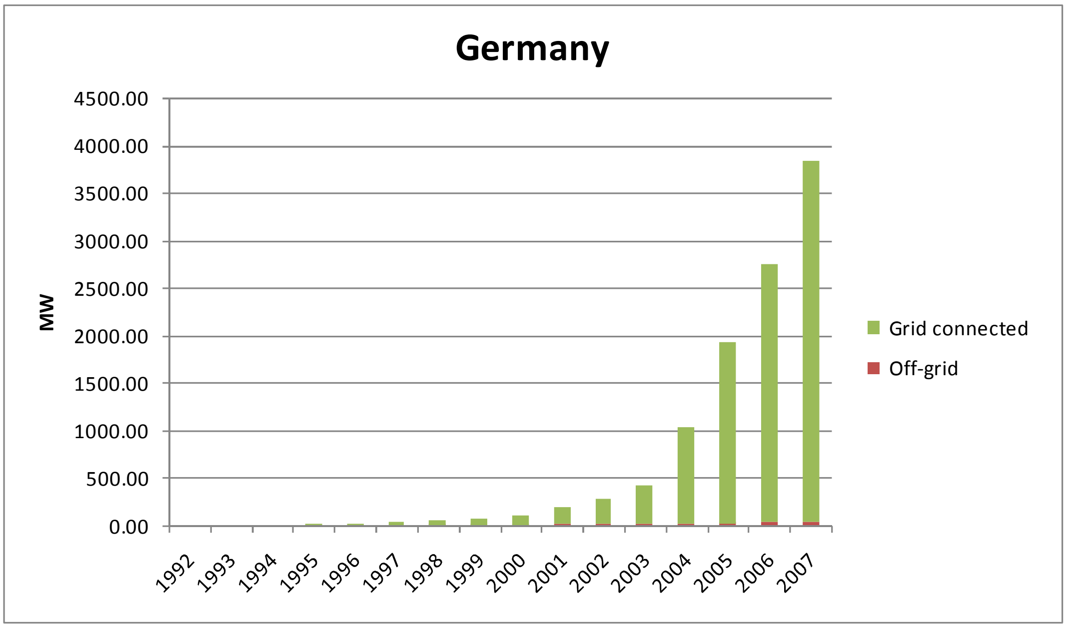

Figure 3.4: Cumulative PV Installations in Germany (Wissing, 2008)

Table 3.4: German PV Feed-in Tariff Rates

System Type	System size	2004 Tariffs c€/kWh	2009 Tariffs c€/kWh
Roof	< 30 kW	57.4	43.01
Facade		62.4	
Roof	30 to 100 kWp	54.6	40.91
Facade		59.6	
Roof	> 100 kWp	54	39.58
Facade		59	
Free Standing	> 1 MWp	45.7	33

Table 3.5: Revised German Feed-in Tariff degression rates (Greenpeace & EPIA, 2008)

Size / Type	2004-2008	2009	2010	2011
Roof <100 kW	5%	8%	8%	9%
Roof > 100 kW	5%	10%	10%	9%
Ground	6.5%	10%	10%	9%
Degression changes				
Upper MWh	If above: +1%	1500	1700	1900
Lower MWh	If below: -1%	1000	1100	1200

3.2.3 Spain

The high feed-in tariffs in Spain have led to a surge of investment in PV manufacturing and installation, particularly of large scale power stations both flat plate and tracking. However, the Government's PV targets have now been met and it has recently introduced a cap of 400 MW per annum, with an additional 100 MW in 2009 and 60 MW in 2010. Installations will therefore fall from an expected 1.3 GW to 500 MW in 2009 and 460 MW in 2010, as shown in Figure 3.5. This drop, combined with the tougher price structure in Germany is expected to see prices drop quite rapidly in 2009, and perhaps some of the anticipated new production delayed. The tariffs applying from 2009 are shown in Table 3.6.

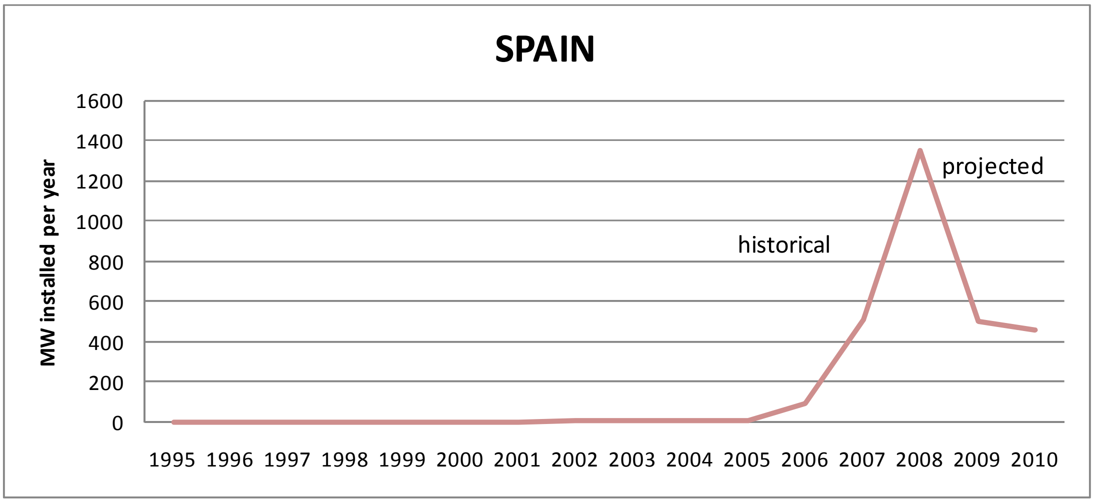

Figure 3.5: Historical and projected annual PV installations in Spain

Table 3.6: PV Feed-in Tariffs in Spain from 2009

System size and type	Tariff c€/kWh
< 20 kW (BIPV & rooftop)	32
≤ 10 MWp Ground mounted	34
20 kW to 2 MWp (BIPV & rooftop)	32

3.2.3.1 Drivers and economic impacts

High dependence on imported fuels, rapid growth in energy use and the need to meet European greenhouse gas emission reduction targets have driven Spain's renewable energy support programs. In the 5 years since the generous feed-in tariff was introduced, Spain became the second largest PV market in the world. Most activity has occurred in the larger scale 5-100 kW range, driven by investors, as well as a significant number of utility scale MW size systems. In 2007, employment in the sector was estimated to be 17,000 (IEA-PVPS, 2008).

3.2.4 Japan

Japan was the first country to aggressively support development, manufacture and use of PV. It manufactures 22% of world production and has over 2GW installed capacity. After many years of

R&D and manufacturing support, it began a market support program in 1995, using grants for residential customers, and in time for commercial and industrial customers as well. These grants gradually tapered off and finished in 2005, although awareness and acceptance of PV is high and support continues to be available through local governments in some areas. PV installations remain relatively high, with many housing companies including PV as a standard component, sales promoted by building component, roofing and electrical appliance companies, net metering offered by many utilities and tax benefits available. However, residential sales have declined since government support was withdrawn. Although the grants were not high, at around 10% of system costs by the end of the program, they were seen as an indication of Government commitment. A new support program, with residential grants of 70 yen per Wp (US$784/kWp) is expected to be announced in 2009, with a budget allocation of 9 billion yen already in place for the first part of 2009. The program is expected to include minimum module efficiency and max system price limits.

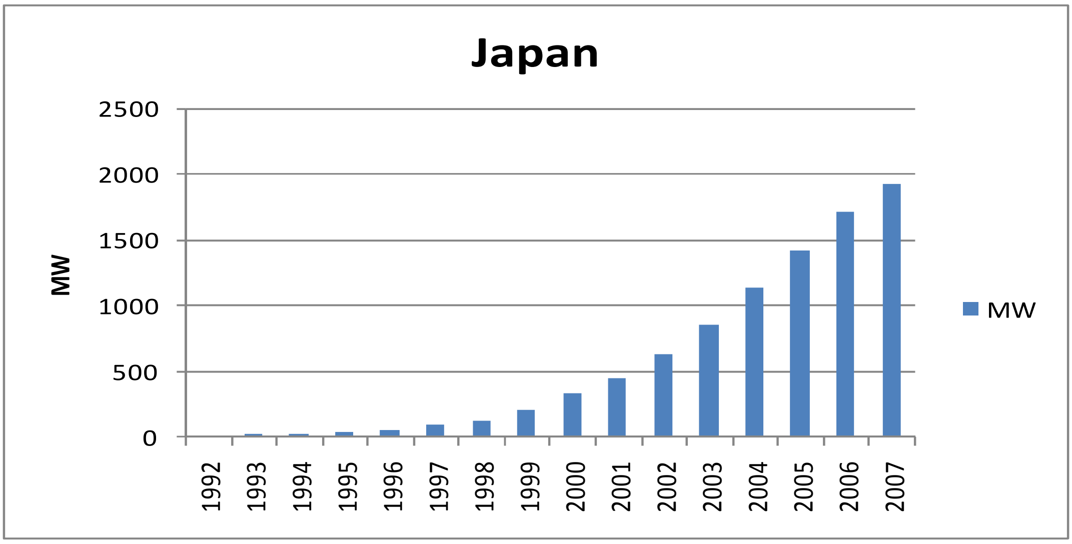

Figure 3.6: Cumulative PV Installations in Japan (Ikki, 2008)

Japan remains a major producer of silicon feedstock, wafers, cells, modules, inverters and batteries. Research and demonstration of new technology is also strongly supported, with Japan spending US$38.9M on R&D in 2007, second only to USA (IEA-PVPS, 2008). The Japanese *Cool Earth 50* strategy for 2050 aims to achieve PV efficiencies of 40%. The Government is now encouraging larger scale PV system deployment in public and industrial facilities, as well as MW facilities for cities. The Japanese Renewable Portfolio Standard has a target of 16 billion kWh by 2014 and PV is allowed to double count its contribution (ibid).

3.2.4.1 Drivers and economic impact

The initial interest in PV from Japan was from the electronics manufacturing sector, which was looking for new products and markets. At the same time, with few local fossil fuel energy resources, Japan has been keen to increase the use of its indigenous renewable energy resources so that research and subsequently deployment has been strongly supported by the Government. The sector employs around 18,000 people and has a turnover of US$1.3 billion.

3.2.5 USA

The US market has grown slowly over the past decade, but has picked up over the last two years, particularly in California and New Jersey which have targets of 3 GW by 2017 and 2.3 GW by 2021 respectively (IEA-PVPS, 2008). At a Federal level, PV is supported by a 30% investment tax credit which are available to residential, commercial and industrial sectors, including utilities, and by the Solar America initiative, which aims to remove barriers to PV so as to reach grid parity by 2015. In addition, the recent extension of the production tax credit (~2.5c/kWh) for 8 years has provided a significant boost to industry confidence and the market is set to expand rapidly, despite some impacts from the financial crisis. Significant levels of Federal funding is also provided for R&D (US$160 million for 2008), with programs focussing on PV technologies, concentrators, market transformation and grid integration.

At the State level, renewable portfolio standards apply in 29 States, with a solar set aside in 11, and net metering is mandated in most States. A range of grant programs, tax exemptions, green pricing, public procurement, manufacturing and utility based incentives are available in many States (see DSIRE, 2008). California is providing US$3.3 billion over 10 years in declining subsidies to support its target (Sinclair, 2008). The market is also being stimulated by PV promotion through some of the major retail chains, including Wal-Mart (IEA-PVPS, 2008).

One of the most interesting developments is the utility call for very large PV plants. Californian utilities in particularly have plans for several multi-MW plants in the desert areas, driven by the 20% renewable portfolio standard. Pacific Gas &Electric have announced 250 MW c-Si and 550 MW a-Si power stations, which are to be built by 2013. Several smaller plants have been built or are under construction, including a 14 MW c-Si plant in Nevada, a 7.5 MW CdTe plant, with options to expand to 21 MW, and several others in the 10-30 MW size range (Hering, 2008). Several of these plants are being built under power purchase agreements, with prices in the range US$0.12-0.15 (ibid).

3.2.5.1 Drivers and economic impacts

The US has been actively involved in PV research for many decades, but its market has been relatively slow to develop overall, although significant markets exist in particular States, such as California, which have had deployment programs. These programs have been driven by local energy supply constraints, as well as by environmental and economic development goals. In 2007 there were over 8000 people employed in the PV sector and turnover was US$1.7 billion (IEA-PVPS, 2008), however, these are expected to grow significantly in the next few years.

3.2.6 China

China has rapidly become a world leader in PV manufacture, however, its local market remains relatively small. Specific PV programs for rural areas and grid markets include 400,000 solar home systems already installed, a PV target of 1.8GW by 2020 and a current installation rate of 20 MW per year. It has recently introduced a renewable energy target of 8% by 2010 and 15% by 2020 and has also instigated some new PV projects as part of its financial support package.

3.2.7 Korea

As in many Asian countries, including Taiwan, Singapore, India and China, Korea is rapidly increasing its PV wafer, cell and module manufacturing capacity. The Korean Government is also providing significant R&D support (US$38 million in 2007).

The off-grid PV market in Korea has been the main focus until recently. Unlike many other Asian countries, however, the Korean Government has also begun to stimulate the local grid market. It has introduced a 100,000 roof-top program, supported by capital grants (60% of system cost up to 3 kW), as well as feed-in tariffs (6 X standard tariff) and low interest loans. The aim is to install 1.3 GW and secure 7% of world production by 2012 (IEA-PVPS, 2008). The feed-in tariffs have driven large scale systems in particular, including several multi-MW plants. There is a 100 MW cap. . These support programs have seen PV installations grow from 13 MW in 2005 to 35 MW in 2006 and 78 MW in 2007.

3.2.7.1 Drivers and economic impact

Industrial development and new industries have been a key driver for the PV manufacturing sector, particularly given Korea's successful semiconductor industry base. Development of the local market is driven by energy self sufficiency goals, climate change and the need to develop infrastructure for the new renewable and distributed energy system. Employment in the sector was around 1600 in 2007 and turnover US$328 million (ibid).

3.2.8 Australia

The Australian PV market has grown steadily at around 15% per year over the past 15 or so years, driven initially by cost effective applications in remote areas and increasingly by government grant support programs. 12.2 MW was installed in 2007 and installed capacity was 82.5 MW by end 2007, of which 47% was in off-grid industrial and agricultural applications. The grid market is growing and now accounts for approximately 20% of installed capacity. The remaining market comprises off-grid residential and diesel grid applications.

The PV market is expected to continue to grow over the coming decade, with grid parity anticipated in some jurisdictions by 2015, and earlier in diesel grid locations. Electricity price increases between 4 and 9% per annum over the next 5 years have been announced by the State Governments, while diesel prices continue to rise in line with international market prices. Australia is to implement an emissions trading scheme by 2010, which will also impact electricity prices because 90% of Australian electricity is generated from fossil fuels. In addition, support is available for renewable energy generally, and PV specifically, through a number of government support programs:

A national Renewable Energy Target (RET) of 20% (45,000 GWh per year) by 2020 has been set, up from 25,500 GWh in 2010. A separate market in Renewable Energy Certificates (RECs) has been established where every MWh of electricity generated from eligible renewable energy sources can earn one REC. Although RET has not been a significant driver for PV to date, since there are no portfolios, REC prices increased after the higher Target was announced and PV systems up to 100 kW can apply for up front deemed credits equivalent to 15 years of production. Systems up to 1.5 kW can also claim deemed 'Solar Credits' of 5 RECs per MWh from 2009-2012, then reducing each year until parity in 2016. This could provide around AUD 5000 per kWp (US$3250) in addition to any other support available and replaces previous grant support mechanisms.

Three States have announced net export feed-in tariffs ranging from AUD 0.44-0.66 c/kWh, which will provide support for larger systems or households with low daytime loads. The PV industry is calling for gross export feed-in tariffs and the ACT Government currently has a bill for a gross tariff of 3.88X retail price. Two other States, NSW and Western Australia, are also considering gross tariffs. The National Government favours a uniform feed-in tariff approach amongst the States.

Grant support has been provided for diesel fuel savings in regional grids, pastoral properties, mining and tourist locations under the Remote Renewable Power Generation Program, although other renewable energy technologies are also eligible. Funding has also been provided over 5 years for 7 Solar Cities across Australia, to provide PV, solar water heaters, energy efficiency and demand management systems while additional support for solar, energy efficiency and water saving projects has been provided in a Solar Schools program, with all Australian schools to have a PV system up to 2 kW.

3.2.8.1 Drivers and economic impacts

PV support programs have been driven by a combination of greenhouse gas reduction and industry development goals. Grant based funding has predominated, although market support through the Renewable Energy Target is soon to take over for small grid systems. This has not been as successful in stimulating the market as have the feed-in tariff programs implemented in Europe, in part because they have been changed constantly and because they have not been perceived to underlie a long term policy objective aimed at increased renewable energy penetration. This may change as carbon signals begin to enter the market in 2010.

3.2.9 Malaysia

Malaysia has instigated an active PV program, including the 1000 Suria program, demonstration and showcase programs, which are operating from late 2006 to 2010 and aim to see 1.5 MW of building integrated PV installed as well as to develop local manufacturing and installation infrastructure. It expects to develop the local market faster after this capacity building phase. It also has a 100,000 solar home system program for rural areas.

Drivers include industry development and the need for secure energy supplies in both rural and urban areas. In 2007 employment stood at 70 and turnover at US$ 1.2 million (IEA-PVPS, 2008). However, this is growing fast with new manufacturing capacity being added and the deployment programs gaining momentum.

3.2.10 India

Like China, India has been keen to exploit its low cost base to establish PV manufacturing for both export and local markets. Its rapidly growing energy demand requires utilisation of all available energy sources.

The PV market in India is potentially large. India has a renewable energy target of 10% by 2010 (about 10 GW) and a growing PV manufacturing base. The main PV market has been in rural areas, such as for the 18,000 Remote Village Electrification program, but the grid market is also growing and annual installations are around 30 MW.

4. PV DEPLOYMENT OPTIONS

The majority of PV systems installed until the mid 1990's were off-grid and relatively small scale. PV continues to be widely used for telecommunication links, remote signalling, navigation aids, pipeline cathodic protection and small-scale domestic power supplies. Solar home systems with a single PV module, a battery, lights and sometimes a dc power outlet for a television, are also widely deployed in remote regions of developing countries where grid power is unlikely to be extended in the short term. Nevertheless, the major market growth over the past decade has been in grid connected PV applications. These now make up 90% of the world market (IEA, 2008). The breakdown by application for the PVPS countries, which make up 87% of the world's installed capacity, is shown in Figure 4.1. The main PV deployment options are described in the following sections.

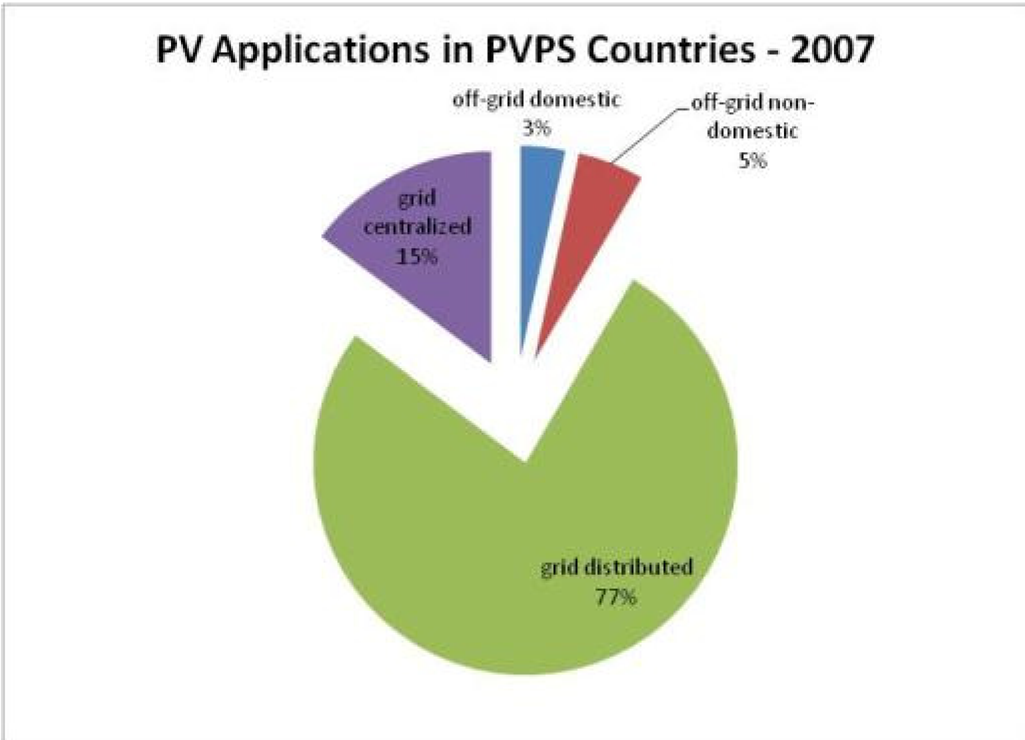

Figure 4.1: 2007 PV Applications in IEA-PVPS Countries (IEA-PVPS, 2008).

4.1 Large centralised installations supplying electricity to the grid

Large ground mounted PV power plants, often called 'solar farms', operate as do any central power station, albeit with a variable output, dependent on solar input. System sizes are typically in the 0.2 to 5 MW range. However, many 5-25 MW plants are now in operation and US utility Pacific Gas & Electric Company plans an 800 MW plant in California by 2012, comprising a 250 MW high efficiency Si plant and a 550MW a-Si plant with combined output of 1,650 GWh per year (Hering, 2008).

The 20MW PV plant in Beneixama, Spain, covers 0.5 km^2 and produces 30 GWh of electricity a year from 12.17% efficient modules. The land area required would be reduced by a third if 18.7% efficient modules were used and increased if lower efficiency amorphous silicon modules were used. The land area required also changes with latitude, as the row spacings change. An increasing number of solar farms use concentrators and / or trackers, which require spacing between rows in one or both directions.

Typically land area requirements for a large flat plate crystalline silicon solar farm would be expected to be between 40Wp/m² and 90Wp/m². This results in expected yields between 43 kWh/m²/year and 135 kWh/m²/year for fix arrays. Specific energy yield for tracking systems could **be** as high as 180 kWh/m² of area. (Assuming 2-2.5 row width to row spacing).

4.1.1 Supply Chains, Ownership and Costs

Vertically integrated companies may undertake the entire project, providing cells, modules, frames or trackers, power management and installation. Although each individual component may not be the cheapest available, internal project management can facilitate coordination and keep overall costs down. System developers on the other hand can purchase components at good prices for such large volumes and then act as integrators on site. A third option is for module manufacturers to link up with site developers or utilities to undertake a joint project. In the US, such joint development may be favoured in future, with PV companies and utilities looking for partners with tax liabilities which can take best advantage of the tax credits.

Some of the solar farms are owned and operated by utilities, others are built under Power Purchase Agreements, with the utility contracting to purchase power at an agreed price for an agreed period. Financing is arranged separately by the PV suppliers and/or the utilities via investment companies and banks.

As PV prices reduce, large PV plants are becoming more competitive with solar thermal power stations, because they can be modular, easier to locate and build, have lower personnel, maintenance and water requirements and have a greater tolerance of solar conditions and undulating land(Podewils, 2008). Nevertheless, electricity costs from large solar thermal plants remain lower than from large PV plants. Prices being quoted for some of the very large new 'utility scale' plants being developed in California are US$0.12-0.15/kWh (ibid) (First Solar, 2008). Such prices would allow PV to compete with both solar thermal and some gas fired generating plant.

Infrastructure costs for large central solar farms depend very much on size and location. To date, most very large solar farms have been built in hot, dry climates where output can be reasonably reliably predicted. Installed costs of US$4,600 – 8,600 per MW are quoted (Podewils, 2008), although, given the increased use of trackers, prices are increasingly being quoted per MWh for the site. The Beneixama site cost US$5,700 per annual MWh (ibid), other sites are quoted at US$4,600 (Siemer, 2008).

4.2 Industrial roof spaces in major cities

PV systems in the multi kW to MW size range can be built as field arrays, however, they are also often installed on large buildings, such as farm sheds, shopping centres, car parks and large industrial sites. Most systems have their own substation. Although the economies of scale may not be as significant as for solar farms, there is no additional land or array frame cost and the electricity produced can readily be used on site. One of the largest systems in the world is 11.8 MW on the General Motors Zaragoza site in Spain. In Germany, the largest system is 5 MW at Bürstadt. In the US,

Auckland International Airport

2 grid-connected PV arrays on Piers A and B installed as part of a recent upgrade. The PV gained credits towards the LEEDS building rating scheme.

Pier B:

29.75kWp of Sharp PV modules (170 x 175Wp PV modules)

6 SMA inverters (3 x SMC6000, 3 x SB3800)

SMA web monitoring and display in management office

Pier A:

21kWp of Sharp PV modules (120 x 175Wp PV modules)

3 SMA inverters (3 x SMC6000)

SMA web monitoring and display in departure hall

Total expected generation (Pier A+B): 61.9 MWh/year

Toyota's 2.3 MW PV system in Ontario is currently the largest. In New Zealand, the Auckland international airport's 500m^2 PV system is an example. Details are shown in the text box. Although some systems can be classified as building integrated (see below) most PV arrays are placed on top of existing roofs. Even if not displacing roof materials, they can provide shading and insulation benefits which reduce heat loads (Tanaka, 1999).

4.2.1 Supply Chain, Ownership and Costs

Large roof systems can be owned by the building owner, or by a developer who leases the roof space. Power produced can be used exclusively on site, or connected to the power grid, with utility power purchase agreements or wheeling arrangements for power purchase elsewhere. Many such systems are installed to meet corporate environmental goals and can take advantage of the diverse company financial arrangements. Nevertheless, most systems installed take advantage of government incentives, including capital grants, tax credits, accelerated depreciation and feed-in tariffs.

Typical 2007 prices for large systems ranged from US$5.40 in Japan, to US$5.50-7.50 in the US and US$5.90 in Germany (IEA-PVPS, 2008). In an industry survey carried out for this project, New Zealand, prices quoted for systems larger than 100 kW ranged from US$6.50 -8.00.

4.3 Distributed installations supplying individual customers

Smaller PV systems, typically in the kW size range have provided the largest PV market over the past decade, and have driven the rapid development of grid connected systems. Most systems are installed on the roofs of individual homes, community and commercial buildings. Other applications include road barriers and street lighting. Distributed systems are connected to the low voltage electricity distribution network via grid interactive inverters. No additional infrastructure is required. They can therefore be installed anywhere in the network where access to direct sunlight is available for at least 6 hours during the middle of the day. This means that PV systems can provide one of the easiest means available of urban electricity generation, which explains some of the rapid uptake, which is occurring despite the high price. Small, modular PV systems have lent themselves to mass production of components, which in turn has facilitated cost decreases. Standardisation of components also facilitates certification and approval procedures. The latter, combined with innovations in roof mounting fittings, has seen typical installation times reduced from 2 days to less than half a day per standard system, which in turn reduces prices.

Most current residential PV installations are in the size range 1-3 kW. To supply the equivalent of the average New Zealand household's electricity load of 7,800 kWh/year (Isaacs, 2006) using available multi-crystalline PV modules would require an array of around 6 kWp in Auckland and about 7.5 kWp in Dunedin. Energy efficiency measures, such as insulation, draft exclusion, appropriate use of curtains and window shades, reducing standby loads and increasing appliance efficiencies, could provide valuable reductions in electricity requirements, with correspondingly smaller PV systems necessary. Conversely, if loads grow, larger systems would be required.

Although individual home systems have been the main focus, distributed systems larger than 10 kW have been instrumental in delivering the large purchase orders which has allowed rapid expansion of PV production, and corresponding production cost decreases, around the world over the past decade. Current examples of non-residential systems include the Waitakere library, the 2 kW Schoolgen systems, the NIWA offices in Wellington and the Auckland Airport discussed above.

Stimulation of the residential, commercial and small industrial PV markets can be a useful way of mobilising private sector investment in the electricity system, taking the pressure off grids and changing the requirements for new central generation plants. This strategy is being actively pursued in places like California. Because of the predominantly daytime load in the commercial and light industrial sector, PV output can contribute usefully to both energy and demand reduction, with the value depending on building ownership and tenant arrangements (Lam, 2008). The coincidence of load and PV output in summer and winter for a predominantly commercial load substation in Homebush Bay, Sydney is shown Figure 4.2 and Figure 4.3.

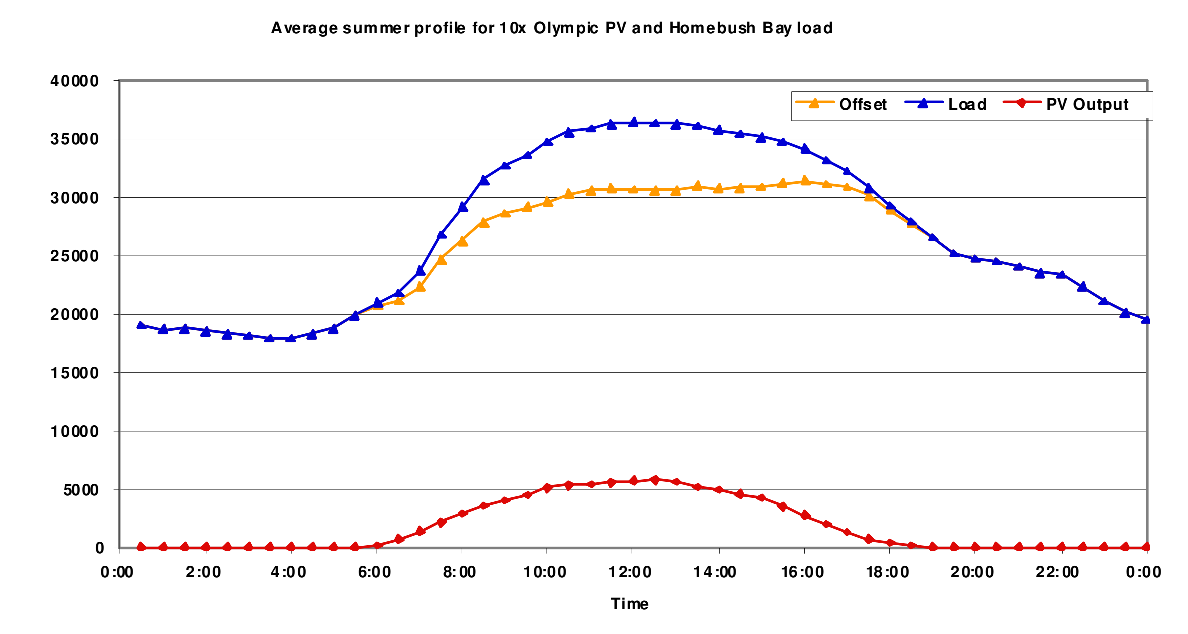

Figure 4.2: Average Summer Load Profile for the Homebush Bay substation showing the impact of 10x the current Olympic Park installed PV capacity (Watt, 2006)

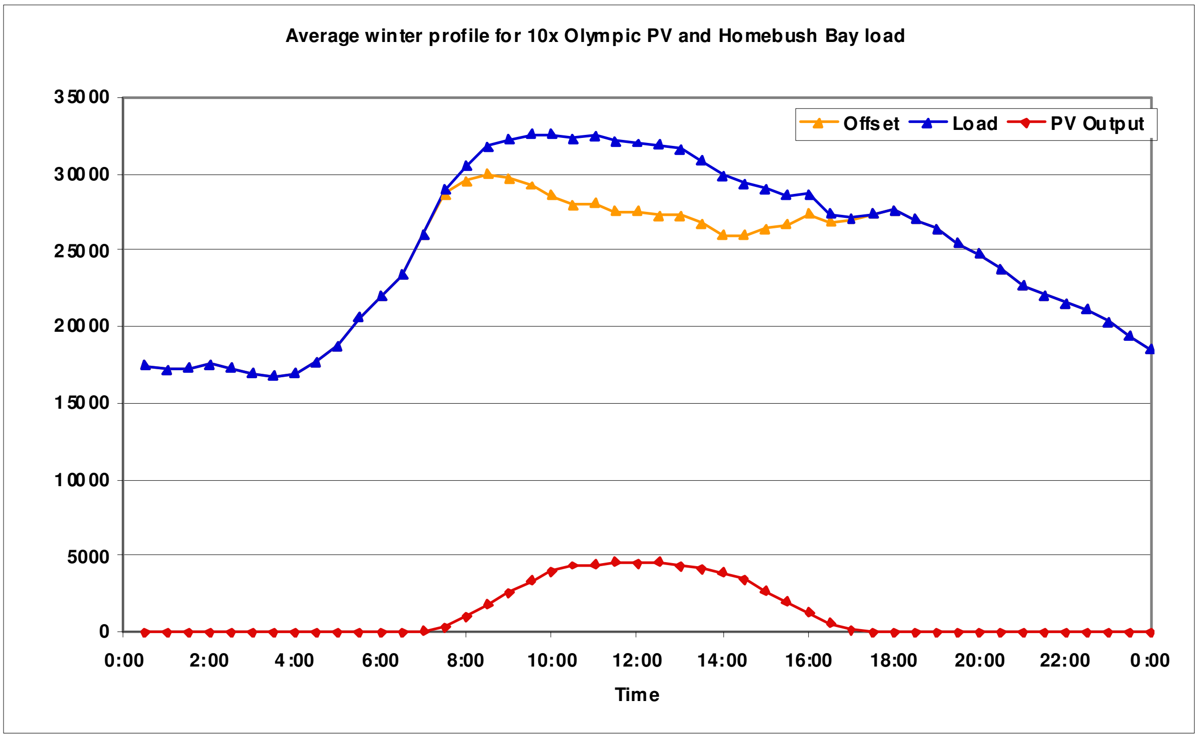

Figure 4.3: Average Winter Load Profile for the Homebush Bay substation showing the impact of 10x the current Olympic Park installed PV capacity (Watt, 2006)

4.3.1 Building integrated PV (BIPV)

BIPV is a special category of distributed PV system where the PV module acts as a building element, thus replacing roofs, walls or windows. The multi-functionality of BIPV systems can allow PV to meet cost effectiveness criteria, particularly for new buildings. For instance, PV can replace high cost marble facades or provide shading, insulation, windows or skylights, in addition to electricity. Architects are potentially more interested in using PV if it can add to the building aesthetic and some interesting examples have been built. However, purpose made PV components results in additional cost. Some generic PV building products are now available, which aim to standardise production and hence keep costs down. The most common of these include roof tiles, roofing panels and window shades, although standard framed modules and frameless PV laminates can also be used for facades.

As PV prices reduce, this market area may well increase, with PV becoming a standard building element. PV technologies which perform better in diffuse light levels, such as organic PV technologies, may also be useful for BIPV, especially for windows and facades, which may not receive much direct beam radiation.

Figure 4.4: BIPV Facade, Melbourne University Private (photo: S.Troman)

4.3.2 Supply Chains, Ownership and Costs

Distributed PV systems are typically supplied by a local PV installation company, which can be owned by a PV manufacturer, or be an independent agent. The installation company may manufacture some or all components, or purchase these from various manufacturers. The majority of small distributed PV systems are installed as retrofits onto existing buildings. However, in countries like Japan, where PV has now been used for several decades, some building companies include PV as a standard component in new buildings. An increasing number of 'green build' developments, which include energy efficient buildings and environmentally sensitive land use, also include PV.

In some cases, such as in the early trials by the Sacramento Municipal Utility District in the US, PV systems have been purchased by the utility and placed on residential roofs. The PV electricity was sold to the household at a premium. A similar arrangement has been used for some of the larger PV systems, where roof space is leased by the PV developer and the electricity on-sold. More commonly, the PV system is owned by the building owner. Electricity produced is used by the system owner, or sold to an electricity retailer for resale as green power or to meet renewable energy targets.

Although per kWp costs of small distributed systems are higher than for the large solar farms, the electricity is competing with retail rather than bulk supply electricity tariffs, so that residential roof-top systems are already close to being cost effective in some areas of the world. Prices per kWp in 2007 ranged from US$5.90 in Japan to US$6.00 - 7.10 in Germany, US$7-9 in the US (IEA-PVPS, 2008). In New Zealand, systems less than 2 kW sell for US$8.50-9.70 while systems between 2 and 10 kW sell for US$7.40-8.60 (Brazier, 2008).

4.3.3 Grid Integration Issues

In many installations around the world, PV generated electricity is merely used by the local load and no grid export occurs. However, with the advent of gross export Feed-in tariffs, it has become more common to allow export to the grid. Hence power can flow to or from a household, which changes metering requirements, safety protocols and grid management.

While grid penetration levels remain relatively small, there is no undue concern about network instability, as PV acts more or less as a negative load. However, once PV begins to supply a significant portion (say more than 10%) of the local load, network service companies may need to consider modifications to their grid management procedures and/or management systems on the PV. The changes required as penetration levels increase are shown in Figure 4.5.

In New Zealand, systems under 10kW are viewed by the Distributed Generation regulations as being able to be installed anywhere on the grid without any adverse effects, requiring only approval that the system has met the relevant standards from the lines company . It is expected that in the majority of urban locations significantly larger systems could be installed without need for grid upgrade. Nevertheless, as overall penetration levels increase to significant levels in the long term, new grid management strategies may need to be considered, as discussed above. Under present regulations, costs of assessment of the effects of the connected system, modifications required, or ongoing costs associated with the connection of the system if greater than 10kW, will be charged to the system owner.

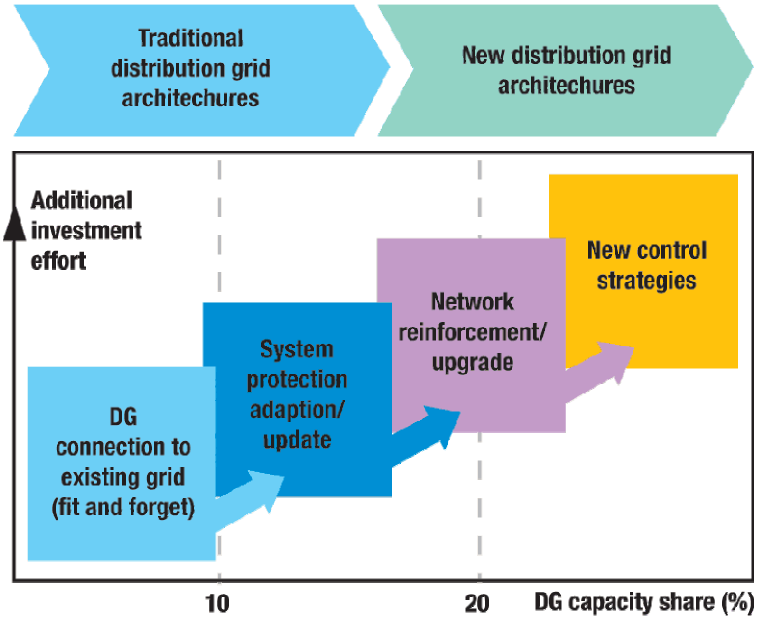

Figure 4.5: Stages in moving from a conventional grid to a distributed grid infrastructure (A. L'Abbate, G. Fulli, S.D. Peteves, 2008, 2008)

4.3.4 Micro-Grids or Smart Sub Networks

The combination of smart meters, energy efficiency, load management, storage and on-site PV generation can facilitate the development of low or zero net energy housing developments and micro-grids. Such developments can significantly reduce the electricity network infrastructure required for new developments, as well as transforming the grid infrastructure for the future. As a simple start, a group of energy efficiency houses with PV systems can be treated as a single connection by the network.

Several different grid configurations possible are shown in Figure 4.6.

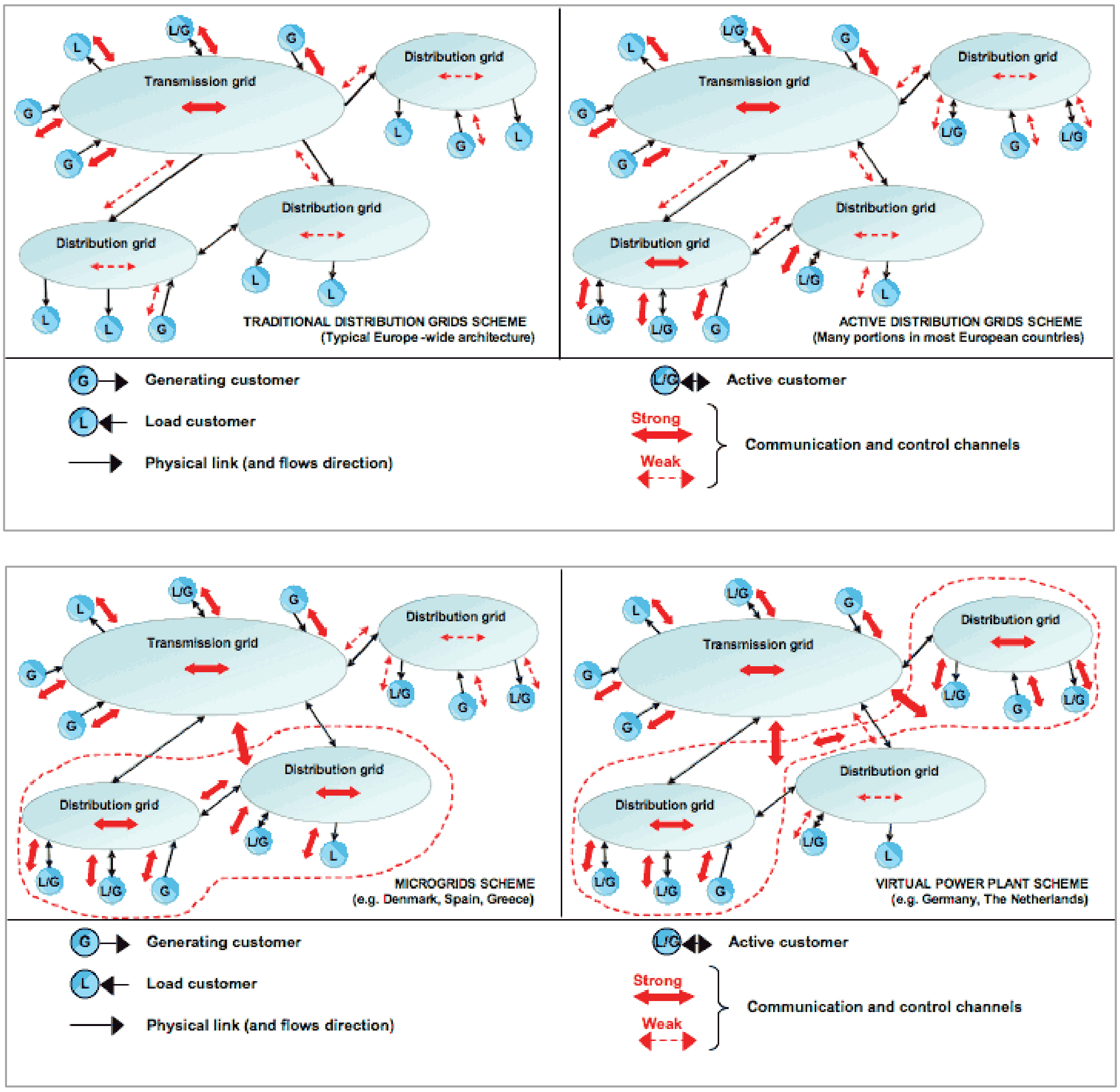

Figure 4.6: Various Distributed Generation Configurations (A. L'Abbate, G. Fulli, S.D. Peteves, 2008)

Simplified versions of smart networks, with generation and storage capacity, could be used at the end of long grid lines where voltage support is needed. The local inverter would supply peak demand at the end of the line, reducing the capacity requirements on the line. In some cases the line may become obsolete altogether. This may be used as a transition strategy in remote areas, if the economics of maintaining grid lines are poor. It would allow customers to gain confidence in the new technology before connection to the grid is severed and also allows staged capital expenditure.

4.4 Fuel displacement in diesel grids

The diesel grid market is large in the Asia-Pacific region and a potentially good market for PV when oil prices are high. Regardless of oil price, difficult access and energy security issues also influence PV use. Diesel mini-grids are often used by private companies engaged in mining activities, as well as on islands and small isolated communities. Improvements in low load diesel technology, as well as sine wave inverters which can run in parallel with diesels, have allowed increased use of renewable energy as a fuel saver. Electricity costs in large diesel grids begin around US$0.25/kWh, depending on size and fuel cost, but can be as high as US$2.00/kWh. PV can be a cost effective option at power station level, or to reduce effective loads on customer sites. Depending on load profile and load management options, PV may also be useful in reducing daytime peak loads.

In New Zealand, a trial is underway on Stewart Island to reduce diesel fuel requirements on its 2 MVA system, serving 420 customers, via a small PV system and a wind generator. Larger installations will follow if the trial can show a cost effective reduction in electricity costs from current levels of 52 c/kWh, with the aim of supplying 30% of the electricity needs via renewable energy. Bio-diesel is also to be trialled in the diesel generators, while energy efficiency measures are to be rolled out to residents (National News, 2008) (McNeilly, 2008). A case study of PV displacement of diesel on Little Barrier and Tiri Tiri Islands is shown on pages 42-45.

4.4.1 Biodiesel opportunities

Stand alone PV-diesel power systems, discussed below, and diesel grids, discussed above, could be a potential new market for biodiesel, increasing the use of renewable energy, reducing diesel fuel imports and providing a new rural industry. The 7 members of the New Zealand Biofuel Manufacturers Association (NZBMA) had plans for production in excess of 170 million litres per year within New Zealand mainly from Tallow (see Appendix 1) prior to the scrapping of the Biofuels Sales Obligation. These plans will now depend on a market being available.

4.4.2 Supply Chains, Ownership and Costs

Diesel grids are typically owned and operated by the local community, the industrial site operator, or a power utility. Hence PV components would typically be supplied in response to a tender. In some cases the tender may include installation and on-going maintenance, in other cases this would be undertaken in-house. PV prices are likely to be the prevailing module price, with additional distance based delivery costs to the remote area.

4.5 Small scale off-grid PV deployment

Small off-grid PV systems are often cost effective against fossil fuel based energy options such as diesel generation or kerosene lighting. However the high up-front capital cost can render PV unaffordable, particularly in developing countries. A large component of aid based PV funding is focussed on provision of solar lighting systems in remote villages, or other DC applications such as vaccine refrigerators, television, water pumping and computers.

Such systems can be for individual homes, comprising for instance a PV module, a battery and a few light bulbs. Others can be community based, with a larger PV system in a communal location. Several models of supply and payment have been tried, including donations or aid assisted purchase from local PV companies. Nevertheless, on-going maintenance, availability of spare parts and appropriate use of appliances remain issues with many deployment programs, especially where cash is not readily available, income is seasonal or service is not locally based.

Larger PV systems are also used in developed countries for off-grid applications including remote household power and a range of agricultural and remote industrial uses, including water pumping, electric fences, pipeline cathodic protection, telecommunication links, navigation aids, signal stations and remote monitoring. Such applications have been cost effective in many areas for over 30 years and the technology is well established. Most systems are dc and hence require only the PV, a battery and a controller. Remote household power supplies have largely moved to ac systems over the past 2 decades, with the improvements in small sine wave inverter technologies. Many of these systems are PV-diesel hybrids, with PV supplying varying portions of the load. The diesel can be used for high loads, such as washing machines, or to top up batteries after long periods without sun. New Zealand examples of off-grid power systems include Great Barrier Island and the Department of Conversation sites at Tiri Tiri Martangi.

PV based water pumping systems installed away from easy grid access are already considered to be cost effective against diesel / petrol based systems. The minor extra capital cost of the PV based system is repaid in a short time frame through the savings in fuel and maintenance costs.

4.5.1 Supply Chains, Ownership and Costs

Most small off-grid PV systems are owned by the user, that is, private individuals, organisations or companies working in remote areas.

In New Zealand, small off-grid PV systems remain the key market and an estimated 150 businesses operate across the country. Systems are designed and put together to meet customer requirements. Simple systems, such as electric fencing kits can be purchased off the shelf and don't require specific skills for installation. Warranties may be provided, as well as maintenance contracts for larger systems. In parts of the US and Australia, electricity utilities have sometimes provided stand-alone power supply systems in lieu of grid connection for remote households, with customers paying quarterly charges as they would for grid power. In Australia, the private sector has gradually taken over this market, as utilities found it difficult to run viable businesses without the cross-subsidies currently provided to grid connected customers.

Telecommunication, pipeline or other companies using PV in remote locations may undertake their own installations, using tender specifications to meet their specific requirements. In Australia, tenders for navigation aids and then for telecommunication links provided the early PV industry market and PV modules were manufactured to suit these end uses. (With the grid market now dominating, few manufacturers continue to make the small modules with output voltages required for off-grid applications).

It is difficult to compare prices for small off-grid systems because their configurations are not standard. Nevertheless, system prices in IEA countries which have reasonable off-grid markets range from US$10-20 / Wp in the US, to US$15-20.80 in Australia and US$20.50-27.40 in Spain (IEA-PVPS, 2008). In New Zealand small off-grid residential systems sell for around US$20 /Wp.

CASE STUDY OF PV-DIESEL HYBRID SYSTEM
TIRI TIRI ISLAND

Overview:

Titi Tiri Matangi and Little Barrier Islands in the Auckland Conservancy were previously powered by diesel generators with diesel needing to be delivered by boat. The dilapidated power supply systems on both islands were upgraded.

The Tiri Tiri Island project received an in-principle budget of NZ$260,000 ($90,000 AIP in 2004/05 and $170,000 AIP approved in 2006/07) with the aim of removing the total dependency on diesel power generation by moving to a mix of solar, wind and back up diesel power generation.

The project involved the purchase and installation of the solar array, battery packs and inverters, along with the required modifications which will allow for wind turbine generation to be affixed at some later stage. The use of multiple inverters and battery banks resulted in a significant increase in the reliability of the power supply on the island. Reliability of the system is essential for the Department's operations on the island: for staff to be resident on the island; for the visitor centre; and for the machinery in the workshop.

System Details:

The Tiri Tiri Matangi solar power system is made up of forty Sharp Solar 175W Modules producing 7 kW of peak solar power. These modules are mounted on ten Unirac PoleTop Array Frames holding 4 modules each. The ten PoleTops are installed in two rows, with five PoleTops in each row. An SMA Sunny Boy 3800 string inverter is mounted on the third PoleTop of each row. These two inverters take the solar power that is produced by the modules and invert it from DC to AC at source.

Two SMA Sunny Island 5048 battery inverters are also connected to the distribution board and these create a "grid" for the island. These inverters manage the power needs of the island, meeting users' demands and charging the two Absolyte 100A33 battery banks. The Sunny Islands also control the Lister generator automatically.

The system is monitored using a SMA Sunny Webbox which has been modified to incorporate the information provided by the Sunny Islands, together with the solar production data from the Sunny Boy inverters.

System Performance:

Table 1 and Figure 1 show the performance of the new PV/diesel hybrid system over the course of a year. As can be seen, in some months the generator is not needed at all. The incorporation of the PV panels into the system has lead to a reduction in diesel use of around 3,000 litres per year. This in turn corresponds to a reduction of approximately 7,900 kg of CO2e per year.

Table C1: Tiri Tiri PV/Hybrid System Load and Output via each Component by Month

Month	Load (kWh)	Solar Generated (kWh)	Sunny island (kWh)	Diesel Genset (kWh)
Jan	1,177	1,151	-120	146
Feb	840	776	-42	106
Mar	956	927	-58	88
Apr	912	570	-24	365
May	856	671	-78	263
Jun	777	575	-101	304
Jul	705	603	-51	152
Aug	632	632	0	0
Sep	782	731	-81	132
Oct	902	930	-28	0
Nov	912	871	-45	85
Dec	1,009	965	-144	188
Total	10,461	9,403	-769	1,828

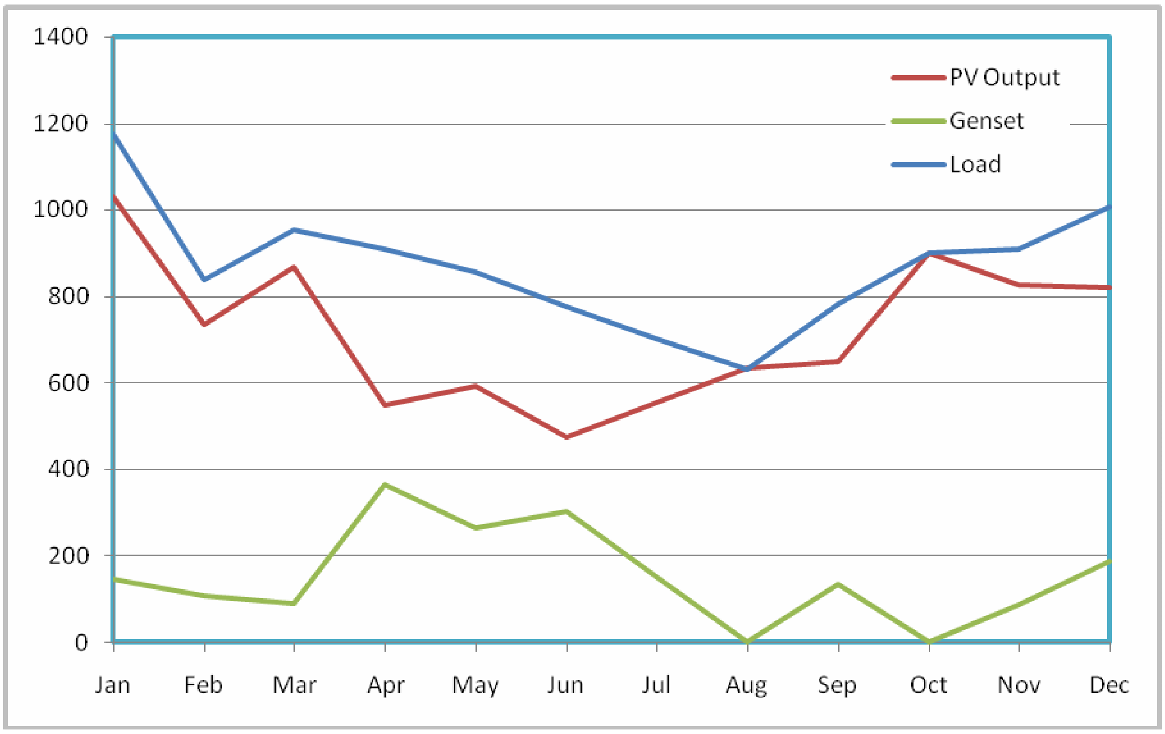

Figure C1: Monthly Contribution to the Load from the PV and the Diesel Generators on Tiri Tiri Island.

5. PV INDUSTRY STRUCTURE, OWNERSHIP AND INVESTMENT

5.1 International PV Companies

There has been significant investment in PV manufacturing over the past 3 decades, with rapid growth in the past 5 years. Until 2008, there were only a few silicon ingot and wafer manufacturers. However, with the world market growing at over 30% per year for the last decade, silicon shortages occurred and prices increased substantially. As a result, existing companies have now expanded their production while a number of new companies, particularly in China have entered the market. This, combined with the global financial crisis, share price drops and the difficulty in raising project finance, has seen 2009 prices fall. The implications of this are not yet clear, but some industry consolidation is anticipated (Koot, 2009).

At present there are more than 100 cell manufacturers, 300 module manufacturers and 80 thin film manufacturers around the world; (Koot, 2008) (Hirshman, 2008)), with a growing number in the Asia-Pacific region, including China, India, Korea, Taiwan, Philippines, Malaysia and Singapore. Plant sizes are increasing from the present norm of around 50 MW/yr to plans for 0.5 – 1 GW/yr plants by 2010 (Koot, 2008). Thin film products are finally beginning to make market inroads and are expected to increase both market share and price pressure from now on.

The production levels, technologies, market capitalisation and immediate expansion plans of the top PV companies are shown in Table 5.1.

There are an increasing number of global companies involved in balance of system supply, particularly of inverters and batteries, but also of trackers and other components. In countries with reasonably sized PV markets, many Balance of System components, such as frames, are locally manufactured. Nevertheless, global system integration companies, such as Conergy, provide their own standardised components.

5.2 The PV Supply Chain in New Zealand

The New Zealand market for photovoltaic systems is relatively competitive. Generally in the past PV module supply in New Zealand has been through a local wholesaler who purchases from an Australasian distributor. There are now a number of local distributors purchasing direct from overseas manufacturers, resulting in more competitive PV module prices. Projects larger than 2 kWp in particular are usually supplied direct from the local New Zealand PV distributor, which keeps system prices down. Figure 5.1 shows the typical supply chain.

5.3 Companies involved in PV

New Zealand companies involved in the PV sector are generally small and diverse, with the majority working in the implementation or supply of imported products. Surveys of the SEANZ member list, and directories[1] identified 111 organisations that currently have reasonable activity in the photovoltaic industry.

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[1] Ecobob (**www.ecobob.com**), EECA find an expert (**http://www.eeca.govt.nz/find-an-expert/Directory/SearchDirectory.aspx**). Websites and yellow page listings were used to determine current participation in the industry.

Table 5.1: Activities of Current Major PV Cell Producers

2007/08 Rank	Name	Location Current Manufacture	Technology	Production Range	2007[a] (MW Actual)	2007 Revenue US$ million [a]	2007 market capitalisation US$ billion [a]	20009/10 (MW Projected)	Location New Manufacture
1	**Q-Cells**	Germany	Crystal Si	Cells	389	395	11	> 1,000[b]	Malaysia
2	**Sharp**	Japan	Crystal Si	Cells, Modules	363			N/A[c]	Japan
3	**Suntech**	China PRC	Crystal Si	Cells, Modules	336	398	9	1,400[d]	China PRC
4	**Kyocera**	Japan	Crystal Si	Cells, Modules, Systems	207			> 500[e]	Japan
5	**First Solar**	USA	CdTe / CdS	Modules	200	201	18	1,132[f]	Malaysia
6	**Motech**	Taiwan	Crystal Si	Cells	176			400[g]	Taiwan
7	**SolarWorld**	Germany	Crystal Si	Wafers, Cells, Modules	170	309		750[h]	Germany
8	**Sanyo**	Japan	Crystal Si	Silicon, Wafers, Cells	165			600[i]	Japan
9	**Yingli**	China PRC	Crystal Si	Wafers, Cells, Modules	145	199	3	600[j]	China PRC
10	**JA Solar**	China PRC	Crystal Si	Cells	132		3	> 500[k]	China PRC
Regional Players									
	SunPower	Philippines	Crystal Si	Cells, Modules	250	224	7	1,000[l]	Malaysia
	REC	Norway	Crystal Si	Silicon, Wafers, Cells, Modules	300	323	13	1.5GW[m]	Singapore
	Oerlikon	Switzerland	a:Si / µ:Si	Production Lines	‘-			30MW[m]	Singapore

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(b) PV-tech.org, 13 August 2008
(c) Sharp’s announced expansion focussed on a:Si thin film in Japan
(d) PV-tech.org, 22 May 2008
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(f) First Solar commercial presentation, November 2008
(g) Motech website (www.motechind.com/ceo.asp), 2008/5/27
(h) SolarWorld website, June 2008 (www.solawworld.de)
(i) Rueters, 26 Sep 2008 (www.reuters.com)
(j) Yingli website (ir.yinglisolar.com/e/press_detail.php?itemid=00096)
(k) PV-Tech 13 March 2008
(l) Clean Tech Group, 19 May 2008
(m) Singapore Economic Development Board (EDB) 2008

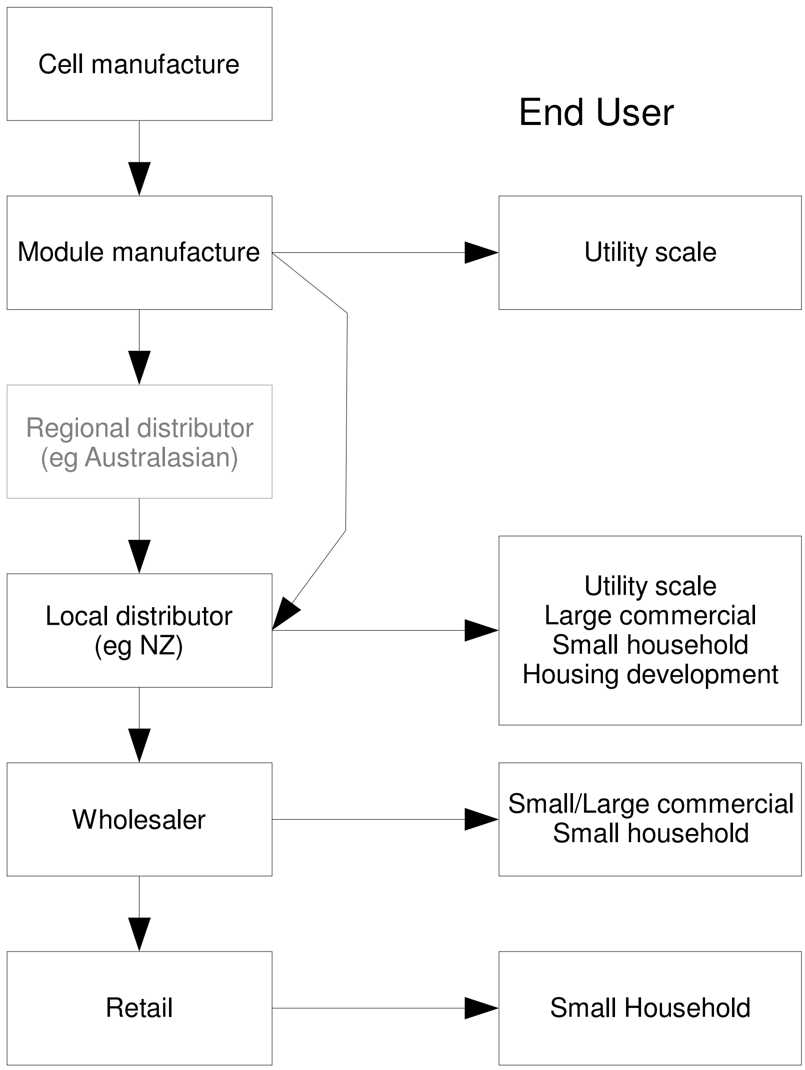


Figure 5.1: Typical NZ supply chain

Due to the nature of the survey, it is expected that there are also a number of other small companies or Sole Traders that have a small involvement in PV or no website or other similar publicly available listing which would not have been identified. These individuals are expected to number approximately 40, bringing the total number to around 150. However some PV distributors put the number of companies active in the implementation of solar PV systems as high as 200. Assuming an average of 1.5 people within each organisation are involved in PV, it is estimated that 225 people are employed in the industry with a reasonable level of direct involvement, although for many of these PV would comprise only a portion of their work.

Established module suppliers include:

- Sharp Solar which is imported directly by Sharp Corporation NZ. Sharp use a multi-faceted strategy with distribution to the reseller channel via a distributor (Reid technology) to the Recreational and mobile market through RVW and Sharp have a direct business model where they work with utilities, large scale implementations and clients directly including Elemental Energy
- BP Solar is distributed primarily through a distributor Able Solar. They sell through the reseller installer channel.

- Kyocera is imported and distributed by SmartEnergy who are based in the South Island. They sell direst and supply the reseller installer channel

The last 2 years have seen some transition in the NZ market, with 3 new entrants.

- Powersmart (Evergreen Solar distribution)
- Black Diamond Technologies (Mitsubishi Electric solar distribution). They use a traditional model and distribute direct to resellers and installers
- Elemental Energy a Meridian Energy Joint venture (Schott Solar). They distribute through a chain of resellers and installers.

There are many other minor brands imported by many resellers and installers who sell direct to the public. Some of these may not meet international quality standards.

Table 5.2: Numbers of New Zealand organisations with a reasonable level of involvement in solar PV

Designers/installers/system integrators	69
Consultants	17
Importers/Distributors	14
Manufacturers with local offices	7
Research organisations	4
TOTAL	**111**

5.4 PV technologies Available in New Zealand

5.4.1 Photovoltaic modules

There are 14 major PV module brands represented in New Zealand at present. The majority are conventional mono and multi-crystalline framed modules, as detailed in Table 5.3.

Table 5.3: Summary of available PV modules in NZ[2]

Manufacturer	Crystalline Silicon Poly/Mono		Amorphous silicon			
	Framed module	Laminate	Framed		Laminate	
			Rigid	Flexible	Rigid	Flexible
BP Solar	✓					
Conergy	✓					
Evergreen	✓					
Flexcell						✓
Helios	✓					
Isofoton	✓					
Kyocera	✓					
Mitsubishi	✓					
Schott	✓	✓	✓		✓	
Sharp	✓					
Solara	✓					
Solarworld	✓					
Suntech/MSK	✓		✓			
Symphony	✓					
Unisolar				✓		✓

5.4.2 Inverters and controllers

A wide range of off-grid and grid interactive inverters and charge controllers are available in NZ. Products represented are shown in Table 5.4

Table 5.4: Summary of available inverters and controllers in NZ[2]

Blue Sky	Latronics	SEA
Ebbet Automation	Mastervolt	SMA
Fronius	Morningstar	Stecca
Helios	Outback	Victron Energy
Kaco	RTL	Xantrex

[2] This is not an exhaustive list of available product

5.4.3 Batteries

Table 5.5: Summary of available batteries in NZ[2]

Century Yuasa	First National Battery	Hoppecke
Concorde	Genergiser	Rolls Battery Engineering
Exide (NZ manufacture)	Hella Endurant	

5.5 Local innovation

There are a number of local organisations actively involved in PV related research and development. Table 5.6 shows some examples.

While there is a limited electrical component manufacturing ability in New Zealand, NMI Design and Enatel are in the process of developing inverter products for both the on and off-grid markets, with the NMI Designs inverter currently undergoing standards compliance testing in Australia.

Further opportunity exists with the development of new PV cell materials, including work at Massey, Otago, Canterbury Universities and Industrial Research Limited (IRL). While there is presently no PV cell or module manufacturing in New Zealand, local organisations are beginning to embrace the technology, incorporating PV technology into building products such as the commercially available "Solar Rib" product produced by Calder Stewart and the building integrated solar PV and thermal products being developed at the University of Waikato.

While the current local market remains small, further export opportunity exists for value added solar building products and PV mountings systems, such as those currently exported by Powersmart to the Australian market. Exide Technologies manufactures batteries for local use and export, although the level of local R&D is not known.

5.6 Industry Capability

Of those working in the PV industry, it is expected that between 100 and 150 are directly involved in the installation of systems. However, more than 50% of installers are not believed to be registered electrical workers and as such are capable of working only on the extra low voltage (ELV) component of Stand Alone Power Systems. New Zealand regulations define work on systems where voltages are greater than 120VDC or 50VAC as prescribed electrical work. To install PV systems involving prescribed electrical work you must be a registered electrician.

Electricians, while well qualified for the installation of electrical systems generally, have limited exposure during training to the specific requirements of photovoltaics, battery installations, ELV/DC wiring practice and safety aspects including working at heights (many PV arrays are installed on the roof of dwellings).

There are few courses run in New Zealand for the design and installation of photovoltaic systems. The Southland Institute of Technology (SIT) has run a number of full-time one year courses at its Invercargill Campus over the past 5 years in the design and installation of Stand Alone Power Systems. These courses are based on an Australian Certificate level course as there are no New Zealand Unit Standards or Qualifications in Renewable energy. Massey University offers a number of papers on photovoltaic power systems sourced from Murdoch University, Perth.

Many of those working in the industry are therefore self-taught, with some training acquired through suppliers of equipment. There is only limited knowledge and application of the relevant design and installation standards and, as a result, a varied level of work quality and system performance.

SEANZ recently announced a competency based accreditation scheme for installers and designers of small scale renewable energy systems. Accreditation can be gained by completion of recognised training. Training will be offered in New Zealand by SIT and GSES. Courses will be offered by distance learning to allow those in the industry to complete training while continuing to work. Training will commence in 2009 with accreditation to begin 2010.

The Electrical Worker Registration Board (EWRB) is currently proposing a category of limited registration as an Electrical Service Technician for the installation of renewable energy systems. Details of how this category would be implemented are not available at this time.

At Consultancy level there is generally limited knowledge of photovoltaics and their application. There are few university level courses and no Continuing Professional Development training available on Photovoltaics. Graduates of engineering degrees have only brief exposure to PV and its application in most degrees.

Table 5.6: New Zealand Organisations Undertaking PV Research & Development

Organisation	Area of Research
Enatel	Developing Grid connected inverter
NMI Design	Developing Power electronics including battery chargers, battery inverters, Grid connect inverters and innovative charge controller/interactive/battery inverter
IRL quantum dot	Ongoing research in distributed generation. Project to develop commercially viable 3rd generation thin film using quantum dot technology
Waikato uni BIPVT	Research projects in process of commercialisation for combined Building integrated photovoltaic/thermal roofing materials and low concentration solar PV concentrators with active water cooling
Powersmart	Locally manufactured solar PV module framing system. Current distributed in NZ and Australia Distribute Evergreen solar PV modules to Australian market
Ebbet automation	Power electronics – including batter chargers and inverters
University of Otago	New PV cell materials, including dye sensitised solar cells
Massey University	New PV cell materials, including dye sensitised solar cells
University of Canterbury	New PV cell materials
Calder Stewart	PV integrated roof cladding

6. THE SUITABILITY OF NEW ZEALAND FOR PV UPTAKE

6.1 The solar resource in New Zealand

New Zealand has excellent solar resource. Radiation levels in New Zealand are significantly higher than those in Germany and Japan, countries which currently have the highest level of solar PV deployment in the world, although not as good as some parts of Spain and California.

Figure 6.1 shows NZ solar radiation levels in the context of selected cities in Germany, Spain, Japan and California.

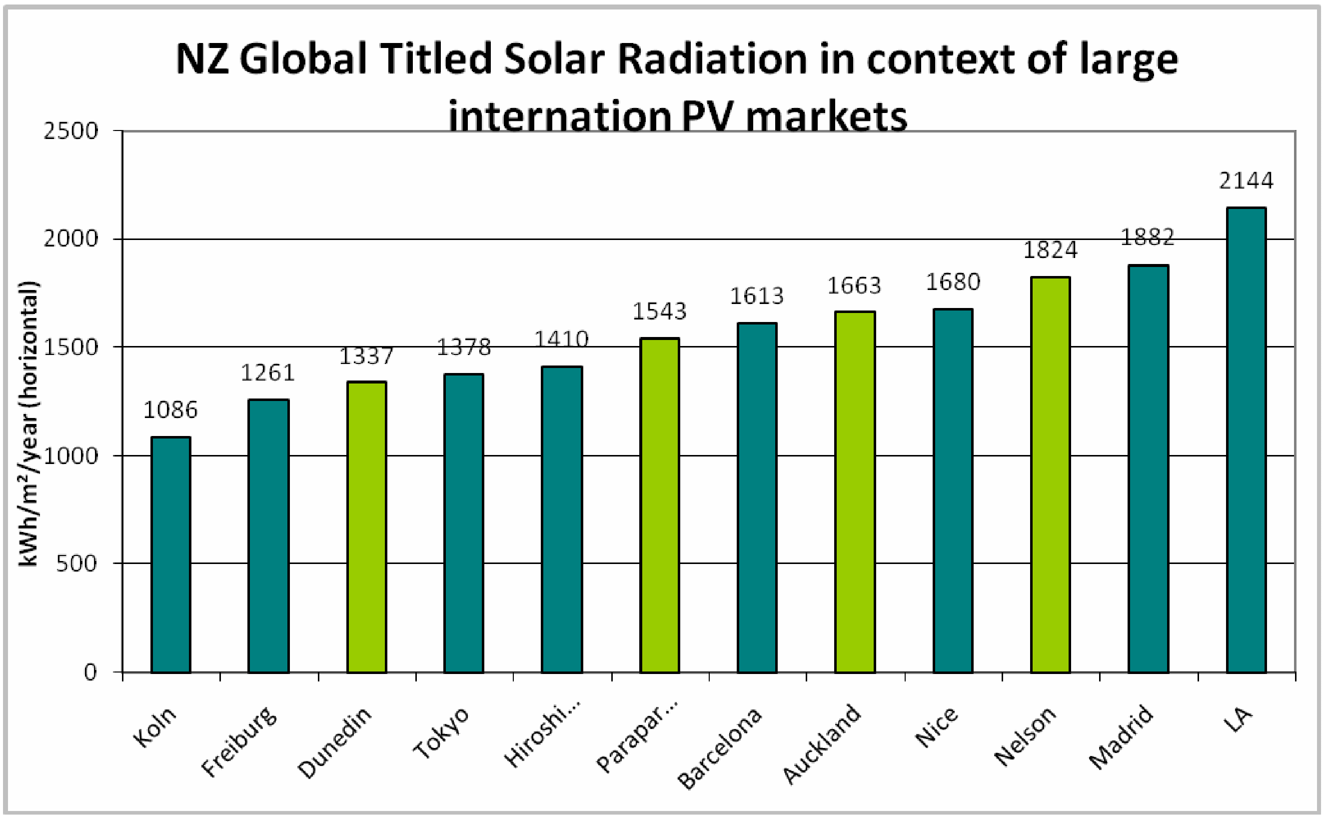


Figure 6.1: NZ Solar radiation vs international sites (based on NIWA (NZ sites) and Meteonorm)

Figure 6.2 shows average solar radiation levels at 16 sites in New Zealand. Dunedin has the lowest radiation levels of any major center in New Zealand, at 1337 kWh/m²/year on the tilted plane (1137 kWh/m^2/year on the horizontal plane) on average, Nelson has the highest at 1824 kWh/m²/year on the tilted plane (1538 kWh/m²/year on the horizontal plane). Solar radiation levels vary across any location on an annual basis and significantly across the country (25% between Dunedin and Nelson).

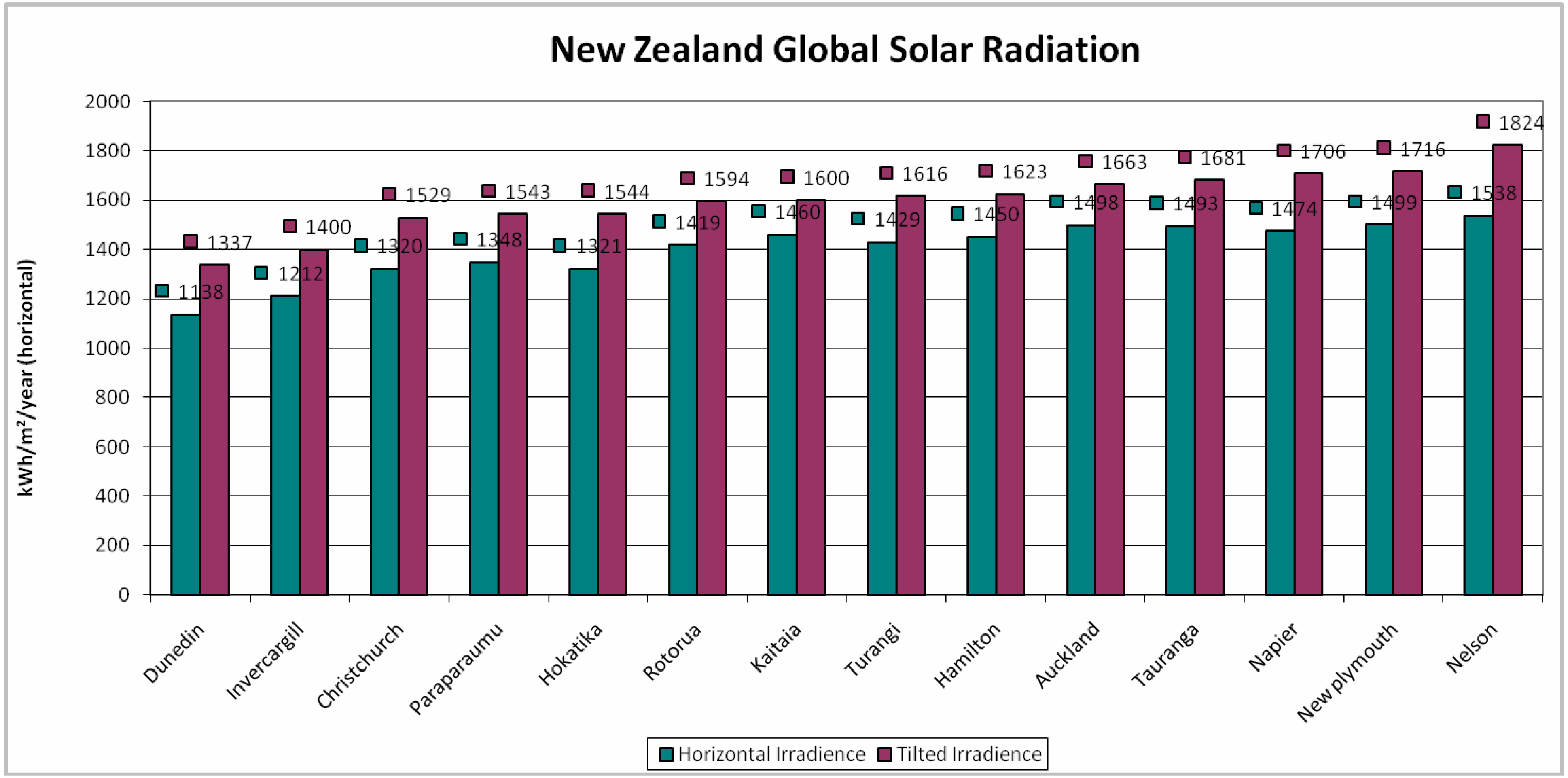


Figure 6.2: Global solar radiation levels of major centres in New Zealand (based on NIWA HER weather files)

6.1.1 Energy Yield for grid connected PV arrays in NZ

Figure 6.3 shows the expected annual specific energy yield of a grid connected PV array in four main centres in New Zealand. Actual yield for any given year will vary as a result of available solar radiation.

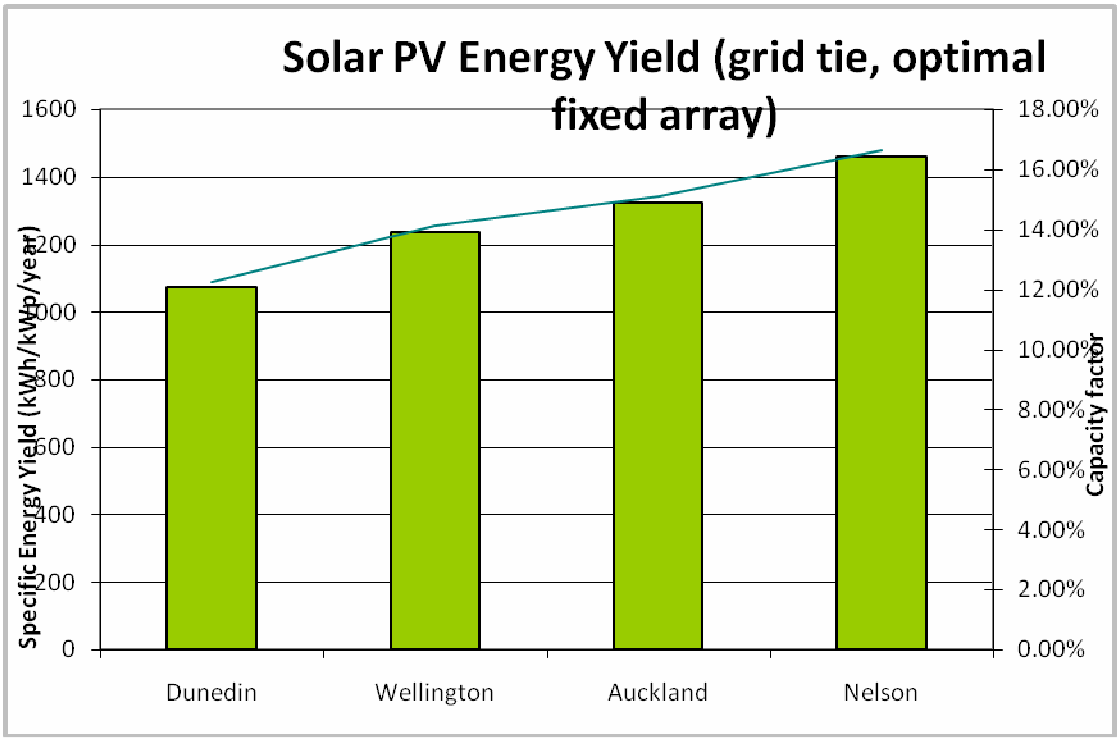


Figure 6.3: Expected annual specific energy yield for fixed grid connected PV arrays in New Zealand

Assumptions for Figure 6.3:

Orientation – north

Inclination – (37°, 33°, 33°, 30°)

Inverter – SMA 6000TL with 97% efficiency

Average module performance based on a range of poly, mono and a-Si modules, expected variation of +/- 5% due to module factors such as technology, power mismatch

Wiring losses – 3%

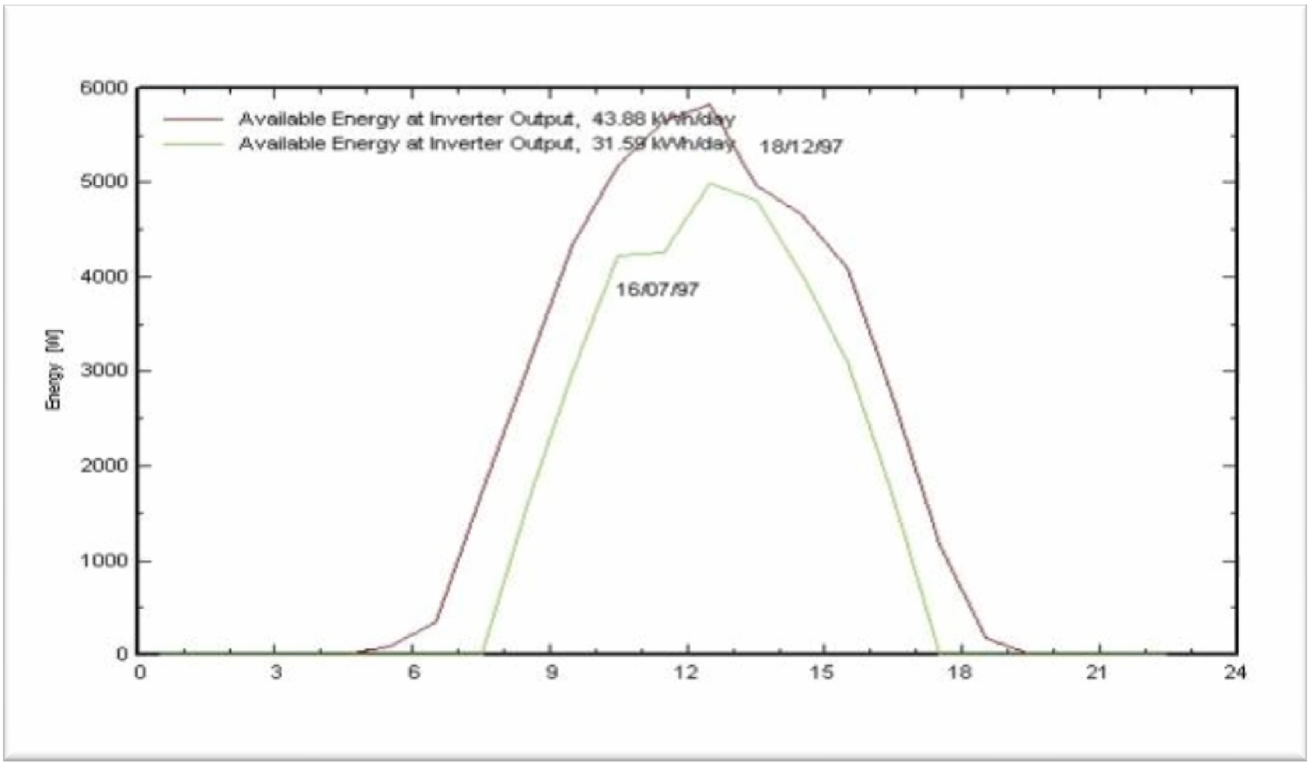
Soiling – no soiling losses assumed

Yield will be greater during the summer months, as illustrated in Table 6.1. For Auckland, a capacity factor of 15% can be achieved and the use of array tracking can increase this to 20%.

Table 6.1: Typical percentage of annual energy yield by month (Auckland)

	Fix optimal array	2 Axis Tracking Array
January	10.93%	11.41%
February	9.45%	10.48%
March	9.15%	9.13%
April	6.76%	6.44%
May	6.33%	6.24%
June	5.44%	5.53%
July	6.16%	6.29%
August	7.16%	7.16%
September	8.07%	7.98%
October	9.60%	9.85%
November	10.20%	10.64%
December	10.74%	11.33%
	100%	100%
Capacity factor	**15%**	**20%**

Energy yield will peak during the day when maximum solar radiation falls on the plane of the PV array. Figure 6.4 shows typical generation over the period of one day for relatively clear skies in



Auckland in the summer and winter.

Figure 6.4: Typical generation by hour for summer and winter days with relatively clear skies for a 7.2 kWp fixed array, Auckland (generated from PVsyst using actual data)

7. STATUS AND PROSPECTS FOR PV IN NEW ZEALAND

7.1 The current state of the market

Industry surveys undertaken by SEANZ (SEANZ, 2007) and by the authors for this report indicate a typical annual market deployment rate between 420 – 750 kWp. 2008 saw the installation of over 110 kWp of grid connected solar PV, which is a significant growth over 2007 and represents 15 - 25% of the PV market. 80 kWp of these grid installations were from 2 projects: the Auckland International Airport (51 kWp) and stage 2 of the Genesis Schoolgen programme (15 x 2 kWp systems) (SEANZ, 2008). The remainder of the solar PV deployment is mainly small off-grid or fringe of grid remote homes with system sizes between 0.5 kWp – 2kWp. There have been a number of larger off-grid installations in the last 2 years. The Department of Conservation (DOC) commissioned two systems on Tiri Tiri Matangi (7 kWp) and Little Barrier Island (3.5 kWp) in the Hauraki Gulf. There has also been a number of larger private off grid systems, including a 24 kWp system near Wanaka in the South Island.

Late in 2007 SEANZ undertook a survey of the long standing companies within the small scale renewables industry of New Zealand. This survey concluded that there was approximately 4.8MWp of solar PV installed in NZ (SEANZ, 2007).

The SEANZ market survey shows that historically the majority of PV installations have been in small (<2 kWp) stand alone systems, with occasional larger installations, such as those on Great Barrier Island in the Hauraki Gulf where all of the electricity for the 850 permanent residents is supplied from stand-alone power systems, including a significant portion of solar PV systems.

Figure 7.1: Auckland international airport stage 1 grid tie installation, 51 kWp (Sharp modules installed by Reid Technology)

7.2 PV Costs in New Zealand

Wholesale PV module prices at the distribution level (including distributors' margin) in NZ are currently between US$4 - 5.40/Wp. Retail prices are between US$6 - $10/Wp[3]. Typical international prices in 2007, shown in Table 3.2, ranged from US$3.70-7.60. Module prices quoted for a particular installation vary depending on the supply chain. As can be seen from Figure 5.1, there can be several transactions involved, with each adding to the system cost.

7.2.1 Grid tie system costs

Wholesale prices are generally seen on systems larger than 2 kWp. Large systems gain price advantages since many PV distributors bid for the project and modules can be purchased in bulk.

Table 7.1: Installed system price for grid tie PV systems by system size (US$/Wp)[4]

Small (<2kW)	8.50 - 9.70
Medium (<10kW)	7.40 - 8.60
Large (>100kW)	6.50 - 8.00

Table 7.2: Cost breakdown of grid tie retail system pricing

Item	Percentage of price	Effected by foreign exchange	Notes
PV Module	65%	Yes	Predominately linked to the US Dollar
Inverter	12%	Yes	Predominately linked to the US Dollar
Mounting	8%	Product dependant	1 local mounting system exists Others are imported from Australia, Europe and the US
BOS	5%	Yes	
Installation	10%	No	

With few components locally made, system prices are obviously highly dependent on the exchange rate, particularly NZ$ against US$, but also NZ$ against AUS$. As discussed in Section 3, the current trend is towards increased manufacture in Asia. Although international module prices may

[3] The higher price of PV module retail in NZ represents a retail price per module. It is unlikely that prices would be this high for PV modules as part of a system

[4] Installed cost in NZ as of December 2008

still be quoted in US$ or Euro in the short term, it may become increasingly possible to negotiate module prices in local currencies, which could benefit NZ PV system prices.

7.2.2 Off grid systems costs

Off grid system costs vary significantly with design, location and equipment specification. In particular inverters and batteries vary in prices with technology. A typical stand alone power system for a home is expected to be in the region of $20 USD/Wp installed, excluding back up generation. Typical system cost breakdown is shown in Table 7.3

Generally, small systems are designed to minimise or remove the need for back up generation. The design of larger systems varies. Some may be designed for a large solar fraction, while others to supplement another form of generation (eg diesel). As such, costs of these systems vary vastly if normalised by kWh of daily demand.

Off-Grid system electricity costs vary due to:

- Location
- Specification and quality of components
- Variation in quality of system installation and conformity to standards
- Percentage of users' energy needs from PV (solar fraction) and effect on ongoing operational costs
- Balance between energy efficiency (reduction of energy needs) and generation of energy – therefore system size
- Use of alternative means of energy generation (eg for heating)

Table 7.3: Typical Off-Grid System Cost Breakdown

Component	Typical percentage of cost	Range as percentage of system cost	Effected by Exchange Rate
PV modules	40%	33% - 45%	Yes
Inverter and controller	16%	6% - 23%	Yes
Batteries	26%	20% - 34%	Yes (some local manufacture but not solar batteries. Materials link to foreign currency)
Mounting	4%	3% - 5%	No (but materials linked to foreign currency)
Switch gear and cabling	5%	5% - 10%	Yes
Installation	9%	8% - 14%	No

7.3 PV and electric vehicles

Approximately 86% of New Zealand's oil consumption is used in the transport sector. New Zealand relies heavily on imported crude oil for the transport sector, thus exposing the country to international prices increases due to high demand and shortage of supply (Ministry for Economic Development, 2008)

The transport sector also has a major influence on New Zealand's greenhouse emissions, contributing 14.9Mt CO_2e in 2007, a 69.8% increase from 1990 levels (ibid). The base case model predicts an increase in energy use from transport of 1.0% per annum (25% to 2030).

Electric vehicles (EV's) are seen as one of the main solutions to reducing dependence on oil imports and reducing CO_2 emissions from the transport sector. The 2007 NZES sets a target for New Zealand to be one of the first countries to widely adopt electric vehicles. The Electricity Commission's modelling for EV uptake predicts electricity demand from EV's and plug-in hybrids to reach 5000GWh by 2020.

A synergy exists between the deployment of EV's and PV generation. Peak PV generation may not typically be at the time of peak electricity demand in New Zealand. The addition of storage in the form of plug in EV's provides a means to shift demand to follow PV generation. This application could be further facilitated by the roll-out of smart grid technologies which allow great demand side management. International companies, such as Better Place, are now establishing renewable energy powered EV recharge facilities in several countries. EV owners lease the batteries and can replace or recharge them as required (Agassi, 2008)

Further opportunity exists with the use of PV to produce hydrogen as an energy storage medium and transport fuel. Honda is currently undertaking a trial of hydrogen fuel cell cars in California, using a network of PV powered hydrogen fuelling stations (Donaldson, 2008).

7.4 Rural Grids

The New Zealand grid, while extensive, suffers from an imbalance of generation in the south island when the majority of demand is the in the north. PV generation is unique is its scalable nature and in its ability to be installed at the location of demand. Resource consenting issues would be negligible, while other projects, for example the gas fired generation plant proposed in the Rodney district of Auckland, suffer from a long and expensive resource consenting process and resistance from the local population.

Many of the remote lines that were installed under government subsidises during the 1940's-1980's are nearing the end of their design life. The replacement of these lines with a stand-alone power systems may, in some cases, be a more economical means of providing electricity than replacement and ongoing maintenance of these remote lines (Empower Consultants, 2008). Presently the maintenance of these lines is effectively subsidised by consumers in areas where electricity distribution is financially viable.

7.5 Diversification of Electricity Supply – Solar Farms

New Zealand's electricity generation is heavily reliant on large hydro, typically 55% or more of electricity generation. Shortfalls in low rainfall years have predominately come from thermal generation using coal.

Coal, and to a lesser extent gas, will eventually be penalised if an emissions trading scheme is implemented, with the price of carbon likely to be linked to the fluctuations in an international market.

Currently 25% of New Zealand's electricity generation is from gas. With limited local supplies of gas, New Zealand will eventually be reliant on imported liquefied natural gas purchased at market rates in a market with growing demand for gas and limited supply.

Investment in PV generation would allow further diversification of New Zealand's electricity supply, hedging against increased fuel cost, availability of fuel and carbon prices. This could be via the smaller scale distributed generation discussed above, or via larger scale central generation plant, or "solar farms", installed and operated in a similar way to wind farms, using electricity sector or private investor finance.

7.6 Demographics and the Residential PV Market

The majority of New Zealand's population live in single family dwellings with significant available roof space per m² of property floor area. An average New Zealand home uses 11040 kWh/year of energy of which 7800 kWh/year is electricity (Isaacs, 2006). Hence, based on the radiation data provided in Section 6, in Auckland a 6 kWp PV array would be required to provide the average annual electricity needs of an average residential property. An array of this size would require <50m² assuming the use of typical crystalline PV modules. Nevertheless, for grid connected homes, it would be more typical under current PV prices, to install systems around 2 kWp. Improvements in building insulation requirements as part of the New Zealand building code and the use of more effective heating solutions such as heat pumps and solar thermal water heating can reduce average building energy consumption. However, reductions in electricity use will also require improved appliance efficiency and reduced standby loads. As PV prices drop, system sizes will no doubt increase. Likely price trends are discussed in Section 8.

Table 7.4: Trends in Rural and Urban Populations NZ 1996-2007 (Statistics New Zealand)

	1996	2001	2005	2006	2007
Urban	85.49%	85.77%	86.12%	86.13%	86.16%
Rural	14.51%	14.23%	13.88%	13.87%	13.84%

Under medium projections, the population of the North Island is expected to increase by an average of 0.9 percent a year between 2006 and 2031, from 3.19 million to 3.96 million. Almost three-quarters of this growth will be in the Auckland region, with the remainder of the North Island projected to grow by an average of 0.5 percent a year during this period. By 2031, the North Island is projected to be home to 78 percent of New Zealand's population, compared with 76 percent in 2006. The population of the South Island is projected to increase by 0.5 percent a year, from just under one million in 2006 to 1.13 million in 2031. The faster projected growth of the North Island mainly reflects its higher rate of natural increase resulting from a higher birth rate and lower death rate than the South Island.

The gradual increase in population from rural to urban will reduce further the loads on rural lines, thus exacerbating the cross subsidy issues discussed above. Similarly, the higher rate of population growth in the north island, will increase the need for electricity supply in the north island, further exacerbating the current generation imbalance.

Of the 1.45 million occupied dwellings in New Zealand at the last census (Statistics New Zealand, 2007), 1.13 were separate houses and close to 67% were owner occupied. These homes represent the most immediate market for residential rooftop PV, although rented accommodation could also provide a useful market if investment incentives are provided. Some of these homes are off-grid and may already find PV a relatively viable option. This is an immediate market sector, but may have limited opportunity to grow. However, the urban population is growing and, in the longer term, grid-connected residences are likely to provide an important market sector. Multi-occupancy dwellings, such as apartment buildings can use PV for common area lighting, such as security, stairwell and garages, if building codes and/or investment incentives favour PV. In the short term, commercial building applications may also prove a good market in New Zealand, if investment incentives are appropriate. This is discussed in Section 8.2.

7.7 Current Issues Impacting PV Uptake

A number of barriers have been identified that are currently affecting the industry or have the potential to affect future growth:

7.7.1 Capital cost

The up-front cost of investing in PV remains high, despite steady decreases over the past 3 decades. For off grid systems this is often assessed against the cost of connection to the grid, the cost of diesel generation, and in conjunction with potential energy savings available through energy efficiency and use of other energy sources as appropriate, such as solar thermal and biomass heating. For grid-connected customers though, the comparison is with ongoing electricity bills rather than capital investments. Nevertheless, for both customer groups, the cost of PV electricity needs to be amortised against their long term alternative energy expenditure. While some customers may pay the up-front cost in cash, many choose to add it to their mortgages, or take out separate financing. Internationally, finance is often offered by the PV supplier.

Some studies have indicated e.g. (Coburn, 2004) increased property values for homes with solar PV. Other financial models attribute additional value to homes with PV systems by assessing the electricity cost savings and the increased ability of a home owner to repay a mortgage. In Australia, Bendigo Bank and others, offer a lower mortgage rate to customers who invest in making their homes energy efficient or who add renewables (Bendigo Bank, 2002). In the US, where the commercial and other non-residential PV markets are significant, a range of financing options is now available (Bolinger, 2009).

While many spending decisions in the construction or improvement of a home could be considered economically irrational or emotive, since they are driven by aesthetics, or desires for comfort or convenience, PV systems are generally assessed on their financial returns. Value is usually not given to the environmental benefits, potential increased home value or the value of hedging against future potential energy price increases. Nevertheless, businesses are now placing increased value on the corporate, social and environmental responsibility aspects of solar PV systems, as demonstrated by installations such as the Auckland International Airport. As carbon prices and the cost of continued increases in electricity demand gradually work their way into electricity pricing, the perceived value of PV will increase.

7.7.2 Awareness

There is generally a poor awareness of photovoltaics and a lack of understanding about how the technology may be applied to a home (urban or remote), a commercial property or a power station. As there are few independent and comprehensive sources of information for consumers, the technology is often over looked or a better known and understood technology utilised.

Solutions include:

- The Schoolgen solar schools program will increase community awareness and understanding of PV. This should be accompanied by educational material.
- PV use in government buildings can be used as a means of technology acceptance and awareness raising
- Information on PV should be made available on relevant government, energy utility and local council energy websites

7.7.3 Competency and Standards

There are currently no means of identifying competent system designers or installers. Customers who have had a poor experience with inferior system design, installation or product may cite the technology as inadequate, unsuitable or the industry as not having sufficient competency. News of poor experiences and poor product performance tend to circulate quickly via word of mouth and it can take many years to re-establish community trust in a technology.

The current set of standards for PV system installation is referenced in the NZ wiring rules AS/NZS 3000:2007. However there is generally limited knowledge of these standards and their practical application, resulting in a wide range of system quality and conformity, as well as significant variations in performance and price. With limited understanding of how to identify a good system over a bad, many consumers opt for the lowest cost solution, which may not perform to expectations.

The lack of workers skilled in direct current work, battery installations and renewable energy systems is reducing the ability of companies to offer high quality, safe and well performing systems. The lack of appropriately skilled workers has the potential to reduce the ability of companies to grow.

Solutions include:

- Promotion of design and installation standards and training in their practical application would help to improve system performance, quality and safety.
- Trade and university based courses on PV system design and installation should be instigated, with associated certification. Businesses with certified designers and installers would then be able to advertise as such.

7.7.4 Electricity Buyback Arrangements

Distributed electricity generators in New Zealand can sell electricity back to the grid. However, under New Zealand law, they must comply with the rules, including the requirements that all generation that is injected into the grid is reported to the reconciliation facility for the market on a monthly basis and that generators obtain certification that their (metering) processes are robust and accurate. Compliance with the rules imposes significant cost and is therefore appropriate for large generators only.

Alternatively, generators can sell electricity to the retailer, rather than directly into the market through the clearing manager, and compliance will be dealt with by the retailer. These requirements effectively limit a small generator to conditions negotiated with the retailer. This raises a few issues:

1) There is no obligation for an electricity retailer to purchase electricity from the owner of a micro scale generator.
2) There are no pricing principles (and perhaps, limited incentives) to ensure that prices offered by retailers are fair to both parties.
3) Owners of micro scale generation do not have a low cost means of receiving the wholesale market clearing price if they cannot agree an acceptable price from a retailer.

Some retailers offer net billing, but net metering, which is widely used internationally as a means of valuing network benefits and is mandated in most US States, is a breach of current New Zealand regulations. However, the more important aspect at present is that the current market conditions do not encourage small generators to sell excess electricity.

Any payment received for electricity exported to the grid is liable for income tax. The Electricity Commission have recently amended rules to allow gifting of electricity to an electricity retailer, thus avoiding costs of settlement, including any liable tax on income. The preferred option of the electricity commission for income tax, although not implemented at this time, is to treat all payments received by consumers for exported electricity as tax exempt. This provision would need to be clarified if feed-in tariffs were to be considered.

The current implementation of smart meters in some areas will help to facilitate connection and remove additional metering cost, providing sufficient channels are available. Smart meters could also be used to provide incentives to encourage demand side load management and matching of load to solar PV generation profile, via suitable time-of use tariff structures.

7.7.5 Building Approval Processes

The building consent process presents delays and increased cost for many installations. The main problems are:

- A poor understanding within Councils about the technology (eg systems are often confused with solar hot water systems). This also leads to misconceptions about issues such as reflectivity.
- Little understanding of how to assess compliance, which is not helped by the lack of standards.
- High and/or inconsistent fees
- Within the PV industry, there is generally a poor understanding of the building consent process, resulting in incomplete applications or incorrect information supplied

Possible solutions:

- Promotion of relevant standards for products and installation
- Standard approval processes agreed by all Councils (guidelines for Councils on handling micro-generation are currently being developed by SEANZ and EECA)
- Solar Access legislation
- PV information and education for Councils. CCP-NZ (Cities for Climate Protection program of ICLEI) could be used as a vehicle.

7.7.6 Energy rating schemes

There is an international trend towards low and zero energy/carbon homes. On-site renewable generation, including PV, can be used to offset or replace energy use from the grid. Voluntary rating schemes such as passivhaus (Germany) and building codes such as the Code for Sustainable House (United Kingdom) incorporate the zero energy home concept.

At present in New Zealand the Green Star rating tool and HERS scheme do not give specific points for the installation of PV. Local energy and sustainability rating schemes could be used to help encourage the use of PV and recognise its environmental benefits.

7.7.7 Market Size and Composition

The small New Zealand PV market lacks buying power in an international market where single projects often install 10 – 20 times the annual NZ capacity. This may improve as supply increases relative to demand but in the longer term requires a consistent and robust NZ market for module and BOS component suppliers to establish retail chains.

There have been a number of new entrants to the solar PV market in New Zealand in the last 2 years, which has increased competition. These include Powersmart Solar, Black Diamond Technologies/Mitsubishi and Elemental Energy.

Currently some NZ utilities are developing strategies and business models to encourage small-scale renewables generation opportunities, including solar PV:

Meridian Energy, through their Right House business have a joint venture called Elemental Energy. They are responsible for installing small-scale renewable energy solutions for residential and commercial organisations, which Right House commissions. This involves a one stop 'shop' for energy efficiency design in buildings and small-scale renewables installation.

7.8 Policy issues impacting on PV Uptake

7.8.1 Electricity Industry Regulation

The Electricity (Low Fixed Charge Tariff option for Domestic Consumers) Regulations 2004[5] require retailers to offer domestic consumers tariff options with a fixed charge of no more than 30 cents per day (excluding GST but after any prompt payment discount). The regulations also require electricity distributors (lines companies) to offer tariff options with a fixed daily charge of no more than 15 cents per day to assist retailers in providing low fixed charges.

Low fixed charge tariff options generally include a higher variable (per kWh) charge to the consumer, but must still be cheaper for the average consumer (defined as a consumer using 8,000kWh per year) on an annual basis. Amendments to the regulations have been introduced to change the definition of an average consumer to 9,000kWh for the lower South Island (Christchurch and below, excluding the West Coast) to take into account the cooler climate. This amendment takes effect on 1 April 2009.

The Electricity Commission is charged with monitoring and enforcing these regulations.

The obligation to provide low fixed charge options to domestic consumers could have implications for the provision of onsite generation because of the constraint it places on the fixed daily charge. Distributors and retailers can apply for exemptions to the regulations if certain criteria are met. For example, distributors can be granted an exemption for remote areas with single lines serving few homes, or for homes served by dedicated transformers. Two new exemption criteria were added in the above mentioned amendments – one for non-grid connected networks, another for homes on 3-phase or greater than 15kVA supply.

If the penetration of distributed generation increases significantly, there will need to be reconsideration of how the electricity network is managed, as discussed in Section 4.3, as well as how the fixed costs of maintaining the electric network are calculated and collected.

Electricity Governance (Connection of Distributed Generation) Regulations 2007 were introduced "to enable connection of distributed generation where connection is consistent with connection and operation standards". Rules are defined for generation with capacity above and below 10kW, effectively ensuring that all generation under 10kWp can be connected, provided it meets the appropriate standards. Generation above 10kWp may require assessment of required network upgrades/changes the cost of which may be borne by the generator.

"The regulations specify processes (including timeframes) under which generators may apply to distributors for approval to connect distributed generation (including the information to be exchanged and the criteria for approval); regulated terms that apply to the connection of distributed generation in the absences of contractually agreed terms; pricing principles to be applied for the purposes of the regulations; and a default dispute resolution process for disputes relating to the regulations."[6]

Nevertheless, since contracts for sale of electricity must still be made with a retailer, lines companies will not connect a customer without an export contract.

7.8.2 Market Support

Recent significant growth in the application of PV in international markets is a direct result of Government initiatives and incentives aimed at encouraging investment in solar PV product development and installations. They have been accompanied by quality training programs for industry workers. For there to be significant growth in the New Zealand PV market at the current price of PV, incentives would be required.

While net billing offers are available from 2 Electricity Retailers, no fixed period is defined for continued purchase of electricity exported to the grid. There is also little or no incentive for

[5] Made under sections 172B, 172J and 172K of the Electricity Act.

[6] MED website

Electricity retailers to buy exported electricity and public awareness of the option is low. Without a legislated metering and billing structure, the continued lack of a guaranteed income from exported electricity further reduces the viability of investing in grid connected PV.

At such a time as PV becomes cost competitive with grid electricity, or should an incentive scheme be implemented in NZ, foreign companies (such as from Australia) would be in a strong position to dominate the NZ market due to greater access to supply, capital, and skills.

8. POSSIBLE SCENARIOS FOR SOLAR PV IMPLEMENTATION IN NEW ZEALAND TO 2035

The largest PV markets internationally are currently grid-integrated and subsidized in one way or another for reasons of national energy supply security, environmental concerns or economic development. Without such subsidies, the most robust markets are in off-grid applications where electricity alternatives are unavailable or economically or logistically difficult to deliver. In New Zealand, the current, unsubsidized market comprises mainly off-grid residential, farming and island applications, as an alternative to diesel generation and in areas where grid connection would be too costly. These markets, though relatively small, will remain and are likely to grow, as the cost effectiveness of PV improves with time.

The potential market for grid applications of PV in New Zealand is larger, and the prospects for this market developing in the longer term are good, since PV is easy to install, modular and widely applicable. Once the cost of electricity from solar PV reaches that of prevailing retail electricity tariffs (so called 'grid parity'), or at such a time as incentives are provided that result in a economically attractive financial return from investment in PV, significant market growth could be expected. If projected PV production cost decreases are realised, investment in utility scale power plants could also occur, as is already occurring internationally, with PV used as a cost effective means of adding generation capacity, particularly to the growth areas of the North Island.

The following Section provides the results of modelled PV system costs and anticipated New Zealand electricity prices, based on the information covered in the earlier Sections of this report. The graphs show possible price parity points for different PV technologies, different applications and different New Zealand locations. The detailed assumptions used for the modelling are provided in Appendix 2 and the projected PV electricity costs to 2035 are summarized in Table 8.1. These are derived from the New Zealand solar resources discussed in Section 6 and projected PV production cost reductions discussed in Sections 2 and 3 and shown in Table 3.3. The latter have been converted to an average annual cost reduction of approximately 6% to 2030 and 3% thereafter for the weighted average mix of technologies. This is currently dominated by crystalline silicon but changes over time to greater penetrations of thin film and emerging technologies, as shown in Figure 3.3. The higher initial price drop is due to the current relatively high price of PV in New Zealand, which is expected to gradually reach world parity pricing as the market matures. For thin film technologies, such as CdTe, the price drop modelled is 10% to 2015, based on projections by leading companies such as First Solar (First Solar, 2008) and 4% thereafter. As the cost of PV modules declines, the relative proportion of the balance of system component costs is expected to increase. For instance, for small PV systems, the modules account for 67% of the total system cost at US$5/Wp and 48% at a module cost of US$1/Wp. The assumptions used are shown in Appendix 2.

The discussion of PV costs so far in this report has been in 2008 $US, because this is the international benchmark price in which PV costs are quoted. However, in this Section, electricity prices are provided in 2008 $NZ, so as to allow comparison with prevailing electricity prices. An exchange rate of 1.68276 US$ to 1 NZ$ has been assumed.

Based on the current New Zealand PV market, its electricity system and international PV trends, four key prospective PV markets are examined in more detail below: residential grid connected systems, commercial/industrial grid systems, central PV power stations and off-grid residential systems.

Table 8.1: Projected PV Electricity Costs 2009-2030 for Different NZ Locations ($US & NZ 2008)

Cost per kWh ($2008) Systems < 2 kWp								
Year	Auckland		Wellington		Dunedin		Nelson	
	$US	$NZ	$US	$NZ	$US	$NZ	$US	$NZ
2009	$0.60	$1.01	$0.64	$1.08	$0.74	$1.24	$0.54	$0.92
2010	$0.56	$0.95	$0.60	$1.02	$0.69	$1.17	$0.51	$0.86
2015	$0.42	$0.70	$0.45	$0.75	$0.51	$0.86	$0.38	$0.64
2020	$0.31	$0.52	$0.33	$0.55	$0.38	$0.64	$0.28	$0.47
2025	$0.23	$0.38	$0.24	$0.41	$0.28	$0.47	$0.21	$0.35
2030	$0.17	$0.28	$0.18	$0.30	$0.21	$0.35	$0.15	$0.26
2035	$0.14	$0.24	$0.15	$0.26	$0.18	$0.30	$0.13	$0.22
Cost per kWh ($2008) 2 -10 kWp Systems								
Year	Auckland		Wellington		Dunedin		Nelson	
	$US	$NZ	$US	$NZ	$US	$NZ	$US	$NZ
2009	$0.56	$0.89	$0.60	$0.95	$0.69	$1.09	$0.51	$0.81
2010	$0.53	$0.84	$0.56	$0.90	$0.65	$1.03	$0.48	$0.76
2015	$0.39	$0.62	$0.42	$0.66	$0.48	$0.76	$0.36	$0.56
2020	$0.29	$0.46	$0.31	$0.49	$0.36	$0.57	$0.26	$0.42
2025	$0.22	$0.34	$0.23	$0.37	$0.27	$0.42	$0.20	$0.31
2030	$0.16	$0.25	$0.17	$0.27	$0.20	$0.31	$0.15	$0.23
2035	$0.13	$0.22	$0.14	$0.23	$0.16	$0.27	$0.12	$0.20
Cost per kWh ($2008) Off-grid 2-10 kWp Systems								
Year	Auckland		Wellington		Dunedin		Nelson	
	$US	$NZ	$US	$NZ	$US	$NZ	$US	$NZ
2009	$1.25	$2.02	$1.34	$2.16	$1.54	$2.49	$1.13	$1.83
2010	$1.20	$1.94	$1.28	$2.08	$1.48	$2.39	$1.09	$1.76
2015	$0.99	$1.60	$1.06	$1.71	$1.22	$1.97	$0.90	$1.45
2020	$0.81	$1.31	$0.87	$1.40	$1.00	$1.62	$0.74	$1.19
2025	$0.67	$1.08	$0.71	$1.15	$0.82	$1.33	$0.60	$0.98
2030	$0.55	$0.89	$0.59	$0.95	$0.67	$1.09	$0.50	$0.80
2035	$0.45	$0.73	$0.48	$0.78	$0.55	$0.90	$0.41	$0.66

Cost per kWh ($2008) Systems > 100 kWp								
Year	Auckland		Wellington		Dunedin		Nelson	
	$US	$NZ	$US	$NZ	$US	$NZ	$US	$NZ
2009	$0.51	$0.80	$0.54	$0.86	$0.62	$0.99	$0.46	$0.73
2015	$0.48	$0.76	$0.51	$0.81	$0.59	$0.93	$0.43	$0.69
2020	$0.35	$0.56	$0.38	$0.60	$0.43	$0.69	$0.32	$0.51
2025	$0.26	$0.41	$0.28	$0.44	$0.32	$0.51	$0.24	$0.37
2030	$0.19	$0.30	$0.21	$0.33	$0.24	$0.37	$0.17	$0.28
2035	$0.14	$0.22	$0.15	$0.24	$0.17	$0.28	$0.13	$0.20

Cost per kWh ($2008) CdTe Systems > 100 kWp								
Year	Auckland		Wellington		Dunedin		Nelson	
	$US	$NZ	$US	$NZ	$US	$NZ	$US	$NZ
2009	$0.37	$0.62	$0.40	$0.68	$0.46	$0.77	$0.34	$0.57
2010	$0.33	$0.56	$0.36	$0.61	$0.42	$0.70	$0.30	$0.51
2015	$0.20	$0.34	$0.22	$0.37	$0.25	$0.42	$0.18	$0.31
2020	$0.17	$0.28	$0.18	$0.30	$0.21	$0.35	$0.15	$0.25
2025	$0.14	$0.23	$0.15	$0.25	$0.17	$0.28	$0.12	$0.21
2030	$0.11	$0.19	$0.12	$0.20	$0.14	$0.23	$0.10	$0.17
2035	$0.09	$0.15	$0.10	$0.17	$0.11	$0.19	$0.08	$0.14

8.1 Residential Grid connected systems

With the majority of buildings in New Zealand connected to the national electricity grid, the largest potential growth long term in the NZ PV market is likely to be grid connected systems. There has been significant growth in this market in the last 2 years, with more than 110 kWp of grid connected PV installed in 2008.

Growth has mainly been driven by corporate clients utilizing solar PV to make a statement about their environmental credentials and to gain credits as part of a green building rating scheme. Smaller private systems have been implemented through a desire to make a personal contribution to the challenges of climate change through the generation clean electricity. Property developers have been investigating the use of PV as part of a wider solution for sustainable residential developments.

As discussed in Section 4, this market sector currently accounts for the largest installed capacity of PV world-wide. To be attractive to residential customers, the amortised cost of electricity from a PV system installed on their home need only reach retail rather than wholesale electricity prices. New Zealand weighted average retail electricity prices from 1999 to 2008 have increased by 6.45% in current $, as shown in Figure 8.1 and currently average $0.248 per kWh.

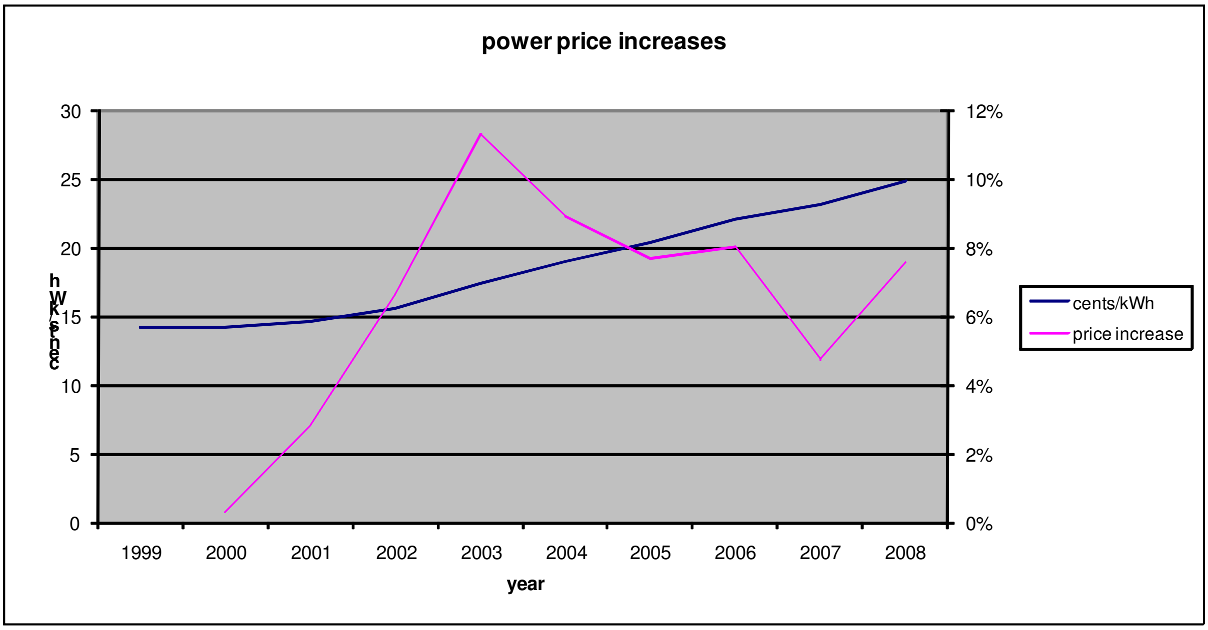


Figure 8.1: Weighted average retail electricity prices (current NZ$) and percentage price increase 1999-2008 (Ministry of Economic Development, Nov 2008)

Electricity generated and used on site displaces electricity drawn from the grid. In a net billing arrangement, any electricity export receives the retail rate of electricity. Price increases over coming decades are expected to be lower than they have been recently. The Electricity Commission Statement of Opportunities (Electricity Commission of New Zealand, 2008) anticipates wholesale prices increasing by 2% per annum in real terms in the short term, falling to 1% in the longer term, while the earlier New Zealand Energy Outlook projected retail price increases of 2.2% per annum in real terms to 2030 (New Zealand Ministry of Economic Development, 2006).

Government incentives can be relatively easily applied to the residential sector via grants, tax benefits, feed-in tariffs or building codes and many countries have chosen to do so, as discussed in Section 3. Although these can be costly in the short term, costs can be offset by increased industry activity, jobs, training and taxes. This has been clearly shown in countries like Germany and Spain, as previously discussed, while renewable energy development is now being actively pursued in the USA as an economic stimulus measure (Renewable Energy World, 2009) (Obama, 2008). Individual investment in PV can also be driven by environmental concerns, architectural merits, housing value and a desire to be more energy self-sufficient in times of rising or uncertain energy prices.

With house types relatively standardised within the country, it is possible to achieve economies of scale in standardised system design and deployment which can minimise prices. Similarly, with economies of scale in large scale purchase of PV modules, inverters and mounting fittings, component prices can be reduced.

Of the 1.45 million occupied dwellings in NZ in 2006 (Statistics New Zealand, 2007), 1.13 million were separate houses and 66.9% were owner occupied. Hence there are 0.75 million houses in New Zealand potentially interested in installing PV. Of course, not all these homes would necessarily have roofs with appropriate orientation, space or unimpeded solar access. Rented homes can also provide a market, but different investment mechanisms are usually necessary, since the home owner typically would not benefit from the reduction in purchased electricity resulting from a PV installation.

Residential system sizes can range from 0.5 kWp to 5 kWp, or even more. In Australia, 1 - 1.6 kWp systems (6-10 modules) are typical; in Japan, typical system sizes are 3 - 4 kWp. 1 MW of PV could potentially be installed relatively quickly in New Zealand, if 500 homes were each to install a 2 kWp PV system. For example, 1.8MW of residential rooftop PV was installed in Australia in 2006, 4.2

MW in 2007 and 12.1 MW in 2008 under a grant based incentive program (Australian Government Department of Environment, Water, Heritage and the Arts, 2009).

Figure 8.2 show projected electricity price increases and PV electricity cost decreases for various New Zealand locations from 2009 to 2035 and indicates that grid parity could begin to be reached in northern regions by 2020 - 2026.

Photovoltaic building integration, in particular, roof replacement, has the ability to reduce cost and improve acceptance with end users and architects. NZ has a relatively high ratio of metal roofs. These are particularly suitable for the application of low cost roof laminates (current products typically use amorphous silicon), which may be a specific market product not currently supplied in New Zealand, but which may have potential to lower system costs. In the longer term, PV cost effectiveness is likely to be achieved via the use of newer technologies and dual function products, particularly for new buildings.

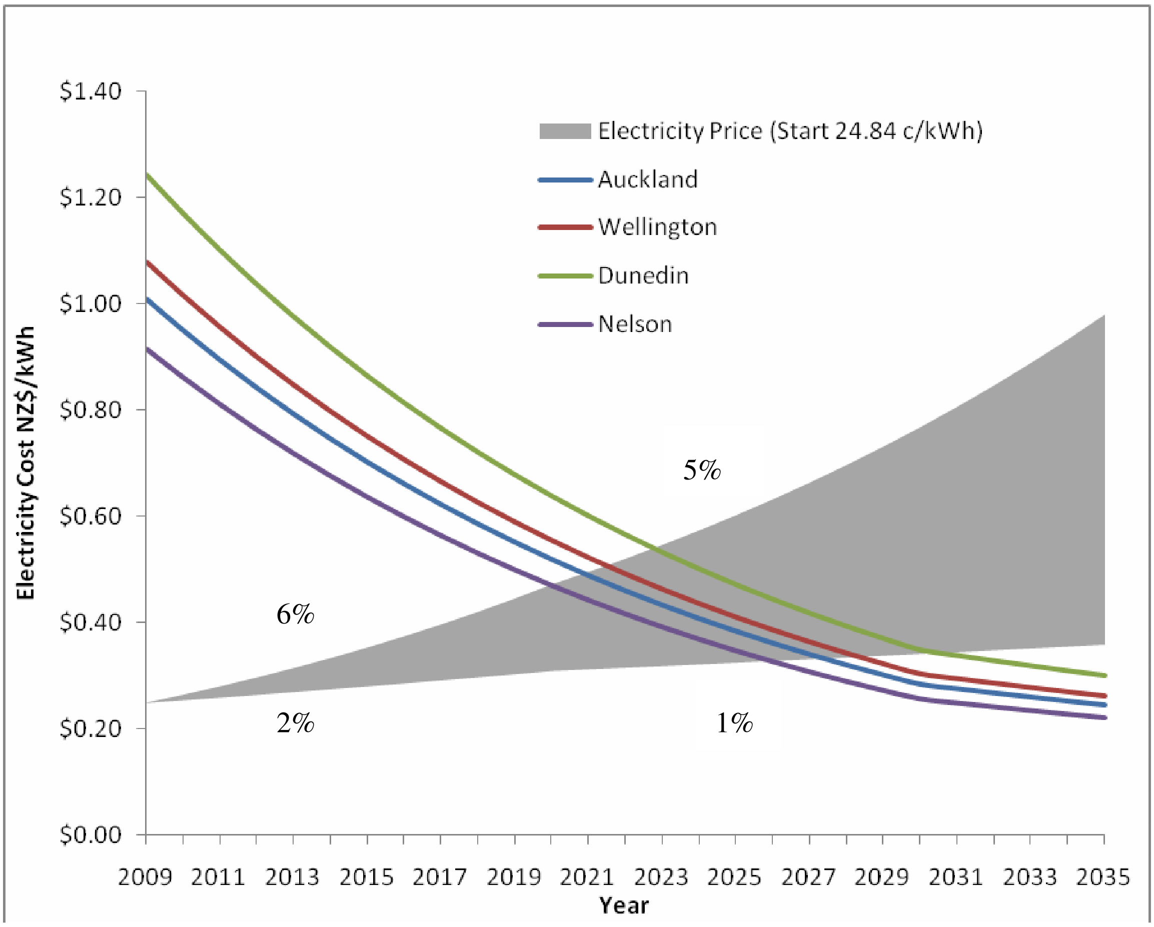


Figure 8.2: Residential PV Projections
Electricity price projections (2008 NZ$), based on increases in the range 2% then 1% and 6% then 5% per annum, and PV electricity price projections for residential roof-top systems using multi-crystalline PV to begin with and progressing over time to include 2nd and 3rd generation technologies. For assumptions, see Appendix 2.

8.1.1 Balance of System Industry and Manufacturing Opportunities

Given the economies of scale in manufacture currently being sought, the New Zealand market is unlikely to be large enough in the short term to attract PV manufacture. Nevertheless, there may be opportunities for NZ designed and/or manufactured balance of system products used in PV systems that can be used locally as well as exported in the region. These could include monitoring systems, Distributed Generation network control systems, Distributed Generation kWh accounting systems, PV system hardware, such as 400V DC bus systems, DC arc detectors and electronic DC break devices. While it is feasible to develop such industries without a local market, as has been done in China with PV modules, this is not usually a successful strategy, since local experience with application of the technology can ensure the product is fit for purpose.

There has been a move away from framed modules to the use of laminates and from installation frames to simple bracket connections. Hence DC wiring, fusing, inverters and meters are the key remaining components. The grid inverter market is reasonably specialised, with a few key companies supplying the bulk of the market.

Meters tend to be specified to meet local utility requirements and hence may be locally sourced. As previously discussed, the deployment of smart meters, as long as they have sufficient channels, can facilitate PV interconnection without the need for a 2nd meter, can provide time of day price signals to consumers, if in-house displays are included, and can also allow for load management, including electric vehicle charging.

There is some interest internationally in the addition of small amounts of battery storage to grid systems, to allow independent operation of the system in the event of grid outage. This is of particular interest in areas which experience frequent grid outages or brown-outs. At present, most utilities require the PV inverter to shut down if the grid fails. However, if the inverter is capable of operating in stand-alone mode, it is possible to manually switch over to this mode until the grid supply is restored. This solution offers a potential extension of the market for solar batteries, which is currently restricted to the off-grid market.

8.2 Grid Connected PV on Commercial and Industrial Buildings

PV systems on commercial and industrial buildings have been one of the biggest markets in Germany and the US, and have provided the volume sales which drove manufacturing scale and cost reduction. Japan also is providing incentives for this market now that the residential market is considered more or less mainstream. The US market is supported by accelerated depreciation, loans and tax incentives. Because most commercial and industrial premises are occupied predominantly during the day, PV output tends to match commercial load much better than it does for residential applications. This has the direct benefit of reducing daytime peak loads on the network. This load reduction can be made secure via small amounts of storage and/or load management (Hoff, 2008).

CBDs and areas surrounding most major towns and cities have large roof spaces on commercial, light industrial, warehouse and supermarket buildings, which are potentially suitable for PV systems between 10 kW and several MW. Commercial buildings may also be suitable for BIPV in windows, window shades and facades, although shadowing from adjacent buildings needs to be considered.

Cost projections of commercial PV systems against commercial electricity prices in New Zealand from 2009-2035 are shown in Figure 8.3. Although PV costs are lower than for residential systems, because of economies of scale, the lower electricity prices mean that grid parity is also reached by 2020 to 2027 in the northern regions. Nevertheless, commercial customers have access to a wider range of cost recovery than do residential customers, including investment allowances and depreciation. They also face the prospect of higher daytime peak tariffs, which can mean that the actual electricity price which PV is displacing is higher than the average modelled here and hence PV may reach grid parity sooner. There is some evidence that ‘green’ commercial buildings can achieve higher tenancy rates and higher rents, which can also contribute to the cost effectiveness of PV (Lam, 2008).

8.2.1 Electric Vehicle Charging

The New Zealand Government’s aim to lead the world in electric vehicle (EV) adoption could also be linked to both PV supply and load management in the commercial and light industry sector. The latter has already been examined by the Electricity Commission and found to have useful peak load reduction potential (Electricity Commission, 2008). Combined with PV charging stations, particularly if sited at work locations, such as commercial centres, shopping centres, and public transport parking hubs, electric vehicles could provide an important PV market as well as a useful means for NZ to reduce transport emissions and oil imports.

Using electric vehicles on the grid has been recently coined *vehicle-to-grid* or V2G. Essentially an EV or a plug in hybrid that has some form of (battery) storage and appropriate controls can potentially be used in a vehicle-to-grid role. Generally, in metropolitan areas, most vehicles are parked for a significant percent of the time, allowing their batteries to be used as short term storage to smooth the grid profile (peak load levelling). US studies have put the value of V2G to utilities at as much as US$4,000 per year per car[7], which comes from saved costs related to grid management and sub-station level fast reactive storage. Following on from this, V2G also has some potential to avert outages through load clipping, as during a load spike the batteries have the ability to respond quickly, and the distributed nature of V2G reduces individual line loads.

These opportunities could see commercial PV systems gain added value, which again would bring forward their cost effectiveness.

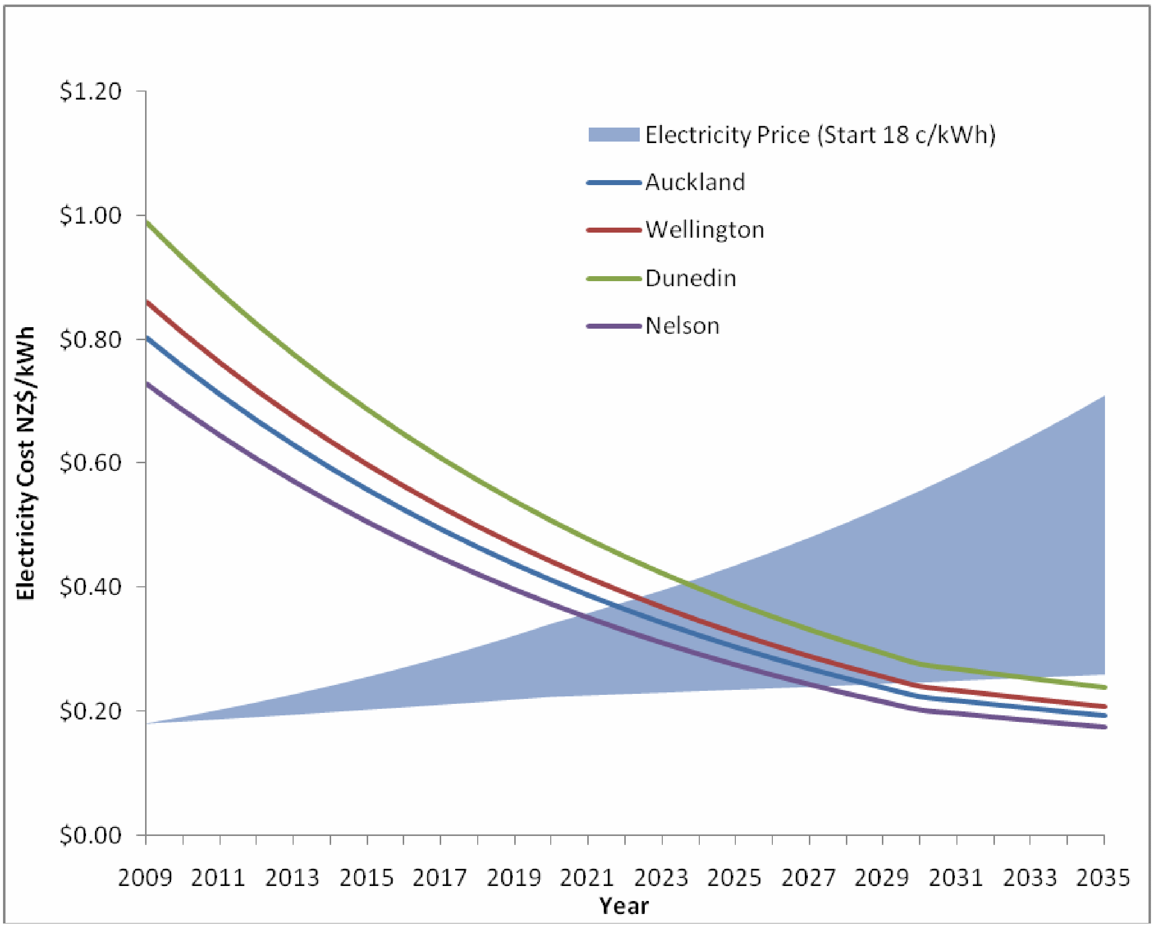


Figure 8.3: Commercial PV Projections.
Electricity price projections (2008 NZ$), based on increases in the range 2% then 1% and 6% then 5% per annum, and PV electricity price projections for commercial roof-top systems using multi-crystalline PV to begin with and progressing over time to include 2nd and 3rd generation technologies. For assumptions, see Appendix 2.

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[7] http://www.udel.edu/V2G/

8.3 Off grid or fringe of grid PV systems

The main market for PV in New Zealand currently is for domestic sized stand-alone power systems, where it is already cost effective in many locations. This market is expected to continue gradual growth, the rate of PV uptake depending on the relative movement of diesel and PV prices. Similarly, the market for PV on farms, national parks and off-grid industrial applications will continue steady growth. This includes electric fences, water pumping, remote monitoring, pipeline cathodic protection, transport signalling and telecommunications links. There are also regional opportunities for locally based companies supplying larger PV or hybrid systems to reduce dependence on diesel generation for island locations such as the Pacific Islands and remote New Zealand communities such as Stewart Island, Great Barrier Island, and the Chatham Islands.

The Review of Section 62 of the Electricity Act "Continuance of Supply" (2013 review) appears likely to allow the provision of electricity via alternative means. This will provide an opportunity for distributors to fulfil their obligation to continue supply[8] by alternatives, such as stand-alone power systems, rather than being required to maintain lines. Each Installation Control Point (ICP) could be assessed on a case by case basis and the most cost effective solution to supply the required energy needs provided. It is expected that alternative means would be a combination of energy efficiency and the provision of the required energy by the most appropriate means, including solar photovoltaics in the form of a stand-alone PV or hybrid power system. This is expected to provide a new market for renewable energy technologies as an effective subsidy for remote lines in these locations in the past has prevented these technologies being utilised even in situations where they could offer the least cost supply of electricity. There were 16,000 ICP's financed with contributions from a fund that assisted with rural reticulation from 1940 to the 1980's.

A study for EECA (Empower Consultants, 2008) looked at 4 remote communities in the South Island and identified that each remote ICP will have unique parameters that will determine the least cost solution. Some of the likely options identified in the Empower report, which could be appropriate for the use of photovoltaics are:

- Replacement of remote grid supply with stand alone generation, particularly where:
    - Line replacement or upgrade is required
    - A long line serves only one or two consumers
    - There is high seasonal demand (e.g. holiday home, woolshed)
- Where line replacement is not required and a connection can be maintained, the return on investment in Distributed Generation (DG) can be improved through exporting excess electricity generated from the DG source. Additional value through voltage support and deferment of new investment can be realised from DG.

Where grid disconnection is being considered, an interim approach, discussed earlier, would be to install PV at the end-use site (DG), while the grid is still connected, then add storage, diesel or other components as necessary to ensure adequate supply if a decision is made to disconnect the grid. Fringe of grid PV based DG installations could also be used to allow load expansion without grid upgrade, in areas of demand growth. Such installations can provide useful voltage support at the end of long spur lines.

Grid supply costs will vary with the site, while the most cost effective distributed generation source will also be determined by the available resources at the site. The solar resource is widely available, except perhaps in densely vegetated locations. However, costs may be lower for wind or micro-hydro systems, where those resources are available. Projected electricity costs from small scale stand-alone PV based power systems and diesel based remote area power systems (RAPS) over time are shown in Figure 8.4. It can be seen that PV is already cost effective in some areas and is likely to be cost

[8] To places supplied as at 1 April 1993.

effective in most areas before 2020. Note also that, in many cases, a hybrid PV-diesel system may in fact provide the most cost effective solution in the short term.

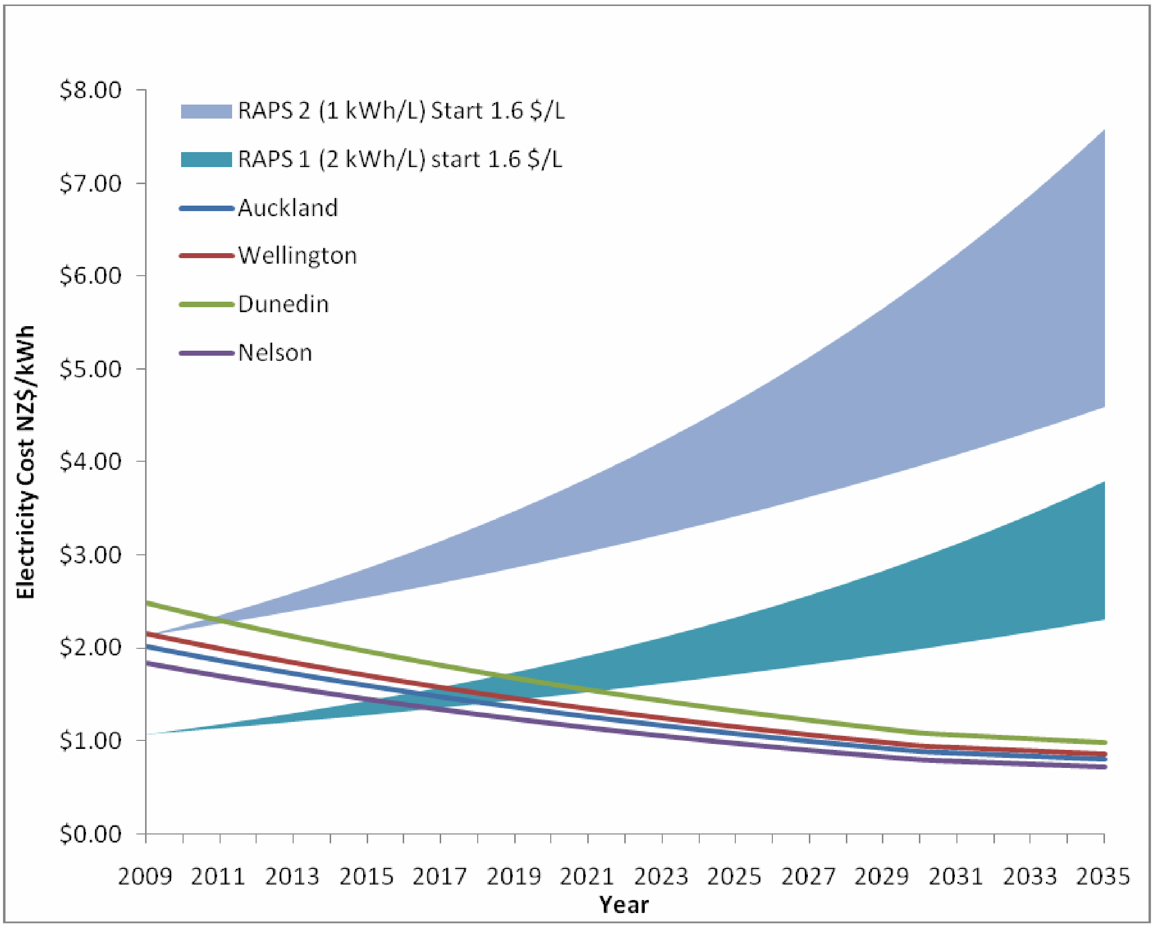

Figure 8.4: Off-Grid PV Projections.
Projected electricity costs from PV based stand-alone power systems and 2 different diesel-based remote area power supply systems (RAPS) in different locations. The range of diesel price increases is between 3 and 5% per annum. For other assumptions, see Appendix 2.

8.3.1 Balance of System Industry Opportunities

The off-grid and fringe of grid PV markets have a potentially high level of BOS components, as well as a higher level of system design and installation skill level than small grid systems. Hence the local content can be higher than for grid systems and there is also potential to develop products and services for the Asia-Pacific region, which has a high level of small scale stand-alone power production.

8.4 Solar Farms

Large scale, central PV power plants have driven the Spanish market and are a rapidly growing segment of the Italian and US markets. These markets are currently subsidized via feed-in tariffs, grants or tax benefits.

In New Zealand, large scale PV systems based on the weighted average mix of PV technologies do not become cost effective against wholesale electricity prices over the time period modelled and under the assumptions used, as shown in Figure 8.5. However, they show potential from 2027 if wholesale electricity prices rise faster than predicted. Thin film technologies show slightly more promise, as shown in Figure 8.6, although again only if wholesale electricity price rises are higher than anticipated. Nevertheless, turnkey thin film plants under private power purchase agreements for multi-megawatt systems are being constructed internationally for electricity prices below US$0.20 per kWh, with some as low as US$0.12 – 0.15 c/kWh (First Solar, 2008) (Podewils, 2008) and prices are expected to continue to decrease.

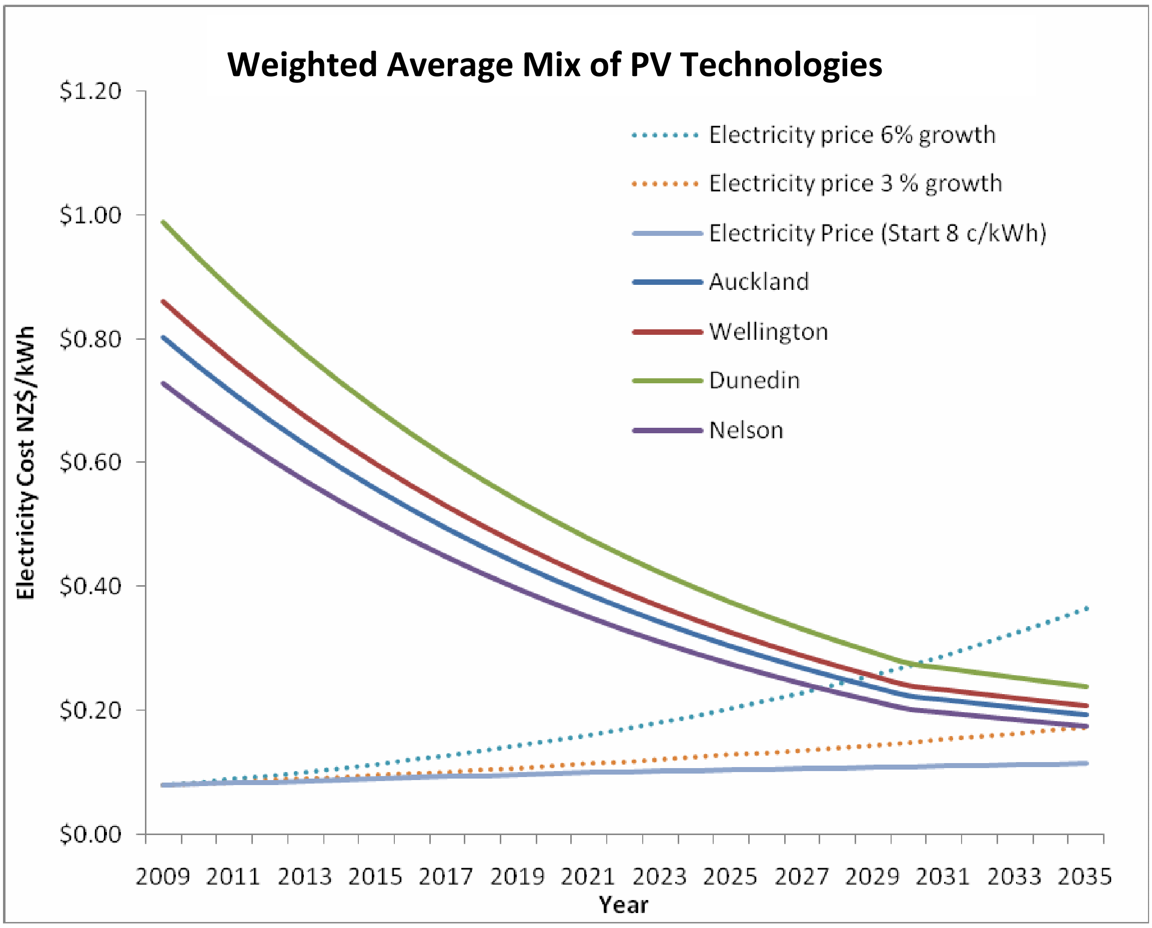

Figure 8.5: Utility Scale PV Projections
Projected PV electricity costs (based on a weighted average mix of technologies) in different NZ Locations against Wholesale electricity prices rising at 2% per annum to 2020, then 1%. The implications of higher electricity price increases also shown.

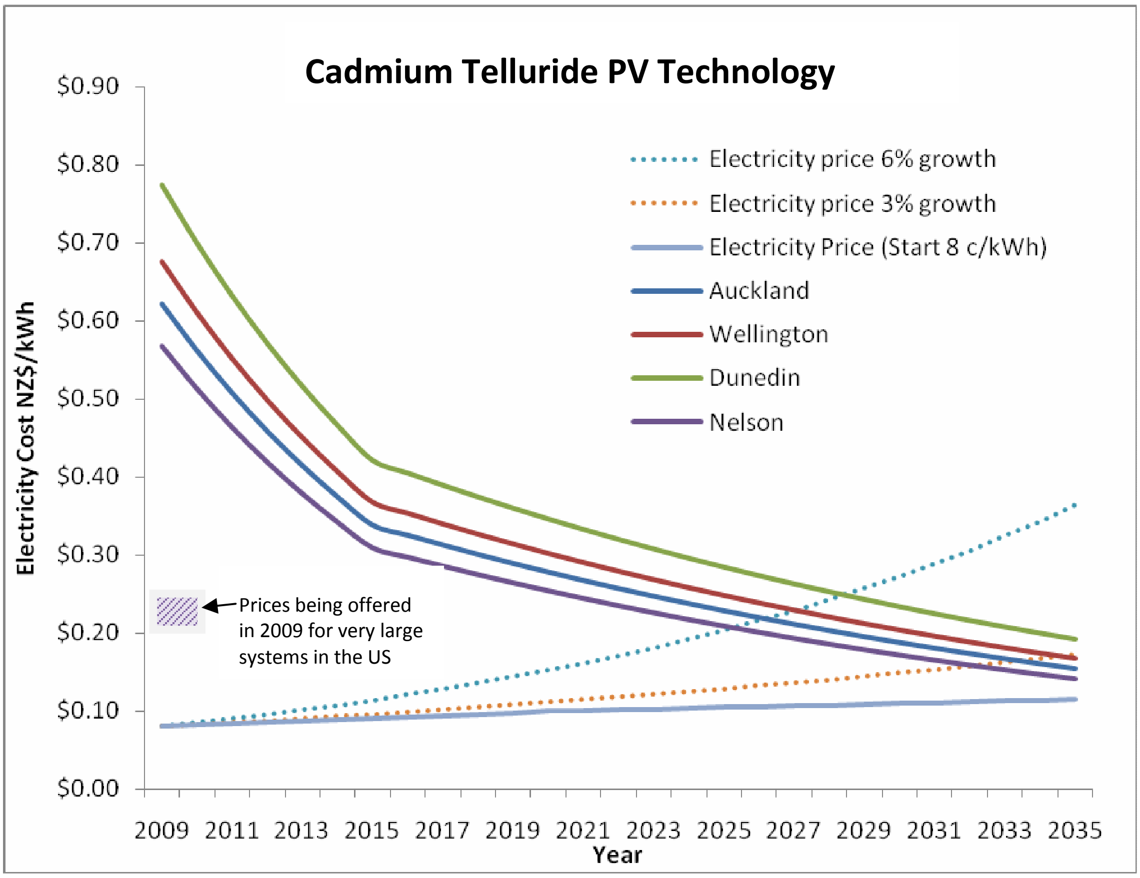

Figure 8.6: Utility Scale PV Projections – Thin Film
Projected CdTe PV electricity costs for large systems in different NZ Locations against Wholesale electricity prices rising at 2% per annum to 2020, then 1% per annum. The implications of higher electricity price increases also shown. For further details see Appendix 2.

8.5 Discussion

PV is already a cost effective alternative to diesel in many off-grid locations of New Zealand and is likely to be cost effective everywhere within a decade. This implies that any policy to disconnect uneconomic customers from electricity lines after 2013 should consider the PV option.

From 2020, PV begins to reach grid parity for residential and commercial customers, after which the market dynamics could change markedly. In the interim, skill levels will need to be developed and experience with installations gained. Building and electrical codes and standards will need to be put in place, as well as public education. Given the challenges of integrating new technologies, there is a case for targeted support to allow industry development and establishment of the institutional requirements previously mentioned. This could be via installations on government buildings, an expansion of the solar schools program, market support for the residential and commercial sectors or other initiatives.

Based on the analyses carried out for this report, large scale PV systems do not become cost effective against wholesale electricity prices over the period modelled, although wholesale prices can be volatile and difficult to project forward since they depend on seasonal conditions and may in future also be more influenced by gas prices and the introduction of a carbon price. If wholesale prices increase faster than anticipated, PV could be cost effective in northern regions within 2 decades. This is within the planning horizon of the electricity generators and there may be advantages for them to maintain their own generation, even if customer based distributed generation increases. In addition, the electricity generated from PV is often highest at times of peak load meaning that, if properly implemented, PV can be used to effectively reduce grid stress at times of peak load.

In summary, the medium to long term potential for PV in New Zealand is little different to that in other developed economies. The New Zealand solar resource is comparable to or better that many areas of Europe where PV is increasingly being deployed. Although PV has a higher cost in $/W or c/kWh than other options being examined for New Zealand, including greater use of hydro, geothermal, wind and biomass, it is relatively fast and easy to deploy and can be used in a wide range of sizes and end-use applications. Its output, though weather dependent on an hourly or daily basis, is highly predicable over longer periods and is also well matched to loads in the rapidly developing commercial and light industrial areas of the North Island. Finally, PV installations rarely need grid upgrades, a cost which is usually not included in the prices quoted for other technologies. For these reasons, the potential value of PV is often higher than its cost alone would indicate.

The private market for PV is likely to grow rapidly once grid parity begins to be reached around 2020. This indicates a need to develop robust regulation around distributed generation in order to achieve the best outcomes for New Zealand. Inclusion of PV in the future energy projections for New Zealand would be worthwhile as would be further examination of options to link PV and electric vehicle deployment.

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APPENDIX 1

Bio Fuel Company Activities in NZ

Argent Energy New Zealand Ltd – pulled out of planned NZ entry - http://www.argentenergy.com/

Biodiesel New Zealand - aims to increase output to 70 ML a year by 2011 - **http://www.coalnz.com/index.cfm/1,117,0,0,html/Biodiesel**

Biodiesel Oils NZ Ltd - large R & D facility in Auckland, a planned commercial site (60 ML per annum) in the North Island and another in the South Island. - **http://www.biodieseloils.com/profile.htm**

Ecodiesel Ltd - 20 ML of biodiesel from May 2009 , increasing to 40 ML per annum by end 2010. – Tallow, 23,000L/year current production - **http://goecodiesel.com/NZOperations/tabid/56/Default.aspx**

Biodiesel Australasia Ltd – Manufacture Biodiesel reactors - **http://www.anzacfueltech.com/**

Flo-Dry Engineering Ltd – Reactive distillation biodiesel demonstration plant for 1000L/hr – sell machinery - **http://www.flo-dry.co.nz/company_f.htm**

Aquaflow Bionomic Corporation – Prototype commercial scale biodiesel from algae - **http://www.aquaflowgroup.com/pressroom.html**

Envirofuels - **www.environfuels.com** - currently supplying commercial users with plans for a number of plants with 2 ML/year capacity each

APPENDIX 2

Assumptions for PV electricity models and projections

- The modelling of future electricity costs from PV assume a project lifetime of 25 years, with a module life of at least 25 years, an inverter life of 15 years and, in the case of an off-grid system, a battery life of 10 years.
- Operational and maintenance costs are assumed be 1% of the total capital cost of the system
- Based on the current economic situation in New Zealand an interest rate of 6% has been used in the model.
- System performance and output data has be simulated for a number of different PV technologies and a number of locations throughout New Zealand using PVSYST.
- The graphs and tables provided for multi-c Si are based on a situation where initially 1st generation technologies (multi-c Si) are employed; however, as they become more mainstream greater amounts of 2nd and 3rd generation technologies are included in the modelling. The CdTe graphs and tables assume that initially 2nd generation technologies (CdTe) are used and that over the period modelled 3rd generation technologies will become more widely used.
- The system sizes are as follows:
    - Small <2kW
    - Medium 2 – 10kW
    - Large >100kW
- Future electricity prices have been modelled using the following assumptions:
    - Residential: the initial price of electricity is assumed to be 24.84 c/kWh. Future costs are based on an increase of between 2% and 6% per year to 2020 and an increase of between 1% and 5% from 2020 to 2035.
    - Commercial possibilities assume an initial price of 18 c/kWh with future costs based on an increase of between 2% and 6% per year to 2020 and an increase of between 1% and 5% from 2020 to 2035.
    - Utility scale possibilities have been modelled assuming an initial electricity price of 8 c/kWh and increases of 2% per year to 2020 and 1% per year after that.
    - Diesel grids: the electricity price for diesel grids is based on an initial diesel price of NZ$1.60/L increasing at a rate of between 3% and 5%, based on historic figures for the past 15 years obtained from the MED website. In addition two different diesel systems were modelled, a good system and a poor system, with differing efficiencies. The ‘good’ system has an efficiency of 2 kWh/L and the ‘poor’ system has an efficiency of 1 kWh/L. In both systems fuel costs are assumed to account for 75% of the total cost of generation.
- The breakdown of module/system components is presented in Table A2.1. The inverter is assumed to account for 12% of the total cost in the small, medium and large cases and 16% in the off-grid case. The batteries are assumed to cost 26% of the system cost in the off-grid systems.
- An exchange rate of 1.683 US$ to NZ$ has been assumed.
- Future costs of PV systems are based on predictions from the International Energy Agency (IEA) and the National Renewable Energy Laboratory (NREL). For mature technologies, such as mono-crystalline and multi-crystalline silicon minimal learning rates are assumed and

real costs are assumed to decrease by about 6% per year to 2030 and 3% thereafter. For newer technologies, i.e. Cadmium Telluride higher learning rates are assumed and costs are predicted to reduce at about 10% per year to 2015 and 4% thereafter.

- Currently due to the limited PV market in New Zealand system costs are up to 1.5 times more expensive than in countries with a greater PV focus (e.g. Germany, Spain, Japan, etc). The modelling undertaken assumes that as the PV market in New Zealand become more established this price differential will gradually decrease. It is assumed that by 2030 PV system prices in New Zealand will be on par with the rest of the world.

Table A2.1: Breakdown of PV Module and System Costs (2008 $US per kWp) for Various PV Module Costs and Different Applications

	Small		Medium		Large		Off-grid	
Module Cost $US/kWp	Module %	System Cost $US/kWp	Module %	System Cost $US/kWp	Module %	System Cost $US/kWp	Module %	System Cost $US/kWp
$5.00	65%	$7.73	67%	$7.42	70%	$7.13	40%	$12.50
$4.80	64%	$7.50	67%	$7.18	70%	$6.88	40%	$12.00
$4.60	63%	$7.26	66%	$6.93	69%	$6.63	40%	$11.51
$4.40	63%	$7.01	66%	$6.68	69%	$6.38	40%	$11.03
$4.20	62%	$6.77	65%	$6.43	69%	$6.13	40%	$10.56
$4.00	61%	$6.53	65%	$6.18	68%	$5.87	40%	$10.10
$3.80	61%	$6.28	64%	$5.93	68%	$5.62	39%	$9.65
$3.60	60%	$6.03	63%	$5.68	67%	$5.36	39%	$9.21
$3.40	59%	$5.78	63%	$5.42	67%	$5.10	39%	$8.78
$3.20	58%	$5.52	62%	$5.16	66%	$4.84	38%	$8.36
$3.00	57%	$5.27	61%	$4.90	65%	$4.58	38%	$7.95
$2.80	56%	$5.00	60%	$4.64	65%	$4.32	37%	$7.55
$2.60	55%	$4.74	60%	$4.37	64%	$4.05	36%	$7.16
$2.40	54%	$4.47	59%	$4.10	63%	$3.78	35%	$6.78
$2.20	52%	$4.20	58%	$3.83	63%	$3.51	34%	$6.41
$2.00	51%	$3.93	56%	$3.55	62%	$3.24	33%	$6.05
$1.80	49%	$3.65	55%	$3.27	61%	$2.96	32%	$5.70
$1.60	48%	$3.36	54%	$2.98	60%	$2.68	30%	$5.36
$1.40	46%	$3.07	52%	$2.69	59%	$2.39	28%	$5.03
$1.20	43%	$2.78	50%	$2.39	57%	$2.10	25%	$4.71
$1.00	41%	$2.47	48%	$2.08	56%	$1.80	23%	$4.40
$0.80	37%	$2.15	45%	$1.76	54%	$1.49	20%	$4.10
$0.60	33%	$1.83	42%	$1.43	51%	$1.18	16%	$3.81
$0.40	27%	$1.50	37%	$1.08	47%	$0.85	11%	$3.53
$0.20	16%	$1.22	29%	$0.70	41%	$0.49	6%	$3.26