SOLAR ENERGY USE AND POTENTIAL IN NEW ZEALAND

Energy Efficiency and Conservation Authority
PO Box 388 – Wellington

Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

May 2001

Acknowledgments

A number of people have made valuable contributions to the preparation of this publication. EECA would especially like to acknowledge Industrial Research Ltd, who prepared the initial version of this report.

Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

Table of Contents:

SOLAR ENERGY USE AND POTENTIAL IN NEW ZEALAND

Executive summary

Introduction

Solar energy is the most abundant, practically inexhaustible primary energy available in New Zealand.

It is a resource of immense potential. Technologies are available at present to convert this resource to heat in a cost competitive manner, and to electricity at a cost suitable for small niche markets. This resource has the technical potential to supply all present and foreseeable residential energy needs and contribute substantially to commercial and industrial requirements as well.

Solar energy would help New Zealand diversify its present energy sources and to grow its existing manufacturing base.

To achieve this potential, new initiatives would be required to help overcome the cost and market barriers facing these modern and continually improving technologies.

Current situation and potential contribution

Solar hot water technologies currently contribute more than 40GWh (0.1% of New Zealand electricity consumption) electricity equivalent per year. They are cost effective in a number of applications at 8-12c/kWh.

Installations are around 1200 units per year, mostly in the residential sector, spurred by government co-ordinated energy saving initiatives.

By year 2003 solar hot water could contribute between 80 and 300 GWh per year. By 2010 their wider adoption would replace upwards of 15 percent of domestic hot water requirements (600 GWh per year) and a proportion of commercial and industrial heat requirements.

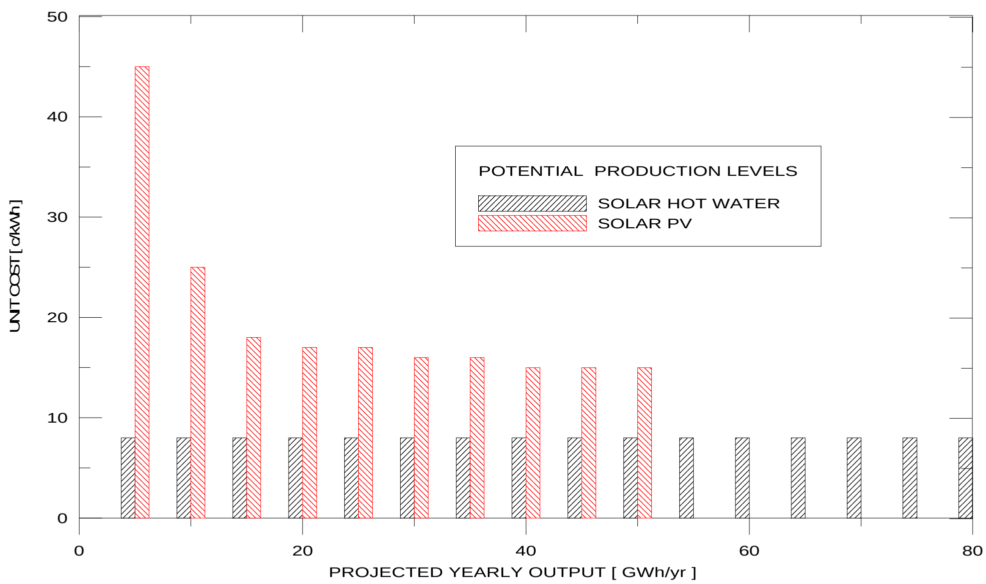
This could replace fossil thermal electricity generation and create employment for over 400 people. It would mitigate in the order of 270,000 tCO_2 annually from alternative thermal generation.

Solar Photovoltaic (PV) electricity is well established in stand-alone applications in remote areas. The lowest cost applications range between 35 and 60 c/kWh. Installations are expected to continue at present trends, which would provide 3 to 5 GWh per year by 2003.

EECA
Energy Efficiency and Conservation Authority
Te Tari Tiaki Pūngao

When the cost of PV electricity approaches 15-18c/kWh it will start to become competitive with retail electricity and delivery prices and expand into the grid-connected market. It could then easily provide upwards of 40GWh electricity per year from rooftop installations alone. This would mitigate in the order of 18,000 tCO_2 annually from alternative thermal generation.

Use of PV electricity in distributed generation (by lines or retail companies as means of deferring capital and maintenance expenditures) is expected to increase this contribution many fold beyond 2003.



Potential Production of Solar Energy

The resource

Solar energy is distributed right across the country, requiring neither transportation nor any special infrastructure for its use.

While the total household rooftop area in New Zealand is exposed to solar energy that is about twice the total national energy use the resource is relatively low in intensity and intermittent in availability.

Research in New Zealand and comparisons with overseas experience show the values of daily energy are similar between Australian and New Zealand sites, and higher than in Europe. The maximum values are in January decreasing to a low in winter. Invercargill, the lowest valued New Zealand site shows lower overall daily values indicative of its southernmost position. All other sites are only slightly lower than those in Australia.

Solar energy conversion technologies
There are two specific technologies used to capture solar energy; solar thermal conversion systems and photovoltaic conversion.

Solar thermal conversion systems are the oldest, most advanced and most economical solar conversion systems yet developed. These are in use in New Zealand

- Presently available flat plate systems (unglazed or glazed collectors) are most often limited to operating temperatures below 60°C in order to maintain a relatively high conversion efficiency. This makes them useful for solar swimming pool heating (~30°C) and solar domestic hot water applications. These two areas have been the main applications in New Zealand.

- Recent advances in the performance of selective surfaces for solar energy conversion have led to recent industrial production of high performance selective surfaces with high solar absorbency and very low thermal emittance. This enables these surfaces to reach temperatures of 300°C and above. Application of this technology is at the demonstration stage at several European projects. So far, no application of these systems has been undertaken in New Zealand even though some evacuated tubes of this type are available here.

- Solar Thermal Electric power plants are the only large-scale commercial solar electricity generation technology implemented to date, but not in New Zealand.

- The solar thermal technologies that seem most appropriate for New Zealand's insolation values are low and mid temperature systems collecting global irradiance. While in relatively common use for domestic water heating, commercial or industrial scale collectors have so far not been widely adopted, despite recent advances and technical feasibility.

- A large number of installations have been retrofits to existing homes. From an economic standpoint, such installations do not benefit from savings in the construction costs that new installations would occasion. Nonetheless, at an average cost of around $4000 for a full installation in a residential home, these systems are expected to save significant quantities of electricity, depending on location

- Solar domestic hot water is cost competitive with retail electricity tariffs throughout New Zealand and that the maximum yearly output from this source is only limited by the number of systems that can be installed.

A most promising trend in the *PV (photovoltaic)* industry worldwide has been the involvement of all major petroleum companies in the ownership, direct production and promotion of solar energy, especially photovoltaic electricity production. This involvement has resulted in new, larger scale PV production plants in Australia, Europe and USA that may realise substantial economies of scale.

The possible markets for PV systems are also very diverse, often with quite different and opposing requirements. The main applications can be divided into four broad sectors, namely consumer products, industry applications, remote area supply, and grid connected systems (two distinct types).

- Consumer products (calculators, watches, toys), individual power supplies (holiday homes, caravans, mobile homes, boats), and individual supplies for novelty products (home security, garden lighting, car sunroofs, fans, and battery chargers) provided the first market for PV.

- There are a number of applications where PV systems are sold to a service industry, which then uses these for its own purposes, in its products or services. Foremost in this area are "professional systems" provided by companies active in the communication industry and the cathodic protection industry. New Zealand's electric fence industry is also a substantial and good example in this category of applications.

- Standalone power system applications include small to medium scale PV technology, ranging between hundreds of watts and a few kilowatts, to supply services in regions away from the main distribution grid. This is thought to be a pivotal growth area for the PV industry in the coming decade in both industrialised and developing countries. The range of services includes water pumping, water treatment, electric supply for small industry, domestic, medical and institutional uses (houses, schools, clinics, small shops, farms) and communication links, both local and long distance via telephone, television and radio.

- Grid connected distributed supply system applications are a newer but vigorously growing example of PV use in the urban environment. These are simple and only require PV panels and inverter to provide AC voltage and connect to the local distribution grid. These systems provide electricity at the consumer end of the distribution chain and hence compete with the retail price of electricity

- Grid connected power plant applications have been trialed overseas and include both full scale central PV stations feeding power to the distribution grid, and embedded generation PV systems used to correct either overloads or degraded power quality at critical points.

In New Zealand, commercial examples of all the above applications, except centralised and embedded power systems, can be found. The largest applications include isolated telecommunication and weather monitoring sites, for marine safety devices along the coast of New Zealand, and for electric fences and navigation lights, both these last products being also exported overseas. There are numerous applications of PV as battery chargers for caravans, holiday homes and boats.

The main impediment to further uptake of PV technology has been its cost compared to grid electricity prices, which is extremely well distributed throughout New Zealand.

Environmental and social advantages of using solar energy

Solar technologies provide sustainable energy. Both solar thermal and photovoltaic (PV) technologies are modular in nature and are therefore adaptable to a variety of applications varying in size, output temperatures and other operating requirements.

Although capital intensive in the case of PV, solar technologies rely on a freely available source and have extremely low maintenance costs. PV is the energy source of choice for navigation lights, telecom sites and isolated or remote areas, including Antarctica where reliability and low maintenance are of utmost importance.

The lifetime of both solar thermal and solar PV technologies are greater than 25 years. Solar PV modules carry a minimum manufacturer guarantee of 20 years; longer than most power plants, conventional or new.

Solar technologies are easily integrated into new or existing buildings; they are unobtrusive, can enhance the aesthetics and architectural appeal of buildings and are often considered a positive asset due to their green image.

Both technologies still show a large potential for cost reduction in the near future due to technological advances and increased production based on substantial market expansion.

Barriers to the adoption of solar energy systems

There are several barriers to the uptake of solar conversion systems in New Zealand and indeed elsewhere. Most are manifest in the implementation of new technologies that attempt to displace existing, well-established technologies. As such they relate directly to the dissemination of solar thermal and solar PV.

These barriers may be seen as a reflection of the way technological progress has a certain momentum, and tends to remain oriented in certain directions. This inertia has as a direct consequence the exclusion of newer, possibly more appropriate technical solutions as either not mature enough, not cost effective or not worth pursuing.

This exclusion can take the form of technical barriers, cost barriers and/or market organisational (or structural) barriers. In the case of solar, these latter two barriers exist for all technologies while the former is relevant to a greater extent for PV than for solar thermal.

For the solar thermal industry, technical barriers have been mostly resolved, at least for low temperature conversion. Systems have existed for some time now with sufficiently high efficiency at low cost to yield a very positive return over their lifetime. The systems will cost substantially less than the cost of electricity needed to produce the same output.

The main cost barrier to the dissemination of solar technologies is ostensibly their total cost (and hence initial capital investment) to the users compared to alternative supply. Here again, for solar thermal systems this cost is lower over the lifetime of the system than for PVs.

Further, the building industry's traditional conservatism, (and that of associated trades and professions- builders, carpenters, plumbers, architects) their lack of awareness, understanding and experience of these technologies constitute a major barrier to adoption of solar technologies.

Solar technologies, which are typical of many renewable energy systems, are often capital intensive and have relatively low ongoing and maintenance costs. Economic means of analysis that would be advantageous to solar technologies would incorporate some assessment of reliability, low maintenance and nil fuel costs. For example lifecycle costs would be more appropriate than a traditional payback period analysis.

There is also in New Zealand an inability to capture the benefits of solar technology by users. Solar is not widely recognised to add value to the price of a house and is not sufficiently valued at national and regional levels or in regulations and standards.

The organisational structure of the residential and commercial building industry engenders conflicting interests for investors and users

Markets for solar energy

The main immediate markets for solar energy technologies in New Zealand are the residential and commercial building industries (and by implication the electricity industry as a whole; generators, lines and retail companies). These markets are by far the most appropriate for solar technologies as they deal in space heating, water heating and electricity.

Solar technologies are eminently suited to providing these requirements by on-site generation; in competition with centralised generation and extensive distribution lines.

SOLAR ENERGY USE AND POTENTIAL IN NEW ZEALAND

1. <u>Solar resource:</u>

1.1 **The primary energy source**:

Solar energy is distributed right across the country, requiring neither transportation nor any special infrastructure for its use.

The sun provides the earth with a long-term supply of high quality energy at an overall rate nearly 10,000 times mankind's present use. This supply reaches a maximum intensity of more than $1000 W/m^2$ at the earth's surface, sufficient for conversion to other forms such as heat, electricity and combustible materials.

Per year, the New Zealand land mass ($268{,}000 km^2$) conservatively collects ($4 kWh/m^2$ /day) x (365 days/yr) x ($2.68 \times 10^{11} m^2$) ~ 4×10^{14} kWh per year or 1.4×10^{21} J per year (over 3000 times our total present usage of ~5×10^{17} J per year). This is easily the most abundant, practically inexhaustible primary energy source in New Zealand. It is freely available to all New Zealanders.

An average house rooftop of $150 m^2$ collects 2.2×10^8 Wh per year, more than 20 to 30 times the house's total requirements. The total household rooftop area in New Zealand is exposed to primary solar energy that is equivalent to about twice the total national energy consumed.

In spite of its widespread availability, the solar resource is relatively low in intensity and intermittent in availability. For some applications it needs relatively large land areas and storage. However for the same land area, solar Photovoltaics produce three times as much energy as a hydro dam and orders of magnitude more than energy forests. The areal conversion efficiencies are in the order of 15, 5 and 0.05 percent respectively.

1.2 **Insolation parameters**

The energy from the sun is traditionally measured according to three parameters:

- Global irradiance – the power per unit area on a horizontal surface from the whole sky.
- Direct irradiance – the power per unit area on a surface always facing the sun direction.
- Diffuse irradiance – the power from the whole sky excluding the direct irradiance.

These three parameters are not independent. Global irradiance is a measure of the total power from the sun reaching us both directly and indirectly through scattering in the atmosphere through clouds, gases and particulates. Direct irradiance is the power directly from the sun. It is high on a clear summer day, low or near zero on cloudy summer or winter days when the sun is occluded by clouds and gases. Diffuse irradiance represents the power reaching the earth after being scattered in the atmosphere. It is the reason we can "see in the shade". Hence these three parameters are seen to be related.

On a more practical level, they each represent the power various practical solar conversion systems are likely to receive at any one time. A flat plate solar collector will receive an amount of power related to the global irradiance, a south facing window (in the southern hemisphere) will receive mostly diffuse radiation; while a two axis sun tracking solar collector or heliostat will receive an amount related to the direct irradiance. In this context, highly concentrating systems which, because of their optics can only "see" a small angle of the sky, are by necessity, two-axis tracking systems following the sun. These can only use the direct irradiance from the sun's beam. Such systems are most useful when the direct irradiance is very high, when clear sky conditions predominate.

1.3 Insolation for several sites in New Zealand.

The calculated values of total daily global energy and total yearly available energy can indicate the "solar quality" of a site.

The global, direct and diffuse irradiances vary as functions of time of day, day of year, and from year to year. For a given site, Typical Reference Years (TRY) are produced. They represent 8,760 hourly expected values for global, direct and diffuse irradiances.

Such values are available for a number of sites in New Zealand (Kaitaia, Auckland, Wellington, Christchurch, Invercargill). They can be successfully used to calculate the expected output from a variety of solar conversion systems at those sites on an hourly, daily and yearly basis. These TRY can also be used to calculate total daily energy expected on a horizontal surface and total daily energy in the direct sun beam. TRY can also be used to calculate the total yearly solar energy available to solar conversion systems.

1.4 Comparison with Australia, and Europe.

Two regions of the world are at the forefront of implementation of solar technologies are Australia and the European Community, especially Germany. In order to understand the potential of solar energy in these three regions, it is possible to compare global irradiances in New Zealand, Australia and Germany.

The first comparison, presented in Figures 1 and 2, is that of the total daily global energy received on a horizontal surface in Kaitaia, Paraparaumu and Invercargill compared with the same quantities in Sydney and Melbourne.

It is clear the values of daily energy are similar for all sites. The maximum values are about 30MJ/m^2 per day in January decreasing to a maximum value in winter of about eight to $12MJ/m^2$ per day for all sites. Invercargill, the lowest valued New Zealand site shows lower daily values (of about 15 percent through the year) indicative of its southernmost position.

All other sites are only slightly lower than Australian sites. Sites in New Zealand such as Nelson, Blenheim, Gisborne and Hawkes Bay, with the highest New Zealand values are expected to have comparable or higher values than Melbourne).

Global energy has maximum daily values that are high for day one in summer summer, low for day 170, ~mid winter and again high around day 340, in summer.

This roughly sinusoidal variation in the maximum possible irradiance illustrates the seasonal variability of the resource. On top of this there is, intermittently throughout the days of the year, occurrence of values below these maximum values. These are an indication of intermittent sunshine or cloudiness and are relatively equally scattered in the New Zealand and Australian data.

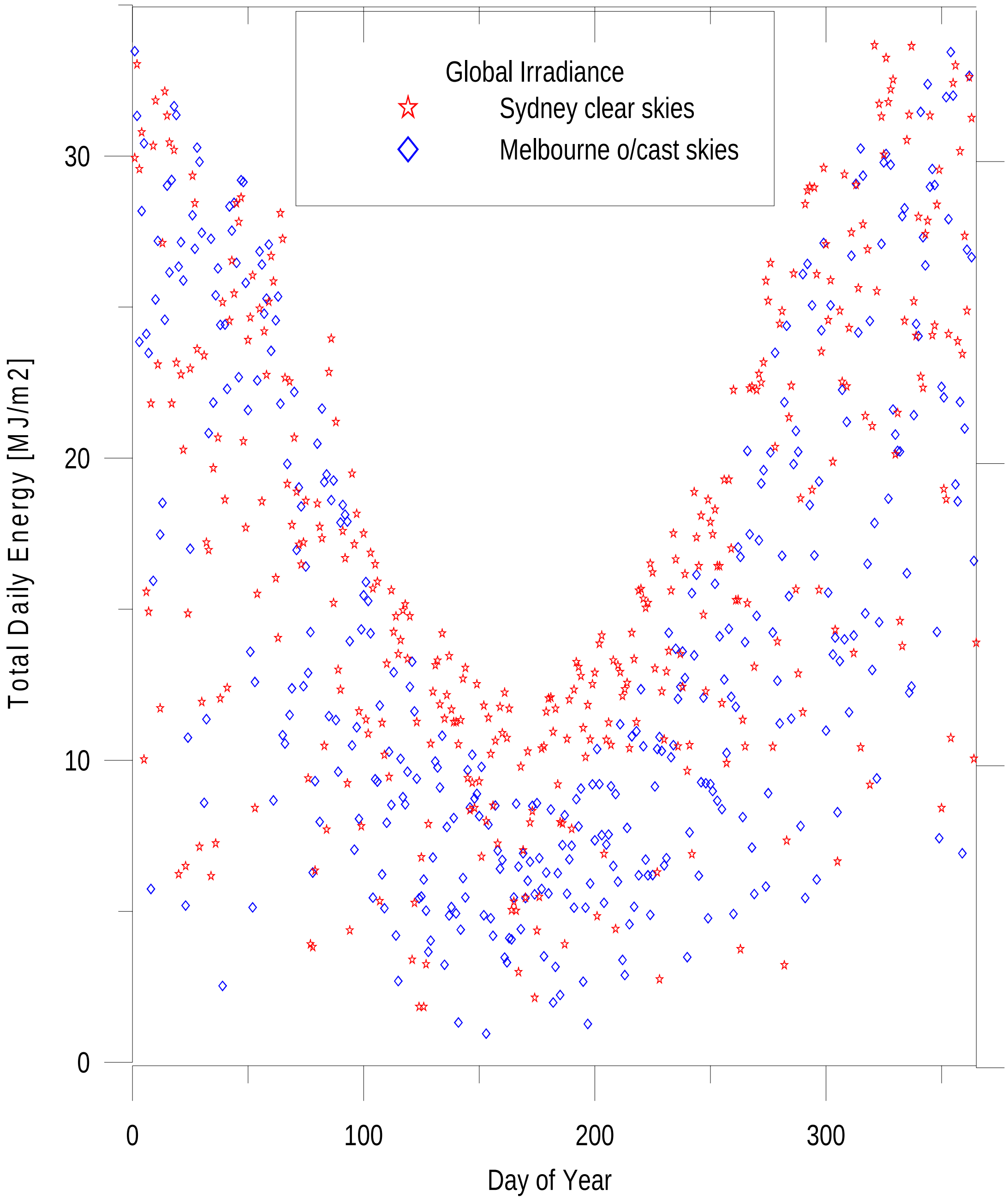


Figure 1: Total daily global irradiance as function of day of year for two typical sites in Australia.

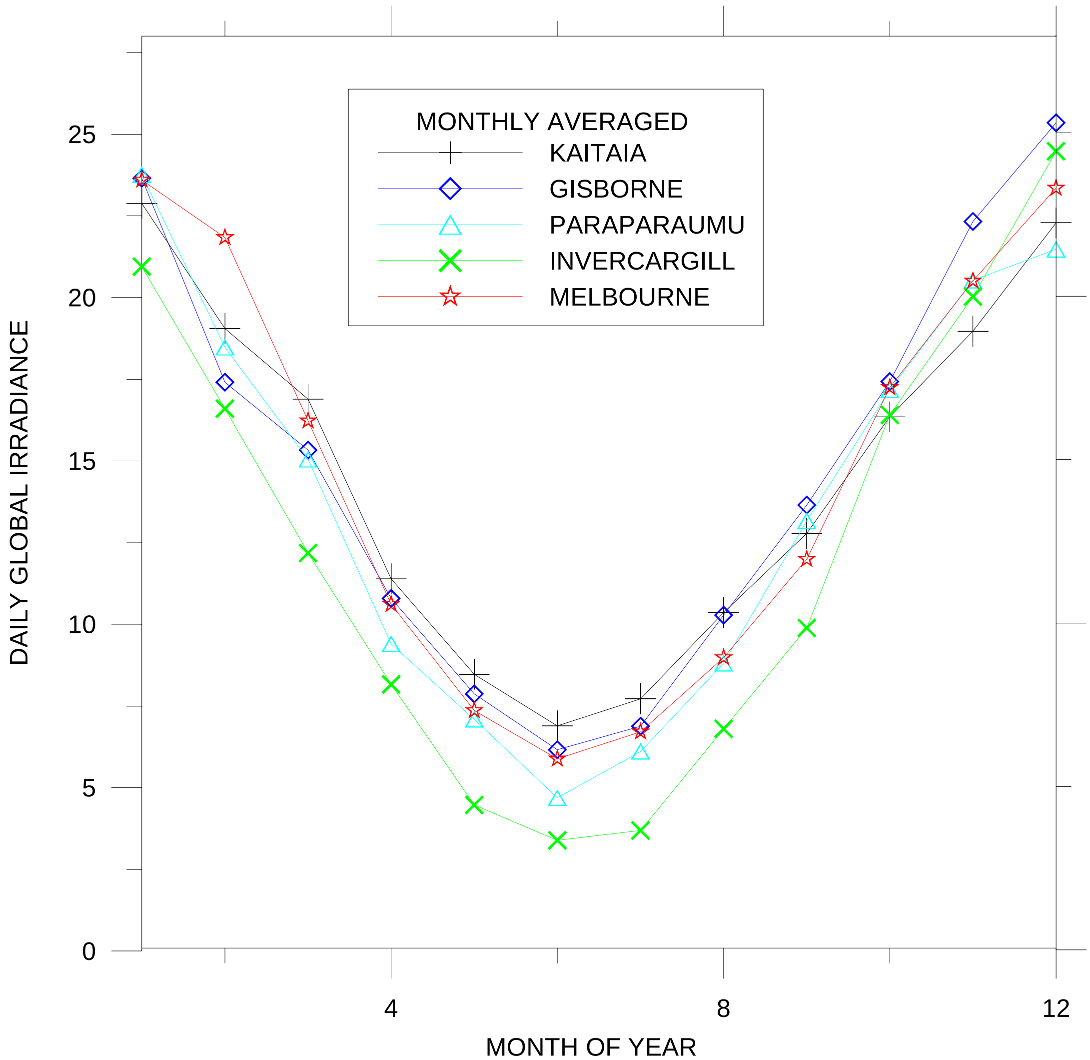


Figure 2: Monthly averaged daily global irradiance at several sites in New Zealand. Values for Melbourne calculated from the above figure are included for comparison

A second comparison of total yearly energy available per square meter is shown in table 1 for each site and for a typical site in Germany (52° north). This value, the sum of all daily values throughout a year, incorporates the effects of the maximum values of irradiance possible, due mostly to the latitude of the site. It also includes the actual atmospheric conditions (clearness, particulates, water content in the atmosphere and cloud conditions) into one "quality" parameter.

Table 1: Typical values of total yearly global energy per square meter for several sites in Australia, New Zealand and Europe. Two units have been used. (1kWh = 3.6 MJ).

	$MJ/m^2/yr$	$kWh/m^2/yr$
Sydney	6150.3	1708.4
Melbourne	5301.6	1472.7
Kaitaia	5288.1	1469.0
Paraparaumu	5035.1	1402.6
Gisborne	5385.9	1497.1
Christchurch	4898.0	1360.5
Invercargill	4651.9	1292.2
Germany	3609.0	1002.5

Again, the availability of solar energy at major New Zealand sites, at about 1400-1500kWh/m^2 per year on a horizontal surface, is seen to be at least comparable to Melbourne's and certainly much higher than at European sites.

Sydney, at around 1700 kWh/m^2 of global sunshine a year is considered a very good site for a variety of solar energy technologies including concentrating systems. Sites with 1400 to 1500 kWh/m^2 a year are considered to also be quite good prospects for solar technologies, especially those technologies, such as flat plate collectors, that use the global component.

In Europe, where indigenous energy sources are scarce or expensive, sites with 1000kWh/m^2 are seen as potential candidates for several solar technologies.

Most solar collection systems are tilted towards the equator, enabling them to collect substantially more than the horizontal values above. For example, in Wellington a flat plate facing Northward and tilted at around 35° from the horizontal, would increase its yearly solar energy collection by about 15 percent or over 1650kWh/m^2 per year.

2. <u>**Solar energy conversion technologies:**</u>

2.1 Solar thermal conversion:

Solar thermal conversion systems are the oldest, most advanced and most economical solar conversion systems yet developed. They invariably consist of a mechanism for capture of solar energy, its conversion to heat at a range of temperatures and its use either directly or in the production of electricity or chemicals using heat.

The main differences between the various solar thermal technology types relate to the temperatures achieved. Systems are available for production of low temperatures (30° to 60°C) medium temperatures (80° to 150°C) and higher temperatures (350° to 2000°C).

Each system type needs a different level of solar concentration to reach target operating temperatures. Low and mid temperature systems require only one sun or two times solar concentration. High temperature types require from 20 to 1000 sun concentration, achieved with linear focus (such as parabolic trough mirrors) or point focus (parabolic dish) optical systems track the sun in one or two axes.

From optical considerations, one sun and low concentration systems "see" virtually the whole of the sky hemisphere and therefore can collect the global component of sunlight without having to be repositioned towards the sun.

On the other hand, high concentration (eg ten sun and higher) optical systems "see" only an equivalently small part of the sky. They therefore require frequent, continuous repositioning to face the highest irradiance coming directly from the circumsolar region. Because they collect energy only from a narrow angle arriving from the sun's direction, high concentration high temperature systems are most useful in clear, high direct irradiance sites where their higher complexity can be justified by their higher output and higher quality energy obtained.

In New Zealand, such systems are not thought to be economic in view of the low direct irradiance component available because of frequent cloud occurrence.

2.1.1 Low temperature flat plate systems:

These systems typically comprise an insulated housing with a cover, a flat plate collector surface, heat conducting fluid and optional storage and delivery systems.
One inexpensive variant, the unglazed collector, has a low insulation housing, a black painted or black coloured surface and transparent plastic cover to reduce heat loss due to windage. This type is often used where a temperature increase of only a few degrees above ambient water temperature is needed, e.g. for swimming pools, as it supplies adequate quantities of heat in a cost effective manner.

In a second system, often called a glazed collector, the housing has higher insulation, and includes a glass front made of relatively high transparency glass. The collecting surface is sometimes coated with a solar selective film to suppress thermal reradiation at the higher than ambient operating temperatures. The construction of the collecting surface can be large flat plates with fluid tubes attached (tube-on-sheet collector), a series of parallel finned metal tubes (channels for the fluid) or integral glass tubes with fin and metal tube inside them, all connected to a header. A simple example of a flat plate collector is shown in figure 3.

Operating temperatures of these systems range from ambient to about 120°C and typically follow a close to linear solar to heat conversion efficiency curve (see figure 4 below).

The conversion efficiency decreases rapidly as the operating temperature is raised above the ambient for a given solar irradiance. Hence in the example illustrated in figure 4, raising the working fluid temperature by 20°C can be achieved with a typical efficiency of 60-70 percent whereas to raise its temperature by 50°C can only be done with an efficiency of ~40 percent, and reaching higher temperatures implies an efficiency close to zero. Zero efficiency, or equivalently a zero fluid draw off occurs at the so-called stagnation temperature (80-120°C).

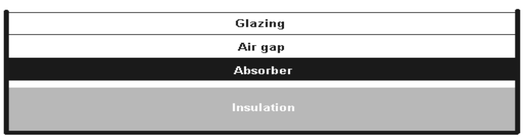


Figure 3: schematic view of the elements in a conventional collector.

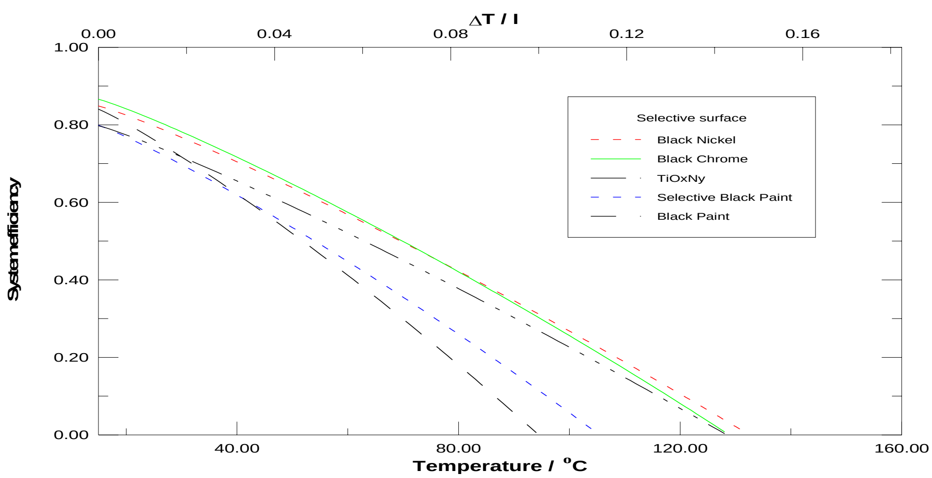


Figure 4: Performance of five selective surfaces in a conventional solar thermal collector.

Presently available flat plate systems (unglazed or glazed collectors) are most often limited to operating temperatures below 60°C in order to maintain a relatively high conversion efficiency. This makes them useful for solar swimming pool heating

(~30°C) and solar domestic hot water applications. These two have been the main applications in New Zealand.

Although the technologies used in the flat plate type solar collector systems are relatively old, incremental improvements have occurred over most of the last 10 years in two main directions. One has led to lower costs, the other to higher system performance. In the latter case, the two main limitations in the performance of the above systems are related to the optical properties of the absorbing surfaces used (selective and non-selective) and to the relatively sizeable heat loss by convection occurring in the collectors.

A typical indication of the application of these systems in New Zealand, a residential solar hot water installation may include a $4m^2$ solar collector area, an adequately sized storage cylinder (~270 litres) with auxiliary booster (gas or electric), providing hot water at around 60°C all year round.

Such a system will provide between 50 and 70 percent of hot water needs and displace 2.2 to 2.5 MWh of electricity use per year.

Depending on size, type and configuration, this solar hot water system including cylinder would cost between NZ$3,500 and NZ$5,500 fully installed.

2.1.2 Mid Temperature flat plates and evacuated tubes including low concentration.

Recent advances in the performance of selective surfaces for solar energy conversion have led to new industrial production of high performance selective surfaces with high solar absorptance and very low thermal emittance. This enables these surfaces to reach temperatures of 300°C and above. When these characteristics are combined with reduced convection losses, the performance of a solar collector follows a substantially improved efficiency curve. This is shown in figure 5.

For these surfaces, not only is the stagnation temperature substantially higher but also the efficiency curve is a strong parabolic rather than linear function of temperature difference. Thus the efficiency remains high over a relatively large range of temperature difference. In figure 5, the efficiency is above 60 percent for temperature differences greater than 100° to 150°C. Systems with these characteristics are capable of operationally producing water at 100°C, steam at higher temperature or, with small concentration, operating at temperatures of 180°C and above.

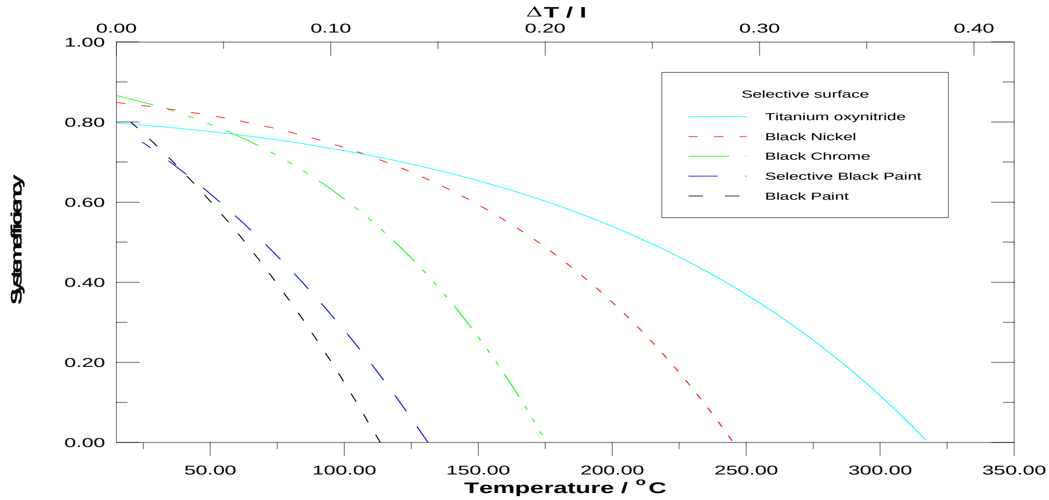


Figure 5: Potential of some selective surfaces when convection losses are suppressed

These surfaces are presently industrially produced on evacuated tubes and may soon be applied to flat plate technology as well. In the case of evacuated tubes, the vacuum ensures very good convection suppression. This convection suppression is essential to achieve the potential of these surfaces and reach maximum performance. However, even flat plate collectors incorporating minimal convection suppression mechanisms have been shown to produce steam with relatively high efficiency.

Also being developed both here and overseas are flat plate based collectors incorporating low solar concentration (up to two sun). In this case, the concentrator is a non-imaging type which still has a wide angle of view and able to collect most of the global irradiance falling on it. These systems are then expected to be capable of higher performances in New Zealand conditions.

These developments are opening up a new set of applications for solar thermal conversion operation at mid temperatures. These include commercial and industrial hot water supplies for food processing and the dairy industry, heat for sterilisation at around 85°C and applications in heating and cooling via high efficiency refrigeration cycles operating at 150°C and above.

Application of this technology is at the demonstration stage at several European projects. So far, no application of these systems has been undertaken in New Zealand even though some evacuated tubes of this type are available here.

An estimate of the overseas price of these ~1.8m long tubes is ~U$12.00; a 4m^2 collector would require between 15 and 20 of these, making it possibly more expensive than conventional collectors. However, where the higher performance is needed, they provide a viable solution to the provision of hot water, steam or heat. As of these last years, such tubes are now being mass-produced in China (millions per year in 1999); hence this price is likely to decrease substantially soon.

It is noted that many conventional systems are also capable of reaching these high temperatures, and some manufacturers have been offering commercial and industrial scale systems in New Zealand. However their uptake has not been high, nor has it spread to the applications mentioned above, possibly due to their lower efficiencies at higher temperatures, the requirement for large areas for solar collection, and the availability of more traditional, fuel and boiler based systems.

2.1.3 High Temperature Systems

Collector systems using selectively coated tubes at the line focus of parabolic trough reflectors are among the oldest high temperature solar technologies developed. In a typical power plant application, reflectors with concentrations of 40 suns or more heat a fluid travelling through tubes to temperatures of 350° to 390°C. This fluid is then used to raise steam for a conventional steam turbine generator. These Solar Thermal Electric (STE) power plants are the only large-scale commercial solar electricity generation technology implemented worldwide.

STE power plants are operational in the Mojave Desert in California generating 590MW. An interesting variant of these linear focus collector fields has been proposed as a steam preheating stage for the Stanwell coal fired power station in northern NSW.

Yet other solar collector systems have full parabolic dish reflectors or a heliostat field which track the sun in two axes to produce a point focus image reaching concentrations between 100Sun and 2000Sun. At the point focus a receiver or reactor can reach temperatures of 700°C to 2000°C, thus providing steam, electricity or sufficient heat for chemical reactions.

In general it is estimated that electricity costs from STE plant are of the order of 10c/kWh or less in areas where the direct beam irradiance reaches approximately 2000kW/m^2 per year.

All these high temperature plants' outputs depend critically on the long-term availability of direct solar radiation. Thus they are not likely to have a high output in New Zealand's relatively variable irradiance conditions. Consequently they are unlikely to be economically viable even when capital costs are reduced.

Summary of solar thermal systems

In summary, the solar thermal technologies that seem most appropriate for New Zealand's insolation values are low and mid temperature systems that collect global irradiance.

The widest applications to date have been low temperature unglazed flat plate collectors providing swimming pool heating and low temperature glazed collectors providing domestic solar hot water. Commercial or industrial scale collectors have so far not been widely adopted, despite recent advances and technical feasibility.

Since pioneering days of the 1970s, when New Zealand had a sizeable initial uptake of solar thermal technologies, a local industry has been established with over eleven manufacturers and importers marketing a variety of mostly local collector systems. This industry has experienced a 10 percent per year growth over the last three years, due in part to greater public awareness and in part to coordinated schemes and initiatives such as EECA's Energy Saver Fund.

Cost of solar hot water energy

A large number of installations have been retrofits to existing homes. From an economic standpoint, such installations do not benefit from savings in the construction costs that new installations would occasion. Nonetheless, at an average cost of ~NZ$4000 for a full installation in a residential home, these systems are expected to save between 2400kWh and 3100kWh electricity per installation per year, depending on location.

Their economic viability can be calculated two ways. The first is using the principle of 'payback period', which is usually between seven and 12 years, depending on the displaced electricity costs. The second is on the principle of "lifecycle cost", the cost of installing a solar system over its lifetime, compared to the cost of electricity paid during that same period.

In the latter case, and for every solar system, a substantial net saving can be shown, which is equivalent to eight to 14 years of displaced electricity or gas supply. Equivalently, the cost of producing a kWh may be calculated for systems installed in New Zealand's major population centres. This results in costs of eight to 12 cents per kWh over a realistic 20 years lifetime of the system.

It is interesting to speculate on the economics of residential solar thermal systems if construction companies or builders of new homes offered them as an option. Since many solar systems are built into the roof structure rather than being placed proud of the roof. In this eventuality, a larger market would almost certainly grow, enabling substantial economies of scale and subsequent reduced production and installation costs. Such trends are appearing already, with some national construction companies and architects investigating options for incorporating these technologies in their standard designs.

2.2 Solar photovoltaic conversion:

2.2.1 Technological aspects:

Direct solar to electricity conversion can be carried out with Photovoltaic (PV) cells. These cells are made from a variety of semiconducting materials either in single crystal form (silicon, gallium arsenide (GaAs), indium phosphide), in multicrystalline and polycrystalline form (silicon, cadmium telluride-CdTe, copper indium gallium di-selenide CIGS etc) or in amorphous form (silicon, silicon-germanium alloys). In each case, laboratory cell production and the corresponding industrial scale production techniques are different and lead to different performance parameters and solar conversion efficiencies.

Of all the above materials and variety of cell designs possible, only a small number have reached industrial production. Some, such as crystalline GaAs, have been shown to be capable of the highest conversion efficiency of all single junction PV devices (35 percent), yet have only found a small volume market in space applications due to their cost of production.

At the present time most industrially produced PV cells are silicon based as silicon technology is the most advanced and has benefited from the several decades of expertise of the microelectronics and computer industries. Efficiencies of laboratory produced cells (~24.5 percent) are far in advance of those for industrially produced cells (15 percent), reflecting the different methods used in their manufacture.

Nevertheless, several laboratory technologies are already, or are being, transferred to industry (eg laser grooved buried contact patterning) with consequent efficiency gains and/or reduced cost. Recently, methods for producing single crystal silicon specifically for the solar cell market, and hence at reduced wafer cost, have been developed in collaboration with industry (eg. The Epilift technique at the Australian National University) and are likely to be commercial realities soon.

In a similar trend, high efficiency, high cost single crystal GaAs cells, which were previously used exclusively in space applications, are now developed for terrestrial applications, at very high concentrations, to produce near-cost-effective electricity generating power plants.

Further technical advances relate to the production of large area (full panel size) polycrystalline, microcrystalline and amorphous thin films in both silicon and other semiconducting materials. For silicon, this is leading to much less material costs and lower production costs. For other materials such as CdTe and CIGS it has raised the possibility of higher efficiency modules (18 percent) with simple production technology and subsequent low cost. These and other technological advances have been incorporated in new production facilities opened in the last three years in Europe (Shell, BP Solar), the US (Canon-Unisolar) and Australia (BP Solarex).

2.2.2 Recent industry trends:

One trend in the PV industry worldwide has been the involvement of all major petroleum companies in the ownership, direct production and promotion of solar energy, especially photovoltaic electricity production. This involvement, which followed oil industry mergers, resulted in amalgamations (eg. BP Solar and Solarex) and new, larger scale PV production plants in Australia, Europe and USA which may realise substantial economies of scale.

This is a sign of the maturity of the PV industry and of potential gains, due to economies of scale, achievable with these plants (10 to 100MW/yr). This latter figure is predicated on the explosion in the PV market worldwide (variously estimated at ~ 30 to 45 percent per year for several years, with no sign of levelling off).

As an example and according to US DoE, the level of shipment for US manufacturers in 1999 was 77,000 kWp, up 52 percent from 1998 levels. Interestingly a large proportion of this increase was aimed at the grid connected market rather than the usual standalone, remote area supply market. It is thought that this is a strong indication that PV's near future growth will certainly include a large market centred on urban applications.

2.2.3 Economics and applications of PV electricity:

Concomitant with the above, a substantial decrease in the price of cells and modules has occurred overseas since 1998. Average cell prices in the US are now U$2.01/Wp to U$3.10/Wp and module prices are U$3.62/Wp to U$3.94/Wp. (US DoE). These prices do not reflect the above mentioned efficiency gains or economies of scale, which are expected to flow through in the next three to five years.

In New Zealand, prices range upwards from approximately $10/Wp depending on the size of module and whether they are bought in bulk.

For complete functionality, PV modules require various components such as charge controllers, inverters, batteries and safety disconnects. These components add a further estimated U$1-3/Wp to the price depending on the size of the installation. In most of their manifestations, PV power systems are versatile as to their size and power output, from microwatts for calculators to megawatts and larger for central grid connected power stations.

The possible markets for these systems are also diverse, often with quite different and opposing requirements. The main applications can be divided into four broad sectors, namely consumer products, industry applications, remote area supply, and two distinct types of grid connected systems.

- Consumer products (calculators, watches, toys), individual power supplies (caravans, mobile homes, boats), and individual supplies for novelty products (home security, garden lighting, car sunroofs, fans, and battery chargers) were the first market for PV.

- There are a number of applications where PV systems are sold to a service industry, which then uses these for its own purposes, in its products or services. Foremost in this area are "professional systems" provided by companies active in the communication industry and the cathodic protection industry. New Zealand's electric fence industry is also a substantial and good example in this category of applications.

- Standalone power system (SAPS) applications include small to medium scale PV technology, ranging between hundreds of watts and a few kilowatts, to supply services in regions away from the main distribution grid. This is thought to be a pivotal growth area for the PV industry in the coming decade in both industrialised and developing countries. The range of services includes water pumping, water treatment, electric supply for small industry, domestic, medical and institutional uses (houses, schools, clinics, small shops, farms) and communication links, both local and long distance via telephone, television and radio.

- Grid connected distributed supply system applications are a newer but vigorously growing example of PV use in the urban environment. These systems are simpler than SAPS as they require only PV panels and inverter to provide AC voltage and connect to the local distribution grid. The main electricity supply acts as a storage facility, receiving electricity at times of PV surplus and supplying it at times of PV deficiency. Agreements and standards for electricity transfer in both directions are usually required. These systems provide electricity at the consumer end of the distribution chain and compete with the retail price of electricity

- Grid connected power plant applications have been trialled overseas to a size of >1MW. These include both full scale central PV stations feeding power to the distribution grid, and embedded generation PV systems used to correct either overloads or degraded power quality at critical points, (thus deferring substantial capital and maintenance expenditures on transformers, lines etc). A very successful illustration of this embedded application is found in the Kalbarri 20kW PV system in Western Australia.

In New Zealand, commercial examples of all the above applications, except centralised and embedded power systems, can be found. The largest applications include PV and hybrid SAPS for isolated telecommunication and weather monitoring sites, for marine safety devices along the coast of New Zealand, and for electric fences and navigation lights. Both these last products are exported overseas. There are numerous applications of PV as battery chargers for caravans, holiday homes and boats. Also, more recently, it is estimated that around a thousand homes have been equipped with PV power supplies, both off grid and grid connected, to provide electricity for household loads across the country.

The PV industry in New Zealand comprises mainly distributors of imported modules and components as well as an extensive network of equipment installers. Some ancillary equipment, such as battery chargers and more recently inverters, have been made locally on a small scale. No commercial modules or cells have been produced in New Zealand.

The variability in size of PV installations makes it difficult to calculate an average price for an average installation. As a consequence PV systems are most often quoted on a “peak watt (Wp)” basis. The price in New Zealand has been around $10-12/Wp for some time with other components adding a further $5 to $10/Wp to the system cost. This has made PV strictly economic mostly in areas remote from the distribution grid, where the cost of grid extension is of the order of $20,000 to $30,000 (around 0.5 to 1km of electricity line).

In other countries grid connected urban supplies are becoming a main growth area in PV applications.

As well as the importers mentioned, New Zealand oil companies Shell and BP, as well as Canon, have published their strong intention to import and supply PV modules and systems in New Zealand.

3. **Present and potential penetration in New Zealand**:

3.1 Solar thermal conversion

Excluding applications using natural conversion processes, such as salt production at lake Grassmere, it is estimated that the present yearly sales of solar thermal systems includes 4000m^2 to 4500m^2 of collector area for swimming pool heating and ~1200 units (equivalent to ~ 4000m^2 to 5000m^2) for residential solar hot water. Given an average energy production of 2500 kWh per year from each hot water system, this yields a yearly increase in energy produced from solar thermal (pool and residential) in 1999 of ~11,500MWh.

As solar thermal is a well established technology in New Zealand, it is possible to assess its present level of penetration and its overall contribution to the energy budget in the last few years. In practice, it has proved difficult to assess the total number of systems installed since 1980 and still operational, since no statistics are collected and some older systems are either replaced or disconnected.

Assuming that the stock of solar systems has increased on average by the value above for a time equivalent to ten years, then a total installed stock of about 16,000 units (pool and residential hot water) is estimated to have displaced around 40 GWh per year electricity production.

Assuming no change in conditions, a survey of the industry in New Zealand indicates a "business as usual" steady growth in the yearly output from solar thermal systems of between 13,000MWh per year to 15,000MWh per year by 2003. Most of this growth is expected to be in the residential hot water sector, with the swimming pool sector remaining steady.

This scenario does not include either a new regulatory regime, government led initiatives, new standards, incentive schemes or adoption of new applications such as solar air systems for space heating, mid temperature commercial water heating for dairy industry and sterilisation. This would take the installed capacity to 80 GWh per year by 2003.

A first optimistic scenario, would expect an increase in the market of 10 to 15 times. This is equivalent to 10 to 15,000 new solar equipped houses – or 25 percent of new hot water cylinders installed per year. This might be brought about by simple measures such as a closer synergy between the solar industry and the building industry suggested below.

A maximum scenario, which might be occasioned by mandatory energy efficiency requirements on all hot water systems. This would see a rate of solar uptake matching the rate of new installations i.e. ~ 60,000 per year. The equivalent electricity savings from this would amount to over 150GWh per year (60,000 x 2500kWh/yr). This would take the installed capacity to 300 GWh per year by 2003 and an estimated maximum

600 GWh per year by 2010. Experience shows maximum uptake is around half of housing stock.

Under these scenarios solar thermal will substitute for fossil fuel generation. The mitigation achieved will depend on the mix of other generation going in over this period. On the basis that combined cycle gas will still be significant at this time, the three scenarios would mitigate from 6000 to 70,000 tonnes of annual CO_2 emissions by 2003.

Should either of these increases occur, the required production can be easily accommodated by expansion and job creation in the present manufacturing facilities in New Zealand and by increases in imports, mostly from Australia. The larger expansion envisaged above would provide increased employment for between 500 and 800 persons directly or indirectly involved in production, sales and installation.

3.2 Solar PV electricity

PV applications in New Zealand have increased steadily over the last four years, due mainly to remote area installations for telecommunication, site monitoring and government department activities in parks and reserves. It is estimated that the 1997, 1998 and 1999 volume of sales has increased from 91kW and 101kW to 146kW per year.

These figures, based on a survey of the main NZ distributors only, include sales to industry for exported items such as electric fences but do not include sales, thought to be 20-30 percent, due to parallel importing. The total yearly increase in electricity generation from this is around 240,000kWh. This level of sales is expected to have resulted in a total installed capacity in New Zealand of between 800kW and 1MW and a yearly electricity production of ~1,280 MWh.

The main impediment to further uptake of PV technology has been its cost compared to grid electricity prices, which is extremely well distributed throughout New Zealand. Previous calculations indicate that the cost of electricity from a grid connected PV system with no batteries with 25 years life ranges upwards from around $0.35/kWh. For an initial system price of $4-6/Wp, it would reduce to $0.19-0.28/kWh, making grid connected systems beginning to be cost competitive with existing retail electricity tariffs in most of New Zealand's regions.

It is interesting to note that this system cost is close to that being offered at the present time for large volume purchases in the US for example[1].

In spite of the present relatively high cost, industry predictions for a "business as usual scenario" are that yearly sales would reach 500kW per year by 2003 under the prevailing conditions. If overseas trends are confirmed in New Zealand, then grid

[1] For a preliminary study and assessment of grid connected PV systems in New Zealand refer to *Market opportunities for dispersed photovoltaic energy sources in NZ*; I. Sanders and A. Gardiner, Industrial Research Limited 2000.

connected urban applications, both in residential and larger buildings, would be expected to more than double this value by the year 2003.

A third, more optimistic scenario, where around 4000 houses per year (18 percent of new stock) are equipped with a 1.5kW PV system each, would quickly increase this uptake to over 6MW per year. Note that a maximum rate of implementation could also be calculated assuming all new housing stock (~21000 per year) is equipped with roof integrated PV. The uptake would then be boosted to more than 31.5 MW per year. This is ~ 60 times the business as usual scenario for 2003.

In terms of installed capacity and energy produced per year, the above four scenarios lead to the following estimates for the year 2003:

Scenario	Installed capacity	Energy produced	CO2 reductions
Business as usual	2.5 MW	2.83GWh/yr	1300 tonne/ yr
Projected trend	4.0MW	4.53GWh/yr	2000 t /year
4000 Grid tied	19MW	21.54GWh/yr	9700 t/ year
21000 Grid tied	32MW	35.70GWh/yr	16000 t/ year

As most PV products are imported from available sources, the more realistic expansion, or even the larger expansion, could be easily satisfied by existing suppliers. At present, PV is purchased for applications where grid electricity is unavailable. As the costs in New Zealand are further reduced (and keep pace with overseas prices) it is expected that a number of new applications will become viable especially in the area of distributed generation and embedded generation, as discussed above.

Summary of solar systems

In summary, it is instructive to detail the hypothetical level of output (in equivalent electricity units) that could be achieved by each technology in New Zealand as the lifecycle cost of production of that output decreases from its present level to a level expected in the next five years.

For solar hot water, the present lifecycle cost of producing a kWh equivalent can be estimated from the equipment and maintenance costs (~$4,000), the lifetime of the equipment (20 years), and the total number of electricity equivalent units produced during that lifetime (20yr x 2,500 kWh/yr). The value of 8 – 12 c/kWh obtained indicates that solar domestic hot water is cost competitive with retail electricity tariffs throughout New Zealand and the maximum yearly output from this source is only limited by the number of systems that can be installed.

Given a value of 32,000 installed systems, the potential output is about 80GWh per year. This is illustrated in figure 6. A similar but forcibly more approximate calculation for solar PV indicates that, at present price levels the expected output in New Zealand is about 3-5GWh per year. A reduction in cost to ~25c/kWh would raise this to approximately 10GWh per year while a further reduction close to 15-18c/kWh would open up the residential electricity market to PV thus boosting its potential contribution to 40GWh per year and beyond.[2]

[2] Some supporting evidence for the above figures may be seen in the article *Market opportunities for dispersed photovoltaic energy sources in NZ*; I. Sanders and A. Gardiner, Industrial Research Limited 1999.

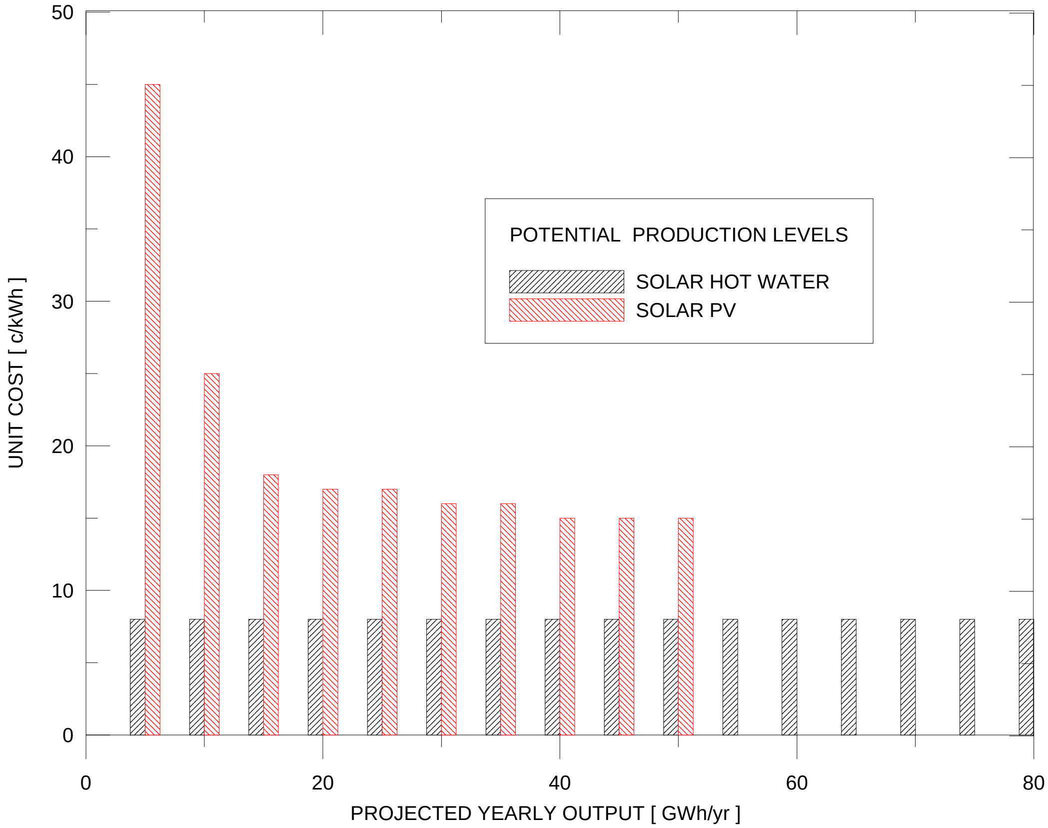


Figure 6: Projected potential total yearly contribution (in GWh per year electricity equivalent) from solar technologies as a function of their unit production cost in New Zealand (in cents per kWh equivalent).

4. <u>Environmental and social advantages</u>:

4.2 Solar technologies provide sustainable energy.

4.2 Both solar technologies are modular in nature and are therefore adaptable to a variety of applications that vary in size, output temperatures and other operating requirements.

4.2 Although capital intensive in the case of PV, solar technologies rely on a freely available source and have extremely low maintenance costs. PV is the energy source of choice for navigation lights, telecom sites and isolated or remote areas, including Antarctica where reliability and low maintenance are of utmost importance.

4.2 The lifetime of both solar thermal and solar PV technologies are greater than 25 years. Solar PV modules carry a minimum manufacturer guarantee of 20 years; longer than most power plants, conventional or new.

4.2 Solar technologies are easily integrated into new or existing buildings; they are unobtrusive, can enhance the aesthetics and architectural appeal of buildings and are often considered a positive asset due to their green image.

4.2 Both technologies still show a large potential for cost reduction in the near future due to technological advances and increased production based on substantial market expansion.

5 Barriers to uptake of solar energy systems:

There are several barriers to the uptake of solar conversion systems in New Zealand and indeed elsewhere. Most are manifested in the implementation of new technologies that attempt to displace existing, well-established technologies. As such, they relate directly to the dissemination of solar thermal and solar PV. These barriers may be seen as a reflection of the way technological progress has a certain momentum, and tends to remain oriented in certain directions.

This inertia has as a direct consequence, excluded of newer, possibly more appropriate technical solutions as either not mature enough, not cost effective or not worth pursuing. This exclusion can take the form of technical barriers, cost barriers and/or market organisational, or structural barriers. In the case of solar these latter two barriers exist for all technologies, while the former is relevant to a greater extent for PV than for solar thermal.

5.1 Technical Barriers:

Solar technologies are mature (solar thermal), mature in some niche applications (PV – stand alone) or near-market (PV - grid connected).

For the solar thermal industry, technical barriers have been mostly resolved, at least for low temperature conversion. Systems have existed for some time now with sufficiently high efficiency at low cost to yield a positive return over their operating life in a number of applications.

For mid temperature systems suitable for implementation in New Zealand as for PV, the technologies are both ready for niche market applications and would benefit from further research and development to reduce costs and open new markets. The breakeven point for a typical grid connected PV installation at a New Zealand urban site can be from 15 to 20 years[3]. The lifetime of the panels is guaranteed by the manufacturers for 20 years.

---

[3] *Market opportunities for dispersed photovoltaic energy sources in NZ*; I. Sanders and A. Gardiner, Industrial Research Limited 2000.

Hence PV can be considered a viable cost for cost replacement for centralised electricity generation even in well-reticulated cities. Further research and development already taking place will reduce materials costs and production costs, making PV a preferred investment option even in these applications.

5.2 **Cost Barriers**:

The main cost barrier to the dissemination of solar technologies is their total cost (and hence initial capital investment) to the users, compared to alternative supply. For solar thermal systems this cost is lower over the lifetime of the system. For PV this cost is already close to breakeven. However even in this latter case, the cost barrier is not a simple reflection of economics alone; it partly exists because the market does not take into account all the costs and benefits involved.

The cost of PV (compared to coal, gas or even large hydro based electricity) does not, as yet, factor in the benefits of clean electricity production and an environmentally friendly image or equivalently traditional technologies do not internalise the costs of environmental damage and international obligations. The absence of this price differential is a barrier to adoption of PV technology in particular.

Present competitive costs of traditional methods of electricity production reflect a reduction in costs through years of implementation and " hands-on " experience. This cost reduction through "technology learning" is yet to accumulate for PV in New Zealand.

5.3 **Market Organisational Barriers**:

The main immediate markets for solar energy technologies in New Zealand are the residential and commercial building industries and by implication, the electricity industry as a whole; generators, lines and retail companies. These markets are by far the most appropriate for solar technologies as they deal in space heating, water heating and electricity. Solar technologies are eminently suited to providing these requirements by on-site generation, in competition with centralised generation and extensive distribution lines.

However, the building industry's traditional conservatism, (and that of associated trades and professions- builders, carpenters, plumbers, architects), a lack of awareness, understanding and experience of these technologies constitute a major barrier to their adoption.

An inadequacy of traditional financial markets for solar technologies arises from the very nature of renewable systems. These are often capital intensive but have next to nil ongoing and maintenance costs. Economic means of analysis such as payback period, used extensively for traditional assessments, are disadvantageous to solar technologies, for which lifecycle costs are more appropriate. These incorporate some assessment of reliability, low maintenance and nil fuel costs.

There is also in New Zealand an inability to capture the benefits of solar technology by users. Solar does not add value to the price of a house, it is not sufficiently valued at national and regional levels or in regulations and standards, hence has little or no marketable value at present.

The organisational structure of the residential and commercial building industry engenders conflicting interests for investors and users for an investor houses and buildings capital costs are to be minimised, for purchasers and users, on-going and lifecycle costs need to be reduced.

Finally there is a lack of adequate information to ensure public awareness of the technology and its advantages. This lack of awareness spreads through to all sectors of this industry and, to a lesser extent through the electricity industry.