United Nations Educational, Scientific and Cultural Organization

RENEWABLE ENERGY TECHNOLOGIES
IN
AUSTRALIA AND NEW ZEALAND

Research and Development, Manufacturing and Field Projects

(Project REF: SC/EST/99/4596)

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A. RENEWABLE ENERGY IN AUSTRALIA

1. Solar Photovoltaics

The Australian Solar Photovoltaic (PV) industry is the world's largest on a per capita basis and is poised to extend its share of the rapidly growing world market for solar energy from PV. Australia has a special position internationally in PV. It was the first large user of solar cells for telecommunications in the 1970's. It is the largest manufacturer of cells on a per capita basis in the world. Its researchers have developed new solar cell technology over the last 15 years**,** which has now become the most successfully commercialised over this timeframe. New solar cell technology under development in its R&D companies appears likely to provide the next round of new cell technology for the next millennium.

The industry in which Australia has played such a large role is growing rapidly. Significant programs have been established in the world's largest industrial nations to help launch PV into the mainstream electricity market.

1.1. World's PV Players

The global PV market consists of a small number of reasonably large manufacturers, (greater than 6% market share) and a large number of small manufacturers (less than 6%). PV manufacturing is concentrated in four countries as shown in Table 1.1, with Australia number one on a per capita basis.

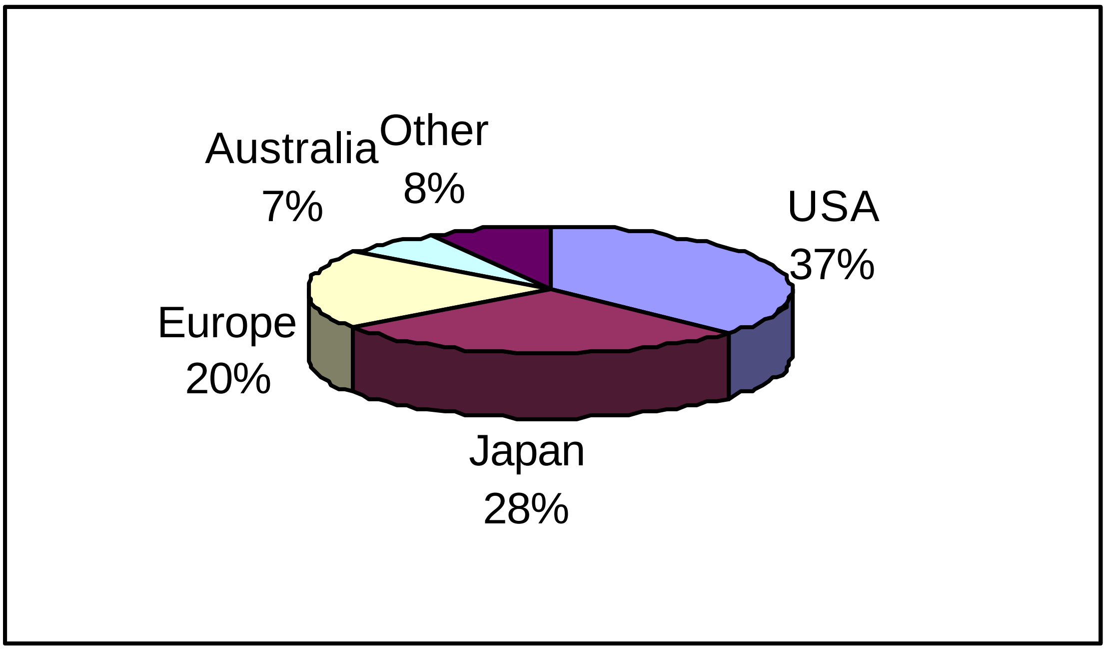

Figure 1.1. PV Manufacture by Country (1997)

1.2. *Research and Development: Australia's Enviable Track Record*

Australia has an enviable track record in PV research. Commencing in the 1970's, The 1970's and early 80's saw significant research efforts underway and the first manufacturing facilities established. Australia is now the largest manufacturer on the same per capita basis.

The infant nature of the global PV industry, together with Australia's expertise, provides a unique opportunity for Australia to maintain its position as a dominant PV producer as the industry grows rapidly over the coming decade. In particular, Australia's leading expertise at the cutting edge of technology developments in PV auger well for a global expansion program that would, among other things, see Australian production technology established locally and overseas through joint ventures and the like.

Australian PV research is acknowledged as second to none. Four major research efforts are underway at:

- University of New South Wales (UNSW)
- Australian National University (ANU)
- Sustainable Technologies Australia Limited (STA)
- Pacific Solar Pty Limited.

Over 200 people are directly employed in PV research in Australia.

1.2.1 Photovoltaic Special Research Centre (UNSW)

The largest and longest running PV research effort is by the Photovoltaic Special Research Centre at the UNSW. Headed by Professor Martin Green, the Centre has a number of internationally acclaimed achievements including:

- holding the silicon solar cell efficiency record since the mid 1980's (it currently stands at 24.4%).

- developing the laser grooved, buried contact technology, licensed to ten manufacturers worldwide and used by BP Solar in its Saturn technology to give the highest efficiency of commercially available PV.

- breakthrough research into multilayer, thin film silicon solar cells and assigned to Pacific Solar Pty Limited for development and commercialisation.

Table 1.2.1: Confirmed terrestrial cell and sub-module efficiencies measured under the global AM1.5 spectrum (1000 Wm-2) at 25° C.

Classification	Effic. (%)	Area (cm^2)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Test Centre (and Date)	Description
Si (crystalline)	**24.4 ± 0.5**	**4.00 (da)**	**0.696**	**42.0**	**83.6**	**Sandia (2/98)**	**UNSW PERL**
Si (multicrystalline)	**19.8 ± 0.5**	**1.09 (ap)**	**0.654**	**38.1**	**79.5**	**Sandia (2/98)**	**UNSW/Eurosolare**
Si (supported film)	16.6 ± 0.5	0.98 (ap)	0.608	33.5	81.5	NREL (3/97)	AstroPower (Si-Film)
GaAs (crystalline cell)	25.1 ± 0.8	3.91 (t)	1.022	28.2	87.1	NREL (3/90)	Kopin, AlGaAs window
GaAs (thin film cell)	23.3	4.00 (ap)	1.011	27.6	83.8	NREL (4/90)	Kopin, 5 mm CLEFT
GaAs (multicrystalline)	18.2 ± 0.5	4.011 (t)	0.994	23.0	79.7	NREL (11/95)	RTI, Ge substrate
InP (crystalline cell)	21.9 ± 0.7	4.02 (t)	0.878	29.3	85.4	NREL (4/90)	Spire, epitaxial
CdTe (cell)	16.0 ± 0.2	1.0 (ap)	0.840	26.1	73.1	JQA (3/97)	Matsushita 3.5 mm CSS
CdTe (submodule)	10.6 ± 0.3	63.8(ap)	6.565	2.26	71.4	NREL (2/95)	ANTEC
CIGS (cell)	16.4 ± 0.5	1.025(t)	0.678	32.0	75.8	NREL (11/94)	NREL, CIGS on glass
CIGS (submodule)	14.2 ± 0.2	51.7 (ap)	6.808	3.1	68.3	JQA (10/96)	Showa Shell
a-Si (cell)[g]	12.7 ± 0.4	1.0 (da)	0.887	19.4	74.1	JQA (4/92)	Sanyo
a-Si (submodule)	12.0 ± 0.4	100 (ap)	12.5	1.3	73.5	JQA (12/92)	Sanyo
Nanocrystalline dye	6.5± 0.3	1.6(ap)	0.769	13.4	63.0	FhG-ISE (1/97)	INAP
GaInP/GaAs	30.3	4.0 (t)	2.488	14.22	85.6	JQA (4/96)	Japan Energy (monolithic)
GaAs/CIS (thin film)	25.8 ± 1.3	4.00 (t)	-	-	-	NREL (11/89)	Kopin/Boeing (4 terminal)
a-Si/CIGS (thin film)	14.6 ± 0.7	2.40 (ap)	-	-	-	NREL (6/88)	ARCO (4 terminal)
a-Si/a-Si/a-SiGe	13.5 ± 0.7	0.27 (da)	2.375	7.72	74.4	NREL (10/96)	USSC (monolithic)

CIGS = CuInGaSe2; a-Si = amorphous silicon/hydrogen alloy
Effic. = efficiency
(ap) = aperture area; (t) = total area; (da) = designated illumination area
FF = fill factor
FhG-ISE = Fraunhofer-Insitut für Solare Energiesysteme; JQA = Japan Quality Assurance
Unstabilized results

The University of New South Wales (UNSW) has developed the highest efficiency silicon solar cells for terrestrial purposes, known as PERL (passivated emitter, rear locally-diffused) cells. These PERL cells have also demonstrated a record high performance of 20.8% efficiency under the space AM0 spectrum, in 1990, compared to 14-15% efficiency for a standard high performance silicon space cell. A previous study has found that the PERL cells also demonstrated higher efficiency than the standard space silicon cells at the end of 5 x 10^{15} electrons/cm^2 1 MeV electron bombardment, although these PERL cells has lower relative radiation resistance. Employing shallow emitters, thin substrates, and other techniques are expected to significantly improve the cell resistance to radiation damage.

Table 1.2.2.: Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25° C.

Classification	Effic. (%)	Area (cm2)	Voc (V)	Isc (A)	FF (%)	Test Centre (and Date)	Description
Si (crystalline)	22.7 ± 0.6	778 (da)	5.60	3.93	80.3	Sandia (9/96)	**UNSW/Gochermann**
Si (multicrystalline)	15.3 ± 0.4	1017 (ap)	14.6	1.36	78.6	Sandia (10/94)	Sandia/HEM
CIGSS	11.1 ± 0.6	3665 (ap)	26.01	2.32	67.4	NREL (4/97)	Siemens Solar
CdTe	9.2 ± 0.5	3366 (ap)	45.59	1.10	62.1	NREL (4/97)	Golden Photon
a-Si/a-SiGe/a-SiGe (tandem)	10.2 ± 0.5	903 (ap)	2.32	6.47	61.2	NREL (12/93)	USSC[27]

Table 1.2.3.: Terrestrial concentrator cell and module efficiencies measured under the direct beam AM1.5 spectrum at a cell temperature of 25° C.

Classification	Effic. (%)	Area (cm2)	Concentration (suns)	Test Centre (and Date)	Description
Single Cells					
GaAs	27.6 ± 1.0	0.126 (da)	255	Sandia (5/91)	Spire
GaInAsP	27.5 ± 1.4	0.075 (da)	171	NREL (2/91)	NREL, Entech cover
InP	24.3 ± 1.2	0.075 (da)	99	NREL (2/91)	NREL, Entech cover
Si	26.8 ± 0.8	1.60 (da)	96	FhG-ISE (10/95)	SunPower back-contact
Si (large)	21.6 ± 0.7	20.0 (da)	11	Sandia (9/90)	**UNSW laser grooved**
GaAs (Si substrate)	21.3 ± 0.8	0.126 (da)	237	Sandia (5/91)	Spire
InP (GaAs substrate)	21.0 ± 1.1	0.075 (ap)	88	NREL (2/91)	NREL, Entech cover
Multijunction Cells					
GaAs/GaSb	32.6 ± 1.7	0.053 (da)	100	Sandia (10/89)	Boeing, mechanical stack
InP/GaInAs	31.8 ± 1.6	0.063 (da)	50	NREL (8/90)	NREL, monolithic 3 terminal
GaAs/GaInAsP	30.2 ± 1.5	0.053 (da)	40	NREL (10/90)	NREL, stacked 4 terminal
GaInP/GaAs	30.2 ± 1.4	0.103 (da)	180	Sandia (3/94)	NREL, monolithic 2 terminal
GaAs/Si	29.6 ± 1.5	0.317 (da)	350	Sandia (9/88)	Varian/Stanford/Sandia, mech. stack
Submodules					
GaAs/GaSb	25.1 ± 1.4	41.4 (ap)	57	Sandia (3/93)	Boeing, 3 mech. stack units
Modules					
Si	20.3 ± 0.8	1875 (ap)	80	Sandia (4/89)	Sandia/**UNSW**/ENTECH (12 cells)

1.2.2. Australian National University

Dr Andrew Blakers at the ANU heads a team developing the Epilift process to reduce the cost of conventional PV wafer technology. Boral Energy has recently provided over $3 million in funding to take the technology to the pilot line stage.

1.2.2.1. High Performance Single-Crystalline Silicon Solar Cells

High efficiency cells (>20%) are manufactured to form the photovoltaic receiver of a PV/trough concentration system. The cells operate under about 30 times normal sunlight intensity. A 1.8 kW system is currently being tested and a 24kW-demonstration plant is expected to be built in the ACT.

1.2.2.2. High Performance Multi-Crystalline Silicon Solar Cells

Cells made at the Australian National University have been independently measured to have an efficiency of 18.2% (4cm^2 cell area, AM1.5, 25°C). Slightly better cells have been measured in-house with an efficiency of 18.6%. These are world record efficiencies, only matched by the work at Georgia Tech who have reached 18.6% with 1-cm2 cells. Further it is aimed to improve the efficiency by optimising the technologies used to fabricate them, in particular the diffusion of boron and phosphorus to form their emitter regions and metal contact formation. Patent protection for the Epilift technology as well as for innovations associated with the PV/trough technology have been filed.

Solahart Industries Pty Ltd have an exclusive licence worldwide to manufacture and distribute the PV/Trough systems as well as to grant sub-licences. A 20 kW system has been planned to be installed at Murdoch University's Rockingham campus. The electricity generated by the system will be fed into the grid and it is expected to be operational by late 1999.

1.2.3. Sustainable Technologies Australia Limited (STA)

Led by joint managing directors Dr Gavin and Sylvia Tulloch, STA, a publicly listed company, is developing titanium dioxide titania PV technology. This differs from silicon PV technology by being chemically based rather than semi-conductor based. It is founded on pioneering work by Professor Michael Grätzel in Switzerland.

The basic Titania cell consists of a sandwich of TiO_2, dye, electrolyte and catalyst between two conductive transparent electrodes. Upon illumination of the cell, charge separation occurs by electron injection from the excited state dye molecule into the conduction band of TiO_2. The dye is then oxidised by a redox electrolyte. Effectively, light excites the dye, sending an electron on its way to be picked up and transmitted by the semiconducting Titania Dioxide (TiO_2) to become electrical energy.

Each of the layers are "screen printed" on to the glass and baked on - using cost effective "tried and tested" standard equipment from the semiconductor industry.

Recently STA team have developed the technique of manufacturing a power module. This prototype module is capable of producing approximately 20V under low light conditions. Such a module has potential applications as an integrated building material for roofing or vertical facades.

Recent Developments: Sustainable Technologies Australia Ltd has received a grant of $1,000,000 from the Australian Greenhouse Office (AGO) to construct the world's first Titania Solar Cell and Wall Panels manufacturing facility in the New South Wales city of Queanbeyan. The project aims to manufacture 100 square metres of Titania solar wall panels for trial and demonstration purposes. Titania solar wall panels will be cheap to produce when manufactured at full volume.

1.2.4. Pacific Solar Pty Limited

Pacific Solar is a joint venture company established by leading utility Pacific Power (70%) and Unisearch Limited (30%), the commercial arm of the University of New South Wales. It was established in 1995 to develop and commercialise the Photovoltaic Special Research Centre's breakthrough research in multilayer, thin film silicon PV.

The Company currently employs 75 people and is spending $51 million in its five-year R&D program in the lead-up to commercial production from its first factory, which will have an annual output of 20 MW of PV systems. This R&D aims to develop a complete Plug & Power ™ PV system for easy rooftop installation and grid connection. The Plug & Power ™ system consists of:

- thin film PV modules
- a grid-interactive inverter attached to each PV module
- a rooftop mounting system for each PV module
- plug and socket wiring and ancillary electrical hardware.

Pacific Solar is investing $45 million in the five-year development of the PV module with the aim of achieving a manufacturing cost of around $1/W and a comparatively high efficiency of 15%. The Company's development of its grid-interactive inverter is being funded separately through a $6 million R&D Syndicate.

At $51 million, this level of combined funding has brought together some of the world's leading PV researchers and developers in the largest renewable energy development in Australia's history. As part of its research effort, Pacific Solar commenced operation of its pilot line in June 1998.

The pilot line enables the Company to scale up its lab bench modules to a size of 300 mm by 400 mm. These modules will be used for accelerated life testing and field trials. The modules are a stepping stone to Pacific Solar's full-scale commercial modules of one square metre in size. Lessons learnt on the pilot line are being applied to the design of the Company's 20 MW factory.

Pacific Solar aims to start construction of its first 20 MW factory at the end of its current five-year R&D program.

1.3. PV Manufacturing in Australia

Australia's two PV manufactures, BP Solar and Solarex, have been manufacturing PV cells and modules in Australia since the 1980's. In 1997, their combined Australian production accounted for 7% of global shipments. Almost two thirds of their production was exported.

1.3.1. BP Solar Australia Pty Ltd

BP Solar Australia Pty Ltd is the largest manufacturer of solar cells and photovoltaic modules in Asia. They have its manufacturing facility at Brookvale in New South Wales.

Two years ago, they have won a $37 m contract from the Government of the Philippines (the largest single contract of its kind ever to be awarded) to install more than 1000 packaged solar systems in 400 remote villages in the Philippines.

Plans announced by BP Solar for a new manufacturing facility to be built in Sydney in 1999 to manufacture Australian developed Saturn technology is currently on hold. With an annual output of 20 MW, it will be one of the largest PV factories in the world. It is estimated to cost $57 million, will employ almost 200 people and will be expandable to 50 MW.

1.3.2. Solarex Pty Ltd

From its first plunge in 1976 into Australian PV module manufacturing at a small factory site in Regents Park N. S. W. , Solarex has continued to invest heavily in both technology and local manufacturing of both PV module and balance of system equipment.

The present facility in Villawood, N. S. W occupies over 3,475 square metres of floor space and is the complete PV module manufacturing plant in the Australasian region. The plant offers employment to over 80 people.

Recent Developments: Recently Solarex has recently received a grant of $482,000 to upgrade the company's current multicrystalline solar cell fabrication facility by implementing laboratory-processing improvements into the commercial cell production. The new techniques are designed to increase cell efficiency to 17% from a present typical efficiency of 12.5%, ultimately resulting in a 36% increase in capacity from the plant without increasing production or silicon consumption. As a result of the work, the manufactured cost per watt for solar energy would be reduced by 27%.

1.3.3. Balance of Systems and Other Systems Manufacturers

In addition to the two PV manufacturers, there are other large numbers of "balance-of-system" (BOS) component manufacturers. They manufacture inverters, regulators, batteries and miscellaneous hardware for PV.

The total Australian PV industry annual revenue is estimated at over $90 million of which almost $40 million comes from the sale of the PV modules themselves. These are not insignificant amounts, given a revenue estimate for the global PV industry of about US$1 billion. It is predicted that this will increase to US$10 billion by 2010.

Advanced Energy Systems: Established in 1987, the Advanced Energy Systems (AES) Group is recognised as a world leading producer and implementer of power and communication technologies for industrial and renewable energy applications.

The founders of AES began work on the company's core technologies in 1980 and have since grown the group to include PowerSearch Ltd; the award winning Research and development division, and Prime Power Systems Pty Ltd; the manufacturing and project engineering division.

AES has proven commercial products, its innovative R&D team, and its worldwide network of distributors and strategic partners. Since its establishment, AES has sold and installed product in over 20 countries worldwide, has expanded to include offices in the United States and India and has developed an international reputation for its pioneering research and commercial successes.

Located at Technology Park, Perth, Western Australia, AES offers a diverse range of skills under the various divisions including marketing, engineering, project management, production, Software Systems and administration. The range of their products include large capacity inverters up to 100 kW mainly for grid-connected and stand-alone hybrid systems applications.

Solar Systems Ltd: Solar Systems Ltd is a specialised solar technology design and manufacturing company. Through extensive research, the company has developed an electricity generation system. The system's proven concentrating photovoltaic technology is based on space technology and semi-conductor manufacturing techniques.

The key patented components include a high-power solar cell receiver, which can accept concentrated solar energy from a laser configured 'smart reflector' – delivering high output at low cost.

The systems are manufactured by state-of-the-art automated processes, ensuring world's best practices. Complementing its sophisticated design and manufacturing facilities, the company operates substantial system proving and utility connection sites.

Ongoing product development programs are conducted with eminent organisations such as Research Triangle Institute (USA), the National Renewable Energy Laboratory of the Department of Energy (USA), Royal Melbourne Institute of Technology (Australia) and Commonwealth Scientific and Industrial Research Organisation (Australia).

Power Solutions Australia: Power Solutions Australia is a Melbourne based large size inverters manufacturing company, which are used in the grid-connected PV installations. They design and build world class inverter products to meet customer needs using power electronics technology. Their product range includes up to 50 kW capacity inverters.

Selectronics: Selectronic Components was established in 1964 by Mr. Brian Scott, a qualified Electrical Design Engineer with eighteen years experience in the Radio and Television Industry. The company has a Melbourne-based production facility. The electronic assembly division commenced in 1983 with the introduction of a range of modified square wave power inverters to the Australian market place. Today this division manufactures a range of high performance modified square wave inverters, and state-of-the-art sine wave inverters. The product range includes 350 W - 2200W.

Solar Energy Systems: Solar Energy Systems is a Western Australian solar pump manufacturing company based at Perth. The company has been developing poly-piston type of solar pumps since early nineties. The poly-piston pumps are designed to allow water flow through a ball valve eliminating friction. Water is pumped on both the upward and downward strokes, making these pumps twice as efficient as a regular pump. These pumps are also 100% non-corrosive. Solar Energy Systems also manufacture electronic, light sensitive tracking array, which follows the course of the sun throughout the day.

1.4. Solar PV Projects

Under Australia's greenhouse response to Kyoto Protocol, all large electricity generators and retailers must source an additional 2% of their electricity from renewable energy by 2010. This represents approximately 4000MW of new renewable energy generation by 2010 (Electricity Supply Association of Australia)

Therefore, throughout Australia, utilities are offering their customers the opportunity to buy renewable energy generated electricity (based on a substantial premium per kWh to be paid for the provision of the renewable energy). A significant number of customers have chosen the renewable energy option and this consumer choice is leading to an increase in grid connected solar electricity generation. A number of solar PV projects have been created under this Green Power program.

1.4.1. New South Wales

400 kW Photovoltaic Power Plant at Singleton: The PV power plant comprises two units of 200 kWp each. The first plant was commissioned in December 1997 and uses conventional 60 Wp poly-crystalline solar cell modules. The second plant has been operating since July 1998 and is based on amorphous silicon solar cells arranged in modules of 60 Wp each. State-of-the-art inverters transform the DC current to 240 V/50 Hz AC, with subsequent stepping-up by the utility to 11,000 VAC for grid feeding.

The first 200 kWp PV power plant unit was designed around the use of 3456 poly-crystalline silicon cell modules of 60 Wp each, supplied by Solarex, Australia. The second 200 kWp unit uses 3312 large-scale (2600 mm by 413 mm) 60 Wp modules by Canon, Japan. This module technology is based on triple-junction amorphous silicon cells, which are laminated to a 0.8 mm thin stainless steel sheet metal backing. All modules are mounted on racks positioned due-north and tilted by 30°.

For the first plant, Power Solutions Australia (PSA) has supplied one 50 kW and three 6 kW voltage-controlled, grid-interactive sinewave inverters, supplemented by thirty three 4 kW inverters by Solar Energy Australia. The second stage however uses only four of PSA's 50 kW inverters.

50 kW PV System at Western Plains Zoo, Dubbo: The Dubbo solar farm was being built by Advance Energy of NSW with the support of the State Government's Sustainable Energy Development Authority to meet the growing demands of Green Power. The farm is made up of 720 photovoltaic panels, producing 100 Megawatt-hours of electricity annually. The solar panels are manufactured by Solarex Ltd. The solar farm will save 100 tonnes of greenhouse gas emissions a year. It will power a kiosk and information centre at the zoo, with any overrun being fed to Advance Energy's customers.

50 kW PV System at Queanbeyan: The Queanbeyan Solar Farm has been developed by Great Southern Energy. Queanbeyan has one of the highest 'sun incidence days' ratings in Australia, making it an ideal location for a solar farm. It will produce 100,000 kilowatt hours (kWh) of electricity each year, which is enough power for about 20 homes.

7.2 kW PV Station at Sydney Central Business District: The capacity of this PV plant is 7.2 kW peak under standard test conditions. The installation is made up of ninety, solar modules manufactured by Solarex Pty Ltd in Sydney. The modules are 83 watt each and are connected into ten series of nine modules with a nominal output of 120 V dc. The output is conditioned and inverted to the 240 V AC Australian standard through a 6 kVA continuous sinewave inverter with an efficiency of greater than 90%. The installation is grid connected through a standard single phase 240 V AC connection.

Olympic Village Newington: Olympic Village Newington has set a new-world standard for residential development. Solar PV modules have been integrated into the roofs of 665 permanent houses in the village. Each of these houses has the security of grid connection at all times. Newington homes will reduce greenhouse gas emissions by up to 75% on the typical homes, with annual saving of up to 6 tonnes of carbon dioxide per house and 3,990 tonnes overall. It will demonstrate the commercial capacity of renewable energy technology to 4 billion Olympic viewers to meet the electricity energy needs of an entire urban residential development.

1.5.2. Western Australia

The Kalbarri Photovoltaic System is part of a research joint venture between Western Power Corporation, Advanced Energy Systems Ltd, Murdoch University Energy Research Institute, Curtin University Power Electronics Research Unit and the Energy Research and Development Corporation. The aim was to develop state-of-the-art electronic power inverters, which will enable power from photovoltaic systems to be fed into main power grids or small stand-alone remote power systems. The project at Kalbarri combines a power inverter with a new adaptive control system and photovoltaic panels. Together they feed electricity into the Western Power grid.

This is small compared with those already operating in other parts of the world. Depending on local weather conditions, it can deliver up to 20 kilowatts (kW) of electricity: enough to supply 20 average-size homes. The inverter can accommodate up to 35kW of PV power and sufficient land has been set aside for possible expansion.

There are 16 single-axis trackers: each supporting 16 PV panels comprising a total of 256 for the whole system. Using "smart electronics" the trackers follow the sun throughout the day with panels optimally positioned to receive maximum sunlight. The trackers can also be adjusted manually to accommodate seasonal variations.

The Kalbarri project is the first PV system to be grid connected in WA. An extensive monitoring programme is providing information on:

- plant operating characteristics;
- the degree to which the PV system output matches the Kalbarri demand;
- the reliability of the various plant components;
- the capabilities of the new inverter;
- the operating and maintenance requirements; and
- the potential improvement to the quality of the local power supply

Installing and operating the PV system is giving Western Power first hand experience with a new technology and is allowing more accurate assessment of the value of end-of-grid generation. It is providing Western Power with vital knowledge of the role PV systems and associated power conditioning equipment can play in improving power supplies in remote locations.

1.5.3. South Australia

The fully automated 100 kW solar PV system is contributing up to 40% of the Tourist Centre's Power demand and has been designed so the power produced by the system will contribute to the instantaneous load as much as possible. The new Wilpena Tourist Centre in the Flinders Ranges is power by the largest off-grid solar electricity system in Australia. The system combines PV panels, diesel generators and batteries and was opened in June 1998. This system will reduce greenhouse gas emissions by up to 300 tonnes per annum compared with an all diesel generators.

2. Wind Energy

There is no manufacturer of large scale wind turbines in Australia but there is a lot of domestic industry living off the power of wind. The Australian companies have been exporting wind mills and small wind turbines to a number of countries. There hundred thousands of wind mills are installed in the country region pumping water for live stocks. Southern Cross and W. D. Moore are the oldest wind mill manufacturing companies while West Wind manufactures Bergey model of wind turbines of up to 20 kW capacity.

At the University of New Castle, a research group is engaged in carrying out wind power generation related R & D.

In Australia New South Wales, Victoria, Tasmania, South Australia and Western Australia enjoy a higher average wind regime and have many excellent sites for setting up of wind farms. At present, while there are a number of wind turbine suppliers in

Australia, the lack of a large market means that big wind turbines are not presently manufactured here. However, this could change in the near future with the development of Australasia's excellent wind resource.

2.1. New South Wales

The largest grid-connected wind turbine in NSW is a 600 kW unit installed at Kooragang Island near Newcastle. The Wind Turbine Generator (WTG) consists of a 50m tower, on top of which a nacelle holds the generator and the three 22m blades. This wind turbine is owned by EnergyAustralia and was installed in November 1997.

A smaller 150 kW wind turbine is situated on the coast near Malabar in Sydney's suburbs.

A 5 MW wind farm was installed near Crookwell in NSW's Southern Highlands. Consisting of 8 wind turbines, the wind farm will be the largest in Australia. This wind farm is a joint initiative by Pacific Power and Great Southern Energy. The wind farm is expected to produce approximately 10,000 megawatt-hours of electricity per annum once it is operational.

Pacific Power is also involved in another wind farm with Advance Energy, proposed for construction at Blayney in the Central West of NSW.

2.2. Western Australia

Over the period 1978-86, thirteen wind turbines, ranging from 5 to 60 kilowatts (kW), were trialed at South Fremantle and Rottnest. A 60 kW model was selected from the turbines tested, and six were installed at Salmon Beach near Esperance. This 360 kW Wind Farm, commissioned in April 1987, was Australia's first wind farm and a showcase for locally available technology. During the late eighties, a second phase of the wind monitoring program identified Ten Mile Lagoon near Esperance as an appropriate site for a larger-scale commercial wind farm.

Denham - 1000km north of Perth - is the home of one of the most advanced wind turbine projects in the world. Western Power has build the wind turbine at a site 2km out of Denham - about 80 metres off the Monkey Mia Road - to operate with the town's small diesel power station. The project, which is the result of many years work by Energy Technology and Environment Branch, has been tested the commercial applications of renewable energy systems on Western Power's small diesel grids.

It is expected that annual savings in fuel consumption will be about 175,000 litres, which will help reduce carbon dioxide emissions by 500 tonnes. The wind turbine will also cut the town's reliance on imported fuels.

Western Power already has another commercial wind farm in Australia, at Esperance. Ten Mile Lagoon has nine 30-metre tall turbine towers, which generate up to 2MW of power into the Esperance electricity grid, supplying about 12 per cent of the town's power.

Ten Mile Lagoon Wind Farm at Esperance was the first commercial wind farm in Australia. It is one of the few in the world to be viable without some form of subsidy. The Wind Farm, with a capacity of 2025kW, was commissioned in October 1993 at a cost of AUD$5.96 million.

Due to its isolated location (720 km S. E. of Perth), Esperance is not currently connected to Western Power's South West Interconnected Grid, the State's major electricity distribution system. In 1992, when construction commenced, Esperance had a population of 6000 people and was serviced by a diesel power station of about 14 megawatts (MW). The Ten Mile Lagoon Wind Farm supplements this power station, which reduces the amount of electricity generated by diesel power. This reduces both fuel costs and diesel atmospheric emissions.

There are also a number of smaller installations throughout the State. In 1997, a 30 kW wind turbine was installed at a small business in Armadale to meet its energy needs, with excess power being exported to Western Power's grid (the South West Interconnected System). In February 1998, two 10 kW wind turbines were installed as part of a grid connected renewable energy system at the Swan Valley Nyungah Community. Wind power is also being used in an increasing number of isolated stand-alone generation systems for households or small communities in remote areas.

2.3. South Australia

The wind turbine generator was installed at Coober Pedy in South Australia in March 1991. The project demonstrated the capability of the wind turbine generator to operate in a predictable manner in a low wind regime, contributing about 4% of Coober Pedy's power requirements.

A Nordex 150 wind turbine was used in this project. The turbine, with a three bladed, 27 metre diameter rotor, is mounted on a 30 metre high steel tower. The turbine is stall-regulated with start and stop wind speeds of 3-4 and 25 m/sec respectively. The rated output is 150 kW at a wind speed of 10 m/sec. It has a hydraulically driven yawing system and is microprocessor controlled. Monitoring was undertaken using Nordex software and loggers, these recorded peak and average power output, wind speed and direction as 15 minute averages based on 5 sec interval readings.

In the first year of operation, availability of the generator was 82.5%, with 363,692 kWh of electricity generated and a capacity factor of 27.7%. Output was about 20% higher than projected from earlier monitoring data.

2.4. Tasmania

King Island is located 85 km off the north west tip of Tasmania in Bass Strait between Tasmania and Victoria. The island has a cool temperate climate and is exposed to the prevailing westerly weather conditions. The wind farm is located about 4 km south east of Currie, the main township on the island. The wind farm is positioned on an old sand dune ridge. The wind farm was commissioned in February 1998.

The average wind speed in the area of the Huxley Hill Wind Farm is 7.8 m/s at a height of 10 m, and 9.7 m/s at the approximate hub height of the turbines, which is 30 m. The maximum demand on the island's grid is about 2700 kW, with a minimum load of 1000 kW, which occurs overnight. Power on the island is distributed using four 11 kV feeders. Energy is supplied to the grid in two ways; by a diesel power station with four 1200 kW diesel generators, and a wind farm with three stall-regulated 250 kW nominal output Nordex N29 wind turbine generators. The wind farm is located about 1 km from the diesel station and is connected via surface transformers and underground cables.

The 750 kW wind farm is expected to produce about 25% of the grid load at times of maximum demand, but initially it will be limited to 40% of the grid load at times of low load demand. Little actual performance data is available at this stage. The expected yearly average production is 2.8 GWh, giving a capacity factor of about 42%.

2.5. Queensland

Thursday Island is located in the Torres Strait, 800 km north of Cairns between mainland Australia and Papua New Guinea.

Two Vestas 225 kilowatt wind turbines were erected in July 1997 and now supply 10 percent of the island's power needs. The turbines start to generate power at a wind speed of 3 metres per second. Optimum performance occurs in winds of 14 metres per second, when 450 kilowatts of power becomes available. At wind speeds exceeding 25 metres per second, the turbines will automatically shut down.

Prior to construction, the anticipated annual output of the two wind turbines was expected to be 1.44 GWh which should have produced savings of around 359 kl of diesel fuel and reductions in carbon dioxide emissions of around 1,000 tonnes.

Thursday Island does experience seasonal wind variations, with generally lighter winds during the summer months between November and March. During February and March there is a doldrums period, where wind power contributes between 2 and 3% of the power used on the island. Between May and October the power generated contributes to between 10 and 15% of the power used on the island.

2.6. Victoria

The privately owned Breamlea 64 kW wind generator is located 18 km south of Geelong, Victoria, about 600 metres inland on flat coastal heath land. Originally commissioned by a state-owned utility in 1987 for demonstration purposes, the wind generator was sold in 1994 to a community group, the Alternative Technology Association and re-commissioned with the intent of testing the new electricity market's level of "transparency" to energy trading. The 3-bladed wind turbine is capable of displacing brown-coal-derived electricity (which produces up to 1.4 tonnes of carbon

dioxide per MWh of wind-derived electrical energy). Annual production of 90 MWh translates to 140 tonnes of displaced carbon dioxide emissions.
The horizontal axis wind turbine (upwind) has a 3-bladed rotor. The GRP blades are Aerostar 7.5 (Danish, 1980s). The 16 metre diameter fixed-pitch rotor drives a 20/60 kW (2-speed) induction motor via a 21.9 step-up gearbox. The tower is tubular, mild steel and 22 metres high. In a wind regime of 6 metres/sec with a swept rotor area of 201 square metres, the wind turbine "mines" 38 cubic kilometres of air (38 billion cubic metres) every year. The microprocessor control provides normal operation from 0-24 metres/sec, with a cut-in speed of 4.5 metres/sec. There is an automated shutdown in wind gusting over 24 metres/sec. (new function, 1997). Since 1995 the wind generator has had remote monitoring of key parameters (and remote start/stop) by data logger and modem. The lack of any power factor correction results in a poor power factor at low power output levels.

3. Solar Thermal Energy

3.2. Solar Water Heating Technology: History of R & D

In 1952, when Commonwealth Scientific and Indusial Research Organisation (CSIRO) started its investigations into the potential for solar energy, there were no Australian solar radiation records available, nor was there any formal study of solar energy utilisation.

Based on the information available from USA and UK, CSIRO developed and tested a prototype solar water heater suitable to Australian conditions. A team of scientists measured the heat output over a year from a flat plate collector inclined at latitude angle. This was obtained by continuously recording the temperature rise of main water at a constant flow through a 1.5 m^2 collector for which the temperature rise was about 30^oC at maximum insolation.

At the same time an analysis was made of thermosyphon flow in a solar water heater to determine pipe sizes for the collector array and connections to the storage system. The results were published in Report ED 1 April 1954, which provided working drawings and listed materials and components.

CSIRO continued developing collectors, which were more durable and better, suited to factory production. In 1957 CSIRO designed a fibro-cement base for a 1.5 m^2 collector and arranged it to be available to individual purchasers. The system were all low pressure and typically used two 1.5 m^2 collectors connected to readily available insulated copper 317 litre hot water cylinder with a 2.4 kW element. Initially the collectors were double glazed but it was noticed that single glazed unit was more cost effective.

Beasley Industries in Adelaide had designed lightweight sheet metal bases for their collectors and in 1962 introduced selective surfaces on their absorbers. It is believed that for a number of years they were the world's largest producers of selective surface solar collectors.

SW Hart in Perth pioneered the close-coupled roof mounted system, which was such a commercial success. Edwards Hot water Systems also in Perth introduced stainless steel hot water cylinder in their close-coupled mains pressure unit.

During the 60s production of solar water heaters increased steadily. Solar R & D programs had been set up in the Universities of Queensland, New South Wales and the James Cook University of North Queensland. In 1970s CSIRO 's Division of Mechanical Engineering was the largest group in Australia engaged in solar energy R & D. During the period up to 1984 production of collectors continued to increase steadily reaching a maximum of 45,000 units.

Now-a-days Solahart and Edwards Energy Systems are two major solar heaters manufacturing companies in Australia.

3.2.1. Solahart Industries Pty Ltd

Originally, in 1953, S W Hart & Co manufactured storage cylinders for use with the West Australian- made F. C. Korwill solar collector. By comparison with today's low profile, streamlined system, the Korwill solar hot water system was less than elegant, but it worked well.

The system operated on the "thermosyphon" principle, as do today's Solahart systems. Water passes through the solar collector panels, and after being heated by solar radiation the water rises to the insulated storage cylinder.

The system attracted a dedicated following, and regular sales were made through to the mid 1960's.

In 1964 the company designed, manufactured and installed two of the largest solar hot water systems in the southern hemisphere, installed in Australia's north-west, providing hot water for up to 140 people. So by the mid-1960 the company had made solar hot water an established and viable alternative for both domestic and commercial applications.

The Solahart 300L (80GE in the USA) established the Solahart product throughout the world, receiving acceptance in the United States, Middle Eastern countries, South East Asia and Europe. Solahart formed its own international sales and technical network and now exports to over 70 countries worldwide.

In 1979 Shell Australia acquired from the employees of S W Hart & Co a 50% shareholding and in 1984 the James Hardie Industry Group, one of Australia's largest companies acquired the remaining 50 per cent of S W Hart and Co from the employees.

James Hardie Industries Limited acquired the remainder of Shell's share in 1987, giving it 100% equity in Solahart. Shortly after this, the name S W Hart & Co was changed to Hardie Energy Products, reflecting the company's association with energy efficient products.

In October 1994 another chapter in Solahart's history was written when the business was acquired by Johan Holdings, a diversified manufacturing and investment group, the name changed to Solahart Industries Pty Ltd.

To be recognised as a leader in domestic solar hot water is a major achievement, but the company is well aware of the need to be an innovator in the field, and is constantly looking to refine and improve its products. This commitment to excellence and innovation has seen Solahart spend millions of dollars in sophisticated machinery and equipment.

The company has an energetic research and development group, which monitors and tests its units under all weather conditions, all year round. It was responsible for the development of the revolutionary closed circuit system which has had such success in countries like Korea, where temperatures can soar to a high as 35 degrees Celsius plus and range down to a bitter minus 30 degrees. No other unit has been able to cope with such temperature ranges.

Solahart solar hot water systems are now a common sight in many countries throughout the world, including the United States, Korea, Spain, Portugal, Italy, Holland, Germany, Denmark, Papua New Guinea, India, New Zealand, Malaysia, Indonesia and Thailand. Solahart continues to make large inroads into the northern European and United States markets where environmental legislation and strong community feeling for sustainable development makes solar water heating the obvious choice.

3.2. Edward Energy Systems Pty Ltd

Edward's heritage dates back to 1963 with the founding of a small firm in Perth. Today, an international organisation, Edward's has progressed to be a leader in producing hot water systems for both domestic and commercial purposes using a variety of energy sources such as gas, electric, solar, oil, or waste heat/reject heat to meet any client requirement.

Edward's has established markets in the Eastern States and overseas gaining a world wide reputation for manufacturing quality products offering excellent value for money and the latest in engineering design. With the financial, engineering and technical resources of Edward's and a commitment to quality, innovation, after sales service and extensive warranty; Edward's has become a major force in hot water systems around the world.

3.3. Other Manufacturers

Other small manufacturers include:

- AB & S Solar Industries Pty Ltd
- Barwick March Pty Ltd
- Free Heat Industries
- Sola-Kleen

- Beasley Industries
- Rheem Australia Pty Ltd
- Somer Solar Pty Ltd

4. Mini-Micro Hydro Power

4.1. Research and Development

A new range of reliable and ruggedly-built micro hydro generating sets has recently become available in Australia. These units are ideally suited for consumers remotely situated from the electricity grid and who have access to a reliable flowing water supply. The turbines can also be run in parallel with the mains supply as an extra and/or backup supply.

The Platypus Power micro hydro plant comprises of essentially a water impulse wheel, or runner, which is directly coupled to an induction generator mounted vertically above the turbine housing. Both runner and housing are constructed of 316 marine grade stainless steel to ensure a corrosion and abrasion resistant long life.

The runner has a high-efficiency Pelton/Turgo hybrid design with stainless steel buckets welded between the centre plate and the outer wheel rim. The induction generator is a three-phase, four-pole machine of simple, robust design. The absence of moving electrical contacts such as slip rings and brushes ensures superior performance, reliability and minimum maintenance.

An electronic controller serves as a governor to regulate the speed of the generator and thereby stabilises the output voltage to within +/- 2% of the rated value. The controller also ensures that there is a constant load on the generator by diverting surplus power to a resistive 'dump' load. When there is no consumer demand, the 'dump' load dissipates the total output as heat to the atmosphere via finned resistor elements.

Switches and control equipment together with meters, indicator lights and excitation capacitors are housed in a compact weatherproof cubicle. If need be, the cubicle can be located remote from the turbine for convenient access.

Remote monitoring of turbine/generator parameters can be readily achieved using an electronic data-logger interface via modem and phone line (or mobile net) to transmit information to a control centre.

The micro hydro units are presently available with outputs of 7, 15 and 20 kWe. There is also a small battery charging version available with an output of 750 watts. The hydro turbines are 4-pole, 1500 rpm induction generators supplying power at a frequency of 50 Hz. The nominal output voltages are 400 V (three phase) and 230 V (single phase).

Standard electrical protection is incorporated in the form of over voltage and over current detection and trip devices. In the event of load loss (including dump load), generator over speed is limited hydraulically to 3000 rpm.

4.2. *Mini-Micro Hydro Power Projects*

4.2.1. Ord River Dam Hydro Project

The Ord River Hydro Project is located in the Kimberley region of Northern Western Australia. It is the largest privately funded renewable energy infrastructure project in Australia. The Ord Project supplies power to the towns of Kununurra, Wyndham and Argyle Diamonds, the World's largest diamond mine.

The station is located at the base of a 70 metre high dam constructed in 1971, which has created the largest fresh water storage in mainland Australia, Lake Argyle. Water released from the lake is used for irrigation and tourism and the area is the centre of growing tourist, sugar, fruit and vegetable industries. Existing outlet works were modified to accommodate the power station. Two 4.42 diameter tunnels constructed at the time of the dam works are connected to four steel intake penstock, each 2.2m diameter. Three pre-existing 78 inch irrigation valves act to bypass flow into the river if the station is not operating.

The power station is rated at 30 MW, although outputs of up to 36 MW are possible, depending on lake level. It is a base load station and supplies up to 220 GWh of electricity to the region. Two 15 MW horizontal shaft generators are each driven by two 7.5MW Francis turbine operating at 375 rpm. Rated lead is 41 metres and rated flow is 83.4 m/sec, through the 4 turbines.

Modern digital electronic governors and sophisticated control systems enable fully automatic operation, under variable load conditions. As a stand alone base load station, the system controls frequency and voltage over long distances with 140 km of high quality 132 kV transmission lines linking load centres via three switch yards.

The Ord project supplies clean renewable energy to a unique environment, replacing three diesel stations and eliminating approximately 170,000 tonnes of CO_2 emissions annually. Existing diesel sets at the mine are linked remotely so that when additional mine loads are required which are beyond station capacity, one or more sets automatically take up load.

4.2.2. 20 MW Mini-Hydro Power Station at the Wyangala Dam

This 20 MW mini-hydro power station at the Wyangala dam in New South Wales is another example of a privately-funded power station. The power station has been operating satisfactorily since the beginning of 1992.

The power station consists of twin 10 MW Francis turbines operating under a head of 70 m and a total maximum discharge 100 million litres per hour through the turbines. An innovative feature of the power station is the circular silo design for the powerhouse, which is 15 m in diameter and was built in 55 hours using a continuous concrete pouring process instead of 2 months by conventional methods. The roof of the power house is removable for access to equipment, eliminating the need for cranes.

The power station is controlled by a communications and data acquisition link (SCADA) from a remote location; no operators are necessary at the power station itself. The water authority advises the plant owners of the amount of discharge, which is entered into a computer program, and the operation is then automatic.

The power station has performed well, generating, on average, 60 GWh per annum.

4.2.3. Lake William Hovell Hydro Power Project

This project is located on the King River about 25 km from the town of Whitfield in north eastern Victoria. Construction was completed in 1994 and the station is connected to the outlet works of a 35 m high earth and rockfill dam, which was built in 1971. The reservoir created by the dam has a capacity of 13.5 GL, which is only about 6 percent of the mean annual run off at the site and is insufficient to regulate annual flows to a significant degree. About 80% of the energy is generated from flows which would otherwise pass over the spillway during winter and spring, and the remainder from irrigation flows over the summer and autumn.

The outlet works comprise a dry well intake tower fitted with a 1200 mm diameter internal stand pipe and a vertical bend connected to a 1400 mm diameter penstock inside a 3.3 m diameter concrete lined tunnel. The penstock was built as part of the hydro development, replacing a pre-existing 900 mm pipe. There are two bellmouth inlets to the stand pipe, each with a butterfly valve for upstream closure. The penstock is connected to the small power station, which contains a single 1.5 MW Francis turbine. Water can be bypassed via a bifurcation connected to a 600 mm diameter sleeve valve to maintain river flows at times when the power station is not operating.

The outlet works and power station are some distance upstream from where the spillway discharges into the river. Spillway flows as high as 10,000 ML/d do not cause the tailwater to rise enough to affect the tailwater level and therefore high winter flows do not have a serious effect on the net head.

The net head is 29 m under maximum flow conditions and the rated generating capacity is 1,500 kW. Power is generated by a horizontal shaft Francis turbine directly coupled to an induction generator rotating at 500 rpm. The civil works for the power station comprise a concrete substructure and a steel clad superstructure. Outgoing power is cabled underground about 50 metres to a 22kV switchyard.

The station is designed for unmanned fully automatic operation and is remotely controlled and monitored by a master station linked to a station controller. Automatic restart capability enables the station to auto restart on momentary line disruptions without remote operator or local maintenance staff attendance. Automatic by-pass valve operation protects the river flows during irrigation times in the event of a station shutdown.

Generation is at 6.6 kV, stepped up to 22 kV for mains transmission. During construction, 21 kilometres of line was restrung and remote telemetry and tripping features installed as part of grid interconnection and transmission.

Lake level, flow and alarm information is provided to the local weir keeper via radio telemetry.

4.2.4. Lake Glenmaggie Hydro Power Project

Construction of a small hydro power station was completed in 1994 at Glenmaggie dam, a 37 m high curved concrete gravity structure, located on the Macalister River near the city of Sale in eastern Victoria.

The reservoir created by the dam has a capacity of 190 GL which is about one-third of the mean annual run off at the site. The major purpose of the scheme is to supply irrigation water. Since the dam was raised in 1956 an average irrigation flow of about 100 GL/year has been released into the main southern channel. A smaller quantity of 60 GL/year has been released into the main northern channel. The remainder of the inflow averaging 380 GL/year passes down the river mainly in the form of large spillway flows during winter and spring. The station is able to take advantage of both winter overflow and summer irrigation requirements, which are diverted via the larger of two, installed Francis turbines. Station intakes are via pre-existing outlet works constructed for the southern irrigation channel.

Generation is from two horizontal Francis turbines directly coupled to a double overhung synchronous generator rotating at 333.3 rpm. The turbines are of different sizes, the smaller having a runner diameter of 1,000 mm and the larger, 1,300 mm. The station is rated at 3.8 MW with a maximum gross head of 30 metres. The smaller of the turbines discharges directly into the river via a short tunnel while the larger turbine can be discharged either into the river, also via a short tunnel or alternatively discharged into the southern irrigation channel.

This design provides for flexible operating arrangements to maximise available river and irrigation flows. Each turbine is capable of generating independently.

The outlet works leading to the main southern channel comprise two 1950 mm diameter pipes which discharge through 1475 mm diameter needle valves into concrete lined stilling basin at the entrance to the channel. Bifurcations from each pipe outlet were constructed to direct water into the turbines. Water cut off is effected by fail-safe butterfly inlet valves. Drop gates in the dam are available to isolate the outlet works pipe for inspection and maintenance.

Civil works include a 10 metre deep rectangular reinforced concrete substructure constructed in excavated rock and a steel clad superstructure, including a mezzanine level control room and store. Concrete work extends to the level of a pre-existing flood protection wall. Two tunnels were constructed from the turbine outlets to the river, under an existing concrete flood apron and the protective wall. A two metre diameter pipe for the second outlet of the large turbine was installed in excavated rock, discharging into the irrigation channel.

The outlet to the irrigation channel is protected by a slide gate as the irrigation outlet tailwater level is 10 metres higher than the river outlet. During irrigation seasons this outlet discharges into the channel and it can also discharge into the river if required via a pre-existing channel-river outlet, increasing the flexibility of the station.

The station has been designed for unmanned remote operation. Control and monitoring is provided at a master station linked to a station controller. Either or both turbines can be operated remotely in any configuration. The only manual operation required is to turn the large turbine draft tube between river and channel which typically occurs twice per year. Design also includes automatic needle valve operation in the event of a station shutdown during irrigation.

Automatic restart capability has also been incorporated for momentary line faults, means that operator attendance remotely or locally is not required. The station is fully designed for safe operation and shutdown if necessary and all alarm functions are signalled to the remote operator.

Radio telemetry and alarm facilities are provided for local weir keepers at their office and remotely via beepers. These facilities cover abnormal channel status and machine operating status.

Generation is at 6.6 kV, stepped up to 22 kV for mains transmission. Approximately 5 kilometres of mains power line was restrung during construction and remote telemetry and tripping features installed as part of grid interconnection and transmission. A dedicated private line is provided for automatic shut down on mains line failure.

4.2.5. Eildon Pondage Hydro Power Project

This project is located at the downstream end of a pondage on the Goulburn River immediately downstream of Eildon Dam. The pondage was built to increase the operational flexibility of the SECV's power station at the dam and to re-regulate releases so as to minimise flow variations in the Goulburn River.

The pondage weir comprises a long low earth embankment with a concrete gravity spillway structure close to the northern end. This contains three 20 m wide and 7.3 m high vertical lift gates through which irrigation water and floods are released. The low head power station was constructed after excavating a cut through the embankment at the northern end of the gate structure and was operational in 1994.

Generation is by a single vertical double regulated Kaplan turbine connected to a speed increaser and generator, which is capable of operating over a range of heads and flows. Maximum rated output is 4.5 MW. A 3.5 metre diameter, four blade runner operating at 120 rpm, delivers power via the speed increaser to the generator operating at 750 rpm.

Rules governing permissible level fluctuations in the pondage to ensure its design functions plus environmental and recreational factors both in the pondage and downstream were taken into account in the design of the station. These rules include requirements that the station be able to operate with pondage levels fluctuating between el 213.5 and el 217.6 while maintaining downstream flows within ± 100 ML/d.

River rise and fall rates of 0.15 m in any hour or 3,500 ML/d in any 24 hour period are not to be exceeded while operating over a range of flows of between 1,500 ML/d and 6,000 ML/d.

The station operates as an unmanned, fully automatic station with remote control and monitoring from a master station connected to a unit controller. Automatic restart on momentary line faults plus automatic trimming during high head operation to prevent cavitation has been implemented in conjunction with the pondage gates which maintain river flows during these times.

Additionally, the unit controller is hard wired to a gate controller installed by Goulburn Murray Water which relays signals by radio telemetry to a central control centre at the Eildon office of GMW. This controller monitors river flows, gate operations and turbine operation as part of a fully automatic and integrated water management system. In the event of a line outage, a stand-by diesel generator has been installed to operate pondage gates.

Alarm functions operate to the remote operator, the GMW control centre and remotely to weir keepers via beepers. This integrated control feature of the Eildon Pondage Station is the result of much co-ordination and co-operative work between the developer Pacific Hydro and Goulburn Murray Water.

Civil works included a 20 metre deep by 12 metre wide cut through the downstream pondage embankment and rock, coffer damming at both ends and temporary and permanent sheetpiling. A concrete substructure was constructed to the top of the existing embankment (el 219) with a steel clad superstructure. The substructure included control rooms for station control and high voltage switchgear.

Generation at 6.6 kV is stepped up to 22 kV via an outdoor transformer and connected to a nearby 22 kV mains line. Remote telemetry and tripping has been installed as part of grid interconnection and transmission. A dedicated private line is provided for shut down on mains line failure.

4.2.6. Micro Hydro Power for Cathodic Protection

A small-scale Turgo turbine connected to an asynchronous generator with a nominal capacity of 2.5 kW (AC) has been built to protect a 4 km stretch of a large, steel water supply pipeline with a diameter of 1.575 m. Water for the micro hydro power plant is taken directly from the main pipeline at a rate of 20 l/s and pressure of 2.4 bar, is eventually discharged into a nearby creek. The main water supply pipeline has a carrying capacity of 2500 l/s and leads through a State Forest in Gippsland, Victoria, serving three major towns and a large paper mill.

Applying an AC-to-DC rectifier, some 30 amps at a voltage of 50 VDC are produced and injected into the pipeline on a 24-hour basis. The output is controlled and the cathodic protection unit can operate automatically in either constant current or constant potential mode.

The cathodic protection system was handed over to the clients in June, 1997 following a four-day installation period. It has operated faultlessly and without the need for maintenance attention, producing continuous power at a rate of 2.5 kW. Because the water feed is regulated by the flow in the main pipe, temperature or precipitation does not influence power output.

4.2.7. Micro Hydro at Myrtleford

The hydro system is connected to an existing gravity fed pipeline. The eight inch (200 mm) pipe is two kilometres long and is supplied by a creek-fed dam. With a head of 60 metres and a flow of 12.8 litres per second, the generator provides an output of 5 kW at 240 volts. The electricity supplies the main house through a 350 metre long transmission line. The system could readily be configured to feed directly into the main grid.

4.2.8. Remote Tasmanian Wilderness Lodge Powered by Hydro

The system installed is a Pelton Model 250P from Tamar Designs. A small weir was constructed on the closest creek, providing a drop of 208 m to the site of the turbine. The effective head, allowing for losses due to pipe friction, is 142 m with flow rate of 46 litres/second. The 52 kW turbine generator operates at an average output of 48 kW. The system provides the lodge with refrigeration, 6 kW of lighting, some instant heating, hot water and other smaller power requirements. It also provides fire fighting abilities.

At times when surplus electricity is generated the customised energy management software dumps power to a large capacity water heating system which is also provided with gas-fired heating for use when required.

On a smaller scale Western Power operates a 2 MW hydro electric power station at Wellington Dam near Collie. This station was constructed in 1955 and recommissioned in 1992 following the completion of the Harris River dam. Output from the power station has been variable due to restricted access to water. There are only a few installations of micro-hydro plants in Western Australia due to a lack of suitable locations.

5. Tidal Power

There is considerable potential for tidal energy production in the North West of Western Australia where there are large tidal basins and high tides. Until recently, the demand for power in the region was insufficient to justify the cost of capital works inherent in developing a remote tidal power plant.

With increased demand in the West Kimberley, Derby Hydro Power Ltd has proposed construction of a 48 MW double basin tidal power station on the natural forked bay at Doctors Creek near Derby. The tides would supply around the clock power with supplementary generation by conventional plant during neap tides. The proposal includes transmission lines linking Derby to Broome and Derby to Fitzroy Crossing and the nearby mine at Blendevale.

Recently Derby Hydro Power has received a $1-million grant to construct this 48 MW tidal power station near Derby to supply electricity to Derby, Broome, Fitzroy Crossing and the Western Metals lead and zinc mine at Pillara. The project will take advantage of the flow from a high tidal range around 10 metres. It will provide continuous electricity output from the flow of water between the high and low basins which the barrages maintain in two adjacent creeks.

6. Wave Power

A grant of $750,000 has been made to Energetech Australia Pty Ltd to construct a 300kWp generator on the breakwater at Newcastle or Port Kembla for converting ocean wave energy into electricity. It's aimed at demonstrating that wave energy can be a commercially viable renewable energy source. The project will mark the first step in commercialising an innovative renewable energy technology, which has been designed and developed in Australia.

Ocean Power Technology Australia Pty Ltd (OPT), an American company with an Australian subsidiary, is constructing a 20 kW demonstration commercial device to be sited off Cape Sir William Grant at Portland on the Victorian Coast. OPT's power units resemble large buoys and converter water motion into electric power for either grid transmission, direct use in place or storage in batteries.

7. Geothermal and Ocean Thermal Energy Conversion

The first geothermal power system in Australia has been operating continuously since May 1986 at Mulka Station in South Australia, a remote area which depends on deep artesian water for drinking and stock watering. A hot artesian bore is located about 500 metres from the homestead. Water from the bore (86°C) provides the heat input to a 20 kW Organic Rankine Cycle (ORC) engine. The prototype engine, estimated to have saved up to 15,000 litres of diesel fuel per year, provides reliable low cost household electricity 24 hours a day. It has also solved the Station's stock watering distribution problem.

The installation has significantly added to the quality of life and productivity of the family at the homestead as well as the value of the property. The 20 kW capacity is much larger than necessary. A 5-10 kW capacity operating 24 hours per day appears to be the right size for remote properties such as Mulka Station. A smaller capacity unit would also require a lower hot water flow rate.

Electricity consumption has trebled since the ORC engine was installed. Average net power consumption by Mulka Station during the first 7 months of operating was 3.5 kW. A major contributing factor has been the ability to pump water more extensively around the property. As a result, stock-carrying capacity has more than doubled, and productivity has increased significantly.

The ORC engine is clearly oversized for the Station. For future installations of this sort a 6 kW plant would be adequate. A lower capacity engine with several technical refinements could reduce hot-water flow requirements to 2-4 litres/sec. This would represent optimum use of a very valuable resource. The hot water bore would save an estimated 15,000 litres of diesel fuel/year as well as watering stock with no wastage.

The engine was designed to utilise low temperature (75 - 100°C) sources of hot water. It contains freon refrigerant R114 as the working fluid, has a screw expander and shell and tube heat exchangers. Hot bore water circulates through an evaporator and the R114 is converted to gas under high pressure. The gas drives the screw expander which drives an alternator and produces electricity. After passing through the screw expander the gas is condensed to a liquid in a condenser cooled by water from a cooling dam. The liquid is then returned to the evaporator to repeat the cycle.

The Mulka Station ORC engine has been operating reliably since installation in May 1986. The bore used for the engine is 980 metres deep and was drilled in 1904. The water comes out at 86°C and under 600 kPa pressure. Since it has been connected to the ORC engine system, the bore's maximum flow has been reduced from 20 to 10 litres per second. The ORC engine results in a water temperature drop to about 83°C. The water has to be further cooled before use for stock watering.

Australia also uses 29 GWh/yr of geothermal heat for swimming pools and district heating (19,000 m^2); far more is cooled for stock watering. Test plants produce 20 and 150 kWe from hot aquifers. The great Australian aquifer, the major source of agricultural water for inland New South Wales, reaches 75degrees C. Hot water is also used for wool dyeing and paper making.

However, there is no Ocean Thermal Energy Conversion (OTEC) research, manufacturing and field project reported in Australia.

8. Biogas and Biomass Technologies

8.1. Biogas

8.1.1. Narre Warren Landfill Gas Power Station

The Narre Warren landfill gas power station utilises landfill gas as fuel for power generation. The gas from the 2.6 million m^3 of waste in the landfill site is extracted, processed and supplied as fuel to six spark ignition gas-engine generator sets. Up to 5 MW of electricity produced from the power station is exported into the power grid. The estimated life of the project based on the availability of gas is about 20 years.

The power plant design is based on water-cooled modular gas-engine generator sets. Initially, four 800 kW generators began operating but two additional 800 kW generator sets were added as the landfill produced more gas than was initially anticipated. Electrical power is produced under constant load at 415 volts which is transformed to 22,000 volts.

Gas is extracted from the landfill by an interconnected pipeline network and condensed to remove any entrained liquid. The gas is then cooled to 4°C and passed though a 0.3 micron filter before entering the engine. Each generator consumes approximately 12 cubic metres of gas per minute under peak load.

The system has been operating above expectations since May 1992 providing up to 5 MW of electricity on peak load or approximately 80 MWh/day. Exhaust gases at approximately 400°C provide up to 500 kW of heat from each generator. This waste heat is currently being used for heating a commercial greenhouse.

Landfill Gas Power Plants at Various Locations

Energy Develop Ltd installed a number of Landfill Gas Power Plants at various locations in Australia. In a Landfill Plant gas is extracted from the landfill site, processed to remove moisture and particulate matter and utilised as fuel for power generation. The power produced is supplied to the utility distribution system.

The gas extraction system comprises gas production wells drilled into the landfill. The wells are fitted with wellheads comprising valves and flow meters to control the flow from each well. An underground pipeline network connects the wells to a central gas compression and processing plant. Gas blowers maintain vacuum on the gas extraction system and compress the gas to the pressure required for supply to the generating plant.

The generating plant comprises several gas engine generator sets. Generation voltage is 415 volts. A unit transformer is installed for each generator set to increase voltage up to 33,000 volts. The plant is electrically interconnected with the utility distribution system at 11,000 to 33,000 volts.

These projects are wholly owned and operated by Energy Developments. All power produced is sold to the local electricity distribution utility. The Table below shows the year of commissioning of these plants and the plant capacity in MW.

Table 8.1.1. Landfill Power Plants Owned and Operated By Energy Developments Ltd

Sr. No.	Location	Year of Commissioning	Plant Capacity (MW)
1	Corio, Victoria	1992	1
2	Berwick, Victoria	1992	7
3	Broadmeadows, Victoria	1993	7
4	Wingfield I, South Australia	1994	2
5	Wingfield II, South Australia	1994	4
6	Lucas Height I, NSW	1994	5
7	Lucas Height II, NSW	1998	13
8	Clayton, Victoria	1995	11
9	Belrose, NSW	1995	4
10	Tea Tree Gully, South Australia	1995	3
11	Springvale, Victoria	1995	9
12	Pedler Creek, South Australia	1996	3
13	Brown Plains, Queensland	1997	1

Recently Energy Developments Ltd has received a grant of $2 million from the Australian Greenhouse Office (AGO) to design and install a solid waste energy and recycling facility (SWERF) at a municipal waste facility near Wollongong, NSW. The facility will recover reusable and recyclable resources prior to the conversion of the organic components into gas and then electricity.

8.1.2. Wastewater Methane Capture and Use

Melbourne Water Corporation operates the Western Treatment Plant, at Werribee Victoria. It is the largest waste water treatment plant in Australia, servicing a population of 1.6 million people, from the western and northern suburbs of Melbourne.

It is one of the largest lagoon, land filtration and grass filtration systems in the world, treating about 500 ML of sewage per day. Treated effluent is discharged into Port Phillip Bay, via four outlets which are licensed by the Environmental Protection Authority (PEA).

The anaerobic section of lagoon 115E (about 33,000 square metres) is covered with a high-density polyethylene (HOPE) plastic cover. The biogas is captured and piped to two reciprocating spark ignition engines (Waukesha) built specifically to operate on biogas with a substantial methane content.

Lagoon 115E treats an effluent of about 55Ml/day, with an average Biological Oxygen Demand (BOD) of 450 mg/l. This generates on average 110 - 140 cubic metres of biogas/ML of waste water. The total amount of biogas recovered is about 6,500 cubic metres per day. The average composition of the biogas is: Methane 75 - 85% Carbon dioxide 11 - 12% Water 4.5% (vapour saturated) Hydrogen sulphide 0.3 - 0.5% (ie., 3,000 - 5,000 parts / million) Nitrogen 5% Gas scrubbers are used to reduce the hydrogen sulphide content of the biogas, before it is combusted for power generation. A private contractor designed the methane collection and use system, constructed and trialed before being handed over to the Melbourne Water Corporation in May, 1996.

The plant generates on average 110-140 cubic metres of biogas/ML of waste water. The total amount of biogas recovered is about 6,500 cubic metres per day. The system has generally performed as expected, however, some-tuning problems have been experienced. Increasing the cooling capacity of the system has provided better temperature control during hot weather. The original reciprocating engine did not have self-tuning capability to adjust to the high variation in the methane content. As a result of this mechanical tuning of the engine was undertaken as frequently as each day. Electronic sensing devices are now being trialed to allow for the continuous automatic adjustment of the fuel/air ratio.

The two 632 kW generators are run at full capacity for more than 16 hours per day during summer when gas production is at its highest. During winter, generators are run at less than 16 hours per day.

8.1.3. Anaerobic Digestion for Steam and Hot Water at Cheesemaking Plant

The system was put in place in 1993. It comprises of a lined lagoon of dimensions 100 metres by 70 metres by 35 metres by 8 metres deep. Associated technology includes a floating membrane cover (XR5), a gas collection system, a sludge re-circulating system and a programmable logic controller (PLC) to enable the gas transmission system to work efficiently. The overall system is conceptually simple, but optimisation of the biological and biochemical technology is operationally complex, and requires skilled plant supervision.

The system has operated at 98% to 99.75% efficiency for BOD removal and 98% efficiency for COD removal. Given the system was designed to run on 45 tonnes per day COD and that the operational loading sometimes reaches 90 tonnes per day, these are considered excellent results. By contrast, the suspended solids were expected to be 550 mg /litre. They are running at less than 1000 mg/litre which may be due to excess gas production in the quiescent zone of the reactor keeping the sludge particles suspended.

The captured methane is being used to produce steam for a 4 MW hot water boiler that maintains a 35°C temperature in the BVF. A 10 MW steam boiler to evaporate the milk for the dryer and a 5 MW hot water boiler for the factory are currently powered by natural gas. They have been equipped with dual fuel burners, and are awaiting commissioning for the use of the methane captured on site.

8.1.4. Anaerobic Digestion of Piggery Wastes at Berrybank Farm

Berrybank Farm is located at Windermere, Victoria, and is owned by the Charles family. The main line of business is a piggery which houses 1,500 breeding sows, and produces 30,000 bacon pigs annually. On average 260,000 litres of slurry are produced every day, with an organic solid content of 1.7%. This compares to the sewage output of an Australian town with about 45,000 people.

Effluent is flushed from the piggery into a collection and homogenisation pit. Before being pumped into the thickening tank, it is passed through a sedimentation tank to remove grit (bone fragments, sand, etc.). The thickening process comprises a 0.5 millimetre screen, a high rate dissolved air flotation system (DAF) and the use of polyelectrolytic flocculant. The thickened sludge from the DAF and the filterable solids from the screen are fed to the primary digester (2,300 cubic metres, 37°C). Partially digested effluent is pumped to the secondary digester (450 cubic metres) where further digestion takes place. The secondary digester incorporates a gas bell (350 cubic metres, ambient temperature) for biogas storage. Undigested material from the secondary digester is returned to the primary digester.

Biogas is taken off and purified through the removal of moisture and hydrogen sulfide (H2S). The gas is used to fire the 80 kW and 140 kW Caterpillar engines that drive generators to produce electricity which is sold into the local electricity grid. Engine heat is recovered and used to heat the primary digester and the piggery.

Sludge from the secondary digester is dehydrated and used to produce a high quality soil conditioner.

Approvals include Environmental Protection Agency (EPA) Works Approval and an EPA Licence to discharge into the air.

The system has performed well. Various modifications have been made as more experience has been gained with the operation of the system. There is very little odour from the process and the area of land occupied by the treatment plant is relatively small. The plant produces around 180 kilowatt hours of electricity for 16 hours per day. The plant itself consumes 25% of the power generated with the balance available for sale to the local grid at relatively favourable buy-back rates.

The stabilised solids from the digester are mixed and composted with other organic wastes. This is sold as soil conditioner and for other garden products. The mineralised water derived from the liquid effluent is irrigated on paddocks as fertiliser.

8.1.5. Landfall Gas Based Power Projects in Western Australia

There are four power stations using landfill gas in the Perth metropolitan area, one each at Redhill, Canning Vale, Mt Claremont and Kalamunda. The total capacity of these sites is around 10 MW. All have been developed and are operated by Landfill Gas and Power Pty Ltd. Electricity from these power stations is sold to Western Power, although most of the gas from Mt Claremont is used on site.

Biogas is also used at the Water Corporation's Woodman Point Wastewater treatment plant to generate electricity. Two 600 kW gas engine generators, fuelled by biogas, provide electricity for use on site. Waste heat from the engines is recovered and used for optimising digester temperature.

8.2. Biomass

Little woody biomass is used for energy production in Australia, apart from wood used for home heating, waste used by the timber industry for steam generation.

8.2.1 Recent Developments

Biomass Energy Services and Technology Pty Ltd (BEST) and Reneco Engineering Pty Ltd have jointly received a grant of $850,000 from the Australian Greenhouse Office (AGO) to install two briqueting plants at the Mugga Lane landfill site in Canberra. One plant will provide clean burning fuel for a co-generation plant to produce up to 300kW of renewable energy for sale to ACT customers. The other plant will produce a high quality fuel for domestic heating, barbecue and power markets.

The Rocky Point Green Energy Corporation Pty Ltd have also received a grant of $3 million from the Australian Greenhouse Office (AGO) to install the latest technology, 30 MWe biomass co-generation plant at the Rocky Point Sugar Mill, south of

Brisbane. The plant will operate year-round, using locally sourced wood waste outside the normal 20 week crushing season to provide green electricity to the Queensland grid.

A $1-million grant from the Australian Greenhouse Office (AGO) will allow Western Power Corporation and its partners to build an Integrated Wood Processing demonstration plant at Narrogin producing 1 MW of renewable energy into the main electricity grid in the south west of Western Australia. Harvesting locally grown mallee, the plant will generate electricity while producing eucalyptus oil and converting wood to activated carbon through a process developed by the CSIRO. The project involves collaboration between Western Power Corporation, the Oil Mallee Company, CALM, and Enecon Pty Ltd.

9. Other R & D Activities

9.1. Australian Cooperative Research Centre for Renewable Energy

The Australian Cooperative Research Centre (CRC) for Renewable Energy was opened for business on 1 July 1996. Its headquarters are at Murdoch University, Perth with members and nodes throughout Australia and New Zealand. It is managed by Australian Cooperative Research Centre for Renewable Energy Ltd, a public company limited by guarantee operating as a scientific institute.

The principal objectives of the Centre are to

- undertake strategic research in generation, storage, power conditioning, energy efficiency and systems integration
- perform effective demonstrations, based on the research, which meet defined price targets, delivering systems to displace fossil fuels and reduce greenhouse gas emissions
- present a strategic policy framework to government and energy agencies which can help provide the basis of a viable renewable energy industry in Australia
- provide a resource of trained energy technologists and serve as a prime point for the dissemination of research information

CRC will receive $15 million from the Federal Government over seven years - to undertake research, development, demonstration, education and training activities. Several WA companies are participating.

9.2. Sustainable Energy Research and Demonstration Centre

The national science agency, CSIRO, has announced plans to build a world-class sustainable energy research and demonstration centre for Australia. The core of CSIRO's scientific effort into sustainable energy technologies will be housed in the new centre, which will also serve as a national and global showcase for the Australian energy industry and its latest technologies.

The centre will be located in the NSW city of Newcastle, where it will directly employ more than 100 research staff and, with an annual budget of around $11 million, will make a significant economic contribution to the community. It has received strong support from the NSW Government, through the $10 million Hunter Advantage Fund and from BHP Ltd who have facilitated the purchase of two hectares of land in the Steel River Eco-Industrial Park.

Researchers at the centre will also work on parts of a major national hybrid-energy project to provide clean power to Australia's cities in the coming century, with low greenhouse emissions.

B. RENEWABLE ENERGY IN NEW ZEALAND

1. Solar Photovoltaics

Most places in New Zealand receive an annual average of 2000 sunlight hours, ranging from 2.5 kWh/m^2/day to 4.0 kWh/m^2/day. However, although there are a large number of solar PV installations, their collective capacity is only 200kW. This is because the use of solar PV is limited to very small-scale applications such as roadside telephones, harbour lights, and electric fences. The application of solar PV still remains small.

The market for photovoltaics is small and involves small systems for remote area lighting and low-current applications. A grid-connected PV system is planned for two industrial projects in the South Island.

Unlike Australia, no R & D activities and manufacturing in Solar PV have been reported in the country. Through the distributors of various foreign companies, small systems are being installed at different locations.

2. Wind Energy

New Zealand's shape, topography and location in the roaring forties give it the best wind resource in the world. The potential has been estimated at 100,000 GWh a year, three times the country's present electricity production.

It is reported that wind energy is a fragile proposition in New Zealand. In a deregulated electricity market with no subsidies or incentives for renewable energy, it competes with hydro generation in which the capital costs have already been sunk, and fossil fuel-burning plants, which take no financial account of the harm, they cause to the environment.

2.1. Research & Development, and Demonstration

2.1.1. The Prototype Vortec Wind Turbine

On a wind-swept coastal farm between the Waikato River mouth and Raglan, a prototype diffuser-augmented wind turbine is at last taking shape. Vortec Energy Ltd (formerly Advanced Windpower Ltd) is constructing the one-third size Vortec 7 prototype.

The high-tensile ferro-cement diffuser is the key to the design. It creates a low-pressure region downstream of the turbine rotor, leading to a suction effect, which doubles the ambient wind speed at the rotor. In wind tunnel tests it augmented the power-generating capacity of the wind by five and a half times.

Expected production is 2-2.5 MWh a day, enough to supply 500-700 households. Power generation cuts in at a wind speed of 5 m/s, and out at 24-30 m/s. A control mechanism monitors the wind direction and swings the support structure around on a

360-degree arc to optimise turbine performance. The structure is built to withstand wind speeds of 70m/s.

The full-scale model is expected to have a single 23-m high tube support structure, and generate 3.5 MW.

2.2. Hau Nui Wind Farm

Hau Nui wind farm, consists seven 500 kW turbines. Wairarapa Electricity's Hau Nui wind farm near Martinborough is producing enough electricity for 500 homes each day. Hau Nui's wind farm capacity factor is of the order of 41% and it is considered one of the world's wind farms, which have been constructed without any subsidy or premium energy price.

2.3. Tararua Wind Power

Tararua Wind Farm is the largest wind farm in the Southern Hemisphere constructed without any subsidies. Tararua Wind Power, is a joint venture between Manawatu Power Company CentralPower and project developer Merrill International. The installed capacity of this wind farm is 31.7 MW with a further expansion potential of 65 MW. The average wind speed at the site is around 35 km/hour, with the wind speed above the minimum turbine operating level for more than 85% of the time.

Tararua can supply electricity at 5% more than the wholesale price. After supplying neighbouring Power Company CentralPower (which is a 50/50 joint venture partner in the project) the farm will have excess electricity available for sale. It would like to be able to sell the "green power" to individuals and companies who are prepared to pay a premium for the clean product, but the costs of MARIA-compliant metering and the reconciliation charges made by network owners make it uneconomic.

2.4. Brooklyn Wind Turbine

Since its installation in March 1993, the Vestas V27 225 kW wind turbine generator at Brooklyn, Wellington, has performed extremely well. The average monthly energy production was 79 MWh. The turbine has a capacity factor of 48% based on all generation to date and an average measured monthly availability of 99.2%. The turbine presents an example of wind generation technology to the public in a way, which is understandable, and, being a feature on the Wellington skyline is unlikely to be missed.

3. Solar Thermal Energy: Manufacturing and R & D

Most parts of New Zealand receive enough sunlight to make this resource a contender for conversion to useful energy. Options include passive solar space and water heating.

In the country a wide range of solar water heating systems are available. However, New Zealand has a low penetration of solar water heaters compared to Australia. There are currently seven manufacturers of solar water heaters operating in New Zealand. These companies are:

- Transheat
- Solar Systems
- Thermocell
- Solarmaster
- Sola60
- Solar Solutions and
- Sunmate.

The market size is unknown, but is estimated to be on the order of one to two hundred domestic installations per year. The systems include pump circulated, thermosyphon and "once through" models, and most are roof-mounted, but one company is promoting "integral" systems with collectors incorporated into the structures of new houses.

There is some private R&D reported to be going on in small companies but no major publicly funded work. Interests range from the heat-pipe steel flat plate collector which Thermocell has been selling for some years, to a flexible membrane covering on Sola60 collectors and prismatic covers on yet another brand. No independent organisation currently collects statistics on the proportion of these firms' budgets, which is devoted to Research and Development.

There are, as far as can be ascertained, three manufacturers' agents for imported solar products in the country selling Australian systems. One Rotorua agent for a heat pump-driven solar water heating system has sold 50 units in that area alone.

4. Mini-Micro Hydro Power

About 75% of New Zealand's electricity derives from hydro with capacity of around 4,768 MW, 66% of which is located in the South Island. Electricity generation from hydro sources is around 77 PJ (about 21,000 GWh). Despite New Zealand's extensive use of hydro electricity, there is a large untapped resource, which could, technically, be harnessed. It has been estimated that the economy's reliance on hydro electricity could be increased by 50% by schemes, which could produce electricity at costs of 4-10 cents/kWh. However, actual development of these schemes will be constrained by economic factors (including the relatively high cost of transmission) and, because of environmental considerations, difficulties in securing consent for the location of the facilities needed to utilise the resource. An additional constraint to development, in the short term at least, is the unresolved issue of resource ownership for a number of locations.

4.1. Research & Development

Auckland UniServices, has designed a system to overcome the shortfalls of existing micro-hydro turbine technology and enhance the performance of small-scale hydroelectric facilities.

It has developed a novel and simple "electronic load governor" (ELG) - a means of automatically controlling small (up to 200W) hydro power schemes to give constant turbine speeds, which reduces fluctuations in voltage and frequency.

This results in improved quality of the AC power supply, which becomes more reliable and avoids the need for constant supervision. It has an easy to follow control panel and it can automatically diagnose and overcome any faults that occur.

The systems supply power as AC, ready to use in lights and appliances, so it does not need to go through an inverter. There is no need for batteries for storage, as the operating principle of the ELG means a constant load is maintained on the turbine - any power not needed immediately by the community goes on water heating and clothes drying.

The hydro turbines controlled by the governor are usually "run of river" - they are not associated with a dam but use the force of water flowing down the river or irrigation channel to produce electricity.

With the ELG, a constant supply of electricity is delivered regardless of variations in the water flow. The load governor regulates itself, and generates surplus power. When the village load is small, the ELG switches in a series of heat loads to keep the load and frequency consistent. The extra heat is used to boil and sterilise water (improving health and decreasing deforestation) and for drying clothes - important in snow-bound valleys.

The system comprises around 10% (US$3000) of a typical total turbine installation cost, but has resulted in the efficiency and utilisation of the hydro turbines improving by 150%-200%. Villagers can use appliances that were previously unusable.

Whereas Powerflow's installations have generally been in developing countries, the controller is also applicable to New Zealand systems.

4.2. Mini-Hydro Power Projects

Pacific Hydro Limited of Australia and Todd Energy Limited acquire from 31 March 1999 Bay of Plenty Electricity Limited's interest in the retailing business and generation assets in New Zealand (including its 50% interest in the 25 MW Kapuni Cogen - depending on exercise of pre-emptive rights) for NZ$100 million. A detailed description of these hydro plants is as below.

4.2.1. Aniwhenua Hydro Power Station (25 MW)

- Aniwhenua is situated in the Eastern Bay of Plenty on the Rangitaiki River, 75 kilometres south of Whakatane.

- Constructed over three years at a cost of NZ$27 million, the facility was commissioned in December 1980.
- The Aniwhenua hydroelectric scheme is a "split" scheme, ie. it comprises a barrage (or dam) to form a storage lake and a canal to divert the water approximately two kilometres north to another storage area (the headpond).

- The powerhouse is situated below the headpond on the shores of the Rangitaiki River. Water from the penstocks drives two 13.8 MW Francis turbines which in turn drive two generators to produce a total of 25 MW at 11 kV.

- The hydrology of the area is particularly reliable with an annual average generation of 130 GWh.

5. Tidal Power

No research and development, manufacturing and field project have been reported in New Zealand.

6. Wave Power

The location of the country means that its coastal and near off-shore waters receive a massive amount of wave energy. Technologies are not yet available to reliably tap this energy source and commercial plant will probably not be developed within the ten-year time frame. In the longer term, this resource could become important to New Zealand.

7. Geo-thermal and Ocean Thermal Energy Conversion

New Zealand has substantial geothermal resources, which already meets some 7% of the economy's electricity needs. Geothermal accounts for 10 PJ (around 2% of primary energy supply) in the form of direct heat.

In the early 1950s, with no oil and little hydropower on the North Island, geothermal development was started at the Wairakei field. By 1960 the power plant was generating 69 MWe of electricity and now produces 157 MWe. Wairakei was the first large hot-water field ever developed. At Kawerau 200 tons/h of geothermal steam is used directly to dry pulp in a paper mill and also generates 16 MWe of electricity. The total geothermal capacity is now 341 MWe with another 306 MWe under construction or planned. Some steam is used at Broadlands to heat a Maori tribal pool and to dry crops, and houses are heated from shallow wells in Rotorua and Taupo. Hot spring waters are widely used for bathing and greenhouses. Total direct use is about 1837 GWh/yr.

Wairakei: Wairakei plant is located on the Broadlands Geothermal Field and uses the steam from BR27, about half a kilometre away, which is reticulated via a two-phase transmission line. The steam is separated from the water close to the plant and piped into finned tube heat exchangers. Air is forced through the heat exchangers by a centrifugal fan. Inside the drying chamber the heated air is circulated through the freshly harvested crop; the separated water being reinjected down BR7, a dry bore.

TG1 & TG2 Geothermal Power Stations: TG1, the first geothermal generation plant of its kind in New Zealand, was commissioned in December 1989. TG2, located on the opposite side of the Tarawera River, was commissioned in October 1993. TG1 and TG2 utilise waste geothermal fluid from the Kawerau geothermal field to generate electricity.

The revolutionary ORMAT binary-cycle energy-converter system passes pressurised waste geothermal water with a temperature of approximately 170°C through heat exchangers. The extracted heat vaporises the hydrocarbon fluid isopentane, which is forced by its own pressure through turbines, in turn spinning generators to produce electricity. The isopentane vapour is then cooled by large air fans and condensed back into liquid form for re-evaporisation.

There is considerable scope to expand the use of this resource, with around 22,000 GWh per annum available for development mainly in the Rotorua and Taupo geothermal areas. But environmental concerns and uncertainty about the ownership of the resource mean that only a small fraction of the resource is likely to be harnessed. Two estimates suggest that geothermal power could meet a further 5% of New Zealand's electricity needs. Excluding transmission costs, geothermal resources are considered to be available at around 5-6c/kWh.

The installed capacity of geothermal power projects is about 341 MW. This capacity is installed via 18 units at 4 sites.

Table 7.1. Installed Capacity of Geothermal Power Projects in New Zealand

Sr. No.	Location	Size in MW
	TG1	2.3
	TG2	3.8
1	Wairakei	157
2	Ohaaki	108
3	Kawerau-Tasman	10
4	Kawerau-Tarawere	6
5	Kawerau	16

6	Other	37.9

8. Biogas and Biomass Technologies

8.1. Biogas

Landfill Gas Plant at Porirua: Nova Gas derives landfill gas (55% methane, 40% carbon dioxide, and nitrogen) from the landfill at Porirua, for use as a replacement for other fossil fuels. Porirua landfill has been successfully operating since 1996. It is the first New Zealand plant to reticulate landfill-derived methane in competition with natural gas.

Nova Gas supplies gas to Kenepuru and Porirua hospitals and a large abattoir in Wellington. It also has contracts for the National Library and National Archives; swimming pools in Wellington, Tawa and Johnsonville; Wellington and Porirua city councils; and supplies most of the big industrial users in Lower Hut. It has contracts for 17% of the Wellington regional gas market.

Nova Gas has constructed a network covering Porirua, Tawa, north Wellington and Petone. Construction of a line into Wellington city, which will eventually link with the southern landfill, is underway.

The plastic membrane covering the landfill to aid gas extraction reduces the amount of polluting leachate from the landfill.

Nova Gas is a wholly owned subsidiary of Independent Energy Ltd, a private energy company with interests in wind power, small hydro developments, and environmental treatment processes. It is 40%-owned by Todd Energy.

8.2. Biomass

In terms of both magnitude and potential for medium term realisation, biomass energy stands out. New Zealand has a very large and growing exotic forest resource, which will produce a substantial contribution in the form of arising and processing residues. While there will be demand for this material as a fibre source, it is likely that a large amount will be available as a potential energy source.

Over 4% of New Zealand's primary energy supply is provided by wood, mostly in the industrial sector. Estimates by the Ministry of Commerce (1995) show that energy-related biomass consumption amounted to 27 PJ: 21 PJ consumed in the industrial sector, primarily by the wood and pulp and paper industry, and around 6 PJ by households (about 606,000 tons). It is also estimated that approximately one-half of New Zealand residences use some firewood. It has been estimated that by 2002, there will be sufficient biofuels available to meet over 10% of the economy's electricity requirements. Outputs from biomass could increase to around 75 PJ by this time and to 300 PJ ten years beyond that.

The costs of recovering the energy from waste are typically much lower than those associated with energy crops because the feedstock has little or no residual value. In fact, in many instances the use of the residue as a fuel can offset disposal cost. The projected cost of electricity from wood processing residues is 4-7 cents/kWh while landfill gas power plants are presently generating electricity for some 4-5 cents/kWh.