Future Alternatives for Non-Polluting Electrical Energy Production

Can Photovoltaics or Wind Replace Australia’s Current or Future Conventional Energy Production?

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Foreword

This study draws attention to the demonstrable futility of using Photovoltaics (PV) and Wind to cater for the whole or major part of Australia’s increasing electrical energy requirements. Any government support for this proposed attempt at solving major energy supply needs would be technically misguided and unattainable, non-cost effective, and a total misuse of taxpayers’ money.

No energy production systems create energy. They only convert part of the available energy source into more useable forms.

All PV and Wind electrical production systems rely on favourable solar energy inputs, which, although sustaining the environment and driving the weather, deliver only a relatively diffuse, non-continuous and unreliable energy supply to any particular location.

When system operational efficiencies are taken into account, then to provide for Society’s demand for a reliable electrical energy supply, huge collection areas are essential, requiring massive material, construction and on-going maintenance costs. The resulting collector area could have serious negative environmental consequences.

Australia’s future total or major electrical energy supply solutions do not lie in the use of diffuse and unreliable energy collection and conversion.

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Introduction

The reality of large scale alternative energy systems, in this case either photovoltaics (PV) or wind turbines (WT), which have been proposed to replace a part, or all of Australia's conventional electrical energy production, is discussed.

All aspects of large scale PV cell and wind electrical production are examined. These include both PV cells and wind turbines, and their efficiencies – present and future – the importance and variability of the site's daily and seasonal exposure to solar radiation and/or wind, the total system embodied energy, the CO_2 produced during manufacture and construction of the systems, the area required and the systems ultimate cost, compared to that of a conventional plant producing the same energy output.

The two options will be considered separately, first PV and then WTs. There may appear to be duplication, but the physical principles and design method for both systems are the same.

This study does not detract in any way from the benefits of using environmentally friendly renewable energy sources, such as solar or wind, thermal applications for heating water or air, and biomass. Hydro is already in extensive use world-wide in suitable locations. Other options, such as wave, tidal, and geothermal - which is not strictly renewable - are being researched.

All of these energy options can have valuable contributions to make, and should be encouraged (if correctly located), and if their applications can be demonstrated to be energy and cost effective – such as for remote power supply with PV.

Some environmental groups have persuaded most of the media and politicians, and together with them a significant proportion of the country's population, that not only is it possible to replace all conventional electrical energy production with stand alone alternative energy solutions, but also that this is the only direction for the future.

The following paper examines the validity of these claims by using observed, recorded and tested facts, together with simple arithmetic, to enable the readers to arrive at their own conclusions.

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Alternative Energy Fundamentals

The 20% Alternative Energy Contribution

A recent proposal by politicians to provide an up to 20% contribution to the total Australian electricity production in the next ten to fifteen years using Alternative Energy Systems will be examined.

To propose using photovoltaics or wind turbines where medium to large amounts of energy is required to drive, for instance, all the appliances, lifts, air conditioning etc required for modern apartments, office buildings and cities that require multi-Giga watts is ill informed and naïve, taking excellent niche market solutions to impractical extremes.

What then is the reality of such a proposition? The following essential factors need to be considered to arrive at a conclusion:

1. What energy is actually available from the sun or wind (this varies with location), and what is the efficiency of the PV cells or wind turbines to be used?
2. What size plant is required (i.e. how much power is required) and subsequently how many PV panels or wind turbines are required to produce the same electrical output (not just the peak power) as a “standard” conventional plant?
3. What is the embodied energy of the plant? This is required to determine if the alternative energy plant is energy positive. I.e. does it produce more energy (collected from the suns radiation or wind and converted to electricity) in its lifetime than is required to manufacture, install and operate it over this period?
4. What is its energy payback time? This is the number of years which the plant needs to run to produce the amount of energy it used to construct.
5. How much CO_2 is released into the atmosphere resulting from its manufacture, construction, operation and ongoing maintenance?
6. What is the cost of such an extensive and dispersed plant compared to a conventional one?
7. What area of land is required?

Alternative energy systems can be used to generate electricity, but are unable to store it. Total replacement of electricity generation by alternative stand-alone systems would require massive storage to take over when the sun is not shining, the wind is not blowing, and when the sea is calm and not producing the necessary waves in the case of wave power.

These questions are raised to demonstrate that there is always a price to pay for everything – although sometimes it is not immediately obvious – in terms of materials, energy, human and manufacturing effort, financial costs, and pollution. Alternative energy systems are no exception.

It is emphasised that to capture the sun and wind’s “free” useful energy using alternative solutions, and for this to be sufficient to drive even some of the services in a 21st century society, is by no means cost or pollution free.

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Understanding the Misconceptions about Alternative Energy

The generic terms solar energy, alternative energy and renewable energy cover a wide variety of processes. The advocates of the complete replacement of conventional energy production usually cite photovoltaic or wind as the most likely methods for solar energy use, so that is what is discussed here.

To help to explain why misconceptions occur regarding the use of the sun or wind’s energy, a few simple technical principles are given to enable the reader to understand the differences between a power plant’s “rated” value and the “amount of energy” it produces.

A power plant, whether “conventional” or “alternative”, has a rated value which is its designed power peak expressed in kilowatts (kW), megawatts (MW) or Gigawatts (GW). Kilo is a thousand or 10$_3$, Mega is a million or 10$_6$, Giga is a billion or 10$_9$.

Further, to have some understanding of what a kilowatt means, it can be envisaged as the power potentially available from a standard one bar, 1 kilowatt electric radiator. The amount of energy (in this case in the form of heat) produced by this radiator when electricity is passed through the coil of wire for one hour is expressed in kilowatt hours (kWh). (For those readers not familiar with “one and two bar radiators”, a standard electric blower heater also produces about 1 kilowatt of heat on half power and 2 kilowatts on full power.) Therefore, 1 kWh can be thought of as a one bar radiator operating for one hour, or a blower heater operating on half power for one hour.

It is essential to understand this concept since the cost of energy measured in kWh is the most important factor for the production and sales of electricity. This is what the consumer pays for. The only time this principle is not adhered to is for some non-technical cost benefit decisions, such as for subsidies to promote ideas, products and sales.

Conventional power plants such as coal, oil, gas, hydro and nuclear are designed to produce energy on demand up to their rated value, for 24 hours a day, 7 days a week. In practice however, the energy produced is less than this with time off for maintenance or on stand-by. For example, the amount of energy that can actually be produced by modern nuclear and gas power stations relative to their theoretical total, is usually over 90% for nuclear and 75 - 80% for coal. This is termed their “load factor” or “capacity factor”. (e.g. a 1GW nuclear power station will produce on average 0.9 GW over a year.)

The following terms are commonly used when describing power generating facilities:

- Availability Factor: A factor that represents the percentage of time that the unit is ready to be used if needed.
- Capacity Factor or Load Factor: The ratio of energy produced by a power plant in a year to the energy it could have produced, if it ran at full power for the year. This is often expressed as a percentage.
- Name Plate or Nameplate Power Rating: The capacity (maximum power rating) of a generator or power station.

The same principles apply to alternative energy systems such as solar thermal, photovoltaic, wind, wave and variations of these. However, these alternative systems only operate when weather conditions are favourable; i.e. when the sun shines for PV and solar thermal, when the wind blows within designed velocity limits for wind mills, and when there are sufficient waves for wave power. Consequently, their ability to produce continual useful energy can vary dramatically and is frequently zero for wind and wave devices.

Systems that rely on the sun can only operate for part of the day, not at night, which optimistically results in load factors of about 15 – 20% for these alternative energy systems, while large offshore and coastal wind farms claim in the order of 30%.

Clearly, the advantage of conventional plants is that they can operate when required to produce partial or full load with high load factors both night and day. Alternative energy systems cannot do this without either the produced energy being stored, or being supported by conventional backup. If fed into the grid, this variable output is covered by the spinning reserve (the continued production of power output at a reduced level), which is there to cope with emergencies, and/or to avoid surging and flagging in the system during operation. Such provisions incur considerable additional energy costs for these systems because of their low load factors, higher plant and operational transmission costs.

Various Energy Comparisons

It is essential to understand the fundamental differences between energy from the sun and energy from fossil and nuclear fuels.

The energy from the sun that reaches the earth is diffuse and weak, when contrasted with the highly concentrated energy of fossil and nuclear fuel.

For instance, 1 kg of coal is used in the production of 2.64 kWh of electricity.

Comparing this to other energy sources used to produce electricity: A fuel pellet of uranium (4% enriched) weighing 0.00032 kg (0.32g) is equivalent to 810 kg of black coal or 566 litres of oil, and all of these produce about 2140 kWh of electricity.

If we compare these to PV cells which produce (after conversion to electricity) an average of 1 kWh/m$_2$/day (see below) for them to produce the same amount of electrical energy would require the equivalent of 5.86 m$_2$ operating daily for one year, or 2140 m$_2$ operating for one day.

To make 2,140 kWh of electricity requires:

- One 0.32g pellet of enriched uranium,
- 810kg black coal,
- 566 litres of oil,
- 2,140 1m$_2$ PV panels (occupying 1.2 acres installed) operating for one day at 1kWhr/m$_2$/day, (see pages 8 & 18)
- One 660 Kw peak WT operating for 3.24 hrs at peak power.

This is the unfortunate reality when comparing rich energy sources to diffuse or diluted ones.

Although this solar radiation is “free”, it is spread thinly over the earth’s surface and the equipment required to collect, convert and process it into useable electrical energy can be sophisticated, and is certainly expensive.

Not to understand these fundamental facts about this apparently “free energy” source is where most misconceptions occur.

Since the reader may not have access to specialised journals, papers and publications, all of the values not specifically referenced can be found on the Internet by entering the appropriate key words. For example to find daily or longer range incident solar radiation enter “Australian solar radiation maps”.

Photovoltaic Systems

This section considers the practicalities of using Photovoltaic (PV) cells (often called “solar cells”) to meet these targets. Wind is discussed later in this paper.

Photovoltaic systems are an elegant solution for remote area power supply when the requirement is only for hundreds or thousands of watts, and when the economics can be justified.

They are ideal to produce electrical energy, using batteries for storage, for low power requirements such as remote telecommunications systems, beacons, recording equipment, marine buoys, other weather recording systems and earth satellites.

Contrary to popular impressions, they cannot be used for deep space probes that range far from the sun or to drive space vehicles such as a shuttle that requires large amounts of power.

A relevant example, is when Ghana introduced (subsidized by U.N. and other funds) small scale PV electricity to some remote rural communities that are inaccessible to the grid, to provide them with modest amounts of power to charge batteries used for low power applications, such as telephones, lighting, radios, television, micro water pumps and small refrigeration units for health clinics. This improved both the health and basic living conditions of these isolated communities.

Can Solar Energy Replace Conventional Energy Processes?

Of all the ways of producing energy, none has greater appeal than solar power, as all the radiation, heat and light from the sun is “free”- so why not use it? Taking advantage of this warmth and natural light is surely an enlightened way to conserve energy.

How Much Energy can be Collected and Used?

The US Department of Energy, in a study headed by the then Deputy Director, Ken Davis, concluded that such systems cannot possibly begin to meet the electricity and other energy needs of a modern urban community and that large scale solar arrays, whether PV or solar thermo-electric, are simply too variable, too unreliable, too expensive and because of the huge areas required too ecologically damaging, whilst making no more than a minor contribution to the national power requirements. The report further states that after all the efficiency calculations for radiation and system components, an optimal figure to be used for incident radiation was approximately 10W/m_2 with an average overall system efficiency of approximately 5%.

The following assessments will use elementary arithmetical calculations to produce approximate estimates size and cost. The proposals examined below use actual Australian and U.S. statistics for energy use and data from radiation records collected and recorded over many years. It also uses established component design efficiencies, rather than the ideal peak figures - almost invariably incorrectly used by the replacement proponents in their calculations.

Other factors affect the results, such as latitude, time of the year, time of the day, weather conditions and also air particle content, which can cause further reductions during daylight of up to 28% reflected and 3% absorbed.

Additionally, long term weather conditions fluctuate. For example, in the thirty year period (1960 – 1990) a reduction of incoming radiation of up to 4% was recorded, attributed mainly to the effects of increases in cloud coverage.

Records from localized semi-desert regions with low rainfall have shown reductions of up to 50% in the efficiency of solar energy collection devices within a few months, if their glass protection surfaces covering the absorber (PV or thermal) were not regularly maintained, not only to remove dust but, in particular, plant spores which have to be scraped off.

How Much Energy is Available from the Sun?

To consider these systems it is necessary to know how much energy is available from the sun.

The earth's atmosphere is about 1000km thick and has been defined in five layers. The one we live in is called the Troposphere and is approximately 12 km thick. This is followed by the Stratosphere to 50 km, the Mesosphere to 80 km, the Thermosphere to 700 km and the Exosphere to 1000 km.

They all play a part in making life on earth possible. There are no distinct edges to these layers with the outermost fading into space.

An average of 47% of the incident solar radiation reaches the earth's surface; the rest is absorbed or reflected mainly by the atmosphere, remembering that the earth is a sphere with incident radiation reducing towards the poles.

Energy arrives from the sun to the outer layer of the earth's atmosphere (facing the sun) at a rate of 1367 watts/m_2.

In good transmission conditions, when the sun is overhead in equatorial regions, about 6% is reflected and 16% is absorbed, giving an insolation value of approximately 1020W/m_2 (some US records quote 950 W/m_2). In exceptionally clear and favourable conditions higher values have been recorded.

For the purposes of the following calculations, initially an optimistic value of 15% efficiency is used for the PV cells. This is the approximate claimed value for field experiments. A simple amendment calculation can be made when the real system efficiency is known.

For design purposes, initially the average solar radiation values are normally used for a particular location, since they take into account the variations and limitations mentioned above. These variables must be considered when the systems location, benefits and cost are being considered.

PV Cell Panels Ratings

To determine the peak rating of a PV cell panel, it is usual to use the maximum, or near maximum, incident solar radiation value of 1000W/m$_2$.

This value is for best conditions in the middle of the day, clear sky, and latitude, such as central or northern Australia. Also required is that the panel has been correctly installed facing north (in the Southern Hemisphere) with its inclination to suit the latitude.

Therefore, the peak value of the panel is for the correct installation and ideal conditions.

A typical current “off the shelf” PV panel claims to produce 110W for a one m$_2$ panel. This means that these PV units are 11% efficient, which is a reasonable claim. However, to actually produce an instantaneous peak value of 1000W, the number of panels required would be:

1000/110 = 9.09 one-square-metre panels.

Remember, that this is for the ideal conditions discussed above, so should there be variations of any of these parameters, a lower output must be accepted or more panels must be used.

Solar Concentrators

Concentrating systems rely on the direct radiation from the sun to be reflected to a point or line focus. This produces higher system operational temperatures.

The collector area facing the sun (the projected area) determines the amount of energy collected. A flat plate collector of the same area collects the same amount of energy, but since the sun’s rays are not concentrated, this results in lower temperatures.

Clouds can dramatically affect the incident radiation, which becomes diffuse (arrives at the collector from different angles). For a concentrating collector most of the radiation would not be reflected to the focus, resulting in lower, or no collection. Flat plate collectors can collect diffuse radiation.

Sun tracking systems using either heliostats or the dish itself, are more expensive, and although they collect more of the available direct radiation, some of the resulting energy must be used to drive the tracking systems. Depending on location, these systems are closed down in adverse wind conditions.

Typical Values of Incident Solar Radiation from Various Sources

Ted Trainer from the University of NSW, and others, used field experimental records to consider the output from, in their estimations, an ideal Australian site in the Tropic of Capricorn region where the average incident solar radiation produces approximately 4.25 kWh/m$_2$/day, which is within the US range of 3 – 6 kWh/m$_2$/day as discussed below.

Long term US records (available on the internet), which are more extensive over a longer period of time are also used. These are similar to Australian field records for equivalent latitudes and regions, recorded by the Australian Weather Bureau, CSIRO, the University of Melbourne, and various other universities.

Solar radiation records can be found on the net, (e.g. for “Australia” enter “Australian Solar Radiation Maps”). The energy values are expressed in kilowatt hours or Mjoules. The conversion from one to the other is 1 kWh = 3.6 Mjoules. For a quick approximation 1-4 could be used.

A typical text “Menial and Menial – Applied Solar Energy” reports daily values of 3.43 – 6.47, average of 4.9 kWh/m$_2$/day for similar latitudes.

With these values, the average radiation results in a variation of 125 to 375 W/m$_2$ which would provide 3 - 6 kWh/m$_2$/day.

Even assuming an optimistic PV cell conversion efficiency of 15% this would still only deliver an average of 19 – 56 W/m$_2$ and provide 0.46 – 1.35 kWh/m$_2$/day. It can be seen that, at best (1.35 kWh/m$_2$/day) this is still only equivalent to a one-bar radiator operating for 1$_1$/$_3$ hours of the day for every square metre of collector area.

Using an efficiency value of approximately 10.27% (see below) the delivery would be an average of 13 to 38 W/m$_2$ and 0.31 to 0.92 kWh/m$_2$/day (average 0.61 kWh/m$_2$/day).

It is claimed by some PV advocates that cell efficiencies of approximately 24% (in some cases over 40%, but yet to be verified) have been achieved. However, these results were recorded under ideal laboratory conditions (discussed later).

In practice PV cells must be protected from the vagaries of the environment and are usually encapsulated under glass to ensure a longer lifetime of high performance.

The solar incident radiation measurements are taken using instruments where sensitive surfaces are cleaned, prior to use and/or protected when not in use. This ensures accurate radiation measurements. These values are used for initial approximate calculations.

However, when the efficiency and design of the actual systems are determined, the radiation value used is taken from the underside of the glass.

For instance, if Australian window glass was used, its transmissivity (because of high iron content) is 81%. Transmissivity is the amount of incident radiation actually passing through the glass. The better quality panels use higher transmissivity glass, which is much more expensive.

As mentioned above, in the field the actual amount of radiation available for use is further reduced by local conditions, such as dust or spores.

The best current working systems are reported to have a measured field efficiency of about 13% and provide 0.67 kWh/day during winter in central Australia. Further system losses of approximately 7% could be expected due to localized conditions, such as those mentioned above, and would include conversion from DC to AC and transmission losses. This results in a long term efficiency of approximately 10.27%, which is closer to the US Department of Energy estimates.

For design purposes, local average insolation values must be used to assess long-term estimates, since these values take into account the variations and limitations mentioned above.

It must be repeated and emphasized that rated values represent only the best or ideal possible peak conditions.

These rated values are invariably quoted and used however, by the presumably enthusiastic, but technically ill-informed, PV advocates who also invariably use the maximum incident radiation value of 1000 W/m$_2$ in their calculations. Using these values is simplistic, and represents a gross misinterpretation of reality.

PV potential users, and the advocates of photovoltaics to replace conventional electrical production should be aware of all the facts described above and below, regarding the strengths and weaknesses of these systems.

For the purpose of the following preliminary calculations, an optimistic (compared to the U.S Department of Energy figures) value of 10.27% efficiency is used, and to be consistent with Trainer’s values from his studies, mentioned above, which resulted in 4.25 kWh/m$_2$/day.

Clearly, where the real values are known, based on the actual location and system efficiencies, a simple conversion calculation can be made.

There is no way for humans to make the sun produce more radiation energy, so for other than low temperature applications, such as heating water or air, this radiation must be concentrated for high temperature solar thermal to electrical systems, or converted directly to electricity by using PV cells.

Other Considerations

Trainer estimates that to compete with the energy produced by a conventional plant a stand-alone 1000MW peak PV power plant would have to produce not only enough energy for 8 hours of the day, but also for 16 hours at two thirds of this value for the rest of the day. He also uses winter radiation values. To use high summer averages, would mean an energy shortfall in winter. Trainer also concluded that the area for the collector plant would be about 50 square miles (see further below).

Because of the huge collector areas required, this makes these systems extremely land intensive with environmental consequences. This should be contrasted to about 75 – 150 acres for a nuclear or fossil fuel plant producing an equivalent amount of electricity.

To build a PV plant of this magnitude, (not including the huge maintenance and component replacement costs), it is not just the PV cells that have to be considered, but also all of the accompanying infrastructure of structural supports, transmission systems, concrete foundations and the access roadways for this huge, dispersed area of collectors.

A 1000 MW peak stand-alone PV plant would be faced with the following approximate major materials list: (Trainer)

- 35,000 tons of aluminium
- 75,000 tons of glass for the cell container boxes and covers

- 600,000 tons of steel
- 1,400 tons of chromium and titanium for the structure supports
- 7,500 tons of copper for the electrical transmission equipment lines
- 2 million tons of concrete for the structural support foundations and access roads

This is 500 times greater than that required for an equivalent 1000 MW nuclear plant.

PV cells are ‘high tech’ and their manufacture requires not only energy, but the use of many materials in the various stages of their processing, such as highly toxic heavy metals, gases and solvents that are carcinogenic. Brookhaven National Laboratories Department of Environmental Sciences, which has amassed 150 studies on the topic, lists poisonous and flammable substances, as well as hazardous chemicals, that go into making the panels. Some of the gases are lethal and others are explosive. Exhaust scrubbers to control accidental releases are not in place at all such factories. Workers in these plants must be strictly protected. If a residential fire burns a solar panel, people would be at risk from exposure to toxic vapours and smoke, however, significant health impacts would probably occur only in the heat of an industrial fire.

When solar panels are decommissioned they must be disposed of in special toxic waste dumps. If they end up in a municipal waste incinerator, the heavy metals such as cadmium and lead based solder will partially vaporise into the atmosphere. The ash must be disposed of in a controlled landfill. If modules are not incinerated but are instead dumped into municipal landfill, the heavy metals - such as arsenic and lead - can leach into the soil and water table. Hundreds of thousands of years from now some of these substances will still not have decayed.

In the US, newer designs are lower in toxicity, but they must still pass the Department of Energy tests about whether or not their dangerous components will be released after they’re decommissioned. Scaling up the technology would present difficulties. Solar farms big enough to supply 1000 megawatts, (US D of E estimates), could cover 50 square miles (129km$_2$), and produce a quantity of toxic waste that would be significant.

Properly controlling it would be costly - perhaps prohibitively so.

The real cost of the production of chips and cells for information technology and electricity production has yet to be fully appreciated.

A recent assessment suggests that the manufacture of (including all the relevant processes leading to it) a simple 2 gram chip consumes 36 times its weight in chemicals, 800 times its weight in fuel equivalent (coal or oil) and 1600 times its weight in water.

The statistic normally quoted by the advocates of the massive or universal use of photovoltaics as a replacement for conventional energy production, is to compare the energy used to manufacture PV cells to the time taken by these cells to collect this amount of energy from the sun. There have been various estimates of this time by the PV cell researchers and manufacturers, of between 1.5 to 4 years. Other than this attempt at justification, no mention has been made of the energy required for the production and installation for all of the other necessary components to make this system work. The energy assessment should not be just for the PV cells but for the whole system. This is termed the systems “embodied energy” or “EROEI – Energy Returned on Energy Invested”.

If the reduction of greenhouse gasses is one of the reasons for adopting these systems, their advocates do not mention the enormous release of greenhouse gasses resulting from the construction of such a massive structure, or the energy used for the whole systems manufacture, construction and ongoing operation.

When energy sources are compared, the tendency is not to think about the comprehensive cost, fuel, metals, plastics etc., required to fabricate, transport and install the solar panels (and of course wind turbines), and 20 or so years later the need to dispose of them. Solar and wind construction on a large enough scale to make any significant contribution, would add hidden costs in their environmental impacts and waste problems to an already expensive way to make electricity.

For the 70 – 85% of the time when nature isn’t cooperating, the grid or conventional energy back up is required. Unless there is a yet-to-be-discovered dramatic idea in the technology of energy storage, these systems will not be able to produce electricity as efficiently, cheaply and reliably as current conventional systems.

Meeting The 20% Renewable Energy Target Using Photovoltaics

The following calculations and discussion consider the proposed 20% contribution to the Australian total energy production using photovoltaics alone.

In practice, these PV systems would be designed for the local conditions and would be fed into the electricity grid, so no storage will be considered.

The following calculations determine the number of panels required to meet this 20% target:

- From the Australian Bureau of Statistics, the latest recorded values (2005) for the total production of electrical energy was 253,000 GWh. Since there is a few percent annual increase, a value of 260,000 GWh will be used for 2008.
- The total Australian electricity production for a year is 260,000 GWh.

♉ 20% of 260,000 = 53,000 GWh/year.

(This is therefore how much electricity must be made each year using PVs)

The average incident solar radiation for Northern Australia is approximately 4.25 kWh/m^2/day (see above) with a PV cell efficiency of 10.27%. This would produce 13 – 30 W/m^2 and 0.31 - 0.92 kWh/m^2/day. These are the radiation and energy figures that should be used. However, for the purposes of this initial approximate calculation, the higher value of 0.92 kWh/m^2/day is selected, but since the ‘off the shelf’ panel claims 11% efficiency (see above), rather than the 10.2% proposed, a convenient value of 1 kWh/m^2/day will be used for simplicity in the calculations.

Therefore, considering the 1 m^2 panel which collects and converts to electricity 1 kWh/m^2/day:

- The 1 GWh/day of energy would require 1 x 10^6 panels, so in one year these panels would collect 365 GWh.
- 20% of the Australian production total = 53,000 GWh/year (from above)
- For 1 GWh/day, 53,000 divided by 365 = 145.2 GWh/day.
- Since 1 GWh/day requires 1 x 10^6 panels then 145.2 GWh/day would require 145.2 x 10^6 panels.
- If the decision was to ensure no shortfall of supply in winter, the winter value of 0.31 kWh/m^2/day would have to be used instead.
- The ratio of 1kWh to 0.31kWh is 1 divided by 0.31, which is 3.3 times.
- This results in 145.2 x 10^6 x 3.3 = 479,160,000

(i.e. Nearly half a billion 1m^2 PV panels would be required to meet the 20% target.)

In his paper, Trainer and colleagues draw attention to the necessary daily energy requirements from the grid when he uses the sum of kWh required for 8 hours of the day, plus two thirds of this value for the remaining 16 hours of the day. His approach is different from the presentation here, which concentrates on the energy available from the sun and its subsequent conversion to useful power and energy.

The final results are however, similar in order of magnitude; consequently his major materials list is used for these calculations.

To illustrate, the PV plant described above uses the energy and conversion value of 1 kWh/m^2/day and requires 1 x10^6 panels for 1 GWh.

The 1 GWh of electricity being discussed does not produce an instantaneous power of 1GW peak, but rather the sum of the sun's energy collection and conversion to electricity, which is spread over the radiation collection part of the day, with its maximum collection normally being around noon.

To reiterate then, there is clearly a significant difference between a power plant capable of supplying 1GW peak of electricity (in ideal conditions) during the day, compared to a plant which could, if required, supply 1GW peak continuously, on call, for the whole day.

For instance, a conventional power plant - say coal - is capable of providing if required, 1GW x 24 hours x the load factor - say 70% - which therefore produces 16.8 GWh daily. (Nuclear has a load factor in excess of 90%.)

A solar plant cannot do this without being significantly larger to enable it to have the energy equivalent of the coal plant. It would then require at least 16.8 GWh x 1 x 10^6 panels (using the same collection and conversion rates as above).

Further; if the winter incident solar radiation value of 0.31 kWh/m^2/day is used instead; (1 divided by 0.31 = 3.3), so, 3.3 times as many panels are required in winter as in summer.

This results in (16.8 x 10^6 x 3.3) = 55,440,000 1 square metre collectors being required.

Of course, the number of panels escalates when less incident radiation is available, or the plant is moved further south or north from the ideal regions.

Remember that the above calculation only considers a 1GW peak plant. As mentioned above, Australian total energy production is about 260,000 GWh and 20% of this is 53,000 GWh.

So for the total of 20% replacement, the figures above would have to be multiplied by the appropriate GWh, as discussed below.

Using elementary arithmetic, the reality should by now be obvious as to the magnitude of the collectors and land required for the infrastructure, labour, materials, as well as the cost to produce and support such a venture (as discussed below).

The reality is that most of the cost of large scale PV power plants is in the support and distribution systems, and not in the PV cells, so that a small cost reduction in the cells would have a marginal effect and not solve the overall energy production and cost problem.

Improvements in cell efficiency would have a greater effect, since less collector area would be required. However, most of the promising ideas have been around for years and have not as yet achieved their claims under working field conditions for improved efficiency and longevity (see below).

There are also scientific limitations to the upper levels of efficiency that can be achieved (discussed below). Although samples of some of these cells are being tested in space, a clear indication of their current state-of-the-art effectiveness and reliability is shown by the fact that they have not as yet replaced the tried and trusted current cells.

Issues/factors to determine before constructing a PV plant

Before the construction of such a plant takes place several factors must be considered as to its viability.

A decision must be made about what is expected from a 1GW peak PV plant. Only then can a design and construction specification be produced to determine the number of collector

panels and other equipment needed for the actual daily amount of power and energy.
The following must be considered:

- Is it 1GWh of energy daily as described above?
- Is it 1 GW peak continuously available on call? i.e. the equivalent amount of energy and subsequent power that is available from a similarly rated conventional power plant
- Where will it be located? If further south or north from the ideal region, an escalation of the number of panels that are required to achieve the same result.

- These will determine the design parameters for the different incident radiation for different locations – for summer, average or winter conditions.
- Perhaps other requirements and variables, not already mentioned above.

Other factors must be considered on completion of the design process to assess the project's viability. They are:

- The embodied energy (energy returned on energy invested), which is the total energy used to produce the plant, compared to the energy it would collect from the sun and convert to electricity in its lifetime.
- From this an energy pay-back time can be assessed.
- The CO_2 released to the environment from the manufacturer of the materials etc., as elaborated above.
- The area it occupies
- The cost

The inclusion of the energy consumed by the other essential components, many of which are to varying extents site dependent, such as labour, manufacturing, fabrication of the panels and support structures etc., site preparation, access roads, transport to the site, plant assembly and ongoing maintenance, and cleaning. These considerably escalate the total energy used, the consequential release of CO_2, pollutants and the ultimate cost.

To include these items, helps to demonstrate the non-feasibility of proposals to use these systems for large scale, peak energy production.

Although no storage has been considered, it would be essential for a stand-alone option. No storage solutions on this scale which are economic or energy efficient are currently available or even envisaged. If they were available, this would only add to all of the above considerations.

Embodied Energy in a PV Plant

For a 1 GW peak PV Plant (stand-alone, no storage) the major materials list (from Trainer) will be used to calculate the total energy used to produce the plant - this is the plant's embodied energy. These preliminary estimations will use only the major materials listed. This should be sufficient to demonstrate some of the energy used, and other consequences for such a massive plant.

These materials are:

- 35,000 tons of aluminium
- 75,000 tons of glass
- 600,000 tons of steel
- 7,500 tons of copper
- 2,000,000 tons of concrete

The embodied energy to produce these materials (kWh/ton) is:

- Aluminium 79,370 kWh/ton
- Glass 8,819 kWh/ton
- Steel 15,118 kWh/ton
- Copper 70,601 kWh/ton

- Concrete 3,147 kWh/ton

The total embodied energy for these materials:

- Aluminium 35,000 x 79,370 =12,777,950,000 kWh
- Glass 75,000 x 8,819 = 661,425,000 kWh
- Steel 600,000 x 15,118 = 9,070,000,000 kWh
- Copper 7,500 x 70,601 = 529,507 kWh
- Concrete 2 x 10^6 x 3,147 = 6,249,000,000 kWh

Therefore the total embodied energy in this plant is: = 20,804,705,000 kWh

or = 20,804,705 MWh

or = 20,804.705 GWh

The above preliminary abbreviated project energy estimate illustrates the huge expenditure of energy just to produce some of the materials.

The final energy and energy pay-back time would depend on the project's location and design decisions (detailed above).

CO_2 Releases for a PV plant

A further claim is that the use of photovoltaics would eliminate or at least dramatically reduce pollution, airborne particles and CO_2 into the atmosphere. The CO_2 releases from a PV plant will now be discussed, considering just the major materials detailed above.

To produce 1kWh of electricity, various energy sources can be used. For instance, coal (which varies depending on the source) produces an average of 2.457 kg of CO_2, heavy oil 3.223 kg of CO_2 and natural gas 0.19 kg of CO_2.

Since the grid is supplied by electricity from a variety of sources, including hydro and gas, a figure of 0.43kg of CO_2 released is generally used for the production of 1 kWh of grid electricity. This value varies and depends on the quantities of the various energy sources used. This figure seems low, but was derived by also using quantities of natural gas and hydro. For the moment, this value will be accepted for the purpose of the initial calculation.

- 1 kWh releases 0.43 kg of CO_2
- 1 MWh releases 430 kg of CO_2

- 1 GWh releases 430,000 kg of CO_2
- Therefore, 430 tonnes of CO_2 per GWh

From above, for 20,805 Gwh of electrical energy to build the plant the CO_2 release would be:

8,946,150 tonnes of CO_2.

This is a lot of CO_2 for a so-called pollution free source, remembering that this is only for the major materials, without including the other essentials as discussed above, to produce an ongoing operational plant, and the thousands of kilometres of electrical distribution lines and associated essential components to transmit the electricity from ideal locations in the north of Australia.

The Cost of a 1GW PV Plant

The one square metre "off the shelf" panel described above, costs approximately $750.

To install this on a roof, the rule of thumb is to multiply the panel cost by two.

Therefore, the installed price of a 1m^2 panel on an established structure is approximately $1,500 per square metre.

This figure will be used for the following preliminary estimations. Any discount for large numbers, or additional costs for support structures etc. can easily be applied and modifications made when these are known.

Using the collection and conversion rate of 1 kWh/m^2/day (from above) for a 1 GWh plant, we have 1,000,000 panels, the cost being $1,500,000,000.

For a winter requirement, we have 3,230,000 panels; the cost would be $4,830,000,000 or if the decision was to produce the same energy daily as a conventional plant (depending on the location), when the load factor is allowed for these figures could result in the order of $100 Billion.

To repeat, this is for 1 GW PV plant that could produce, if required, the same amount of energy daily as a conventional plant. How this energy could be stored for a stand-alone application (i.e. no other conventional power available on the grid) so that it could be accessed on call has still not been included.

Comparison of a PV Plant's Cost to a Conventional Plant's Cost

How does this then compare with the cost of a standard conventional coal plant?

The cost of the 1000MW (1GW) peak capacity Piper Power Station built a few years ago in NSW cost approximately A$800 million, say a A$1000M in current costs. For comparison, the coal consumed over a twenty year period would cost approximately A$2 billion. This is assuming that the comparative PV plant lasts twenty years without major PV cell and other replacements.

Therefore, the total cost is in the order of A$3-4 Billion.

Although these figures are approximate, they give a rough initial comparison. They clearly show that the stand-alone PV plant, providing a constant base load if required, would be in the order of twenty to thirty times the cost of a conventional one.

Land Area Required for the 1GW Peak Plant

The area required to accommodate the proposed 1GW peak plant as discussed above, which would provide the same amount of electrical energy as a conventional 1GW peak plant is now considered.

From above, this plant uses: 55.4×10^6 collectors

or 55.4×10^6 m^2 (1 collector/m^2)

or 55.4 km^2 of collector area.

These collectors are usually arranged in rows, which have to be spaced apart to provide access for maintenance and cleaning, and importantly to ensure no shading occurs from one row to the row behind.

This further increases the area, and both Trainer and the U.S. estimates take this into account. Their estimates suggest fifty sq.miles (or 129 km^2) for a 1GW plant. The area would increase with less incident radiation.

If 20% of Australia's total use of electricity is 53,000 GWh, this area would then be 55.4 sq km x 53,000 = 2,850,000 km^2 of PV cell area.

(For 100% of Australia's total use of energy, multiply x 5 = 14,250,000 km^2 of cell area.)

If we include the access areas mentioned above, (i.e. multiply this area by 2.3) we have approximately 129 km^2 (US and Trainer's estimates) per 1GW peak, which works out to:

- 6,863,468 km^2 of installed PV cells for 20%, or
- 34,317,342 km^2 of installed PV cells for 100%.

Note that Australia's total land area is only 7,686,855 km^2.

For the total replacement of Australia's base load of electrical energy using PV, storage would also be required. This has not been included in these estimates since nothing practical of this magnitude exists, or has even been envisioned.

Surely the above simple calculations – all based on factually recorded energy data – are enough to demonstrate whether these proposals would present a viable option for large scale photovoltaic electricity production.

Solar Cells

This section provides an overview of the principles, limitations, uses and current development of photovoltaic cells.

Photovoltaic solar cells do not create energy. They can only convert some of the sunshine (incident solar radiation) that they absorb. The theoretical efficiencies are limited by a range of photon energies.

Limitations of PV Cell Efficiencies

It must be understood that there are physical limitations to a PV cell efficiency when used to convert incident solar radiation to electricity.

On the atomic scale, there are energy states that electrons can occupy, however, they cannot occupy non-states. An electron can transfer from one state to another. To be able to do this, it must either absorb or release the exact amount of energy to account for the energy difference between these two states. The ”quantum leap” refers to “energy” not “location”.

On the atomic scale, these amounts of energy are tiny, in the order of 0.2 attojoule (aJ). This is a unit used by physicists and is equal to 0.000,000,000,000,000,000,2 Joules (0.2 x 10_{-18}).

An electron volt (eV) is the energy gained by one electron moved by 1 volt. 1 ev = 0.16 aJ. If an electron moves from an energy level of say, 5eV to another of 6eV, it requires 1 eV to do so. If it goes from 6eV to 5eV it releases 1 eV possibly as heat or light in the infrared region.

The term quantum refers to well defined states, and well defined energy differences.

Quantum has nothing to do with big.

Little bundles of energy (photons) have a certain amount of energy - the shorter the wavelength, the higher the energy. On the blue end of the spectrum, photons have about 3eV and on the red end about 1.8eV.

A photocell consists of a pair of dissimilar semiconductors. Without going into further technical details, what matters is that a photon of light striking the surface of the cell causes electrons to undergo a quantum leap. The energy gap of the leap is called the ”bandgap”.

This leap is the source of the electrical current that the PV cell produces.

A silicon solar cells’ band gap is 1.1eV. This energy corresponds to a wavelength of about 1,130nm, which is in the infrared region of the spectrum. Photons of less than 1 eV energy (wavelength larger than 1130nm) cannot cause this transition to occur.

However, if a photon of 2.5 eV (about 500 nm) strikes the cell, it has more than enough energy to cause the quantum transition. In fact, it has 1.4 eV more than is necessary - the excess is wasted as heat.

This is a major limitation of PV cells. There is a broad spectrum of sunlight ranging from infrared to ultraviolet to do a quantum job of causing electrons to transit between welldefined states.

Whether the transition involves 1.1 eV or 2.8 eV etc., some of the light will have too much energy and the excess will be wasted as heat. This is the reason that even the best ”silicon” cells have an efficiency in the order of 10%. The peak practical rates are further reduced through reflection from cell surfaces and leakage currents.

PV Cells in Use

Since output power varies with the amount of sunlight, the load output circuits for the PV cells have to be maximised for the various intensities of sunlight, so that the output voltage remains approximately constant for the various solar radiation intensity levels.

Batteries are best charged at constant voltage, with the charging rate really determining how fast the job is done. For this reason, the most frequent PV cell application is for charging batteries for all the off the grid applications.

The overall efficiency of the delivery power to the load is the efficiency of the PV cell multiplied by the efficiency of the battery charger multiplied by the battery efficiency itself (accounting for energy losses by internal battery currents).

PV cells can provide power to anything, provided that there is an immediate back-up system to compensate for the variations in the PV’s output power, allowing the PV systems to operate at constant voltage.

PV Materials

Silicon is one of the most abundant elements that cells can be made from, but again there is a limiting factor. To make the silicon PV cells, they have to be doped with other elements to cause the device to have semi-conductor properties.

Silicon based PV cells have an efficiency in the order of 10%. The efficiency is low because the “band gap” of silicon – 1.1eV is so low that most of the spectral energy is wasted as heat.

To make PV cells of a higher efficiency requires the use of exotic materials such as germanium, gallium, iridium and cadmium, with possibly gold or platinum conductors.

As a point of interest, a study by the American Physical Society (APS) investigated how much of these materials would be required to produce 1% of the U.S.’s electricity in 2000. They found that 250 metric tons of germanium would be needed (this is three times the world’s annual production), and twenty times the world’s annual production if gallium were used.

It also mentioned the structures used to support the panels, stating that, for instance, 17% of the US’s annual production of cement would be required to support these structures. This is discussed elsewhere in this paper.

PV Costs

A further fallacy regarding cost must be addressed. The proponents of the replacement of conventional energy production by alternatives, in this case PV, claim that the PV cell cost will dramatically fall.

They say “just look at the prices of transistors for computing which have dramatically fallen”.
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Computers have become faster, because the technology enabled manufacturers to pack more transistors into smaller areas, tens of millions of them into one cm$_2$. The smaller the transistor, the shorter the distance the signals have to travel, and the smaller amounts of energy that has to be stored and/or released. The speed of computation is inherently linked to the small size, and high-density packaging of the transistors in integrated circuitry, with consequential dramatic price decreases.

This is not the case for PV cells, where the most important factor is the area exposed to the sun to increase the collection of solar radiation. To intercept very large amounts of sunlight, very large areas of PV cells are required. Therefore, the comparison of the cost of the PV cells to that of transistor cost is completely irrelevant. Again, the US Energy Information Agency tracked the price per peak kW of PVs from 1989 to 2002 and recorded a price drop of 20-30%. In the same period, the price of transistors in CPUs (Central Processing Units) dropped by 99%.

In the U.S, the total PV cell manufacture from 1982 – 2001 amounted to 588 peak MWe. The current efficiencies for their silicone based cells are about 10%, and this would therefore represent about 6 sq. km of actual cell area produced. Even in best conditions of peak output, this is about half of the output of one conventional power plant, and would result in an average of 100MWe (e=electrical) for a year.

If these cells are used in the correct applications of small-scale power, for remote areas, this is a valuable contribution. However, if these cells are intended to be used to replace conventional power stations, for all of the fuss and bother, this is pathetically small to be of practical use for anything other than a superficial gesture.

The same APS study commented on the costs associated with encapsulation, foundations, support structure, and installation of the PV array fields. It concluded that the cost of large scale solar PV electricity would be prohibitively expensive, even if the cells were free (zero cost), unless the efficiencies were very high to enable it to compete in some applications. At the moment, as described above, there are physical limitations, some of which cannot be overcome, since they would violate the laws of nature.

Current PV Research and Development

Small-scale experimental demonstrations, using cells made from the various exotic materials mentioned above, have claimed efficiencies in the range of 20%.

One experimental method is to make the PV cells in layers. The layer exposed to the sun uses blue light, but is transparent to other colours. The next layer down absorbs green light, but is transparent to the other wavelengths and so on. The sequential transition through the various layers is engineered for the current to be the same for all layers, the limitation being the current in the weakest layer.

Large efficiency gaps still remain between theoretical, laboratory and field performance, as well as between high purity, single crystal, poly crystalline cells and the film cells made from amorphous silicone, of such compounds as gallium arsenide (G As), cadmium telluride (CdTe), and copper indium disclenide (Cu In Se_2). Theoretical single crystal efficiencies are 25 – 30%, with about 23% achieved in laboratories.

Multi-junction amorphous silicone cells convert about 8 – 11%. This micro-crystalline silicon currently is showing about 17% efficiency.

As mentioned above, making cells sensitive to different parts of the spectrum are being investigated to try to boost efficiencies to claimed theoretical values of 50%. To date, laboratory experiments have only managed values of 30 – 35%.

Other trials use lenses and/or reflectors that can be focused onto smaller areas to hopefully boost conversion efficiencies to 30%.

Actual efficiencies of commercial single crystal modules are now about 12 -14%, however, after a time in the field, they tend to drop to below 10%. These film cells can convert 11 - 17% in laboratories, but modules in the field can drop to as low as 7 – 13% after several months of operation.

Recently, the University of New South Wales PVC research group claimed to have achieved a world record of 25% conversion efficiency from their latest cells, and also that this was 6% higher than the world’s next best technology. They claim that their development “pushes the boundary of response into the extremes of the spectrum”. In view of all the counter claims of success from other research groups, it has not been revealed if this efficiency has been achieved in the laboratory or long-term in the field, subject to the adverse effects of the environment.

About a decade ago, it seemed that silicone based PV cells may not be the only way of converting sunlight into electricity. New PV cells, photoelectron chemical devices based on nano-crystalline materials and conducting polymer films, offer a possible combination of cheap fabrication and a bifacial configuration. This allows them to capture light from nonoptimal angles without re-aligning the panel, giving them greater flexibility and more predictable outputs. Transparent versions in different colours can also be made into electricity producing windows.

Further investigations are underway with electrochemical cells, tandem junction systems, dye sensitized nano-structural materials and bipolar cells.

Despite the vast sums of money invested over many years on investigations and field trials, by corporate and university research teams, the quest for high efficiency photovoltaics still remains elusive.

Large Operational Concentrating Systems

Large mirror systems, tracking or otherwise, have been seriously investigated, resulting in several being built world-wide; for instance, in the US, France, Japan, Spain and Australia. World-wide, a few of these systems are still operating in experimental mode some supplying relatively marginal electricity to the grid. Several Japanese systems operated for about 10 years before being decommissioned in the 1980’s.

It should be noted that in the U.S over the last 30 years, since the construction of these above mentioned large facilities, there have not been any further solar power stations built of this magnitude.

Also, the Spanish Government subsidies, which made various Spanish solar systems possible, are being scaled down with suggestions of the removal of support funds.

The simple reason for the hesitation and doubt associated with their reliability, viability and costs, is that over the intervening 30 years of operation of these few systems, the operators have not been able to come close to their energy production and cost reduction promises, sufficient to satisfy the community's expectations for its financial support.

Wind Systems

The reality of large scale alternative energy systems, in this case wind, which have been proposed to replace either part, or all of Australia's conventional electrical energy production, is now discussed.

All aspects of large scale wind electrical production are examined. These include the wind turbines, their design considerations and efficiencies, the importance and variability of the sites daily and seasonal exposure to wind regimes, the total system embodied energy, the CO_2 produced during manufacture and construction of the systems, the area required and the systems ultimate cost. This will then be compared to that of a conventional plant producing the same energy output.

The following examines the validity of these claims by using observed, recorded and tested facts, together with simple arithmetic to enable readers to arrive at their own conclusions.

The recent proposal by politicians to provide an up to 20% contribution to the total Australian electricity production in the next ten to fifteen years, using Alternative Energy Systems will also be examined with particular reference to wind.

Wind Energy

Humans have used energy from the wind for thousands of years. Egyptian pottery of 4000 B.C. depict large canvas sails for sailing crafts, and from ancient until modern times, wind has been in constant use to grind corn. The blades of these early windmills also had sails made of loose canvas, to catch the wind.

Traditional multi-bladed windmills have been used for the last hundred years or so in the United States, Australia and elsewhere to pump water for farm homesteads where they are an ideal and inexpensive solution, used in conjunction with pumps, and corrugated iron storage tanks which are covered to minimize evaporation and exclude pests.

After being used for 6000 years, it is only in recent times that generators have been attached to produce electricity.

The wind is subject to daily variations due to the convective effects which are caused by the sun's radiation heating the land, sea and air as the world rotates. For example, because the specific heat of the soil is less than water, air temperatures rise more rapidly during the day over land than over the sea. The hot air over the land expands, becomes lighter and rises; the cooler, heavier air from over the sea blows in to replace it. This inflow is called a sea breeze.

During the night, the direction is reversed because the land cools more quickly than the water, affecting the air above it. The cool air from the land blows seaward, replacing the warm air that rises from the sea surface. These breezes may extend up to 50km from the shore line in medium latitudes, and up to 200km in the tropics.

Similar land breezes occur in mountainous regions. In the mornings, the summits heat before the valleys, the air becomes lighter and rises, the cooler, heavier air in the valleys moves in to replace it, causing the wind to flow up from the valleys to the mountains during daytime and the reverse at night.

Wind characteristics records show that the wind directions and speed are constantly changing. In a short interval of time, such as a second, the velocities may double and the direction could be considerably modified.

Wind maps tell how much energy there is in the wind.

Wind power density figures for wind sites do not refer to land areas, but to the crosssectioned area intercepted by the spinning wind turbine blades.

It should be realized that there is a limited amount of wind power available from any given land area, and that the power which can be harnessed per unit area of land is independent of the size of the wind turbine.

In the U.S. the EPA comments that contemporary wind projects are typically rated at 25-100 MWe. A 25MWe project may have 60-70 turbines covering 1500 acres. This amounts to 16,700 watts/acre or 4.1 W/m2 (maximum capacity, not average output). The wind turbines are spaced apart, as described below. Correctly located projects, to maximize wind collection and conversion to electricity, typically produce some power about 90% of the time, with an average output of 28-35% of rated capacity. For a 30% capacity factor, the EPA’s estimate works out at 1.23 W/m$_2$ of land.

From the above, a Wind Farm can generate electrical power at about 1.2 W/m$_2$ for most sites, and a hypothetical of up to 4 W/m$_2$ for rare, if existing, continuously prevailing wind sites.

The EPA estimates that if the requirement was to produce the same amount of energy as a typical conventional 1,000 MWe plant around the clock at 1.2 W/m$_2$, the land area requirement is about 833km$_2$, varying with the number of turbines per square kilometre.

Considerations before Constructing a Wind Farm

Before the construction of such a plant takes place, several factors must be considered as to its viability.

For the sake of this discussion, a 1GW wind facility is considered. Decisions needs to be made about what is expected from the 1 GW peak wind farm. Only then can a design and construction specification be produced to determine the number of WTs and other equipment needed for the required daily amount of power.

The following must be considered:

- Is it 1 GW of energy daily?
- Is it 1 GW peak continuously available on call?

i.e. The equivalent amount of energy and subsequent power that is available from a similarly rated conventional power plant

- Where will it be located?

If it is located further from an ideal region, more WTs will be required to achieve the same results.

The answers to these questions will be determine the design parameters for the different wind conditions.

For design purposes, initially average wind values are normally used for a particular location, since they take into account the variations and limitations mentioned above. These variables must be considered when the system’s location, benefits and costs are being considered.

It must be repeated and emphasized that rated values represent only the best or ideal possible peak conditions, and that the number of WTs required escalates the further they are sited from ideal locations.

The rated values are invariably quoted and used, by the presumably enthusiastic, but technically ill-informed, Wind advocates who also tend to use the maximum wind values in their calculations. Using these values is simplistic and grossly misrepresents reality.

Potential users of Wind, and the advocates of Wind to replace conventional electrical production should be aware of all the facts regarding the strengths and weaknesses of these systems.

The following assessments will use elementary arithmetical calculations to produce approximate estimates of size and cost. The proposals examined below use actual Australian and US statistics for wind energy and data from records collected and recorded over many years. It also uses established component design efficiencies, rather than the ideal peak figures.

The 1GWh of electricity being discussed is not produced by instantaneous power of 1GW peak, but rather the sum of the energy collection and conversion to electricity, which is spread over the 24 hours in a day, and there is clearly a difference between a power plant capable of 1GW peak of electricity (in ideal conditions) sometime during the day, when compared to a plant which could, if required, supply 1GW peak continuously, on call, for the whole day.

If the reduction of Greenhouse Gasses is one of the reasons for adopting these systems, their advocates do not mention the enormous release of greenhouse gasses resulting from the construction of the massive WTs structures, or the energy used for the whole system's manufacture, location, construction and ongoing operation.

To build a wind plant of this magnitude, (not including the huge maintenance and component replacement costs), it is not just the WTs that have to be considered, but also all of the accompanying infrastructure of structural supports, transmission systems, concrete foundations, and the access roadways for this huge, dispersed area of WTs.

No mention has been made by the advocates of Wind, of the energy required for the production and installation for all the components to enable this system to work. The energy assessment should not just be for the WTs themselves, but for the whole system. This is termed "embodied energy" or EROEI – Energy Returned on Energy Invested.

As is the case with solar systems, when energy sources are compared, the tendency is not to think about the comprehensive cost, fuel, metals, plastics etc. required to fabricate, transport and install the wind turbines, and twenty or so years later the need to dispose of them. Wind construction on a large scale to make any significant contribution, would add hidden costs in their environmental impacts and waste problems to an already expensive way to make electricity.

As is also the case with solar systems, for the 70-85% of the time when nature isn't cooperating, the grid or conventional energy back-up is required. Unless there is a yet-tobe-discovered dramatic idea in the technology of energy storage, these systems will not be able to produce electricity as efficiently, cheaply and reliably as current conventional systems.

Meeting The 20% Renewable Energy Target Using Wind

The following discussion considers the proposed 20% contribution to the Australian total energy production using WTs alone.

In practice, these systems would be designed for their local conditions and would be fed into the electricity grid, so no storage will be considered.

From the above PV section, the total Australian electricity production for a year is 260,000 GWh, so 20% is one fifth of 260,000 = 53, 000 GWh/year.

Issues/factors to Determine Before Constructing a Wind Farm

Other factors must be considered on completion of the design process to assess the projects viability. They are:

- The embodied energy, and energy returned on energy invested. This is the total energy used to produce the plant, compared to the energy it would collect from the wind and convert to electricity in its lifetime.
- From this an energy pay-back time can be assessed.
- The CO_2 released to the environment from the manufacturer of the materials etc., as

elaborated above.

- The land area it occupies
- The cost

In considering these points, the following preliminary estimations will use only the major materials listed. These should be sufficient to demonstrate some of the energy used, and other consequences for such a massive plant.

The inclusion of the energy consumed by the other essential components, many of which, are to varying extents, site dependent; such as labour, manufacturing, fabrication of the turbines and support structures etc., site preparation, access roads, transport to the site, plant assembly and on-going maintenance, and cleaning. These considerably escalate the total energy used, the consequential release of CO_2, pollutants, and the ultimate cost.

Although no storage will be considered, it would be essential for a stand-alone option. Nothing economic or energy efficient on this scale is available or even envisaged. If it were available, this would only add to all of the above considerations.

Number of Wind Turbines Required

The viability of using wind to supply a considerable proportion of Australian Energy, say 20% as proposed, and how many wind turbines (WTs) this would require will now be considered.

- As described above, 20% of Australia's electrical energy usage is 53,000 GWh/year.
- The European Union have stated that their Wind Farms operate with a less than 20% load factor. One would assume that their locations have been chosen for optimal wind conditions. This means that 20% of the energy is being produced when compared to the ideal peak or rated values of the WTs. This value clearly is finally determined by the wind regimes and the WT's optimal design values. The 20% load factor will be used for these calculations.

To estimate the number 1 GWe peak WT Farms required to meet the 20% target:

Usually, Wind Farms operate with load factors of approximately 15-20%, although on average, some power is being produced for about 90% of the time.

♉ With a 20% load factor the equivalent energy production time for one day would be: 24/5 = 4.8 hrs/day.

A medium-sized conventional power plant is designed to be about 1,000 MWe at peak. So, the energy that this hypothetical 1,000 MWe peak Wind Farm theoretically could produce would be:

♉ 4.8 hrs x 1000 MWe = 4,800 MWh/day
or by 365 = 1,752, 000 MWh/year
= 1,752 GWh/year

Since the proposal is to produce 20% of the Australian electricity total, then:

- Total wind power required = 53,000 GWh/year
- A 1GW peak WT Farm produces = 1,752 GWh/year

♉ The number of 1GWe peak WT Farms required = 30.25 wind farms.

To estimate the number of turbines required in a 1GWe wind farm:

For the purpose of this estimate the Danish Vesta – 660 kWe peak WT, similar to the ones installed at Koorangong in NSW, will be used.

Since the proposal is to use this model (660kW peak) of WTs in a 1,000 MWe peak power Wind Farm, we have to consider the following:

♉ 1.52 turbines would be required to produce 1 MWe peak.

However, operating with an optimistic load factor of 20% this would require:

♉ For 1,000 MWe peak = 1.52 x 1000 = 1,520 WTs
♉ For a 20% load factor = 1,520 x 5 = 7,600 WTs per one GWe farm.

To estimate the number of turbines required to meet the 20% target:

Since 1 GWe peak at a 20% load factor requires 7,600 of these WTs, and 20% of the Australian electrical energy load is 53,000 GWh/year:

♉ This then requires 30.25 one GWe peak Wind Farms,

Since each Wind Farm requires 7,600 WTs:

♉ Therefore the total number of WTs = 30.25 x 7,600 = 229,900 WTs.

Materials Required for a 1 GW Wind Farm

Materials required for the single WT described above will now be given. To estimate the major materials list, not including all of the additional necessary material for transmission lines and other components, described above, only the major materials for one turbine will be used.

The steel in the nacelle and the 65 metre high tower is 93 tons. The steel for the other parts, including the massive rotor, is 7 tons. The concrete for the foundation and base, required to anchor this huge structure to often rough terrain and be able to withstand exposure to high winds, is in the order of 260 tons.

So, for 7,600 WTs, the major materials used for this 1 GWe peak WT farm would be:

☐ Steel : 100 x 7,600 = 760,000 tons

☐ Concrete: 260 x 7,600 = 1,976,000 tons

Note that all of the other components mentioned above have not been included, since they are to some extent site-dependent, but only using the steel and concrete estimates above gives an indication of the magnitude of the materials required.

Embodied Energy and Payback Time

As mentioned above the Embodied energy is the total energy used to produce the plant. The embodied energy in one 1000 MWe peak Wind Farm (as above) will now be considered:

☐ Steel used = 760,000 tons

☐ Concrete used = 1,976,000 tons

Energy required to produce:

☐ 1 ton of steel = 15.118 kWh

☐ 1 ton of concrete = 3.147 kWh

So the embodied energy is:

♉ For steel = 760,000 x 15,118 kWh/ton

= 760x15.118 x 10_6 kWh

= 11,490 x 10 $_6$ kWh

= 11,490 x 10 $_3$ MWh

= 11,490 GWh

♉ For concrete = 1,976,000 tons x 3, 147 kWh/ton

= 1,976 x 3.147 x 10_6 kWh

= 6,218 x 10_6 kWh

= 6,218 x 10_3 MWh

= 6,218 GWh

♉ Total energy required to produce the above materials

= 17,708 GWh

The Energy Payback time is:

Since the WT farms produced 1,752 GWh/year (see above), this therefore means that the energy pay-back time for these two items alone would be:

♉ 17,708 / 1752 = 10.11 years.

This is just for the production of the steel and concrete. It does not include the energy used for all of the following: to convert the steel ingots into the various shapes required, such as sheets and angles etc, which are then fabricated into the working wind turbine; steel for reinforcing the concrete bases; and all the other materials for the electricity systems.

All of the above has to be transported to the individual WT sites scattered over 100s of sq.km and assembled into the operational Wind Farm.

There is also the network of roads to be considered; they need to be robust enough to carry the WTs, transport trucks, concrete trucks, and the electricity network to firstly join the individual WTs to each other and eventually the Wind Farm to the grid.

Contrast this to a conventional power station, which, including storage for the fuel and waste, covers a few hundred acres and, depending on the fuel used, a railway line extension for coal, pipelines for oil or gas, a road for miscellaneous transport and an electricity line out for the electricity produced.

CO_2 Releases for a 1 GW Wind Farm

The CO_2 releases from steel and concrete to construct the plant are as follows:

♉ Number of kWh = 11,490 x 10_6 + 6,218 x 10_6 = 17,708 x 10_6 kWh

Since 1 kWh electricity production releases about 0.43 kg of CO_2 (see above)

♉ The total CO_2 = 17,708 x 10_6 x 0.43 = 7614.44x 10_6 kg

= 7614.44 x 10_6 tons

Or 7,614,440 tons of CO_2

Area and Spacing for a 1 GW Wind Farm

To avoid a “shadowing effect” which reduces their efficiency, the WTs are spread apart and staggered, resulting in, in this case 8 or 9 per sq.km. This is discussed further below.

These calculations are only accurate to a rough order of magnitude since the final dimensions of the grid would vary depending on the location and wind conditions, so to be generous, this calculation will use 9 WTs per km_2.

♉ Therefore for 9 WTs per sq.km, and 7,600 turbines required for a 1GWe equivalent wind farm, the area would be: 7,600 / 9 = 844km_2

 This is very close to the EPA’s result mentioned above of 833 km_2

So if approximately 844 km_2 is required for a 1Gw peak WT Farm, then for the 30.25 plants required to meet 20% of Australia’s total energy needs, the area would be:

♉ 30.25 x 844 = 25,531 km_2

♉ For 100% of energy production, clearly this would require five times this area:

25,531 km_2 x 5 = 127,655 km_2

However, without back-up from conventional power supply or storage of the magnitude required, which is not available, the whole proposition is untenable.

WT Cost Estimates for Commercial Scale WTs

(Taken from the Internet – search for “wind turbine costs”)

For Nameplate capacity – from M$1.2 – 2.6 per installed MW

 Under 100 kW – from $3000- $5000 per kW capacity

 Assuming a low average general cost $2,000 per kW

♉ Therefore the Vesta 660 (selected) would be approximately:

$2,000 x 660 kWe = $1,320,000

♉ So for one Wind Farm of 7,600 of these WTs, producing the same yearly energy as a conventional plant: $1,320,000 x 7,600 = $10,032,000,000

♉ Therefore the cost to meet for 20% of electrical energy production is 30.25 times this: $10,032,000,000 x 30.25 = $303,468,000,000

(i.e. 300 Billion dollars, which is greater than the Australia’s entire annual budget)

The above costs are only for the installation of the WTs and do not include all of the other necessities described above, which, because of the huge areas involved, would escalate the total cost considerably.

Wind Turbines

This section provides an overview of the principles, limitations, uses and current development of Wind Turbines.

A Wind Turbine (WT) extracts only some of the energy from the air, interrupted by the turbine's blades. Because of the extreme dilutions of the wind power, to try and make these systems more cost effective, the size of the components must be optimized for all the variables of climate, wind force and variable directions, and the subsequent stresses imposed by these sudden variations. The power output is highly variable with wind speed and the WT has an upper maximum wind speed at which point the blades must be feathered or stopped to avoid damage or disintegration.

The WT has the same rotational properties of a gyroscope, when there are sudden wind deviational changes. This causes either an upward or downward twist of the whole superstructure assembly, which can cause superstructure failure and/or the loss of a blade, which although the rated output may be for 28m/s, the blade tip could be travelling at 64.5m/s (232 km/hr).

Modern high efficiency wind turbines use relatively thin blades (resulting from World War 2 design improvements in propeller design) rotating 5-6 times faster than the wind and are more efficient than the multi-bladed farm WTs.

A theoretical perfect wind turbine can only extract – at most – 59% (Beitz limit) of the available kinetic energy in the wind. Under ideal wind conditions, the best achieved in practice is approximately 50%, however, the usual is about 45%. Clearly, it is necessary to intercept a lot of wind since the density of air is about one seven hundredth of the density of water.

The larger the WT, the more power it can generate, and the faster the wind the more power available (up to the maximum designed speed of the WT). The most efficient have fewer blades.

The WTs cannot be placed immediately behind each other. For in line applications, the normal spacing for good practice is 10 blade diameters apart. The side by side spacing must accommodate the spread of the air behind the WTs. Good practice for the prevailing wind is 4 diameters apart and for varying wind conditions, 10 diameters apart. Obviously the larger the turbine the further apart they must be placed. WT blades should be high above the ground to avoid turbulence from the ground.

Wind Turbines in Use

Most electrical generators are designed for fast rotation of approximately 3600 RPM which is not practical for large wind turbine blades because of the high tip velocity, so initially only small diameters were possible which produced very little electricity. This resulted in the use of transmissions to match the variable rotation and more recently modified permanent magnet generators rotating at the slow rate of the turbine.

The wind turbine voltage, to be properly matched and tied to the power grid, should have exactly the same voltage, exactly the same frequency and exactly the same timing in order to match the power line voltage. The principles are that the output voltage of the generation must match the power line voltage at all times. The following techniques are used to provide this match:

- Induction motors are run as generators, with the AC power line providing a rotating magnetic field in the generator. RPM is controlled by the pitch of the blades.
- DC generators (often using permanent magnets) can generate DC, which can be converted electronically to AC to match power lines.
- A system using variable "slip" also uses AC power, but introduces variable slip to allow for variations in RPM.

In a typical induction motor the line voltage causes a magnetic field to rotate at a certain RPM but the motor rotates at a slightly different RPM. This difference is called the "slip RPM" and the fraction of the difference is called slip, usually expressed as a percentage and usually about 4.2%. In an induction generator the same principles apply. Transmissions (gears) are used to convert the turbine RPM to the higher RPM required for the generator. The generator operates on the slip principle, the motor turns faster than the magnetic field, always adding energy to the power line.

In some modern induction-generator systems, it is possible to vary the RPM of the turbine by varying the amount of slip. An optical signal is sent to an electronic circuit on the rotating shaft that causes it to adjust the slip to compensate for the varying wind speed. It is easier to adjust the slip electronically than to adjust the turbines RPM mechanically.

In recent years there has been an increase in the capacity factors for wind turbines from about 20% to a design figure of 30%. This however has little to do with increased efficiency or an advancement of knowledge of wind turbines but rather a more careful scaling between turbines and generator sizes to allow for the use of a wider range of wind velocities.

The voltages produced by the generators are raised to the required level by a transformer in their base.

To protect them from the turbine blades, the transmission lines that carry the power are located underground. These lines are formed into a wind farm grid. Depending on the layout of the wind turbines, they are eventually fed into the common line carrying the current from all of the wind turbines. A number of those lines are connected in series producing an accumulated power loss, which, because of their spacing can be as high as 6% for 10 in series (say, 1MW wind turbines).

Power Quality

Sudden changes in load can be caused by large loads either being added to or disconnected from the power line causing both the voltage to change and also fluctuations in frequencies. This also applies even if the frequency varies only slightly. When applied to wind farms, the wind can be gusty causing the power to fluctuate wildly and sometimes almost instantaneously.

In a gust the power increases, increasing the line frequency and in a lull the frequency decreases. The power station engineers who monitor, control and whose responsibility it is to maintain quality power, consequently have to call for more or less power from the

conventional power stations to try to hold the line frequency constant (chasing frequency) to accommodate the variations in the wind. This results in additional wear on the conventional plants as they need to be constantly speeding up and slowing down.

Capacity factors are typically 20%-30% in good conditions, showing that wind farms spend most of their time operating in low power region and are also very sensitive to wind speed, causing engineers responsible to comment that “wind power is the lowest quality power” available.

A further major operational problem is if all the wind turbines were producing full power (which is about three times the average power) this excess power could not actually be fed into most electricity grids to be used, since the connection to the grid from most wind farms is not designed to carry those loads and would fail. The result is that the output from the wind turbines would have to be drastically cut back by up to two thirds, resulting in a serious drop in their overall capacity factor.

This is one of the major reasons that wind turbines cannot provide a huge percentage of the average electrical power into the electricity grid. A 1,000MWe (rated) wind farm would have at least (discussed below) 1,000 of these 1MW turbines. No matter the layout of the wind turbines the problem is keeping power losses within reasonable amounts, whilst using the highest voltage possible consistent with underground power lines and of laying out a grid that keep the wires from being overloaded.

Problems in Use

Since large wind turbine farms cover wide areas (many kilometers in both directions) environmentalists’ pressures in some places, at huge expense, have forced these farms to run their transmission lines underground.

Although being promoted by alternative energy environmentalist groups, projects have been opposed or stopped by the intervention of other environmental groups who are more concerned by the effect upon the local environment such as removal of trees (to reduce turbulence for the wind turbines), the killing of birds, and the local complaints of noise and aesthetics.

Very large turbines cause low frequency ground vibrations.

Current blade designs can cause interference with aircraft navigation and T.V. signals in their vicinity. Their rotating blades, whether metal or carbon fibre, (with metal lightning conductors imbedded in them) are picked up by the radar which can’t distinguish between planes and rotating wind turbine blades. The air traffic control radar is designed to screen out stationary objects, causing the Doppler shift from reflected signals, but the resolution of current systems cannot distinguish between the blades and aircraft. New research is working to overcome this problem by applying stealth technology, exotic coatings, and improvements to radar sampling software.

In some locations, particularly in winter, there is a build-up of ice on the blades, also in summer there can be an accumulation of dead insects on the blades. High efficiency requires smooth blades, but with the above roughness - particularly on the leading edges - there can be a reduction of power by up to 25%, and, at worst, cause violent shaking of the entire structure and possible failure. This necessitates automatic controls to shut the system down.

Wind turbines require a high maintenance commitment.

Although the wind farms are spread over very large areas, the actual use of land for the wind turbines occupies only 2% of the land, with claims by their proponents that the rest can be used for farming and animals. However, failures of structures and blades have occurred from time to time, presenting a hazard to people and animals in close proximity.

When it is calm weather across the entire region, the power has to come from elsewhere which means that the utilities must retain their full resources (i.e. conventional power plants) to enable them to handle the load. This therefore means that these wind turbines do not add meaningful additional capacity to the system.

These lessons are being learned the hard way in Denmark and Germany after initial enthusiasm and fanfare. By 2004, Denmark decided not to build more wind farms, either inland or at sea, because wind power was producing for them the most expensive electricity in Europe. The Danes had become dependent on it, but they found the wind to be unreliable. They couldn’t buy electricity from German wind farms because their supply was just as unreliable at the same times (i.e. when the weather was calm across the whole region), so they had to buy reliable electricity from the Nordic grid (hydro and nuclear), or from France (80% nuclear); sometimes well above market prices. When the winds were strong, they had a surplus and the grid controllers claimed that as early as 2001, they couldn’t sell it and had to get rid of it for nothing. Germany’s wind farms along the northern coast reported similar difficulties.

Reports state that a 20% wind power contribution, results in a net saving of only 6 – 7% overall, because base-load plant has to be kept on-line, at great additional expense, to absorb sudden wind power shortfalls.

Except for remote and special applications, the International Energy Agency recognizes that most wind power use exists only because of generous government subsidies. A recently released report (Nov-08) by the OECD commented that although electricity prices across the E.U. rose by 15%, UK prices rose by 29.76%. It suggested that the UK wind subsidies were the prime culprit for the difference.

Although the UK has natural advantages, such as one of the longest and windiest coastlines in the EU, and in spite of the increased cost to the consumers, the wind turbine infrastructure still had to be supported by a one billion dollar subsidy payment to the owners of the wind turbines. This is projected to rise to 6 billion dollars by 2020 if the government goes ahead with its current plan to produce 25GWe using wind. Thus, UK doubling of the electricity cost increases - compared to the EU - provides only 1.3% of the UK's electrical energy needs using wind. The UK government statistics state that the key issue in the load factor (LF) which has an average of 27.4% (worst performing 7%), which means that the typical wind turbine rated at 2MW peak produced only an average of:

0.54MW / day. (Of course, no electricity is produced on calm days)

In the UK, calm conditions occur on a fairly regular basis, extending across the country and reaching France and Germany. Worse still, over recent decades, long calm periods have occurred in the middle of winter when electricity demand is at its highest.

The Journal of Energy Policy in a recent report concluded that from experience, not only has wind power proven to be far more expensive and unreliable than previously thought, it could not avoid using high levels of natural gas (for the supporting gas turbines providing the spinning reserve), concluding that this type of high efficiency base load plant is not designed or developed for load cycling. (Discussed above).

A WT's peak power output is put into perspective by comparing the above Vesta 660 kW peak WT, which is an average representative model, to a mass-produced Holden V8 engine as used to power the Holden Commodore Utility:

Vesta 660 kW = 660kW Peak Power

Holden V8 engine = 225 kW Peak Power

So the peak power output of this Vesta WT is equivalent to the combined peak output of three of these V8 engines, or alternatively, a single engine such as a Cummins QST30-G2 generator set with a power output of 640 kW peak.

An interesting comparison could be made of the WT's total systems cost, embodied energy, subsequent release of CO_2, and its limiting load factor; to that of an engine driving a generator, plus its long term fuel use to produce an equivalent electrical energy output.

If the wind were a viable power resource, utilities would already be using it extensively. Utilities use every viable technology available to cut their fuel and electrical production costs and would gladly use wind and photovoltaics if they were reliable and cost effective.

Energy Storage

Energy from environmental sources, such as solar and wind, is intermittent. If the systems are stand alone, the electricity produced from these alternative energy conversion systems must be stored, so that it can be used as required.

Various storage systems are in use:

Batteries

- For Photovoltaic, normally batteries are used for small scale installations
- Battery limitations are discussed elsewhere in this study.

Pressure Vessels

- For high temperature solar concentrators, high temperature pressure vessels for super heated steam and molten salts are necessary.
- High temperature storage would require large numbers of pressure vessels with adequate installation to minimize the heat losses from the high storage to ambient temperature differences.
- For low temperature domestic water and air systems, standard hot water tanks can be used.

Pumped Storage

- For general alternative energy use, pumped storage - electrically driven pumped water to elevated storage reservoirs, converted by standard processes back to electricity is required.
- Pumped storage is site dependent, since it requires large, reliable water supplies and huge elevated reservoirs.

These storage systems have considerable and unavoidable efficiency losses. For relatively small scale stand alone systems these losses are usually accommodated and justified. For the same total system energy supply output, additional collection area would be required to compensate for the storage efficiency losses.

For the large scale being discussed all of these storage systems are, for various reasons, inappropriate.

The storage system scale proposed would use large quantities of materials and consumed considerable amounts of embodied energy for its construction and operation. It must be remembered that the storage materials and costs are in addition to these described above for the PV and Wind energy conversion systems. This further escalation of materials and costs make these alternative energy systems and storage of the electricity on this scale, as described above, even more unrealistic.

Summary– PV & Wind

No energy production systems (including PV and wind) create energy, they only convert part of the available energy into more usable forms; i.e. electricity.

All alternative energy systems rely on favourable solar energy inputs, which although driving the weather, do not deliver a reliable, continuous energy supply to any particular location.

For photovoltaics, claims based on qualified statements such as “can achieve” are only for best conditions around midday. The reality is, whilst also being subjected to seasonal variations, for the rest of the day the incoming radiation is tending either from or to the night conditions of zero.

To make a quick “approximate” assessment of the relevance of a PV system for a particular application, proceed as follows:

1. Select the radiation records for the particular location (usually recorded in kWh per square metre per day),
2. Multiply this value by the field efficiency of the PV being used - not the cells theoretical or laboratory efficiencies.

This results in the electrical energy (per m_2 per day) produced after conversion from solar radiation to electricity by the PV cells. The amount of energy required for a particular application will then determine the area and the number of $1m_2$ panels required.

(Remember, this is only for a quick approximate calculation, the final area of collectors will be greater once all the other system component efficiencies are accounted for.)

A similar quick approximation of available energy can be carried out for wind by using the relevant wind density ratios as described above, and multiplying the average wind density by the WT’s load factor. This will then determine the energy available, and consequently the number of WTs to provide the energy requirement.

The embodied energy of any system is the sum of the energy used during its lifetime; from its manufacture, installation, operation, maintenance, and for its eventual disposal.

Conventional systems, with efficiencies improving over the years, convert energy stored from the past in its various forms, such as fossil fuels, uranium, and in the future thorium, into steam and then electricity to drive machines to do useful work. Hydro produces electricity by using falling water; the greater the height of the water, the greater the energy production potential.

To substantiate the claims of any system that purports to convert “free energy” to power, then the ratio of all the energy used to construct and operate the system, versus all the energy produced by the system, must be positive. If it would only produce enough in its lifetime to make and operate itself, then clearly common sense dictates that its creation is a waste of time and money – unless of course it can be justified for special purposes such as remote areas power supplies.

Energy Units

It is essential to understand that energy and power are not the same, though frequently and erroneously used as if they are.

- For energy, the basic unit is expressed in joules (J)

Where 1 joule is defined as 1 watt second.

- For power, the basic unit is expressed in watts (W)

and is defined as 1 watt.

- The amount of energy collected is defined as Kilowatt hours (kWh)

This is the most important factor for any system since it provides the impetus for work to be done, and it can be inter-converted into other forms such as mechanical, thermal, electrical, chemical, light, sound and nuclear.

- The claimed peak power output (kW) for wind and PV systems only applies to peak ideal conditions.

Conclusions – PV & Wind

- PV systems are an ideal and, in some cases, an elegant solution for low power and remote area applications, for up to hundreds or thousands of watts, using batteries to store the energy produced.
- All PV and thermal, radiation converted to electricity systems, are dependent on the systems' conversion efficiency, the available radiation, and the collector area.
- Similarly, WT systems are dependent on the WT's operational design limits, and the load factors which are determined by the variable local wind and energy densities.
- For both PV and Wind, very large electrical generation requirements, require very large areas. This results in a huge use of materials for construction etc., major on-going maintenance and cleaning, and an enormous use of land, which could have serious environmental ramifications.
- Current research suggests cell efficiency improvements; however these are as yet unproven for longevity and consistent outputs under working conditions, particularly at the higher efficiencies. If this work is eventually successful this would result in a reduction of collector areas. However, because of the size and the physical limitations to efficiencies, these large scale PV system proposals could not possibly begin to meet the present and future multi-gigawatt electrical and other energy requirements for a modern, urban community such as Australia.
- Although Wind is an excellent solution for some remote area applications, if a continuous power supply is required it must be supported by storage such as batteries, or by conventional power supply. It is unrealistic to rely solely on wind to provide the continuous power and energy that is required to support the needs of a large urban society
- Because of the variability of the energy inputs to these systems from the environment, they cannot be seriously considered as a total or a major replacement for a continuous, uninterrupted energy supply. These proposals are ill-informed and naïve, taking an excellent niche market solution to impractical and impossible extremes.

The proposals for large scale PV and wind facilities as a replacement for conventional electrical energy production are being promoted by a relatively small number of self appointed pressure groups, mostly using rhetoric rather than using properly detailed careful analysis. They are opportunistically joined by manufacturers and product sales marketers from energy suppliers and distributors of “solar” equipment. Together, they exert an influence well beyond their technical competence.

The simple answer to these groups is to demand that they produce the evidence in the form of calculations supporting their claims. It is not enough for them to avoid the issue by saying “Scientists say”.

The practical conversion of various energy resources to electricity is the domain of engineers who are specifically trained to use the laws of mathematics, science, thermodynamics and electro-magnetism, to enable them to be responsible for the design, manufacture, economics and ongoing operation of these energy conversion plants supplying electricity to the grid.

A basic rule of science is that hypothesis must be consistent with the facts and must be verified by testing any predictions against observed data – past and present. This promotes a maturity gained from experience to recognize what is achievable and what is not achievable.

Other than for a few exceptions, the media panders to, and consequently is responsible for, many of the popular misconceptions of sustainable energy production, having made little or no attempt to confirm or discredit, by disinterested independent expertise, the validity of the claims made by these groups. This exacerbates the influence of these groups, who clearly demonstrate by their claims, a lack, or at least a shallow knowledge of basic engineering and scientific principles, and who have clearly no energy system design, production or operational experience.

For the majority of the nation’s citizens, their exposure to current information is via the media, and without any informed critical comment, is it therefore any surprise that their opinions are distorted and ill-conceived?

Future Alternatives for Non-Polluting Electrical Energy Production

When Australia finally decides to produce a major part of its electricity using non-fossil-fuel systems, are there any reliable, on-call, non-polluting, and safe energy production replacement technologies available?

Using facts, rather than hearsay based claims and the erroneous use of ideal peak-condition calculations (disguised as “can achieve” claims) it is demonstrably clear that with the magnitude of Australia’s increasing electricity needs, photovoltaic (PV) and wind power, or any other systems which depend on unreliable energy collection from the environment and its subsequent conversion to electricity, cannot possibly cater for this demand for a large, continuously available and reliable supply infrastructure.

Hydro power production is limited by the scarcity of suitable new sites. Other alternative ideas are in their infancy, but are unfortunately plagued by the same restrictions as PV and Wind, such as finding suitable sites and/or unreliable environmental inputs, and huge energy collection areas which result in large energy use for materials, manufacturing, installation and operational costs.

Statements, such as “all we have to do is to improve the efficiency of these systems and their energy storage” again demonstrates an abysmal lack of knowledge of both the topic and the limitations imposed by Nature.

Since Newcomen’s first operational beam engine nearly 300 years ago in 1712, Watt and thousands of other engineers have continuously improved efficiencies to the point where only incremental improvements to current systems can possibly be achieved. Similarly, since the understanding and inception of electricity production over 100 years ago, its storage has been investigated and improved; however, nothing is available or even envisaged to accommodate the huge scale that would be required.

Clearly, incremental improvements to generally used current technologies will not solve our future energy needs.

Rephrasing the question: If we wish to reduce the use of fossil fuels for the production of electrical energy, are there any other proven, reliable and available alternatives that are long term, relatively pollution free and safe?

Is Nuclear Electrical Energy Production A Viable Alternative?

There are hundreds of nuclear power facilities throughout the world operating continuously and safely, both on land and at sea. On land, allowing for maintenance and modification about 450 plants are operational at one time, and another 45 are under construction. Generation 2 light water reactors already produce about 20% of world electricity. In France, nuclear power facilities produce 80% of the country's electricity, with any excess fed into the European grid. In the USA this figure is 20%. Reactors have also powered hundreds of naval ships and submarines worldwide for many decades, in numbers similar to public utility plants.

Thirty countries that jointly represent two thirds of world population are using, or planning to use nuclear power production. A concern is that the current nuclear industry will not be able to cope with the demand. However, the biggest problem – in the short term - is likely to be the lack of skilled operational staff, which will require appropriate education programs.

So, the answer must be Yes to the question: Is nuclear electricity production a viable alternative?

Nuclear Safety

Many past and present concerns appear to be based on designs and safety procedures now several decades of out of date. Previously controversial facilities have practically all been scrapped, or radically updated or replaced. Such concerns would only be relevant if real faults were repeated.

It is worth putting nuclear power generation into perspective by comparing the safety and accident death rates of nuclear reactor facilities with other accident statistics. The following are a few examples from the US Accident Death Rate combined statistics for the 30 year period 1966-1997, which is contemporary to the 3 Mile Island and Chernobyl accidents.

Number of US Deaths:

- Roads 1,511,272
- Falls 457,389
- Drowning in Bathtub 6,344
- Lightning Strikes 2,954
- Nuclear Power Plants (including Three Mile Island) 0

Fatalities from Radiation Exposure

Deaths due to accidents, other than Chernobyl, causing harmful human radiation exposure have been claimed but not validated. Despite these incidents, all other operational plants have demonstrated remarkable reliability, efficiency, safety and longevity.

It would be reasonable to assume that the many thousands of civilians and naval personnel who have worked, and still work, in close proximity to these reactors for decades would not do so if there was a real danger to their health. There are no validated reports of premature deaths of these people, compared to the rest of the population.

In Australia, the very mention of the word "nuclear" produces in some individuals near pathological anxieties, quite possibly strongly influenced by association with nuclear warfare, and possible accidents in nuclear power stations that could release radiation into the environment. These fears may be the result of lack of knowledge and of up-to-date general information about nuclear energy.

Major Accidents

The two major accidents which have occurred in the last half century of nuclear power production have become the symbols of concerns about nuclear power generation. It is important that the actual facts become as widely known as the names of these plants have become.

Three Mile Island

The accident at Three Mile Island resulted in no deaths because the concrete containment vessel worked as designed. After the clean up the system was redesigned, re-built and recommissioned.

Current operators claim that the facility is now the most cost-effective in the U.S.

Chernobyl

At Chernobyl in April 1986 there were 42 confirmed deaths, caused mostly from fighting the fire. Chernobyl happened because multiple safety procedures were not adhered to, and the containment shell was inadequate to the point of being virtually nonexistent. Even when first commissioned, this early Soviet reactor design would not have passed any Western safety requirements, and is considered inherently unsafe compared to western reactor designs.

The explosion which occurred was an explosion of steam, not from nuclear fission, and the subsequent fire and radiation release from the burning graphite in the damaged reactor was what caused the majority of deaths. The huge number of deaths reported to have occurred, has been demonstrated by the European Community to have been misreported and grossly exaggerated.

The accident occurred in Unit 4 of a group of four reactors, all operating within tens of metres from each other. The other three were only marginally damaged but were closed down for precautionary reasons. These remaining three were restarted in 1993. All were finally decommissioned in December 2000. 3000 workers were employed in this facility during the continuing 8 years of operation following the accident.

Both the nuclear accidents described above would have been completely avoidable if the “in place” safety procedures had not been overridden by operators.

Radiation

Radiation occurs when the nuclei of a radioactive particle, such as Uranium or Plutonium, disintegrates over time, producing two or more radioactive particles during its disintegration. The ionizing electromagnetic radiation or atomic particles, are capable of displacing electrons from around atoms or molecules, producing in the process charged atoms, molecules or ions. The most common types are Alpha, Beta or Gamma particles and X-rays.

The fear of this radiation and radioactivity is due to the harmful ionizing effect it can have on human cells and tissues if they are over exposed. Consequently, over exposure must be strictly controlled.

However, radioactive particles can be produced both by nature as occurs everywhere around us, and can also be artificially produced by humans in nuclear reactors.

Radioactivity, when controlled, is extremely useful to humans by helping to treat several types of Illnesses. The mild, radioactive waters in health spas have been used for centuries.

The waste from nuclear power production is relatively easy to deal with, when compared to the continuously increasing many orders of magnitude higher levels of toxic waste from industry and hospitals, which are a significant threat to human health and safety because of its toxicity, inflammability, corrosive and reactive effects on the air, water, soil and the environment generally.

The background radiation measurements on the site after the Chernobyl accident, were about twenty times higher than normal, but it must be appreciated that this is still twenty times less than the normal background radiation at Guanapari, in Brazil. Guanapari is recognized as having naturally occurring radiation levels far above those normally recorded in most regions, and people have been living here for centuries.

Much was reported about the increased radiation levels recorded across Europe, however, it is necessary to put the radiation attributed to the accident in proportion to the actual values measured and documented in the European Community Report N7, 1986.

- The unit of radiation used is the Sievert, or Milli Sievert (msv).
- The amount of radiation absorbed by the average person over fifty years is 70-140 msv from nature and 21-35 msv from medical X-rays etc.
- 1 msv is 400 times less than the natural radiation in certain regions of India, Iran, Paraguay and Guanapari, Brazil. People in these regions live normal lifetimes without any demonstrated effects, or premature deaths, when compared to other people less exposed to radiation in these countries.
- The EC Report states that the radiation attributed to the Chernobyl accident ranged from a maximum of 1 msv in Hungary, to 0.001 msv in Spain.
- After two weeks, the atmospheric radiation in most locations in Europe was back, almost to normal.

- This, at worst, is on a par with the increase in personal radiation due to spending a few weeks vacation on parts of the Brittany coast, a few days on the ski slopes of the Alps, or a half a dose of dental X-ray.

Further, all radiation is not the same. We are surrounded by radiation of various kinds.

In addition to nuclear facilities, our technology uses and produces other types of radiation such as radar waves, microwaves, television and radio waves, UHF, long waves, short waves, radiation from light bulbs, cathode tube electrons, medical X-rays, radio and TV transmitters and antennas. Examples from nature are ultra violet, infra red, visible light, X-rays and Gamma rays, electrons, protons, neutrons, alpha particles and neutrinos. Some of it is emitted by the ground, called: “terrestrial radiation” and some from the sky as cosmic rays, sunlight, starlight and even neutrinos from stellar explosions. Radiation is a natural phenomena, without which the world would not be as it is. All life forms evolved with and adapted to the natural forms of radiation long ago, or became extinct.

Nuclear Reactors

Over the sixty years of experience in the design and operation of nuclear reactors, like most other new technologies, it has suffered “growing pains”. Largely, the lessons have been learned regarding the faults of the early Generation 1 reactors, which three decades ago, caused accidents at Three Mile Island and Chernobyl.

Except for a few of the early reactors in Europe (now operating with up-graded safety features and procedures), the rest of the old-design reactors throughout the world are past their use by date and have been scrapped, or where possible, completely updated into later generation facilities.

Already, in addition to these new and upgraded reactors, there are third and fourth generation facilities incorporating the most recent designs based on past experience and new ideas. These have multiple safety procedures intended specifically to avoid repetition of the problems caused by the inadequacies subsequently discovered in some of the earlier reactor designs and safety measures.

The promises of these designs are now being realised, making this an exciting development, because in these new generation reactors the long term waste from past and present reactors and weapons could be used as fuel and gradually safely disposed off, or at least hugely reduced. This will improve both the energy production efficiency and costs of the uranium and thorium reactors, and also the safety of radioactive waste disposal.

It is estimated that the energy produced by using the uranium and thorium in this way could provide the world’s power needs for thousands of years.

Reactors Generations

Generation 1

Generation 1 reactors were of the pressurized water type. These were also used in submarines and surface vessels.

Generation 2

Generation 2 reactors were pressurized or boiling water types, the technology being fundamentally the same.

Generation 3

Generation 3 reactors adopt a standardized design that allows faster construction, insulation and approvals. Generation 3 reactors were basically Generation 2 but modularized to be factory mass produced. This design standardization enables fast and less costly assembly, leading to faster certification and the production of safer technology, which are orders of magnitude safer than earlier models.

Around the world 45 Generation 3 designs are currently being built and a further 350 are planned.

Generation 4

An international task force called the “Generation IV International Forum” (G4IF) has been developing since 2002, six nuclear technologies for deployment between 2020 and 2030. The countries involved at the moment are: USA, Argentina, Canada, China, France, Japan, Russia, South Korea, South Africa, Switzerland and the UK. All six of these new technologies represent systems advances. Each was selected on the basis of being clean, safe and cost effective to meet increased energy demands on a substantial basis. As well as being resistant to the diversion of materials for weapons proliferation and secure from terrorist attacks.

Generation 4 reactors are being planned to get 99.8% of the energy from uranium instead of the 1% of early reactors. Consequently, this would mean that enough uranium has already been mined to run the new reactors for 500 years.

Generation 4 reactors are likely to be much more efficient than any designs in use today and will make uranium supplies last much longer. These reactors can also burn much of the current and future waste which will produce shorter or no half life radioactive residue.

All these reactors will operate more efficiently at higher temperatures than reactors today. Temperatures will operate in ranges from 510°C to 1000°C compared to present reactors operating at 330°C.

Sizes are planned to range from 150 – 1500 Mw.

A lead cooled option available as a 50-150 Mwe battery with a long core life of 15-20 years without refuelling is also being considered.

A Condensed Review of the Most Promising Contemporary Nuclear Reactor Developments

Conventional Light Water Reactors (LWRs) use uranium 235 fuel, initially enriched to about 3.5% purity. This fuel is replaced when it falls to 1.2%. A 1 Gw LWR power plant consumes 30 tonnes of this fuel per year. (A 1 Gw Coal Fired Plant consumes 9000 tonnes of fuel per day.)

The uranium enrichment used by LWRs is not appropriate for nuclear weapons. For this reason LWRs are called “proliferation resistant”.

In addition to active mechanical control of the reactor, two natural processes provide negative feedback which stabilizes the reactor. The first is “negative temperature coefficient”. As the fuel temperature increases, the vibrational energy of the uranium 238 increases the rate of neutron absorption, and the reaction rate slows down of its own accord. The second is called “negative void coefficient”. If the water which cools and moderates the neutrons decreases in mass, it no longer is an effective neutron moderator of the vibrational energy, and the reaction rate slows down.

LWRs are inherently stable. If any instability were to occur, this is normally corrected by routine supervised automatic adjustments of the reactor parameters. The worst thing that could happen is for a massive loss of coolant.

Were this to occur, the nuclear reaction would stop, the fuel would continue to generate heat and melt the fuel elements. This is called a meltdown. The reactor would be damaged but the public would remain protected by the extremely strong shell of the containment vessel, which Three Mile Island had but Chernobyl did not. Historically all Western designed reactors have a containment building, whereas some early Soviet design reactors often did not.

Reactors using Thorium as a Fuel

Still later model reactors are being researched, designed, planned and built with some of the latest incorporating the use of thorium. These future thorium reactors are considered to be able to produce almost as much energy as the uranium reactors, whilst being an order of magnitude safer to operate.

Thorium is about 550 times more abundant in nature and also less complex to mine than uranium. Additionally, it cannot lead to the development of nuclear weapons. Although experimented with for decades, the contemporary thorium reactor technology is new and minimises if not eliminates most of the current drawbacks of nuclear power.

The problem with thorium in the past has been its reluctance to be usefully activated; however, recent research has produced activation, either by using lasers, or by the inclusion of small quantities of either the waste products of current reactors, or even weapons grade materials.

Unlike uranium 235 and plutonium 239, thorium is not fissile and cannot sustain a nuclear chain reaction by itself. The thorium reactor requires a particle beam to keep it running. When the beam is switched off it is impossible for the fuel to sustain a chain reaction –or cause a meltdown. The rate of fission immediately slows down, the fuel cools and dies out.

This is called a “sub critical” reactor, with clear safety benefits over uranium reactors since it has zero chance of a Chernobyl type accident.

A US company “Thorium Power” avoids sub-criticality issues with thorium by using a mix of fuels. The centre seed of the fuel rod is plutonium. Wrapped around this is a blanket consisting of a mixture of thorium and a small amount of uranium, which is designed to kick start the thorium fuel cycle. The benefit of Thorium Power’s system is that with minor modifications it can be used in most existing nuclear plants.

The cooperative US / Russian project is aimed at initially building four thorium powered plants which can be used just for plutonium disposal. (I.e. For disposing of waste or weapons grade materials)

India is also developing its own advanced technology to utilize both thorium and a breeder reactor.

Fast Neutron Reactors

Another type of reactor, the fast neutron reactor (FNR), produces plutonium and is called the “breeder reactor”. When modified to consume plutonium, rather than produce it, the fast neutron reactor would require fifty times less uranium than a conventional reactor. This could be considered as a long term ecological solution, since by using the easily accessible uranium from currently known world reserves, at the present rate of world total energy consumption, reserves could last five thousand years or so.

Future Modular Reactors

There is a huge future worldwide market for small packaged, and completely sealed, reactors. The US and other nuclear users are investigating and producing these packaged, called ‘modular’, nuclear reactors.

For example: The South African pebble bed reactor introduces the concept of a factory mass production module of about 110 Mw with other commercial modules of about 160 Mw planned for 2013, which are planned to be sold and maintained internationally.

The US small packaged and completed sealed reactors, based on more recent submarine power unit technology, could be installed virtually anywhere. This is currently being investigated for general use. Versions of these small reactors have outputs from about 11 Mw to 44 Mw and have operated safely in US and UK submarines and ships for four decades.

The units need only a small supply of nuclear fuel that is deliberately inappropriate for weapons and would be equipped with internal security, safety and location measures. Units could be delivered by appropriate transport to any site. When the fuel is depleted, after years of operation, the unit could be retrieved and replaced by a newly refuelled one.

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It is worth noting that a small 11 Mw reactor, of a type used for many years in the smallest US nuclear submarines, when operating with a conservative 90% load factor, could produce a reliable 87 Gwh per year of controllable electrical energy supply.

To produce this amount of energy using wind turbines, working at the whim of the environment, and operating with say, a 20% load factor, would require at least 80 Vespa wind turbines of the 660 kilowatt peak variety, as used in Australia at approximately 8 wind turbines per square kilometre. Of course, energy storages, like batteries, would be required, or some conventional supply backup for a standalone facility. (See EEC Report on European wind turbines the actually recorded load factors were 15-20% (worst 7%)).

Some Case Studies of the Latest Developments in Reactor Technology

Vattenfall's Forsmark Nuclear Plant

Vattenfall is a large European energy utility that operates a variety of energy-generation technologies, including nuclear, hydro, natural gas, coal, oil, peat, biomass, wind and photo voltaic solar panel collectors.

Vattenfall operates the 3090 Forsmark nuclear plant in Sweden. This plant has had independent government audits for the entire life cycle of the reactor process, which includes the long-term disposal of waste.

Vanttenfall reports, that, averaged over the entire life cycle of this nuclear plant, including uranium mining, milling, enrichment, plant construction, operating, decommissioning and waste disposal, the total CO_2 emitted per kilowatt hour of electricity produced is 3.3 grams for every hour that one kilowatt of power is produced.

Vantenfall measures the equivalent CO_2 output from natural gas to be 400 grams per kilowatt hour and from coal to be 700 grams per kilowatt hour. Thus, nuclear power generated by Vattenfall, omits less than 100th of the CO_2 emitted from fossil fuel based generation.

The plant produces approximately 93 times more energy than it consumes. Or, put another way, the energy investment required to generate electricity for forty years is repaid in five months. Normalized to 1 Gw of electrical output capacity, the energy required to construct and decommission a plant is repaid in 1.5 months. The energy required to dispose of the waste is repaid in 1.5 months. In total, this is less than .8% of all the electrical energy produced by the plant.

Therefore, the performance of nuclear power can be compared to other energy sources by calculating the energy to build and run it, called the 'embodied energy', with the energy it produces over its lifetime. For 1 Gw output the Forsmark reactors have a total mass of about one million tonnes, mainly of concrete and steel, which would produce less than two million tonnes of C02 emissions during construction. A 1 Gw coal fired power station consumes about three million tonnes of coal per year which emits 10 million tonnes of C02.

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This is over five times as much for one year than required for the direct construction emissions from a nuclear plant.

CERN’s ADS Reactor

CERN is the European organization for nuclear research. CERN is developing a waste disposal technique that relies on thorium (not uranium or plutonium), as the primary fuel source, and using accelerator drive fission to disintegrate radioactive substances. This was initially called the “Energy Amplifier” but now the “accelerator driven system” (ADS).

The ADS reactor is sub-critical, which means that it needs help to get the thorium to react. This is achieved by a particle accelerator firing protons at a lead target. The target then releases neutrons into the Thorium fuel to start and maintain a fuel cycle. Improvements in conventional nuclear fission allow current nuclear waste to be burned up as fuel in ADS, which can also produce electricity. Most resulting waste is radioactive, but short lived, and decays away quickly to stable and harmless products. Longer lived types of radioactive waste can be rendered harmless by ADS, using a system called: ‘Adiabatic Resonance Crossing’. These techniques have been tested and by CERN and are being evaluated using a variety of operational procedures.

University of Texas

More recently, the University of Texas has devised what could be an alternative disposal solution, by using nuclear fusion to destroy the waste permanently. However, this work is still in the early stage of research.

General Electric –Hitachi Reactor

Another design in development is a General Electric -Hitachi (GEH) recent model, called the “Economic and Simplified Boiling Water Reactor”. This design has an estimated accident risk factor of 1 in 29 million reactor operational years.

The GEH model, S-PRISM fast reactor, costs about the same as a comparable fossil fuel power station and is produced in modules of about 300 Mw. These can be looped together to produce 2.5Gw, which is larger than any coal power stations, and can even be used in many coal fired sites by removing the coal fired unit and replacing it with a nuclear power unit.

Westinghouse AP1000 Reactor

New designs such as the Westinghouse AP1000 use physical principles i.e. phase change and gravity, to maintain cooling water in the event of a major accident. This particular design is simpler, smaller, safer and cheaper than comparable current reactors.

Disposal and Storage of Reactor Waste

Of the three levels of radiation, low and intermediate levels have a half-life of less than thirty years, and represent 90% of the total volume of all radioactive waste. In operation, this low and intermediate radioactive waste is compressed in concrete drums for safe storage and transport. These drums are eventually stored in specially designed and monitored sites.

Alpha, Beta and Gamma radiation are all stopped by a few dozen metres of soil. When stored at this depth, regardless of the degree of radiation, absolutely no radiation can reach the surface.

The remainder of world radioactive waste, with longer half lives, has accumulated over the years. High level radiation wastes are usually vitrified so that they cannot possibly leak or leach into the soil. These, high level wastes, must be stored, either permanently, or until the systems mentioned above become available and most of it could be usefully disposed off.

In addition to waste disposal systems mentioned above that are currently being researched, the most likely immediate storage scenarios for the future are being examined by several countries. Other storage scenarios are being examined by several countries such as:

- The USA, Germany, Sweden and Finland. Here the thrust is developing deep underground repositories in stable geographical locations.

♉ France, the UK and Japan. In these three major cases the aim is to dramatically reduce most of the radioactive waste by 97%. For example, the total volume of vitrified waste from all 58 reactors in France over 38 years is a volume of 13 metres cubed.

Availability of Uranium and Thorium Fuels

There is an estimated 40 trillion tonnes of uranium in the earth crust. To date, we have mined less than 1 ten millionth of this, as compared to about half of the known world conventional crude oil supplies. Estimates of the uranium distribution in different types of rocks shows that shales and phosphates can contain 8000 times as much uranium as the currently known bodies of 10-20 ppm. Most of this is not easily accessible with current technology.

Australia owns about 30% of the most easily accessible uranium deposits in the world, and about 40% of the known more easily accessible thorium.

Even for a low grade deposit[1], such as the Rossing Mine in Nambia, if the energy cost of the acquisition process was about 1 pettajoule for 3000 tonnes, this uranium would provide about 470 pettajoules so the energy gain is about 500 times.

Unlike other energy resources, Uranium exhaustion is not an issue for the foreseeable future and this is even before we consider using thorium.

[1] The uranium at Rossing Mine is 0.035% by weight (35 PPM).

A typical 1 Gw nuclear reactor consumes about 200 tonnes of natural uranium per year. Currently, world consumption of uranium per year is about 65,000 tonnes.

Conclusions - Nuclear

Dangers from nuclear powered electricity generation have been examined worldwide. The dangers have been recognized and precautionary modifications made that are now considered controllable and safe.

This acceptable level of safety has been clearly demonstrated by the very large number of nuclear power plants that have been operating on land and sea, worldwide, for almost half a century.

Almost all public concerns are based on technology and safety procedures, now thirty years out of date, that have long since been upgraded and replaced.

From the above, it is obvious that more individuals and countries are examining the environmental disadvantages and advantages of various forms of electrical energy production. Increasingly, most advanced nations are supporting, using or planning to use, Nuclear, Uranium and Thorium as the most safe, and the most acceptable, environmentally sound options.

During operation, nuclear reactors produce negligible greenhouse gases. The introduction and increasing use of Nuclear produced electricity into the national grid would make a huge contribution to, if not solve, any international CO_2 reduction commitment made on Australia’s behalf by the government.

Australia is conspicuously absent from this informed, international, step into the future.

Since it would take a number of years to have any new technology operational, there is no rational reason why Australia should not be acting now by investigating the latest international progress and informing its citizens with a view to select what is most advantageous to the National welfare.

Australia could and should be a leader in a field that has the potential to create tens of thousands of secure new jobs for centuries ahead.

In addition to the materials, Australia has the engineering, scientific, mining, manufacturing, trading experience and skills to use and create opportunities in this field to its advantage, for both domestic and international markets.

Australia is well placed to be amongst the leaders of the inevitable world Nuclear Energy market, either by itself or more likely in co-operation with the US, France, India (Thorium), China, Japan and others already active in this field.

Recommended General Reading

Environmentalists for Nuclear Energy
By Bruno Comby
Nuclear Engineer and President of the Society of Environmentalist for Nuclear Energy
Preface by James Lovelock, FRS, a Founder of Greenpeace.
Printed in France ISBN: 292490-02-6
Booklets:
Nuclear Energy Fallacies
Nuclear Common Sense
Nuclear Radiation Exposed
Nuclear Electricity Gigowatts
By Colin Keay, Ph.D, D.Sc.
Former Physics Department, University of Newcastle
Printed by Longworth & Goodwin Press, Pty Ltd.
General Nuclear Information
By members of the Physics Department, The University of Melbourne.
Found on nuclearinfo.net