AUGUST 2013

vic roads

Renewable Energy Roadmap

keeping victorians connected

Renewable Energy Roadmap

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Contents

Glossary

CEGT	Centre for Energy and Greenhouse Technologies
GW	gigawatt (Unit of power)
HPS	High Pressure Sodium
kW	kilowatt (Unit of power)
kWp	kilowatt peak (Power produced by VP cell with full light exposure)
LED	Light Emitting Diode
MW	megawatt (Unit of power, one million Watts)
MWh	megawatt hour (Unit of energy)
PJ	petajoule (Unit of energy, one billion Joules)
PV	Photovoltaic
RDDC	Research, Development, Demonstration, Commercialisation
REC	Renewable Energy Certificate
SRES	Small Scale Renewable Energy Scheme
STC	Small Scale Technology Certificate (type of REC)

1 Introduction

VicRoads is a major consumer of electricity, which is mostly used to power street lights and traffic signals. This electricity is generated from coal, and hence is a contributor to climate change. However, VicRoads' core business, which is managing Victoria's arterial road network, is threatened by climate change. This Renewable Energy Roadmap seeks to provide guidance to VicRoads planners and engineers as to the options for greater uptake of renewable energy generation within the road network in order to reduce VicRoads' greenhouse gas emissions. In doing so, VicRoads aims to generate a greater proportion of its electricity from renewable sources to the extent that is cost-effective and technically feasible.

By increasing the quantity of electricity generated from renewable sources as well as improving the energy efficiency of the road network, VicRoads will continue to provide leadership in the area of sustainability and climate change.

The addition of renewable energy sources to the network will also help the State meet the community's long term energy needs, while supporting the growing economy. Renewable energy projects support future energy security, help lower emissions from the energy sector and enable Victoria to contribute to the national renewable energy target of 20 percent renewable generation by 2020.

This requires the consideration of innovative technologies, some of which are highly prospective, whilst others are mature, cost-effective technologies. Technologies that may potentially be utilised for road infrastructure may be grouped into the following classes:

- solar energy, including small devices such as variable messaging signs
- wind energy, including vehicle generated
- kinetic energy recovery from vehicles.

Each of these classes offers different opportunities for VicRoads in terms of potential scale, cost, risk and application.

In addition to generating energy sustainably, the energy footprint of VicRoads' operations can be significantly reduced by the use of efficient technologies.

VicRoads' annual electricity consumption is approximately105GWh/year (Table 1). Of this, approximately 30 percent is used for pedestrian and traffic signals and 60 percent is used for street lighting (these figures include VicRoads' cost share of street lights which are owned and operated by electricity distribution businesses). The remaining 10 percent of electricity consumption is used for a wide variety of purposes such as office lighting.

Table 1: VicRoads Electricity Consumption

	MWh/year total	Tonnes CO2e
Street Lights	63,030	86,350
Traffic Signals MWh/year	32,060	43,920
Facilities	9,950	13,630
Total 2011	105,040	143,900

Over the next 10 years, further efforts to reduce VicRoads energy consumption will be achieved through the following actions:

- elimination of all incandescent and quartz halogen traffic signals in Victoria
- installation of LED traffic signals for all new sites
- preferential installation of high efficiency street lighting, using technologies such as intelligent voltage controllers and LED lamps.

2 Drivers for Renewable Energy

2.1 Climate Change

In general, there are three different strategies to address climate change. Option one involves reducing the degree of climate change by lowering the level of greenhouse gases in the atmosphere. Option two involves adaptation to climate change such as protecting against sea level rise and increased flooding or relocating to higher ground. The third option is the "do nothing" option.

Figure 1 represents the various options to deal with climate change including the "do nothing" option. Areas in the middle of the triangle represent a combination of approaches. There are costs associated with mitigation and adaptation. However, under the "do nothing" or "no action" option, there are potentially higher costs associated with climate impacts because this leaves the organisation ill prepared to deal with the effects of climate change.

Strategies to mitigate and adapt to climate change are therefore essential. As such, whilst adapting to climate change is clearly a priority to VicRoads in order to manage the impact on road assets, it is also important that VicRoads does its share to minimise the emissions of greenhouse gases which cause climate change.

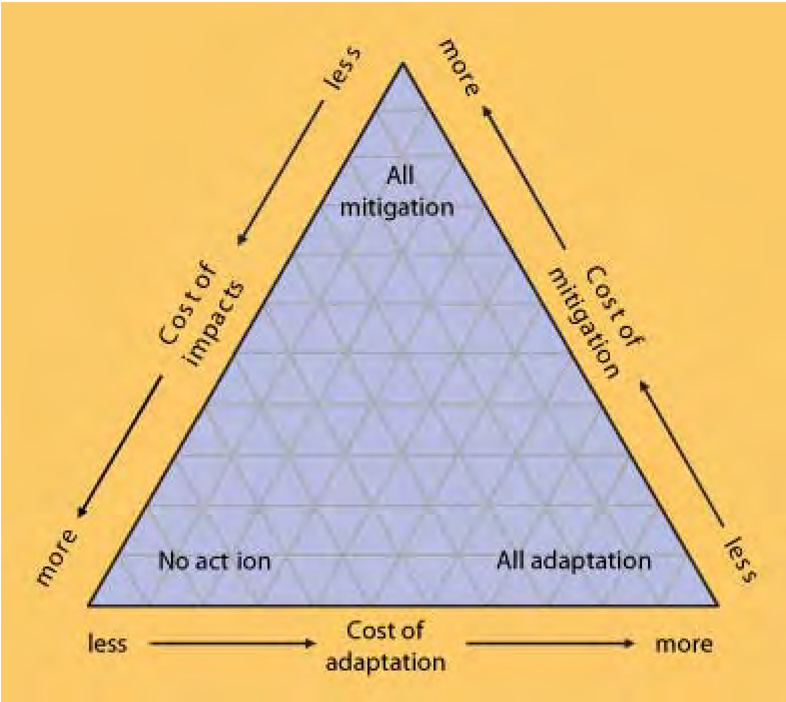

Figure 1: Climate Change Options (IPCC Fourth Assessment Report Chapter 18)

Through the VicRoads *Sustainability and Climate Change Strategy 2010-2015* (VicRoads, 2010), the organisation has committed to reducing the greenhouse gas emissions from the road network (refer Objective 1.1).

Reductions in greenhouse emissions are usually accomplished through reducing energy use and/or switching to energy sources that do not generate greenhouse gases. Technologies available to minimise greenhouse emissions include hydrogen fuel cells, solar power, tidal energy, geothermal power and wind power. Some ideas are easy and inexpensive, such as replacing incandescent lights with compact fluorescent bulbs that use less electricity than their conventional counterparts. Many mitigation technologies, such as fuel cells and geothermal, are still in the development phase and will require further research to determine their usefulness and viability. Nonetheless, there is no shortage of technology options and the most prospective options for the road network are discussed further in Section 3.

2.2 Electricity Prices

Growth in electricity prices represents a potential cost risk to VicRoads. Electricity prices are expected to increase faster than inflation due to the following factors:

- increases in the price of fuels used for electricity generation
- the costs of upgrading the electricity distribution network due to the need to replace aging assets and support increased demand.
- increased costs for electricity distributers due to bushfire liability. (This is likely to consist of both increased insurance costs and increases in maintenance efforts aimed at reducing the likelihood of bushfires being initiated by power line defects.)

Over the 2008 to 2012 period, retail electricity prices in Victoria have risen approximately six times faster than CPI (Figure 2). There are many reasons for this increase, and the introduction of a $23 per tonne carbon tax on 1 July 2012 is only a small factor. A much greater contribution to the increase in the retail cost of electricity is the cost of investment into transmission and distribution infrastructure. Nationally, annual investment in transmission and distribution reached $7.4 billion in 2011/2012 (Australian Energy Regulator, 2011).

Purchase of green power costs approximately five cents per kWh more than black power. However, it is not as desirable an option as the development of in-house renewable energy generating capacity. First, on-site generation protects VicRoads from future price increases that are driven by costs for transmission and retailing. This represents a genuine saving to the community because generating electricity close to where it is consumed avoids loading the transmission network, and defers future network upgrade costs.

VicRoads can reduce its exposure to electricity prices by reducing consumption through improvements in energy efficiency and/or increasing the use of renewable sources in the network.

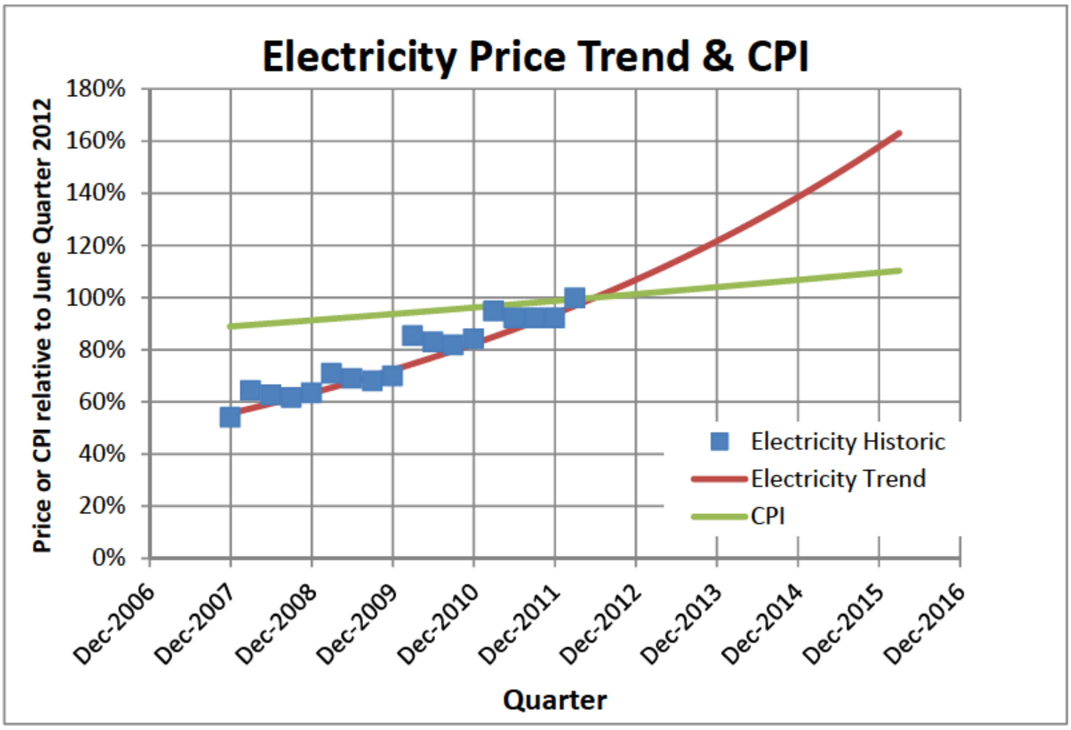

Figure 2: Retail electricity price and CPI (ABS, 2012)

2.3 Creating New Business Opportunities

The generation of renewable energy presents an opportunity for VicRoads to generate revenue from its extensive road reserves. Business arrangements whereby VicRoads makes land available to a utility for electricity generation, and commits to purchase electricity from the utility, may be very attractive to both parties.

Arrangements of this type are well established in the United States, with examples including solar farms on airport land at Denver International Airport, Colorado (Figure 3), the nearby E470 toll road, and the I5 / I205 Highway interchange at Portland Oregon.

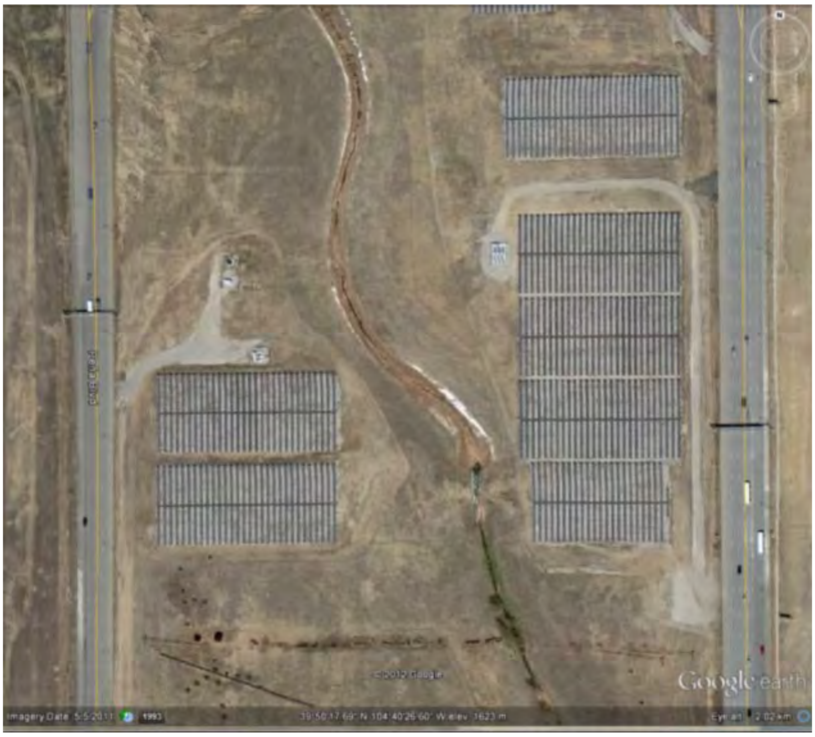

Figure 3: Pena Boulevard Solar Farm, Denver International Airport, Colorado (Google Earth)

The advantages of such an arrangement to VicRoads include:

- ability to negotiate long term electricity prices
- avoid the need to cut grass or conduct other maintenance works on road reserve
- gain value from “land locked” ground which would otherwise lay idle
- potential branding opportunities.

The advantages for a utility could include:

- access to land
- long term electricity contract
- night time sale of electricity when demand is generally minimal
- increased capacity for generation during sunny weather when wholesale electricity prices are highest
- potential branding opportunities.

Long term leases of VicRoads’ land may compromise the corporation’s ability to expand road capacity in the future. However, photovoltaic installations can be relocated at relatively modest cost if required. Unlike large scale wind turbines, photovoltaic (PV) farms require only minimal foundations. For example, the photovoltaic panels at the Greenough River Solar Farm in Western Australia are mounted on frames on steel columns which are simply driven into the ground (Figure 4). This means that it may be feasible to install solar farms on VicRoads’ land which is slated for long term future road construction. It is noted that the Pena Boulevard Solar Farm at Denver International Airport is located on land that will be an attractive location for car parking space if the airport expands its capacity in the future.

Figure 4: Greenough River Solar Farm, Geraldton WA
*(*http://www.greenoughsolarfarm.com.au/photos*)*

The use of renewable energy generating systems on the roadsides provides the opportunity for VicRoads to demonstrate its commitment to sustainability and to leverage its brand.

The Oregon Department of Transportation (ODOT) has actively marketed its solar farm near Portland to enhance its environmental brand. This marketing effort includes showcasing Oregon's roadway solar installations in a range of publications, as well as providing extensive information on its web site. In particular, ODOT publishes up to the minute performance data for the solar farm on the internet. See Case Study on page 14 or refer to http://live.deckmonitoring.com/?id=solarhighway.

VicRoads already has two substantial sized solar electricity generating installations, at the Tullamarine Calder Interchange and on the M80 at Sunshine. There is potential to market both of these installations by signage at the actual sites, or by the provision of information via media including the Internet.

2.4 Renewable Energy Incentives

In recent years, the installation of renewable energy generating technology has been financially supported by a range of measures including renewable energy certificates and feed-in tariffs. The Federal Government has legislated a target of 20 percent Australia's electricity to be generated renewably by the year 2020 (Department of Resources, Energy and Tourism, 2012).

A major feature of the Federal Government's renewable energy target is the use of Renewable Energy Certificates (RECs). Certain liable entities, generally electricity retailers, are required to purchase a certain percentage of their electricity from renewable sources. The REC system allows renewable energy generators to sell the "renewableness" of their energy separately to the energy itself. The system allows VicRoads to gain income from the "renewableness" of electricity it generates. Alternatively, it would provide income to a utility which produces renewable energy on VicRoads land.

Any renewable energy generating facility that VicRoads constructs is most likely to be integrated into some form of road infrastructure, be it a wind turbine to support lighting for a rest area, or a medium scale photovoltaic array integrated into a noise barrier. Consequently, the business case for the facility will depend on the marginal cost of constructing the infrastructure with energy generating capacity compared to constructing the infrastructure without generating capacity. For example, a solar noise barrier should be considered by comparing the costs of building a noise barrier with or without PV capacity. Part of the business case will depend on the sale of RECs.

For small and medium scale installations, RECs are normally sold at the time of commissioning of the system instead of annually. If this is done, the number of RECs will be based on the calculated capacity of the system over fifteen years, which in turn will be based on the rated system capacity. No additional RECs can be sold after commissioning.

Alternatively, irrespective of system capacity, RECs may be sold annually based on actual electricity generation, for as long as the system is in operation. Over the long term, more RECs would be available for sale under this arrangement. However, the cost of measuring actual electricity yield, and difficulties with managing the process mean that sale of RECs may be an unreasonable administration burden.

More detail on the REC system and the costs and considerations for developing a business case for renewable energy installations is provided in Appendices 1 and 2.

3 Renewable Energy Technologies

3.1 Small Scale Photovoltaic Electricity Generation

VicRoads currently generates a small but increasing proportion of its electricity from photovoltaics (PV). The use of PV electricity generation for small devices such as variable messaging signs and radio operated roadside help phones represents a mature and low cost technology. PV is well established for powering roadside devices where it avoids the cost of providing grid power connections. It is anticipated that the use of small scale PV will continue to expand for the simple reason that it is more cost effective than the alternative of connecting mains power.

A listing of the small scale PV devices within VicRoads is summarised in Table 2.

Table 2: VicRoads Small Scale PV Electricity Generation

Plant	Number of Units	Capacity kW/Unit	Estimated Annual Yield MWh/Year
Help Phones	233	0*	0*
School Speed Zones	306	0.05 Estimate	25
Freeway Data Stations	29	0.1	5
Hazard Signs	12	0.1	2
Total			32

Note: * Solar powered help phones are used where a wire connection would be unreasonably expensive. They use radio signals when operating, but due to the low frequency of operation, the energy used, and hence the displaced electricity generation, is negligible.

In addition to help phones and variable messaging, PV may also be used to power street lighting. Solar powered flag lighting has recently been installed at intersections along the Hume Freeway in New South Wales. Operated by NSW Transport Roads and Marine Services, these installations consist of 500W capacity PV panels with 70W high pressure sodium luminaires mounted on shared poles. They have sufficient battery capacity to run for five nights without solar power.

Similarly, solar powered public lighting is in place at a number of locations in Victoria. These typically use LED lights due to their higher efficiency. For example, the City of Boroondara has installed 26 solar powered lights along the Gardiners Creek bike path in Markham Reserve, Ashburton. The installation was designed to P2 standard to provide appropriate light for pedestrian activity, with a pole spacing of around fifteen to twenty metres.

The use of PV panels to power street lighting represents a potential area for expansion of small scale photovoltaics. Pedestrian standard installations incorporating PV and LED lights currently cost approximately $8,000 each. They are entirely self-contained, with pole, PV panels, battery, and controller in one unit. PV powered lighting is likely to be cost effective at locations away from the electricity network, where the cost of connecting to the grid is high.

An obvious constraint to the use of PV street lighting is the size of the panels required to achieve adequate electricity generation. A 250W streetlight would require a PV panel with an area of approximately twelve square metres inclined at an angle of forty degrees from horizontal. The wind loading on a panel of this size located several metres above the ground would be considerable. However, it is anticipated that future improvements in both the efficiency of PV panels and efficiency of LED lighting will reduce the size of solar panels needed to power street lights.

3.2 Medium Scale Photovoltaic Electricity

The integration of solar panels into freeway noise barriers is well established, with many PV noise barriers in Switzerland, Germany, Holland and Italy. The Tullamarine Calder Interchange PV noise barrier, installed in 2007, is believed to be the first road traffic noise barrier with solar panels integrated as part of the structure to be constructed outside Europe (Figure 5). As such, it represents an example of VicRoads' leadership in environmental sustainability.

Figure 5: Tullamarine Calder PV Noise Barrier

It has been argued that road and railway noise barriers are the single most attractive application for building-integrated solar panels for the following reasons (Nordmann, et al., 2005):

- they can replace material used for another purpose, replacing the cost of that material, and exploiting foundations and structure that would have been otherwise required
- they can make efficient use of land
- they can be constructed on a large scale using simple, uniform design and pre-fabricated structures.

In pure monetary terms, inclusion of PV panels in a noise barrier is no longer financially advantageous due to recent reductions in feed-in tariffs for renewable energy. An indicative cost comparison is presented in Appendix 2. The costs associated with PV noise walls assume that PV installation does not exceed 100kW capacity or 250MW/year yield. Provided that a PV installation does not exceed these limits, it is eligible for the Small Scale Renewable Energy Scheme (SRES). This allows the owner of the installation to sell renewable energy certificates (RECs) at the time of commissioning based on the capacity of the installation.

The Tullamarine Calder Interchange PV noise barrier (Figure 5) was architecturally designed to achieve a flush, integrated appearance. In order to achieve this appearance, and in order to maximise the height of the barrier, the PV panels were installed vertically. Whilst this is not ideal from an electricity generating perspective, it represents a compromise between conflicting design requirements. In response to the vertical installation, amorphous silicon PV panels were used due to their relatively high efficiency at low light levels.

At the time of writing, a second PV barrier is under construction, on the M80 Ring Road at Sunshine West. The M80 structure is not a noise barrier but a visual screening device, with its panels inclined to maximise electricity yield. With the installation of this PV array on the M80, it is expected that VicRoads will generate approximately 80MW of renewable power from its two barrier installations. The current listing of medium scale PV installations is detailed in Table 3.

Table 3: VicRoads Medium Scale PV Electricity Generation

Plant	Year of Installation	Area of Panels	Capacity kW/Unit	Estimated Annual Yield MWh/Year
Tulla Calder PV Noise Barrier	2007	$500m^2$	24.4	21
M80 PV barrier	2013	$500m^2$	47.6	59
Total				80

Traffic noise barriers which are aligned in a generally east – west orientation are often ideal locations for integrated photovoltaic panel installations. However, site-specific factors such as overshadowing from trees or buildings, the need for some barriers to be acoustically absorptive, or security factors may render a site inappropriate for PV installations.

Arrays of ground mounted PV panels, sometimes referred to as solar farms, have been established at several locations on road reserves in the United States. Typically these installations have belonged to third parties, who rent land from the road authority, and exploit tax offsets which are not available to government organisations (Oregon DOT, 2012). Whilst generating a small percentage of the annual energy usage, the use of road reserves is seen to be a critical step in the widespread use of solar energy.

It is likely that suitable sites could be identified in Victoria. Ideal sites would display the following attributes:

- land which will not be required for future road expansion in the short to medium term
- not required for a safety clear zone
- highly visible for passive surveillance
- appropriate level of access, balancing security with maintenance considerations
- free from overshadowing, now and in the future
- in a region of high electricity demand, to reduce loading on the electricity transmission system
- areas within freeway interchanges which are unlikely to be subject to vehicle run-off (Figure 6)
- "land locked" parcels of land that are surplus to road construction requirements, but of no commercial value due to lack of access
- land owned for the purpose of constructing a road in the distant future (say twenty years)
- close to an appropriate grid connection.

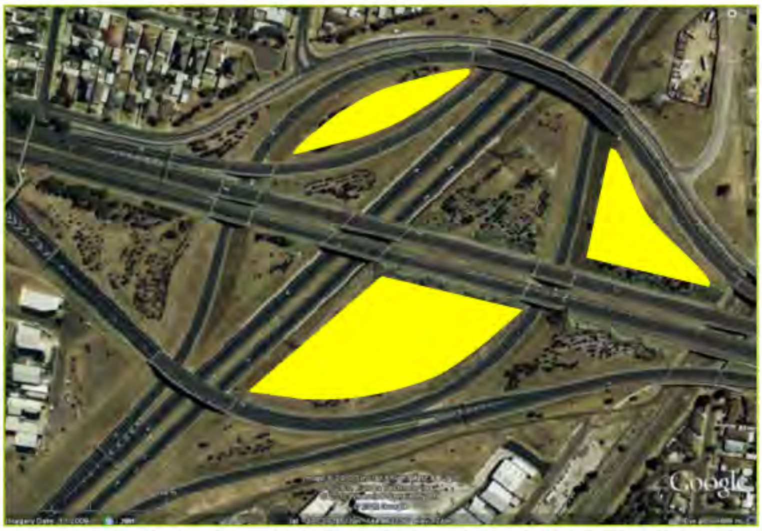

Figure 6: Potential sites for Solar Power Facility – M80 / Calder Interchange

Case Study: Solar Farms, Oregon Department of Transportation

At the interchange of Interstate 5 and Interstate 205 near Portland Oregon, a row of solar panels about 1.5m wide and 160m long has been installed. The panels have a capacity of 104kW and feed electricity directly to Portland General Electric's system wide grid. They count for 28 percent of the energy needed to power lights that illuminate the highway's interchange at night.

The I5 / I205 solar array was the first major roadside solar installation in the USA. Two larger PV systems have subsequently been installed in Oregon, at Baldock and West Linn. Further proposals by the Oregon Department of Transport are planned for next year.

SolarWorld (a German company) supplied solar panels and PV Powered of Bend, Oregon provided the inverter. Real time data on the performance of the first solar highway installation is available on the Internet at http://live.deckmonitoring.com/?id=solarhighway as shown below. (Oregon Department of Transport, 2012)

3.3 Micro Wind Power

Generation of electricity from natural wind is well established. In recent years, micro wind turbines with capacities up to about 20kW have become available. They have reportedly been used with a degree of success in North America to provide power for facilities in roadside rest areas that are not easily accessible from the electricity grid.

The potential for electricity generation from small scale wind in Victoria is constrained by generally low wind speeds. When assessing the energy potential from wind at a particular site, it is necessary to consider the percentage of time at which the wind blows at various speeds. Also, it should be noted that wind speed increases with height above ground. This means that the amount of energy that can be generated at a particular site can be increased by increasing the height of the wind turbine, at the cost of increased structural requirements, increased difficulty of access for maintenance and increased visual amenity impacts.

Micro wind turbine capacity is typically rated at a wind speed in the range of 10m/s to 15m/s. Figure 7 shows the distribution of wind speeds at a test site 34m above the ground at Sunshine West (Memery, 2012). As can be seen from Figure 7, speeds as high as 10m/s are rarely reached in Sunshine West (and are rarely reached elsewhere in Victoria).

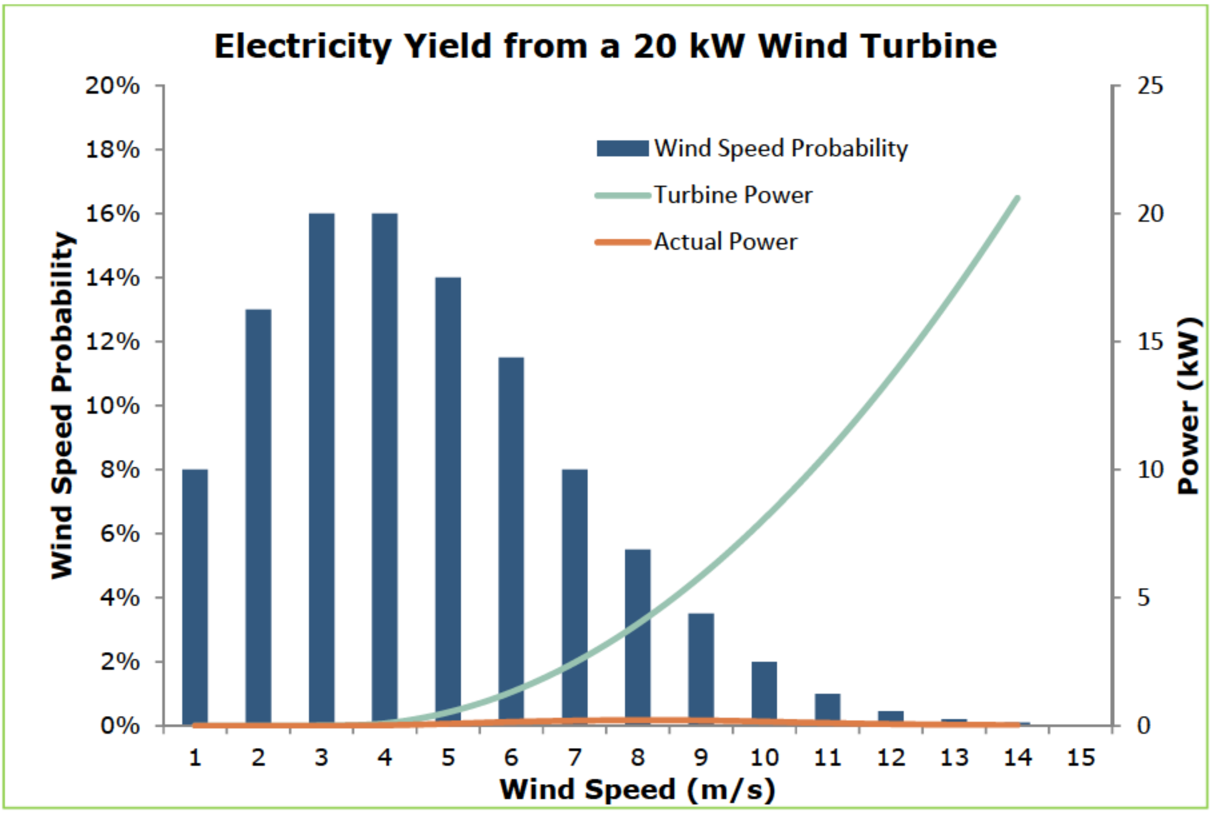

Figure 7: Wind Speed and Turbine Performance

The green curve shows the rated power as a function of wind speed for a typical 20 kW wind turbine. The red curve at the bottom of the graph shows the expected power from the wind turbine weighted according to the percentage of time the wind blows at each speed increment. This was calculated by multiplying the capacity of the turbine at each wind speed by the percentage of time at which that wind speed occurs. For example, the turbine has a capacity of 8kW when the wind blows at 10m/s. The wind blows at this speed for two percent of the time. This means that for two percent of the time, the turbine is generating 8kW. By adding up the contributions from all wind speeds, we can determine the total power that the turbine will generate over a time period, assuming the normal wind speed distribution. From this, it can be concluded that an average of 1.2kW would be generated.

A 20kW turbine would cost approximately $140,000 fully installed if connected to the electricity grid, and approximately $180,000 if installed off-grid with battery backup. Assuming a green power price of $0.19 per kWh, the price of the annual electricity yield would be around $2,000, which would be less than the cost of maintaining the turbine.

It is recommended that micro wind turbines not be considered as a method to generate renewable energy unless it can be shown that a major saving in grid connection costs can be achieved. In locations where a saving in grid connection costs is achievable, it is likely that PV solar power will have a more favourable business case than micro wind. However, wind turbines designed specifically for low wind speeds are under development, and this technology should be monitored in the future.

3.4 Emerging Technologies

3.4.1 Stages of Technology Development

New technologies typically pass through four stages of technology creation: Research, Development, Demonstration, and Commercialisation (RDDC).

Engagement by VicRoads in the support of new technology may be appropriate, but it is important that there is a clear understanding where a product is in the RDDC continuum. As the demonstration stage is the process of creating a realistic pilot product that works at full scale with full efficiency and provides proof of concept, it is recommended that VicRoads only participate in technologies that have reached this point of development.

Any decision by VicRoads to purchase less mature technology should be justified on the basis a desire to support the technology development rather than on the basis of the energy which will be produced. As well as variations in maturity, emerging technologies vary significantly in terms of the potential energy availability. For example, solar roadways have a potential to generate very large amounts of energy due to the large area of road that could, if financial considerations were ignored, be covered with PV panels. By contrast, devices to capture energy from wind caused by passing traffic have less potential capacity due to the low wind speeds causes by traffic. Emerging technologies vary widely in terms of potential costs and risks.

A range of emerging renewable energy technologies are described below. The maturities of these technologies are presented in Table 4. These technologies are ranked in terms of their perceived potential capacity and cost in Figure 8. It must be emphasised that these technologies are experimental and unproven. They may pose significant risks to VicRoads, such as compromising road safety or pavement durability, or simply fail to generate as much energy as expected.

VicRoads Environmental Strategy staff will continue to monitor the development of less mature technologies, with a view to providing a recommended list of technologies for demonstration at large scale within the road network.

Table 4: Emerging Technologies

Technology	Maturity	Potential Scale	Potential Cost	Risk (Technology – Pavement)
Solar Roads	Development	Large	Very High	High – High
Traffic Induced Wind Power	Research	Very small	High	High – Low
Kinetic Energy Mechanical	Development	Small	Medium	Medium - High
Kinetic Energy Piezoelectric	Research	Small	Medium	Medium - Medium

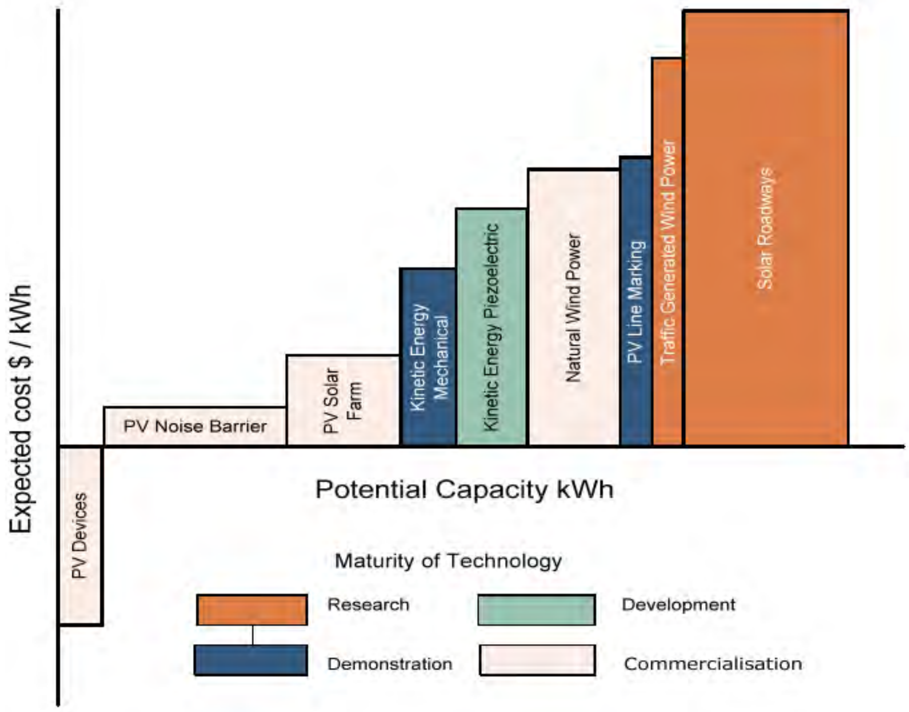

Figure 8: Potential Renewable Energy Technology Price

3.4.2 Solar Roads

The most significant development in solar technology in recent years has been the development of thin film PV panels. These consist of very thin layers of active material bonded to a substrate. Examples of novel materials include GA (Gallium Arsenide), and GIS (Gallium Indium Selenide). Whist the active materials for these panels may be extremely expensive on a dollars per kilogram basis, modern manufacturing processes exploiting nano technologies allow them to be deposited in very thin layers on an inexpensive substrate. As a result of improving technology, the active materials are expected to be used more sparingly, reducing costs.

A particular implementation of thin film solar technology under development in the USA is the Solar Roadway(Solar Roadways, 2010). Essentially this is an attempt to integrate photovoltaic panels into a road surface (Figure 9). An American start-up company, Solar Roadways Inc, has constructed a 3.5 metre square prototype, using a $US100,000 grant from the US Department of Transport, and at the time of writing is developing a prototype in a car park using a $750,000 grant from the US Federal Highway Administration.

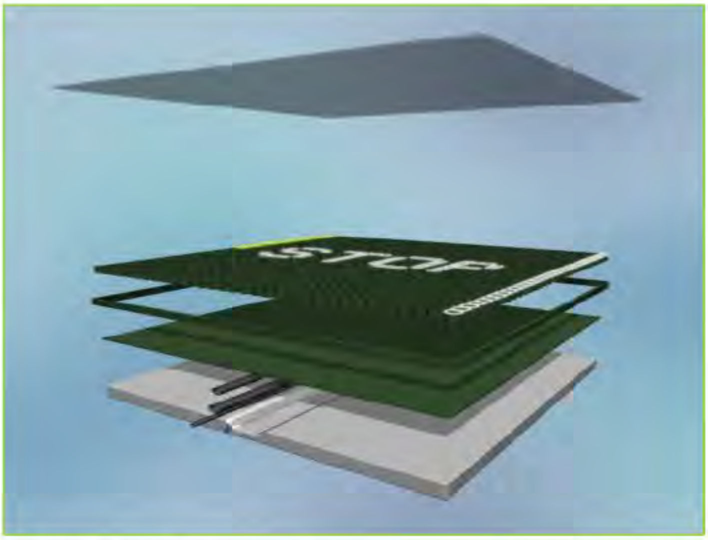

Figure 9: Solar Roadway Concept (www.solarroadways.com)

The solar highway concept consists of a translucent friction course, with PV panels and other circuitry underneath, and a structural base underneath that. The proposal includes LED lighting in the surface in order to provide variable messaging.

The potential scale for implementation of the solar roadway concept is very large; potentially all future roads could be solar provided they are sufficiently exposed to sun light. However, it is far from clear whether the proposed concept can achieve acceptable wet road grip or be sufficiently durable. In particular, if the surface is roughed by abrasion from passing vehicles, it may lose its ability to transmit light into the PV panels. The technology is considered to be very immature, and potentially very expensive.

3.4.3 Traffic Induced Wind Power

It has been proposed that wind generated by passing traffic could be harvested by small wind turbines located above or beside roadsides (Figures 10, 11). The obvious advantage of collecting wind power from traffic is that the available energy is as predictable as the traffic volume. Also, the greatest energy yield will be during day time when traffic volume is high and electricity demand is high.

Figure 10: Traffic Generated Wind Concept (http://www.engadget.com/2007/04/30/proposals-would-turn-highways-into-wind-farms/)

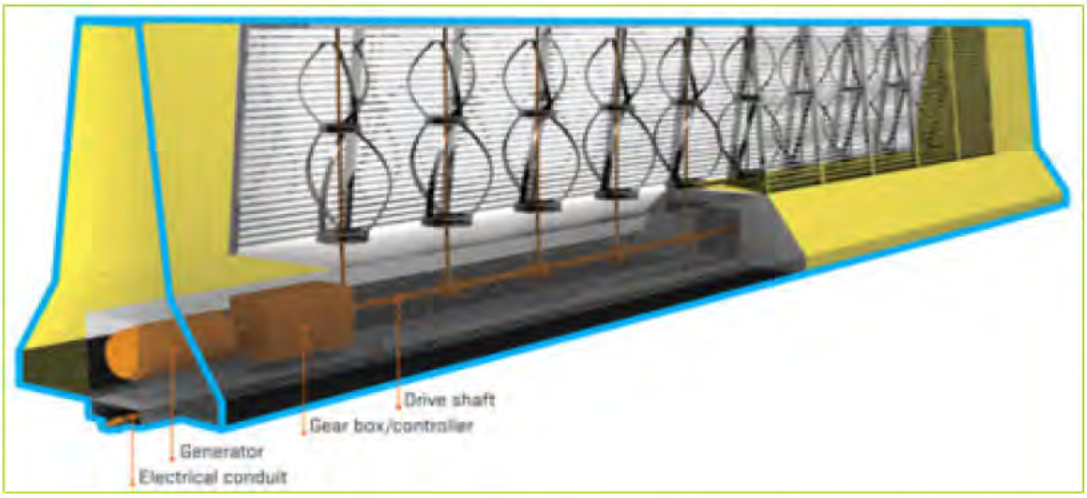

Figure 11: Traffic Generated Wind Concept (http://www.engadget.com/2007/04/30/proposals-would-turn-highways-into-wind-farms/)

In 2009/10, two "Windpods" were installed above the West Gate Freeway in Fishermens Bend. These turbines (Figure 12) - an Australian invention - were designed to exploit the acceleration of wind as it passes over or through a building structure. The Windpods represent a hybrid between Darrieus and Savonius designs, whilst being mounted in a horizontal position. They are intended to work in a Savonius mode at very low speed, allowing them to self start, which is generally not possible for Darrieus designs.

Windpods are claimed to generate 500W of power with a wind speed of 12.5 metres per second. As shown in Figure 7, natural wind of this speed occurs only rarely. Also this wind speed is approximately one half of the speed of passing traffic. It is not reasonable to expect wind of this speed from traffic, given that any turbine installation must be sufficiently far above or to the side of the road to provide space for passing vehicles.

The design on the West Gate Freeway, allowed for wind in an easterly or westerly direction to be accelerated by the structure of an overhead sign gantry above the road shoulder. Traffic on the freeway would generate a westerly air flow, which would potentially provide energy to the Windpods.

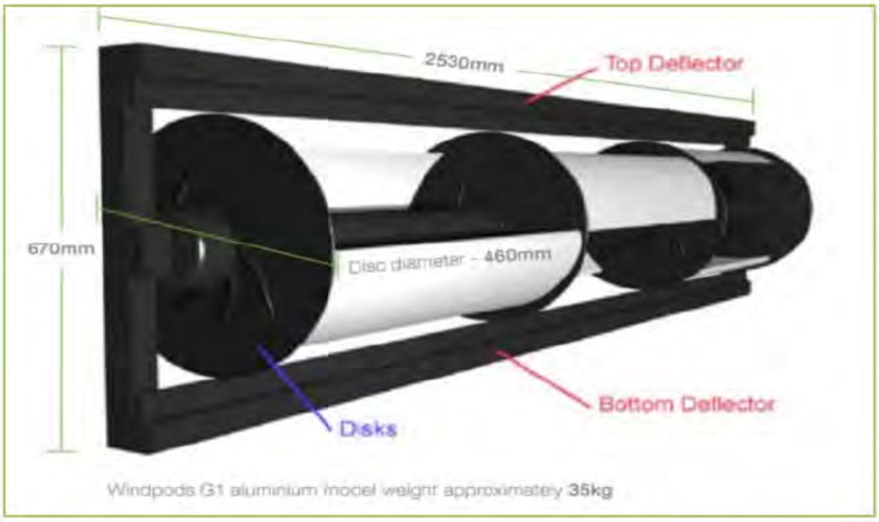

Figure 12: Windpod (Windpods Pty Ltd, 2012)The Windpods have not generated significant amounts of electricity, due in part to low wind speeds. Had the concept of traffic induced wind been a valid source of energy, the Windpods would have been more effective.

3.4.4 Kinetic Energy Harvesting

In principle, it may be possible to acquire kinetic energy from passing vehicles. This would have the effect of reducing the speed of vehicles, so it is only appropriate where vehicles otherwise need to use their brakes. Where kinetic energy is harvested from conventional vehicles, the impact on the vehicles will be a reduction in the wear of their brakes or engines and transmissions rather than an increase in fuel consumption. (However, it would reduce the available energy for recovery by the regenerative braking systems which are common in electric and hybrid vehicles.)

There are currently two broad classes of road kinetic energy recovery systems – mechanical and piezoelectric.

- Piezoelectric Case Study
  A pilot piezoelectric energy system has been installed in a road in Israel (Innowattech Technical Information, 2012). It uses a piezoelectric material that directly generates electricity when a force is applied to it, causing it to distort. The pilot scheme in Israel uses discrete generators located under a thin layer of asphalt. The performance of the system is unknown.
- Mechanical Case Study
  California-based AEST has developed a mechanical road technology that uses mobile plates to drive a hydraulic system. When force is applied by a passing vehicle, fluid moves through a machine which drives a generator. A similar system, marketed by Highway Energy Systems in the UK achieves a similar function, using a system of gears to turn a generator. Highway Energy Systems claims a capital payback period of two to four years for its systems. England's supermarket chain, Sainsbury, has recently trialled one of these systems at one of its stores, in Northampton, England. It is assumed that a mechanical system would require maintenance due to the wearing of moving parts, and may also generate noise

If a kinetic energy harvesting system was installed on a downhill road grade, the theoretically available energy can be calculated from the traffic volume, average vehicle mass, and the reduction in altitude over a length of road.

By way of example, over an 800m length of Ferntree Gully Road east of Jells Road in Wheelers Hill, approximately 10MW/h of energy per day is theoretically available. At current green electricity price of about $0.19 per kWh, approximately $70,000 worth of green power per year would be available. Of course, actual energy yields would depend on the system efficiency. This analysis assumes that only ten percent of the energy available from the traffic is in fact converted to electricity. In contrast to wind power from motor vehicles, the energy production potential of harvesting kinetic energy from passing vehicles is very large.

A fundamental challenge with kinetic energy harvesting system is the fact that it requires movement of the road surface in order for energy to be transferred from the vehicle to the road. (This is due to the principle that energy = force X distance.) The need for the road surface to be flexible enough to deflect when vehicles pass over it as well as be durable will clearly provide technical challenges. Given the substantial potential, kinetic energy recovery technology developments should be monitored and may eventually become feasible at a commercial scale. If the system uses mechanical components, there will be a need for maintenance due to the potential for wear of parts, particularly due to the possible entry of dirt into the system. Also, the system will need to be capable of accommodating a range of tyre loads. This means that it must be compliant enough to absorb energy from relatively light cars, whilst being strong enough to avoid damage from heavy trucks. It must also operate quietly.

How does purchasing green power compare with generating our own power?

Purchasers of green energy pay a price premium which goes to subsidise utility generation of renewable electricity. The electricity retailer then purchases green power from renewable energy generators such as wind farms.

The levelised cost of alternatives is a common way to compare alternative supplies of power. It can be calculated by adding the capital costs of various options to the cost of supply over an extended period of say twenty years, and dividing by the amount of power produced and consumed. Both the capital and recurrent costs are discounted to net present values. A 20 year calculation period, a 5 percent discount rate, and reasonable assumptions about future electricity prices costs give the following levelised costs:

Purchased black power	$ 0.14/kWh
Purchased green power	$ 0.19/kWh
Solar power from noise barrier	$0.24/kWh

These costs indicate that purchasing green power is more cost effective than constructing generating power from a PV integrated noise barrier. [It should be noted that this calculation is based on the incremental cost of building a PV noise barrier instead of a timber noise barrier and assumes that the price of black power will increase 5 percent per year in real terms, while the difference between green and black power will not rise.]

4 Future Opportunities

Renewable energy only currently accounts for about 5.5 percent of Victoria's electricity generation. Whilst a broad range of technologies are available for renewable energy generation, photovoltaic electricity stands out as the most appropriate for VicRoads to exploit. This is due to its technical maturity and the potential to integrate solar panels into structures such as noise barriers as well as the potential for deployment on road reserves. Energy technologies will continue to develop and become more cost effective and as such will be monitored with a view to future implementation.

It is estimated that Victoria receives at least 2,500 petajoules (PJ) of useable solar energy annually. The estimate takes into account land availability, with approximately 8 percent of the state considered 'available' or as non-urban land with suitable solar exposure and not under other use. An additional 11 PJ per year of useable solar energy is available in urban locations. Whilst there is considerable scope for VicRoads to reduce its energy intensity, there is also potential for the organisation to generate a proportion of its energy renewably.

There is only a small amount of VicRoads land that is potentially available for renewable energy utilisation. After unsuitable land area is removed from consideration, the amount of land and therefore energy potential (practical electricity) is still subject to a set of additional constraints that will vary depending on the particular energy source and will also include economic, environmental, social and regulatory constraints. These constraints may change over time.

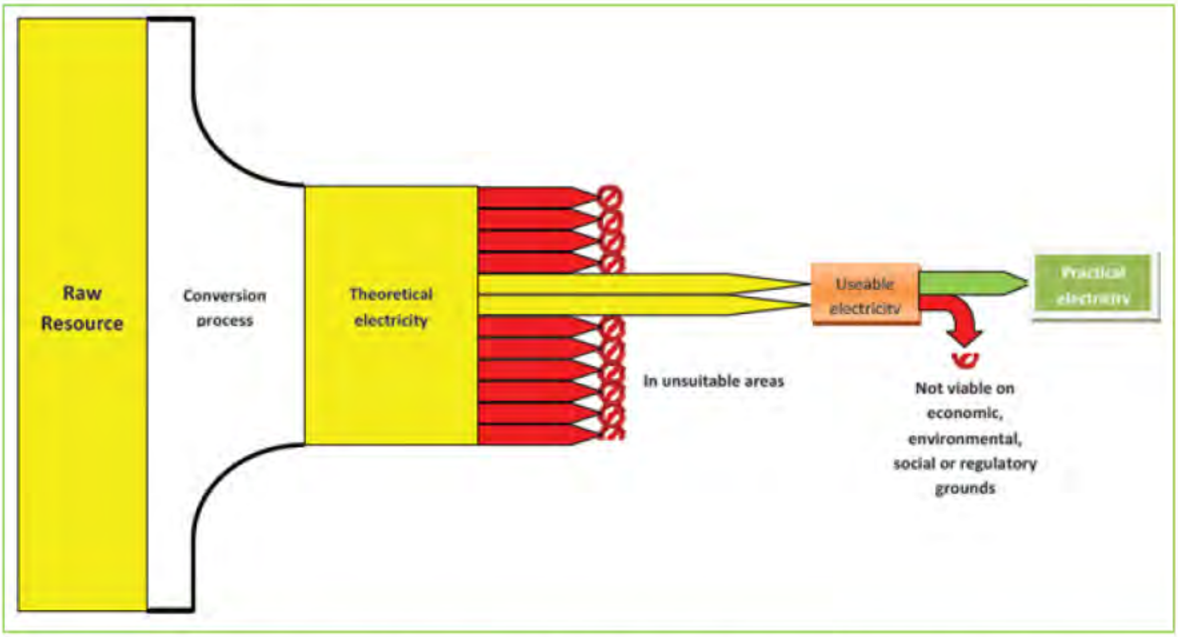

Figure 13: Calculation of Theoretical, Usable, and Practical Resource Potentials (SKM, 2009)

Currently, VicRoads has installed 90kW in renewable energy with the potential for incremental growth in small and medium scale PV electricity in help phones, school speed zones, freeway data stations, hazard signs and noise barriers. However, as technology develops and prospective technologies such as solar roads and traffic induced wind power become commercially viable, the scale of change could be dramatic. So the challenge remains to find the right way to develop these resources.

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Appendix 1: Renewable Energy Certificates

The expansion of both small and large-scale renewable energy generation capacity in Australia in recent years has been made financially viable by a system of Renewable Energy Certificates (RECs).

The renewable energy certificate system allows renewable energy generators to sell the "greenness" of the energy they produce, as well as selling the electricity.

In January 2011, the REC system was reformed in response to criticism that it did not appropriately recognise the initiatives of domestic renewable energy generators. The new system, known as the Enhanced Renewable Energy Target provides for two separate renewable energy certificate schemes as follows (DCCEE, 2010)(Hawkes, 2010).

- The Small-scale Renewable Energy Scheme (SRES) is focused on small and medium scale schemes. Certificates issued under the SRES scheme are known as Small Technology Certificates (STCs). It is intended to ensure that renewable energy generated by home owners is in fact additional to what would have been generated had the home owners' generating capacity not existed. (Previously, if an individual installed PV panels at home, and sold the RECs, that individual's generating capacity would be subtracted from the obligation of the liable party, which purchased the RECs.)
- The Large-scale Renewable Energy Target (LRET) is directed toward the funding of utility scale renewable energy generating infrastructure such as commercial wind farms. Certificates issued under the LRET scheme are referred to as Large Technology Certificates (LTCs).

The SRES scheme is available to renewable energy generators with capacity up to 100kW capacity or 250MW/year yield. This represents a capacity four times the size of the Tullamarine Calder Interchange PV noise barrier, and a yield 14 times its size. It is anticipated that most renewable energy generation systems installed by VicRoads will be small enough to qualify for the SRES scheme.

The SRES scheme is more "user friendly" than the LRET scheme because it allows fifteen years' worth of certificates to be created when a scheme is commissioned, based on the system capacity. In fact, it is normal for a renewable energy system installer to manage the selling of certificates, and simply discounting the sale price by the value of the certificates. By contrast, the LRET scheme requires that the certificates be created annually, based on measured actual energy yield. Using the LRET scheme would pose a significant administrative burden for VicRoads, and will not be discussed further.

The SRES scheme is governed by Australia's *Renewable Energy (Electricity) Act 2000, Renewable Energy (Electricity) Regulations 2001*, and subsequent amendments. The Act is administered by the Office of Renewable Energy Regulator.

STCs are traded though a clearing house, and have a volatile price that moves with supply and demand. At the time of writing (April 2013), the spot price for a STC was $37.00 (Clean Energy Council, 2012). The sale of STCs can offset a significant proportion of the cost of a renewable energy generating installation. It is important to understand how the number of STCs is determined for a particular installation, as this may influence the design of the system.

For PV generators, the number of STCs available is calculated as follows (Government of Australia, 2011):

- The solar zone rating is determined according to the site's postcode. For sites in North Western Victoria, the zone rating will be 1.382; in the remainder of Victoria, it will be 1.185.
- Multiply the rated capacity of the generator by the zone rating to get the base number of STCs available per year. This is to be rounded down to the nearest whole number.
- Multiply one year's number of STCs by fifteen to get the number that can be created at the time of commissioning.

For wind generators, the number of STCs available is calculated as follows (Government of Australia, 2011):

- If the number of hours each year of wind resource availability exceeds 2000, multiply the rated capacity of the generator by the number of hours of resource availability and then multiply by 0.00095 to determine one hour's STCs.
- If the number of hours each year of wind resource does not exceed 2000, then multiply the rated capacity of the generator by 2000 then multiply by 0.00095 to determine one year's STCs. (This method would most likely be used to calculate STC eligibility for VicRoads applications.)
- Multiply the rated capacity of the generator by the zone rating to get the base number of STCs available per year. This is to be rounded down to the nearest whole number.
- Multiply one year's number of STCs by fifteen to get the number that can be created at the time of commissioning.

There are some subtleties in the STC calculation that are not listed above. In particular, a small number of additional STCs are available where generators are installed before the end of 2013 and are at an address. There is also a limit on how many STCs are issued annually. These subtleties are unlikely to have a major impact on the number of STCs available for VicRoads installations.

The Office of the Renewable Energy Regulator maintains an on-line STC calculator at

https://www.rec-registry.gov.au/sguCalculatorInit.shtml

It is worth noting that the number of STCs available for a generator is dependent on the rated capacity of the generator rather than on its actual yield. This is particularly significant in the case of wind turbines, which are rated at much greater wind speeds than will commonly be available in Victoria.

Appendix 2: Developing a Business Case for a Photovoltaic Noise Barrier

The following costing, with approximate numbers, demonstrates the potential business case for a PV Noise Barrier. It assumes that an area of 700m^2 of average quality silicon solar panels are used in the top third of a 3.3m high timber noise wall, in place of timber. This size of PV installation is intended to have a capacity of 37kWp, and will generate 49MWh of electricity per year if located in Melbourne.

Table 2-1: Assumed PV Barrier Costs

Base timber noise barrier cost	$ 546,334
Avoidable cost of timber panels (20%)	($109,267) (A)
Cost of PV panels (after sale of RECs)	$137,000
Cost of Inverters	$52,000
Cost of Framing	$85,000
Cost of Electrical Wiring	$48,000
Cost of Installation	$82,000
Contingency (7% of Solar Portion)	$30,000
Solar Proportion	$434,000 (B)
Net Capital cost over timber noise barrier	$324,733 (B-A)

Note: The number of STCs for a proposal is available from an on-line calculator at

https://www.rec-registry.gov.au/sguCalculatorInit.shtml

Three alternative operating costs are presented below. They represent the following scenarios:

1. 94MWh per year is purchased as black power
2. 94MWh per year is purchased as green power
3. 94MWh per year is generated by the PV noise barrier. It is sold into the electricity grid at a premium tariff and then purchased back as required. (An allowance has been made for gradual degradation of the solar power generating capacity.)

The following assumptions are made:

- the initial price of black power is $0.15c/kWh, typical for a small VicRoads site.
- the real annual price increase of black power is 5 percent per year
- the initial price premium for green power is $0.05/kWh
- the feed-in tariff for solar power is $0.08/kWh
- the real annual premium increase for green power is 1 percent per year
- the inverters will not need to be replaced within the first twenty five years
- other maintenance costs will be no different from the alternative timber noise wall
- discount rate is 5 percent.

The discounted costs of the three scenarios are plotted over a twenty-five year period and represented in Figure 2.1.

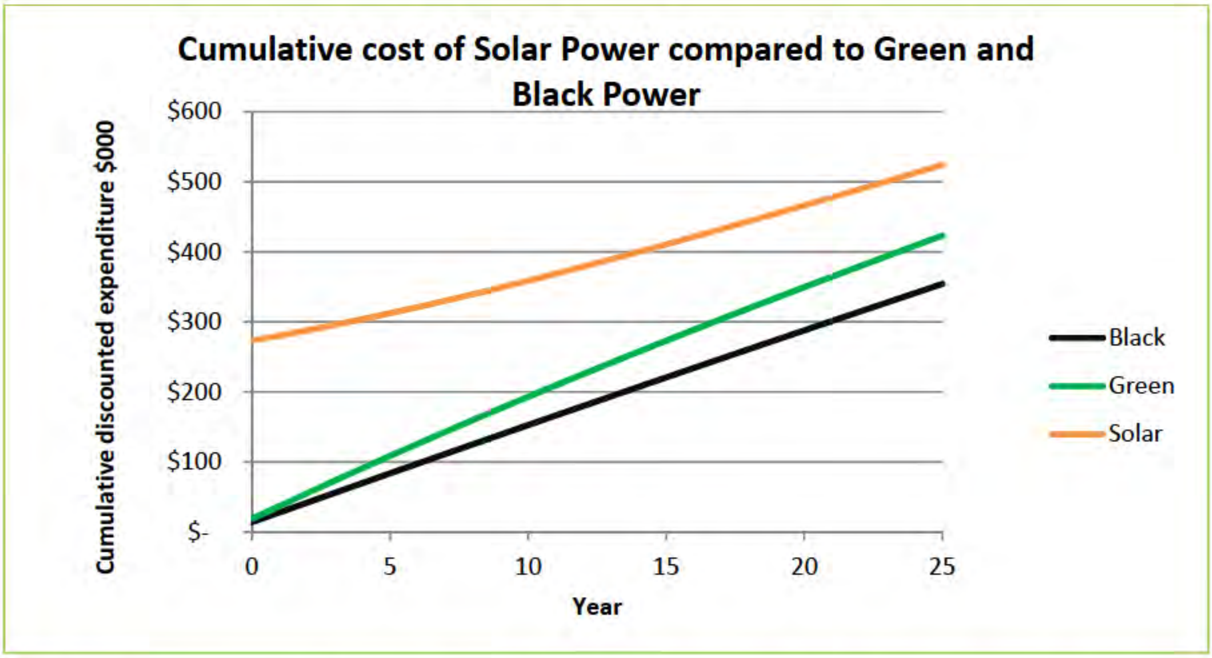

Figure 2-1: Cumulative Electricity costs assuming 5 percent pa real electricity price inflation

This analysis shows a "worst case", comparing a PV noise barrier with a low cost timber noise barrier. However, if it were compared to the cost of a more expensive concrete barrier, the cost differential would be more favorable to the PV option.

In addition, there are non financial benefits to a PV noise barrier, including corporate branding and improved appearance.

Appendix 3: Photovoltaic Noise Barrier Design Considerations

The design and installation of a major renewable energy generating system will require specialist expertise which does not currently exist within VicRoads. However, some design considerations are presented below for guidance of VicRoads staff who may be involved in renewable energy projects.

Location

An obvious consideration in the location of a PV generator is the intensity of solar irradiance at candidate sites. The variation in solar irradiation across the state is only moderate, but it is obviously higher in the north. Annual average peak sun hours on a surface facing north at latitude angle is 4.7 hours per day in Melbourne, compared to 6.0 hours per day in Mildura (Energy Partners, 2006). This level of variation is much smaller than the variation in the wind speed across the state. Figure 3-1 shows the distribution of solar irradiance across Victoria, based on data from Sustainability Victoria's renewable energy map.

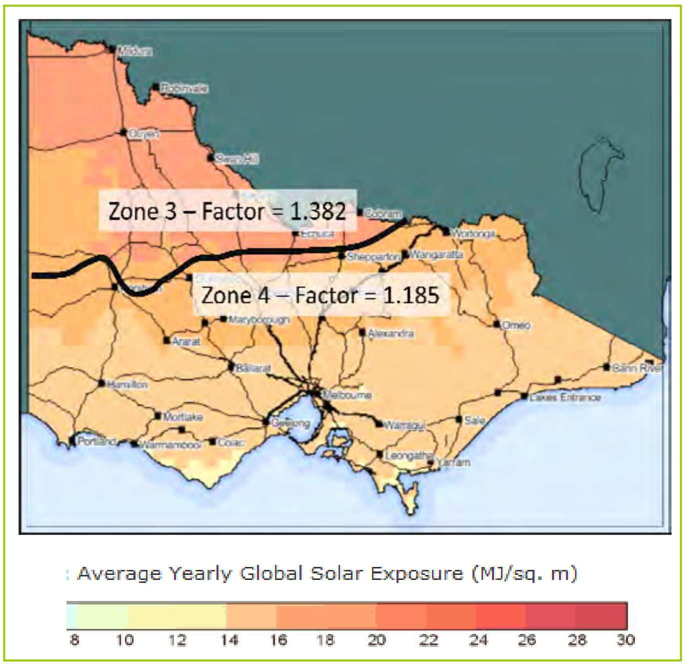

Figure 3-1: Victoria's Annual Irradiation (Sustainability Victoria, 2006)

The curved black line shows approximately the boundary between two zones defined in the *Renewable Energy (Electricity) Regulations (2001)* for the determination of the number of STCs for PV generators. The position of this boundary is approximate only; the boundary is in fact defined in the regulations by postcodes. (The number of STCs for a generator north of the line in Zone 3 is 1.382 times the generator's capacity in kW, south of the line in Zone 4 the number is 1.185 times the generator's capacity.) For a given PV generator capacity, more STCs can be created if the generator is north of the boundary, allowing more of the cost of installation to be offset.

Critical factors in the selection of a suitable site for PV noise barrier include the following:

- The road must be reasonably straight, and run in a roughly east west direction.
- The site must be free from over-shadowing by trees, gantries, signs or buildings. (Even minor over-shadowing can significantly impair PV panel function.)
- There must be negligible risk of the land being required for other purposes in the short to medium term, such as for road widening.
- There must be safe access for maintenance, including cleaning of the panels.
- A highly visible site is preferable in order to enhance passive surveillance and hence security.

Orientation and Inclination of PV Panels

The inclination of photovoltaic panels is important to their energy yield. The optimum angle for a single sided PV panel is north facing, and inclined from the horizontal at an angle equal to the latitude of the site. Figure 3.2 shows how the total annual solar irradiation falling on a surface in Melbourne varies with angle with 100 percent representing the irradiation for a north-facing panel at an angle equal to Melbourne's latitude of 38°. Data was sourced from the Australian Solar Radiation Handbook (Energy Partners, 2006). It will be seen from the figure that a deviation in either direction or angle of inclination of a few tens of degrees will result in a reduction in yield of only a few percent.

Assuming that a photovoltaic noise barrier will be oriented parallel to the adjacent road, allowing a five percent reduction in electricity yield means that roads that are oriented within ±30° of east – west are suitable for noise barrier installations.

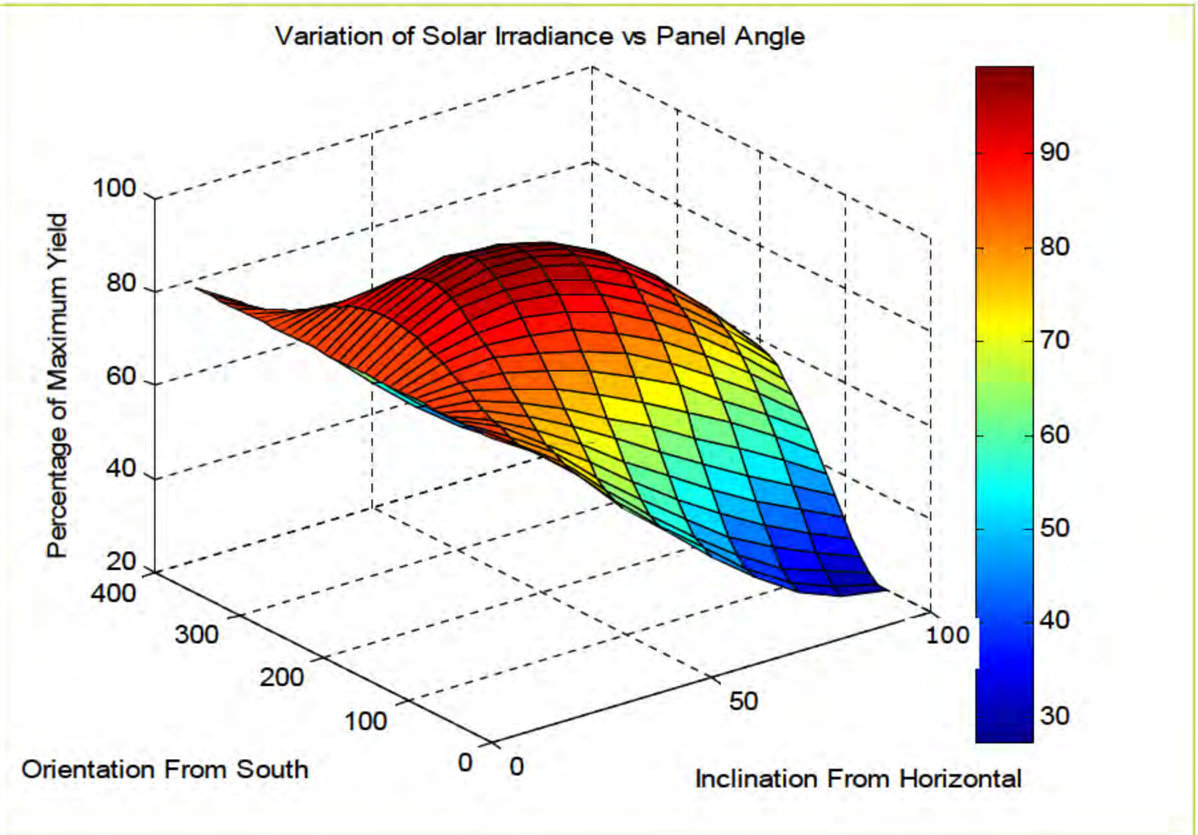

Figure 3.2: Relative Electricity Yield from Alternative Solar Panel Angles

In addition, a north-facing barrier may be inclined at any angle from 20° above horizontal to 50° above horizontal and still capture at least 95 percent of the available irradiation. However, a vertical barrier will only catch two thirds of the available irradiation.

Another aspect of inclination is the ability of the panels to collect dirt. The collection of dirt on solar panels may reduce the performance significantly. The closer the panels are to vertical, the less cleaning will be required.

The 20° to 50° range of elevation is recommended as a constraint that architects should consider when designing photovoltaic noise barriers. This range gives considerable scope for the design of dispersive barriers on either side of a road, and for the design of overhanging barriers on the north side of a road.

Security

Security problems have been anticipated by several installers of photovoltaic installations on road reserves, due to the high cost of solar panels. However, the recent reduction in prices of PV panels is likely to have reduced their attraction to theft.

Measures that have been taken by various road authorities have included:

- using very heavy panels in high locations, where removal would require a crane (e.g. Tulla Calder Interchange)
- attaching solar panels to the supporting structure with one-way screws
- attaching solar panels to the supporting structure with adhesives
- installing alarm systems and video surveillance
- installing GPS transmitters to a proportion of panels to so they can be found if stolen (Elia, 2007)(Hamilton, 2011).

An additional potential risk to PV panels is graffiti and other forms of vandalism. There are suggestions that because solar energy generation is well regarded in the community, that PV panels are thus unlikely to be attacked by vandals (Elia, 2007). Nonetheless, freeway noise barriers are popular targets for vandals, resulting in a significant maintenance cost burden for VicRoads. High strength glass panels in noise barriers were very quickly destroyed by vandals in Queensland, once a method for breaking them had been found (Hall, 2010).

Several types of PV panel, including those used in the Tulla Calder Interchange Noise Barrier are essentially glass laminates, and are at risk of vandals.

Electrical Considerations

One of the first considerations in the design of a PV system must be its connection to the electricity grid. A suitable location for the connection must be found, in cooperation with the local electricity distribution business. Where a connection is not available locally, a high cost for the provision of cabling will be required, and this may make the project financially unviable.

The connection of a generator such as a PV installation to the electricity grid poses a risk to the stability of the grid, so it is necessary that the generator meet certain requirements. For generators with capacity less than 10kW, the requirements are specified in Australian Standard *AS 4777 – Grid Connection of Energy Systems via Inverters*. For larger systems, it will be necessary to negotiate commercial and technical requirements with the relevant electricity distribution business. This would most likely be achieved with support from a contractor engaged to install the system. The publications *Guide to Connecting a Distributed Generator in Victoria* (Sustainability Victoria, 2011) and *Guide for the Connection of Embedded Generation in the National Electricity Market* (Australian Business Council for Sustainable Energy, 2003) provide more information.

PV panels are usually installed in such a way that “strings” of panels in series connect to a single inverter. It is also possible for several strings to be installed in parallel to a single inverter. In the case of large installations, a number of inverters are used. For example, the Tulla Calder Interchange PV noise barrier has five inverters for a total of 210 PV panels (Going Solar, 2009).

The function of the inverter is to take the direct current electricity generated by the PV panels, at whatever voltage they deliver it at, and convert this to alternating current electricity at the appropriate voltage, frequency, and phase, and feed it into the electricity grid. Most inverters have the ability to adjust their electrical resistance to ensure that the PV panels operate at their maximum power point at all times.

It is highly desirable that all the PV panels connected to a single inverter are exposed to the same level of light at all times. This is because when multiple panels are in series, they will only supply the current that is equal to that generated by the weakest panel. Where strings of PV panels are in parallel, they will only produce the voltage of the weakest string. Consequently, all the panels connected to a particular inverter should be inclined in the same direction to ensure they receive the same amount of light. Where there is a curve in a long PV noise barrier, multiple inverters should be used to ensure optimum electricity generation.

It is recommended that specialist contractors be engaged to design and install renewable energy systems.

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