Key Opportunities for the Future of Roads to Contribute to Australia's Climate Change Response

Karlson 'Charlie' Hargroves, Curtin University Sustainability Policy Institute
Colin Beattie, Curtin University Sustainability Policy Institute
Kimberley Wilson, Queensland University of Technology
Professor Peter Newman, Curtin University Sustainability Policy Institute
Dr Annie Matan, Curtin University Sustainability Policy Institute
Dr Cheryl Desha, Queensland University of Technology

Abstract: Road agencies face growing pressure to respond to a range of issues associated with climate change and the reliance on fossil fuels. A key part of this response will be to reduce the dependency on fossil fuel based energy (and the associated greenhouse gas emissions) of transport, both vehicles and infrastructure. This paper presents findings of investigations into three key areas of innovative technologies and processes, namely the inclusion of onsite renewable energy generation technologies as part of road and transport infrastructure, the potential for automated motorways to reduce traffic fuel consumption (referred to as 'Smart Roads'), and the reduction of energy demand from route and signal lighting. The paper then concludes with the recommendation for the engineering profession to embrace sustainability performance assessment and rating tools as the basis for enhancing and communicating the contribution to Australia's response to climate change. Such tools provide a rigorous structure that can standardise approaches to key issues across entire sectors and provide clarity on the evidence required to demonstrate leading performance. The paper has been developed with funding and support provided by Australia's Sustainable Built Environment National Research Centre (SBEnrc), working with partners including Main Roads Western Australia, NSW Roads and Maritime Services, Queensland Department of Transport and Main Roads, John Holland Group, the Infrastructure Sustainability Council of Australia, Roads Australia, and the CRC for Low Carbon Living.

Keywords: sustainability and roads, climate change, renewable energy, smart roads, energy efficient road lighting

Introduction

Unleashing Engineering Creativity to Combat Global Challenges

The acceleration of climate change due to the combustion of fossil fuels presents a significant challenge for the engineering profession that will call for substantive changes in all disciplines. In particular the engineering disciplines associated with major infrastructure will be required to rethink the application of engineering knowhow to deliver solutions that no longer rely on a legacy of environmental damage and pollution, and provide the basis for ongoing prosperity. This new focus for engineering has provided a catalyst that is seeing the profession redefined and is set to lead to a period of extraordinary creativity and innovation. The coming century will be reminiscent of the Renaissance period when at the time the Mona Lisa was being created, Leonardo da Vinci created mechanical marvels that '*culminated a century-long transformation of the technical arts and those who practiced them*'.[1]

Impacts on road and transportation infrastructure from climate change

A key area that is vulnerable to the impacts of climate change is that of roads and transport infrastructure. Roads and transport infrastructure will face growing challenges related to the need to reduce greenhouse gas emissions, increases in temperature and severe droughts, increases in extreme

[1] Bjerklie, D (1998) The Art of Renaissance Engineering, MIT Technologogy Review, 01 January 1998.

rainfall events and flooding, increased severity and intensity of cyclones, storm surges and sea level rise, as summarised in Table 1.

Table 1: Impacts of Climate Change on Road Infrastructure

Issue	Implications for Roads
The need to reduce greenhouse gas emissions	– The need to reduce energy intensity and greenhouse gas emissions of aggregates, cement, and asphalt. – Reducing energy requirements of route and signal lighting. – The need to reduce automobile fuel consumption through the design of road alignments (vertical and horizontal). – The need to reduce fossil fuel use in construction vehicles.
Temperature increase & severe droughts	– Increased maintenance due to potholing and rutting from the softening and expansion of pavements. – Increased stress on bridge members and joints. – Increased maintenance of road surfaces due to surface cracking, warping and asphalt bleeding.
Increased extreme rainfall events & flooding	– Increased road rehabilitation and maintenance due to flooding events inundating and destroying roads and road infrastructure. – Increased amount of road maintenance caused by potholing of pavements and water erosion of easements. – Road flooding putting pressure on road network and drainage systems.
Increased severity and intensity of Cyclones	– The destruction of bridges, culverts, overpasses, and roadways – Associated storm surges inundating, undercutting, and damaging roadways. – Increased debris on roads causing road damage and traffic hazards.
Sea Level Rise	– Salt water corrosion of roads due to sea water infiltration from rising sea levels. – Increased storm surge and wave impact on coastal and low-lying coastal areas.

Source: Adapted from SBEnrc (2012)[2]

The contribution to climate change by roads and transport infrastructure

Considering greenhouse gas emissions, the emissions from the mining, transport, earthworks and paving associated with road construction, as well as emissions from road users, makes roads one of the greatest contributors to climate change, responsible for some 22 per cent of global carbon dioxide emissions. Each kilometre of road constructed required large quantities of rock, concrete and asphalt to be sourced, transported and placed, and these activities account for some 95 percent of emissions from road construction. A typical two-lane bitumen road with an aggregate base can require up to 25,000 tonnes of material per kilometre, showing why aggregates are the most mined resource in the

[2] SBEnrc (2012) The Future of Roads: How road agencies are facing a conflicted future, Sustainable Built Environment National Research Centre (SBEnrc), Curtin University and Queensland University of Technology

world. Within the construction phase the most sizeable reductions in greenhouse gas emissions can be gained by altering the materials used in road construction, including aggregates, asphalt, and concrete. An example of the breakdown of emissions in the construction phase is shown in Figure 1 for the Mickelham Road Duplication Project, the first carbon nuetral road constructoin project in Victoria.[3]

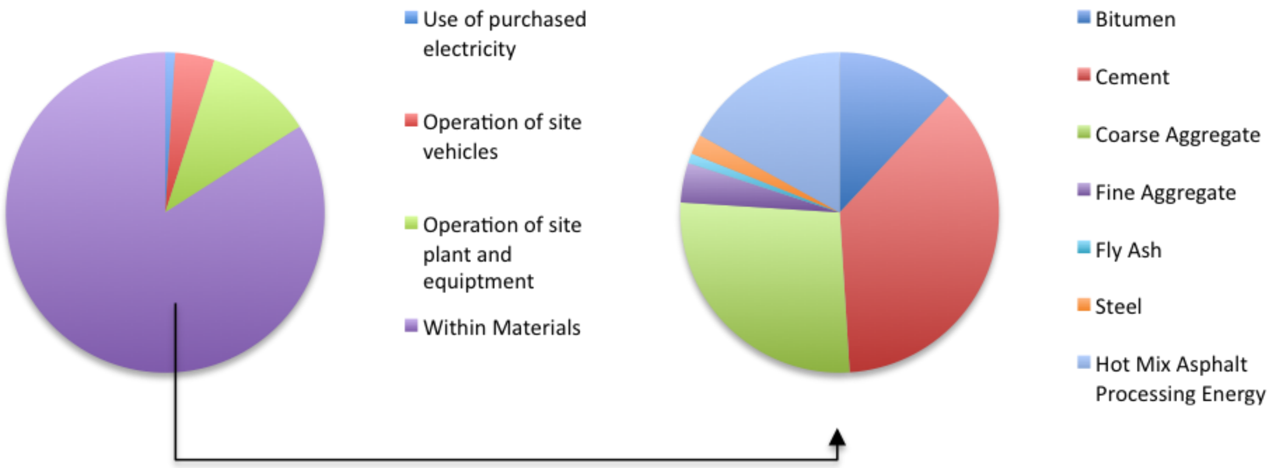

Figure 1: Relative greenhouse gas emissions sources during construction of the Mickelham Road Duplication Project in Victoria. *Source*: Humphrys, T. (2006)

Innovation - The future of roads

Just as the past decade has seen a focus on the footprint and alignment of roads to minimise ecological disturbance, coming decades will see a significant focus on responding to climate change. For example, alternative road base materials may provide opportunities for reducing greenhouse gas emissions, such as a shift from Portland cement to geopolymer compounds;[4] roads may be designed to enable electricity generation through capturing solar, wind or kinetic energy; the electricity consumption of route and signal lighting can be significantly reduced using new lighting technologies; and congestion can be reduced on highways and motorways through the use of communication technology.

This paper presents the findings of industry led research into two key areas of innovation that stand to affect the future of roads and make a positive contribution to Australia's repsonse to climate change long into the century. Firstly the paper overviews an innovative sustainability assessment and reporting tool developed in Australia that is having an impact on the greenhouse gas emissions of infrastructure projects, and secondly the paper investigates the use of innovative technologies to harness roads and transport infrastructure to generate electricity.

[3] Humphrys, T. (2006) Victoria's first carbon neutral road construction project, VicRoads, Australia.
[4] TNEP (2009) *Factor 5 in Eco-Cement: Zeobond*, ECOS Magazine, CSIRO Publishing.

Sustainability Reporting and Roads

A shift in environmental reporting by road and transport agencies

It is important to understand that a key part of the response to climate change from the infrastructure sector will be informed by and in large part structured by the tools that are used to report on sustainability and greenhouse gas emissions performance. The early decades of the 21st Century will see a change in the focus of environmental reporting in roads agencies, from the current practice of 'environmental management' which seeks to minimises ecological disturbance, to a second generation of reporting that expands this scope to include sustainable development associated considerations, including a focus on areas such as the energy intensity raw materials, both in their extraction and transportation, and the potential for alternative 'low-carbon' options. Such a shift in focus will form an important part of a road authorities approach to issues of growing concern such as increasing energy costs and increasing impacts from climate change, such as greater weather and natural disaster damage to road infrastructure. [5]

The shift in environmental reporting focus has been heralded by the emergence of an array of sustainability assessment frameworks, all with varying purposes, reporting requirements, and outcomes. The research team has identified that much of the data that is required to fulfil the new generation of environmental reporting is already being collected across many, if not all road construction projects. However, it is clear that this data is not systematically reported on in a way that encourages use or transparency of such data. When considering the sustainability of a road project there are two key aspects, firstly the performance assessment of the projects and secondly the rating of the performance against an industry benchmark. As shown in Figure 8 either can be self-assessed or assessed as part of a third party tool, such as those as listed in Table 2. In short, 'Assessment tools' provide a framework to collect data on the actual performance of projects across a number of selected indicators, and 'Rating tools' consider this data to provide a rating that can be used to compare with industry benchmarks and/or internal targets.[6]

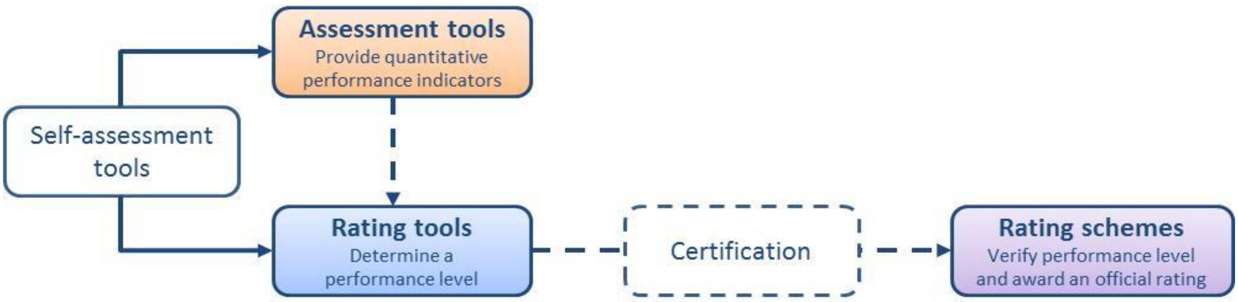

Figure 8: *Self-assessment tools and rating schemes*

Source: Wilson, K (2014)[7]

[5] Wilson, K. (2014) *A Literature Review of Sustainability Performance Assessment by Road Agencies for the Sustainable Built Environment National Research Centre*, a collaborative project between Curtin University and Queensland University of Technology.

[6] Ding, G. K. C. (2008) 'Sustainable construction – the role of environmental assessment tools', *Journal of environmental management (0301-4797)*, *86*(3), p.451.

[7] Wilson, K. (2014) A Literature Review of Sustainability Performance Assessment by Road Agencies for the Sustainable Built Environment National Research Centre, a collaborative project between Curtin University and Queensland University of Technology.

According to a review by the Engineering and Physical Sciences Research Council in the UK in 2004, there were over 600 tools evaluating social, environmental and economic dimensions. Given the growing concern regarding the impact of road and transport infrastructure projects on the environment, and visa versa, a number of national and international sustainability performance and rating tools have been developed that include a focus on roads and transportation infrastructure, as shown in Table 2.

Table 2: National and International Sustainability Rating Tools Specific to Roads and Transport Infrastructure

Australian Tools	International Tools
IS (Infrastructure Sustainability) Rating Tool, developed and administered by the Infrastructure Sustainability Council of Australia (ISCA).	'The Global Reporting Initiative' (GRI), economic, environmental, social, and governance performance, developed by an international non-profit group.
INVEST (Integrated VicRoads Environmental Sustainability Tool) rating tool, developed by VicRoads.	CEEQUAL, developed by the Institution of Civil Engineers and with an estimated £24.5 billion in assets being assessed since its launch in 2003.
Carbon Gauge® Calculator, developed by HAC and jointly funded by six road agencies across Australia and New Zealand.	Changer Greenhouse Gas Calculator, developed in Switzerland by the International Road Federation.
Bottom Line2 software, developed by the Dipolar Pty Limited and Integrated Sustainability Analysis – ISA, at the University of Sydney.	GreenLITES (Green Leadership in Transportation Environmental Sustainability), developed by the New York State Department of Transportation.
	Greenroads Rating System, developed by the Greenroads Foundation in the US.

Source: Wilson, K (2014)[8]

On the international scale the most widely used sustainability reporting framework is the Global Reporting Initiative. The GRI can be used by Road and Transportation Agencies, with Main roads Western Australia saying that '*We continue to use the Global Reporting Initiative as we remain focussed on our commitment to achieve a fully integrated reporting framework that meets international standards of transparency and accountability*.'[9] A number of sector specific supplements are provided to assist efforts to tailor the generic sustainability reporting elements to the sector to ensure meaningful information is captured, however there is not currently a roads and transportation sector supplement (however a 'logistics and transportation' supplement is under development). Organisations may elect to undergo an independent third-party review of their performance against the GRI criteria to validate their data findings.

[8] Wilson, K. (2014) A Literature Review of Sustainability Performance Assessment by Road Agencies for the Sustainable Built Environment National Research Centre, a collaborative project between Curtin University and Queensland University of Technology.

[9] MRWA (2013) Annual Report 2013, Main Roads Western Australia.

The emergence of an industry developed infrastructure sustainability rating tool

In Australia the recent release of the IS Rating Tool by the Infrastructure Sustainability Council of Australia (ICSA) has provided the built environment sector with an infrastructure focused rating tool that is quickly becoming a requirement of infrastructure project contracts.[10] The 'IS rating tool' is designed to be used to evaluate the sustainability of infrastructure across design, construction, and operational phases. The tool can be used for self-assessment as well as being able to be formally certified as 'Commended', 'Excellent', or 'Leading'. Considering specific themes within a range of social, economic and environmental sustainability categories across each project, the users of the rating tool nominate a performance level (1, 2, or 3) that they believe they have achieved for each credit and provide supporting evidence as outlined in the tool's technical manual. An assessment is carried out and based on predetermined weightings designed into the tool, the overall rating is calculated, and compared to a possible level of achievement. For example Figure 9 shows a sample rating across the various performance areas with a score of 6 attained for 'Management Systems' out of a possible 10.5.

There are a number of ways that the IS rating tool stands to impact on the climate change related aspects of road and transport infrastructure. In particular the tool provides an industry designed tool to standardise documentation related to sustainability project/asset performance (including greenhouse gas emissions) that can be requested as part of pre-qualification or tender documentation. For instance the tool provides a materials calculator that is designed to compare a 'reference design' with an 'actual design' to allow consideration of the impacts of various sustainability related inclusions and initiatives. The tool can calculate the greenhouse gas emissions of both design options and also provides an overall sustainability measure, called '*eco-points*'. This is an important tool for the industry as it allows direct quantified comparison between design options, along with the potential to demonstrate the value of an innovative design at the tendering stage.

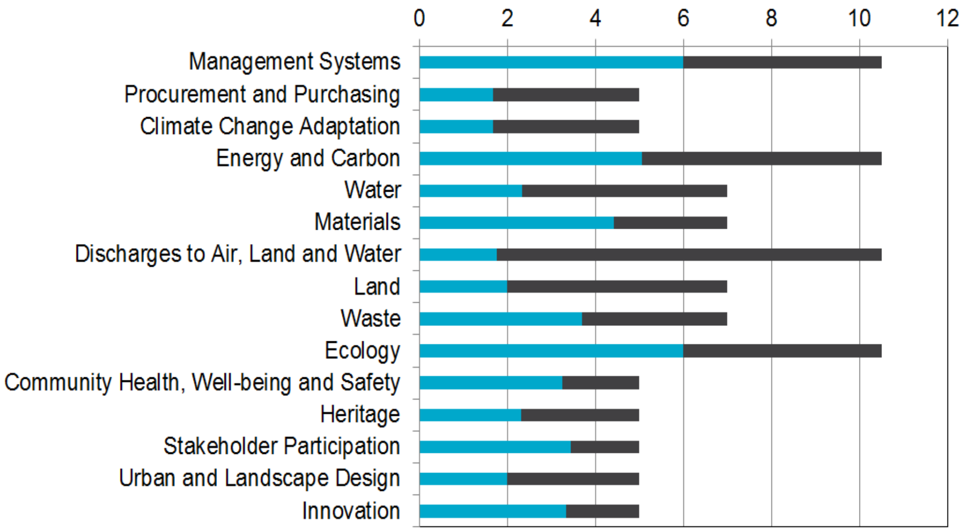

Figure 9: An example of IS rating tool outputs

Source: ISCA (2014)

[10] Hargroves, K (2014) *ISCA 'Infrastructure Sustainability' Rating Tool and Low Carbon Tendering: A Report to the Sustainable Built Environment National Research Centre and the CRC for Low Carbon Living*, Curtin University Sustainability Policy Institute, Curtin University.

The IS Tool comprises a number of themes each containing specific credits, with a subset of the credits related to greenhouse gas emissions and climate change shown in Table 3. An early trial of the tool was undertaken on the $45 million Eastern Busway project in Brisbane, Queensland, delivered as alliance between Department of Transport and Main Roads Queensland, Leighton Contractors, SKM and AECOM. The trial found that the tangible changes resulting from the ISCA trial and the inclusion of sustainability as a key performance area included a reduction in busway grades to save fuel, the lifting of bus stations to prevent flooding, the incorporation of water sensitive urban design, and significant reduction in lighting and operation costs due to improved design.

The ability for companies to provide the evidence required by each of the credits in Table 3 stands to provide an indication of 'Low Carbon Readiness'. This will become an important measure as the focus on reducing energy demand and associated greenhouse gas emissions in the future intensifies. It can be used by industry to create a performance benchmark, along with providing a measure of industry readiness to provide low carbon offerings for government agencies and other major infrastructure procurers. For example considering the first credit in Table 3, 'Energy and Carbon – ENE1: Energy and carbon monitoring and reduction' aims to reward monitoring and minimising of energy use and GHG emissions across the infrastructure lifecycle. This credit directly relates to low carbon tendering by requesting evidence of the modelling and monitoring of actions to reduce energy use and greenhouse gas emissions (Scope 1, 2, and 3 emissions).

As with each of the credits included in the IS Tool, following assessment of evidence provided for the project or asset points are awarded in three tiers, and in the case of ENE1 the points are awarded as follows:

– *1.56 pts for provision of a report on initiatives undertaken to reduce energy use and GHG emissions, including a summary of actual and modelled GHG emissions across the infrastructure lifecycle,*

– *3.11 pts for the above evidence along with a report comparing actual and modelled GHG emissions to a reference footprint,*

– *4.67 pts for the above evidence along with a method for identifying significant sources of Scope 3 emissions.*

Performance in this credit, and other credits shown in Table 3, is a very strong indicator of low carbon readiness as if tenderers perform well against this credit, it is likely that they have process for modelling and monitoring energy use and greenhouse gas emissions, and using the outputs to inform the selection of actions to be taken.

Table 3: Summary of 'IS Rating Tool' credits related to Low Carbon Tendering

Code	Credit	Evidence requirements relevance to Low Carbon Tendering
Credits Related to 'Low Carbon Readiness' (43/100)		
Energy and Carbon		
Ene-1 4.67	Energy and carbon monitoring and reduction	Evidence of the modelling and monitoring of actions to reduce energy use and greenhouse gas emissions (Scope 1, 2, and 3 emissions).
Ene-2 4.67	Energy and carbon reduction opportunities	Evidence that opportunities to reduce energy use and greenhouse gas emissions are identified and implemented.
Ene-3 1.17	Renewable energy	Evidence that renewable energy opportunities have been investigated and implemented.
Procurement and Purchasing		
Pro-1 1.25	Commitment to sustainable procurement	Evidence of a commitment to sustainable procurement that includes environmental, social and economic considerations.
Pro-2 1.25	Identification of suppliers	Evidence of supplier pre-qualification questionnaires including items related to the presence and implementation of a sustainability policy.
Pro-3 1.25	Supplier evaluation and contract award	Evidence of sustainability consideration in supplier evaluation criteria and contract documentation, including provision for auditing.
Pro-4 1.25	Managing supplier performance	Evidence of the sustainability performance monitoring of suppliers, with active management of non-compliance and rewards available.
Materials		
Mat-1 6.29	Materials lifecycle impact measurement and reduction	Evidence of the modelling and monitoring of materials lifecycle impacts across infrastructure lifecycle, and demonstrated reductions.
Mat-2 0.74	Environmentally labelled products and supply chains	Evidence of the use of major material products with environmental credentials nominated or approved by ISCA.
Climate Change Adaptation		
Cli-1 2.50	Climate change risk assessment	Evidence of the assessment of climate change risks, including direct, indirect and flow on risks with system and regional implications.
Cli-2 2.50	Adaptation options	Evidence of the assessment and implementation of climate change adaptation measures for extreme, high and medium risks.
Innovation		
Inn-1 5.00	Innovation	Evidence of contribution to broader market transformation towards sustainable development, locally, nationally and internationally.
Management Systems		
Man-1 1.07	Sustainability leadership and commitment	Evidence of a commitment to sustainability through a sustainability policy and inclusion in management plans and project contracts.
Man-2 0.43	Management system accreditation	Evidence of accreditation of asset management systems to ISO14001 standard for environmental management systems.
Man-3 0.86	Risk and opportunity management	Evidence of the assessment of environmental, social, and economic risks and opportunities in a risk register with annual reviews.
Man-4 1.07	Organisational structure, roles and responsibilities	Evidence of a member of the project senior management with central responsibility for managing sustainability, with position description.
Man-5 0.86	Inspection and auditing	Evidence of regular environmental and sustainability inspection of on-site performance and reported auditing of the management system.
Man-6 0.86	Reporting and review	Evidence of sustainability reporting that is reported to senior management and the public and involves community participation.
Man-8 3.21	Decision-making	Evidence of decision making guidelines that evaluate options by considering environmental, social, and economic aspects.

Source: Hargroves, K (2014)

Innovative Technologies for the Future of Roads

Harnessing road and transport infrastructure to generate electricity

A key area of focus for the future of roads is the potential for road infrastructure to contain renewable energy technologies to reduce demand for electricity from the grid, which is predominantly generated using fossil fuel. Much progress has been made to date to demonstrate feasibility of incorporating renewable energy into road infrastructure, as the following summaries will demonstrate (such as tidal and wave power associated with bridges, solar and wind power associated with road easements and structures, thermal power associated with pavements, etc.). Note that the use of solar panels as road surfaces is not covered as it is yet to be shown to be technologically or economically viable.

Harnessing Solar Energy in Road Easements and Structures

There are a growing array of options for incorporating solar energy generation into roads and pavements as demonstrated in the following case studies.

- *The Solar Highway Program (Oregon, USA)*: In 2008 a 1.75 MW solar array, containing just under 7,000 solar panels, was installed in the easement of Interstate 5 south of Wilsonville by the Oregon Department of Transport, shown in Figure 2. The primary value of the system is to provide electricity for the highway lighting, and it also generates renewable energy certificates.[11]

Figure 2: Oregon Solar Highway Project, 2008

Source: Solar Highway Program: From Concept to Reality, August 2011[12]

  The commercial feasibility of the project relied on a public-private partnership between ODOT and Portland General Electric (PGE), Oregon's largest electricity utility. Advantages for ODOT include not having to find the capital for the project or to be involved in managing the generation of electricity. Also, having a predictable, long term picture of energy expenditure is advantageous in forward planning and at rates which can often better those on offer from competing utility companies. PGE have the benefit of having a ready-made long term customer locked in providing an income stream that will assist in gaining finance for the asset as well as capitalising on the tax benefits and incentives available.

---

[11] ODOT (2011) *Solar Highway Program: From Concept to Reality – A Guidebook for Departments of Transportation to Develop Solar Photovoltaic Systems in the Highway Right-of-Way [Easements]*, A Report for the Oregon Department of Transport by Good Company.
[12] Ibid.

- *Photovoltaic Noise Barriers (PVNB):* Along with the use of easements an obvious place to consider the use of solar power is as part of the structure of noise reduction screening along roadways, such as along the A22 Autostrada at Brennero in Italy shown in Figure 3. According to World Highways in 2014 the energy generated from such structures can, '*help reduce the life-cycle cost of noise reduction devices by up to 30%.*'[13]

Figure 3: A photovoltaic noise barrier installed along the A22 Autostrada at Brennero in Italy.
Source: World Highways.

- *Solar Thermal:* Given that roads in Australia absorb heat during the day this heat may be able to be harnessed to create electricity. It has been suggested that this may be done by either running pipes through the hot asphalt or cement to heat water or installing thermoelectric wiring within the asphalt surface. A paper published in 2006 suggested that not only can heat be extracted for energy generation using thermoelectric generation techniques, but this will also lead to a reduction in the temperature of road surfaces, increasing operational life of surfaces.[14]

Figure 4: The use of pipework to extract heat from road surfaces for energy generation using aquifer heat exchangers in the Netherlands.
Source: Ooms Avenhorn Holding

[13] Bellucci, P. (2014) Photovoltaic finish to road noise pollution, World Roads, 2014
[14] Hasebe, M., Kamikawa, Y., Meiarashi, S., (2006) 'Thermoelectric Generators using Solar Thermal Energy in Heated Road Pavement', Thermoelectrics, 25th International Conference, 6-10 Aug. 2006.

Harnessing Energy from Vehicle Movement

- *Wind Power*: As with solar power, road easements and structures may be suitable for the installation of wind power generation technologies. However a report by VicRoads published in 2013 presented findings of an investigation into the use of wind turbines to harness natural wind in road easements and found them to be unfeasible at this scale, in the order of 20kW. The report conclude that '*micro wind turbines not be considered as a method to generate renewable energy in Victoria unless it can be shown that a major saving in grid connection costs can be achieved*'.[15] Hence it may not be feasible to rely on natural wind for wind energy generation, however there is another source of wind associated with roads that can be harnessed – that of moving vehicles, as shown in Figure 5.

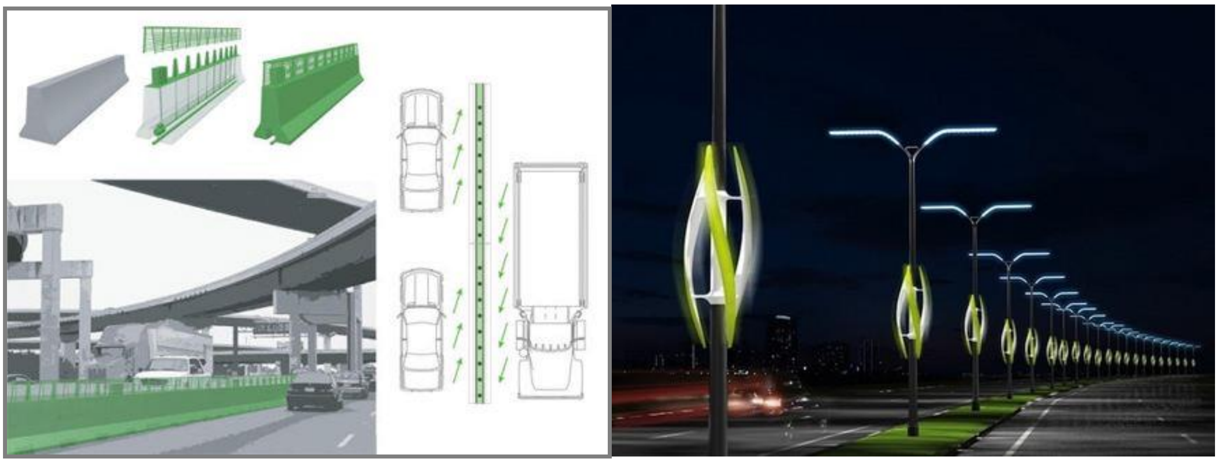

Figure 5: Examples of wind generation systems that harness air movement from passing traffic

- *Piezoelectric Generators:* Along with the wind generated by vehicle movement energy may be able to be harnessed from the movement of vehicles and the pressure created in road surfaces, as shown in Figure 6.[16] This concept, referred to as the 'Piezoelectric Effect', was discovered by the Curie's in 1880, when they found that strain or deformation of a piezoelectric material causes charge separation across the device, producing an electric field which can generate an electric current. There is currently ongoing research on the principles behind the effect, and the practical application to harnessing vehicle energy is in its early stages.

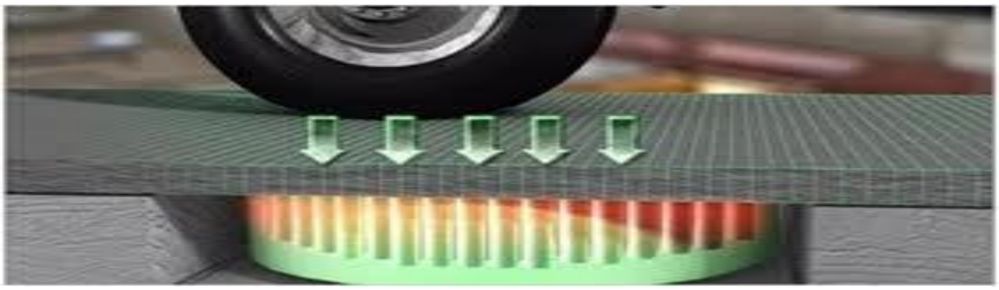

Figure 6: Piezoelectric device located under road surface

Source: Abbasi, A. (2013)

[15] VicRoads (2013*) Renewable Energy Roadmap*, VicRoads, July 2013.
[16] Abbasi, A. (2013) 'Application of Piezoelectric Materials in Smart Roads and MEMS, PMPG Power Generation with Transverse Mode Thin Film PZT', *International Journal of Electrical and Computer Engineering* (IJECE), Vol. 3, No. 6, December 2013.

Upgrading lighting technologies and practices to save energy

LED lighting for streets and parks is now widely acknowledged as a viable energy saving option for the future of roads and is being utilised around the world. According to a strategy paper by the Australian, State and Territory and New Zealand governments, '*Street lighting is the single largest source of greenhouse gas emissions from local government, typically accounting for 30 to 60 per cent of their greenhouse gas emissions… The major lighting types are mercury vapour (12% of major road lighting national numbers – down from 25% in 2002/3) and high pressure sodium (86% of national numbers – up from 75% in 2002/3)'*.[17] There is a growing number of international case studies of significant value being created for governments that seek to rapidly retrofit street lighting to new technologies, such as a 2009 study from the United States that found that for a 10km stretch of double lane highway, with poles located 30 meters apart, using LED lighting over the conventional mercury lights would reduce as much as 75% of energy consumption with a payback period of 2.2 years, that is increased to 3.3 years if the LED's are powered by onsite solar energy.[18]

More recently the mayor of New York City, Mayor Bloomberg, announced that the city plans to replace all 250,000 high pressure sodium streetlights with LED's over a three year period.[19] Such projects are contributing to an expected rapid increase in the roll-out of LED's in streetlights globally, anticipated to rise from less than 3 million in 2012 to more than 17 million in 2020.[20] In 2008 the City of Los Angeles began a 4 year process to replace 141,089 streetlights with LEDs, becoming the largest retrofit of street lighting in the world, with staggering results in the amount of night light across the city, as shown in Figure 7. The program has a payback period of 7 years and following this the city estimates that it will benefit from some $10 million/year in savings in electricity and maintenance costs, while reducing greenhouse gas emissions by 47,583 tons/year.[21]

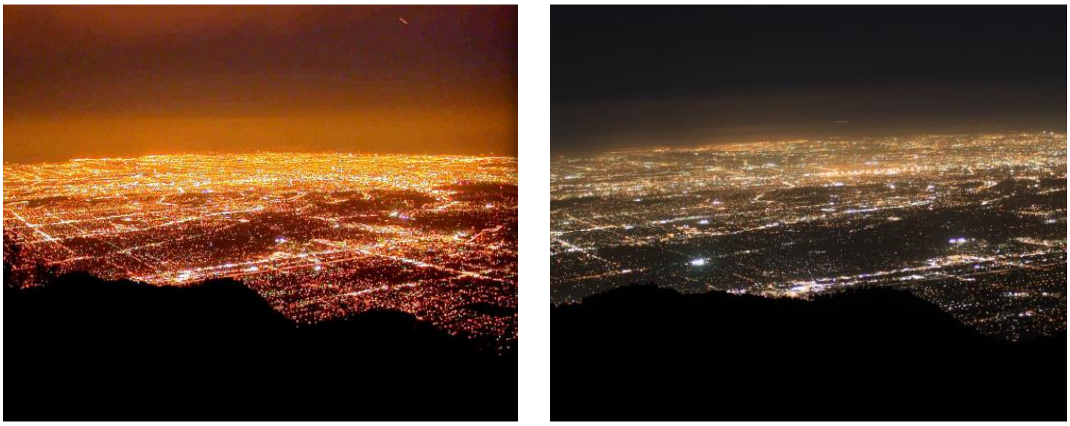

Figure 7: Los Angeles Basin View from Mount Wilson Before and After the Retrofit

[17] Commonwealth of Australia (2011) Street lighting Strategy, prepared for the Equipment Energy Efficiency Program, a joint initiative of the Australian, State and Territory and New Zealand Governments.
[18] M.S. Wu, H.H. Huang, B.J. Huang, C.W. Tang and C.W. Cheng (2009) Economic feasibility of solar-powered led roadway lighting, *Renewable Energy*, Volume 34, Issue 8, Pages 1934–1938, January 13, 2009.
[19] Bloomberg, M (2013) 'All 250,000 NYC Street Lights Will Be Replaced with Energy-Efficient LEDs by 2017', Press Release, 24 october 2013.
[20] Martin, R. (2012) 'Shipments of LED-Based Street Lights Will Surpass 17 Million by 2020', Navigant Research, 16 October 2012.
[21] Office of the Mayor City of Los Angeles (2012) 'Mayor Villaraigosa announces completion of largest led street light replacement program', Press Release, 18 June 2012.

In Australia, the City of Sydney has installed 2,600 LED street and park lights and is planning to replace a further 6,500 over the next three years, and the City anticipates saving $800,000 per year. A public survey revealed that over 90% of participants though the LED lighting was appealing and 75% thought that they improved visibility.[22] In Western Australia Main Roads WA has a rolling program, upgrading traffic signal lanterns with LED lamps, which started in 2012. Thus far 670 traffic signal controlled intersections have been upgraded to LED lamps with a further 50 planned for 2014. The overall cost savings from operation and maintenance is projected to be in the order of 71%. In addition, key environmental benefits will include a saving of 320 tonnes of GHG emissions annually and a reduction of materials sent to landfill due to the longer life of the lamps.

[22] City of Sydney (2014) LED lighting Project, City of Sydney.