How will the Future of Roads be Navigated?

A Sustainable Built Environment National Research Centre (SBEnrc) literature review by Curtin University and the Queensland University of Technology

<u>University Research Team</u>
Program Leader: Prof. Peter Newman (Curtin)
Project Leaders: Charlie Hargroves (Curtin) and Cheryl Desha (QUT)
Academic Advisor: Prof. Arun Kumar (QUT)
Research Team: Luke Whistler (Team Leader - QUT), Annabel Farr (QUT), Justine Beauson (Curtin), Anne Matan (Curtin), and Leon Surawski (Curtin)

Acknowledgement

This literature review has been developed as part of the Sustainable Built Environment National Research Centre (SBEnrc) 'Greening the Built Environment' Program, led by Professor Peter Newman. The project is supported by the QLD Department of Transport and Main Roads, Main Roads Western Australia, Parsons Brinckerhoff, John Holland Group, and the Australian Green Infrastructure Council (AGIC). The 'Future of Roads' research team is based at the Curtin University Sustainability Policy Institute (CUSP) and the QUT Faculty of Built Environment and Engineering (FBEE). Professor Arun Kumar (QUT) is acknowledged for his strategic support in considering research directions and collaborations.

Citation: Whistler, L., Farr, A., Matan, A., Surawski, L., Beauson, J., Hargroves, C. and Desha, C. (2011) '*Future of Roads: How will the Future of Roads be navigated? A Sustainable Built Environment National Research Centre Literature Review'*, Curtin University and Queensland University of Technology.

Contents

Introduction

In the coming decades the design, construction and maintenance of roads will face a range of new challenges - that in many ways will bear little resemblance to the challenges previously faced - and as such will require a number of new approaches. Such challenges will result from a growing number of interconnected environmental, social and economic factors, which are set to apply significant pressure on the future of roads. For instance, environmental pressures will include the impacts of climate change on rainfall patterns and temperature profiles; economic pressure will be affected by shifting global economic balances and flows, and will include materials and resources shortages, along with predicted increases in energy and resource prices globally,[i] and social pressures will include potential shifts to lighter vehicles, reduced use of cars due to higher fuel costs, and political pressure to respond to climate change.

Why focus on reducing the environmental pressures of roads?

Roads and road infrastructure will be faced with many challenges over the coming decades. These include the considerable number of rapidly expanding economies around the world, significant changes to weather patterns and extreme weather events, and predicted increases in energy and resource prices.[ii] Leading efforts around the world are now showing how such challenges can now be met with creativity and innovation across many aspects of roads.[iii,iv,v] The dominant message emerging from these efforts is that the opportunity exists to transform the way road infrastructure is conceived and constructed, to assist society to respond to climate change and reduce a range of environmental pressures. A particular interest in the future of roads has been expressed by both the Queensland and Western Australian governments, due to their recognition of the potential for sustainable transport strategies to reduce both greenhouse gas emissions and the associated financial costs anticipated in a carbon constrained economy. This paper draws on the early activities and findings of the first stage of ‘The Future of Roads’ project,[vi] to be completed in September 2012, and focuses on exploring such opportunities for road infrastructure design, construction, maintenance and operation. Within this context, the paper highlights findings from literature regarding opportunities for reducing the environmental pressures of road building. The project team invites feedback to further inform the findings and ongoing research.

It is important to consider the direct environmental impact of roads because of their role in our society and the scale of the infrastructure we have built to date. It is also important, but more challenging, to consider the indirect environmental impact of roads through their end-use as transportation corridors, and how this might be addressed through strategic directions in road building. For example, roads support an automobile industry that employs millions of people and sells a copy of its product every 1.5 seconds.[vii] Road infrastructure also supports vehicles that combust 310,000 barrels of oil every day in Australia and emit 17 percent of Australia’s greenhouse gases, in turn threatening global climatic stability, local ecology and agricultural industries.[viii] Recent history clearly shows that roads are a cornerstone of economic activity. Improved road transport has contributed to 6 percent annual global economic growth over the past 50 years. A single cup of coffee can use some 29 different transport related activities in its lifecycle. While the economic benefits of road construction and use is well known, the environmental impact and associated future economic impacts are underestimated. The past decade has seen a focus on changes to the footprint and alignment of roads to minimise ecological disturbance. The coming decade will see a focus on the resources required to build and maintain roads. For example, each kilometre of road constructed required large quantities of rock, concrete, asphalt and steel to be sources, transported and placed. 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 world. The emissions from the mining, transportation, earthworks and paving associated with road construction, as well as emissions from road users, makes it one of the greatest contributors to climate change, some 22 percent of global carbon dioxide emissions.[ix]

Considering possible climate change impacts

The basis of this research is that there will be increasing impacts of climate change and population pressures on Australian cities that the application of more sustainable practices could mitigate. The most recent Intergovernmental Panel on Climate Change (IPCC) Assessment Report concludes from the body of global evidence that 'warming of the climate system is unequivocal', and increasingly visible in observations of global air and ocean temperatures, melting snow and ice, and a rising global average sea level, which will have significant impacts on the world's cities (see Table 1 for a summary of these impacts on Australian cities). The anthropogenic contribution to these observed changes is now virtually undisputed amongst the scientific community. As evidence mounts for the potential impacts of rising greenhouse gas concentrations in the atmosphere, the timeframe in which we have to act to minimise the most severe of these impacts contracts.

These global changes have been reflected in Australian over the past century, where average surface air temperatures have increased by 0.7°C, accompanying marked declines in regional precipitation, in particular along the eastern and western coasts.[x] Furthermore, climatic modelling shows that, due to the time lag between greenhouse gases being emitted into the atmosphere and the resultant increased temperatures, we are already committed to an additional global warming of between 0.2 and 1.0°C. In addition, the world's fossil fuel economy is so embedded in global systems that it is unlikely that anthropogenic greenhouse gas emissions will be able to be eliminated in the near future, and hence Australia's temperatures are projected to increase by between 0.4°C and 2.0°C by 2030 and 1-6°C by 2070.[xi]

As shown in Table 1, Preston and Jones (2006) outline the predictions that these temperature increases will have on Australian cities in their report for the Australian Business Roundtable on Climate Change. They report that Australian cities may be impacted by tropical cyclones, heat waves and extreme precipitation that would degrade infrastructure and have public health implications. Inland areas are expected to warm faster than the global average, while coastal areas would warm at around the global average. This warming will result in more extreme heat events, and the average number of days in which the temperature exceeds 35°C is expected to increase by 10 to 100 percent by 2030, which the average number of days where the temperature is below 0°C could decrease by 20 to 80 percent. Changes in average precipitation are also expected to result in more extremes, with areas in which rainfall increases are expected seeing more extremely wet years, and those in which the rainfall is likely to decrease seeing more droughts. A further decline in average precipitation in southwest and southeast Australia is predicted, with increases in precipitation in the northwest. Sea level rise of between 8 and 88 centimetres along Australia's coastlines, where all the major cities are, is expected to result in erosion and inundation.[xii]

Financial implications of these impacts would include the need to fund significant upgrades to electricity infrastructure to meet rapidly increasing energy demand (driven to a large extent by mechanical cooling requirements), maintenance and repair of transportation infrastructure, and repair of other damage caused by extreme precipitation and coastal flooding. Australia's coastal zone is of particular concern given that the vast majority of Australia's population, commerce and industry are concentrated along coastal areas. Climate modelling suggests that even for warming of 1-2^{o}C, more intense storm winds and sea level rise would result in higher storm surges and larger flood areas. Storm damage, which tends to increase with the square of wind speed, would also increase and coastal inundation and beach erosion would likely have impacts on tourism. The IPCC anticipates that population growth and ongoing coastal development will exacerbate these risks.

Average temperature increases of 1^{o}C would be sufficient to increase peak energy demand in Adelaide and Brisbane and would reduce transmission efficiency. For this level of average warming, electricity demand in Melbourne and Sydney is expected to drop, however for higher levels of warming Melbourne's electricity demand is also expected to increase. Some of these impacts are summarized below in Table 1.

Table 1: *Projected impacts to Australian Settlements*

Temp Change(^{o}C)	Projected Impact
<1	3% decreases in thermal efficiency of electricity transmission infrastructure
	Decrease in demand for natural gas for heating in Melbourne
	Peak electricity demand in Melbourne and Sydney decreases up to 1%
	Peak electricity demand in Adelaide and Brisbane increased 2 - 5%
1 - 2	100 year storm surge height around Cairns increases 22%; area flooded doubles
	Peak electricity demand in Melbourne and Sydney decreases 1%
	Peak electricity demand in Adelaide and Brisbane increased 4 - 10%
2 - 3	17% increase in road maintenance costs over most of Australia
	Decreases in road maintenance costs in S Australia
	Peak electricity demand in Adelaide, Brisbane and Melbourne increases 3 - 15 %
	Peak electricity demand in Sydney decreases 1%
3 - 4	Oceania experiences net loss of GDP
	Peak electricity demand in Adelaide, Brisbane and Melbourne increases 5 - 20 %
	Peak electricity demand in Sydney decreases 1%
4 - 5	Peak electricity demand in Adelaide, Brisbane and Melbourne increases 9 - 25 %
	Peak electricity demand in Sydney decreases 0.5%
>5	Peak electricity demand in Adelaide, Brisbane and Melbourne increases 10 - 25 %

Source: Preston and Jones (2006)[xiii]

Predicted climate impacts on agriculture, forestry and natural habitats will in turn affect food security, resource availability and tourism. The Great Barrier Reef, a UNESCO World Heritage Area, has already experienced unprecedented bleaching over the last 20 years, and with an additional 1°C of warming, and considerable losses of the reef and associated species are anticipated. Australia's agriculture and forestry may initially benefit from longer growing seasons and increased atmospheric CO_2 concentrations, but the IPCC anticipates agriculture and forestry will decline throughout southern and eastern Australia by 2030 due to increased drought and fire. A further decline in average precipitation in southwest and southeast Australia is predicted, with increases in precipitation in the northwest. Sea level rise of between 8 and 88 centimetres along Australia's coastlines, where all the major cities are, is expected to result in erosion and inundation.[xiv]

Can Roads contribute to Climate Change Mitigation and Adaption in Australia?

The Australian road network spans a wide variety of geographic areas and according to the Bureau of Infrastructure, Transport and Regional Economics (BITRE) extends a distance of 814,000 kilometres[xv] - enough to circle the Australian coastline 31 times.[xvi] Furthermore, the value of road construction in Australia has been estimated to be in the order of $17.5 billion per year, with road maintenance costs in the order of $5 billion per year and rising. According to the Australian Government, when combined with population growth and internal migration, changes in temperatures and rainfall are expected to increase road maintenance costs by over 30 percent by 2100.[xvii]

Road building is inherently an efficient practice that seeks to minimise the costs of construction and maintenance, and to consider current and future environmental issues. Its practices include balancing earthworks to optimise cut and fill levels, utilising local sources to minimise the import of materials, ensuring impacts on the local environment and biodiversity are appropriately managed, optimising pavement thickness for anticipated conditions, and effectively scheduling associated capital expenditure. These practices have enhanced Australia's extensive road infrastructure over the last two decades and will be a key part of road building in the coming decades as part of the response to a changing climate. Complementing such practiceswill be a range of new practices incorporating design and performance considerations in areas including material extraction, transporting, earthwork and paving.

Roads currently contribute significantly to climate change through their construction, maintenance and use. Imbedded within this, however, is a key opportunity for road designers to contribute to climate change mitigation efforts through the use of innovative design and technologies. Currently, efficiency measures and alternatives to a range of materials can reduce the impact of road construction, while investments in alternative automobile fuels, increased automobile fuel efficiency, and alternative transport modes and options can minimise the impact of road use. There may furthermore be opportunities for roads to go beyond reducing negative environmental pressures to provide net climate change mitigation benefits. For example, alternative road base materials may provide opportunities for sequestering carbon, or roads may be designed to enable electricity generation through capturing solar or kinetic energy. Roads may be designed in ways that encourage pedestrian and cycle transport, and the existing amount of road surface maybe reduced and replaced by green space. Consideration of these pressures facing road design, construction and use can reveal opportunities for such holistic, whole-system innovations in roads, innovations that can provide significant environmental, social and economic benefits.

Roads are a vital component of our social and financial systems, providing mobility corridors for people, enabling freight networks to transport food, goods and services and distributions paths for emergency services and disaster relief teams. Climate change is likely to impact road infrastructure and use as climatic conditions become more extreme in many areas of Australia, threatening the viability of essential services and systems that rely on them. A key challenge for road designers is to understand the impacts of climate change and reduce the vulnerability of road services. Furthermore, roads can enhance the resilience of human settlements and systems by, for example, reducing the risk of bushfires by acting as a firebreak, or providing mobility during extreme climatic events such as floods or cyclones. Roads provide access for emergency services and the consequences are life threatening when this access is compromised. In the face of increasing frequency in natural disasters such as floods, cyclones and bushfires, roads become a nation’s lifeline to affected communities and will thus need to be able to resist inundation, heat and stress damage. An understanding of how climate change will affect Australia will need to underpin the future design of roads, to ensure that the services that rely on roads will still be viable during such conditions.

Determining a road’s level of susceptibility to the effects of climate change, and its ability to adapt to and mitigate these climatic effects, is an important part of investigating the future of roads.

Strategic Area 1: Reducing the Environmental Pressures of Current Road Construction

Investigate ways to reduce environmental pressures from road building, including road materials (including the extraction, crushing, transportation and placement of traditional and alternate materials and aggregate replacement options); the use of concrete (including aggregate alternatives, cement alternatives, placement and carbon storage options); the use of bitumen (including raw aggregates, mix design, warm and cold mix technologies and placement); and impacts on watersheds and biodiversity (including toxicity, leachate, runoff pollutants and groundwater pollutants, erosion issues, changes to hydrology, changing stability of road and surrounds, and changing porosity of road and surrounds).

Roads are classified into a number of different categories based on their use. High traffic volume roads are defined by the Permanent International Association of Road Congress (PIARC) as highways, or simply roads, and include expressways, motorways, arterial and main roads. Lower volume roads are referred to as streets, local roads or pavements.[xviii] The physical structure of a road is similar regardless of its intended use. All roads require a pavement structure consisting of a seal or pavement layer and a base, a sub base and a lower sub base layer. Underneath this pavement structure lies a foundation of compacted fill and in situ natural material.[xix] In modern roads, the type and thickness of materials used in both the grade and subgrade layer are strictly controlled by design specifications produced by local government authorities. These specifications cover the design and construction of roads based on design traffic, environmental characteristics and construction and maintenance considerations. Pavements materials can be classified as unbound granular, modified granular, stabilized granular, lean mix concrete, concrete and asphalt materials. The sub grade layer consists of a combination of fill and treated or untreated in situ material.[xx]

Road Construction

Road construction introduces huge quantities of foreign material to the natural environment and disrupts the soil conditions and runoff behavior for hundreds of kilometres. Consequently, the choice and use of road construction materials is important in reducing the environmental impact of roads. The environmental impact of road construction materials is governed by two major factors – the choice of materials and the processes through which those materials are used to construct the road. In general, the materials used for road construction affect the chemical composition of the surrounding environment (through the toxicity of leachate, runoff and groundwater) while the design and construction methods cause mechanical damage (erosion, soil disruption, watershed changes). There are, however, correlations between chemical and mechanical impacts. For example, the level of compaction and stabilization of road materials, especially in the base and sub base layers has a significant effect on the rate of leaching and the toxicity of the surface and groundwater.

A major process involved in road construction is quarrying or ‘extraction’ of the source rock that is used to form the aggregates necessary for the sub base, embankments, and use in concrete and asphalt mixtures. This is done with through drilling and blasting to reduce the rock mass to a particle size that can be dug from a loose rock.[xxi] This can be achieved through chemical means (explosives) or mechanical breakage. The extracted materials are then processed to make them appropriate for end use (as part of concrete or asphalt or in base layers). The requirements are defined in terms of particle size and distribution, shape and mechanical properties, for example compressive strength. The process of crushing involves the continual reduction in size of the extracted material using either compaction or impact crushers. The aggregates produced are then tested to determine the relevant properties and transported (either wet or dry) to road construction sites or to plants to act as additives into concrete or asphalt, via road or rail.

The industrial asphalt used for road construction is refined from petroleum through a process of vacuum and steam refining. The asphalt is usually further processed through air blowing at elevated temperatures and is mixed with water to make it fluid for ease of placement. This emulsion process requires high temperatures (121ºC for the asphalt and ~50ºC for the water in traditional procedures).[xxii] The asphalt is shipped to an asphalt production facility and stored in large containers where it must be constantly heated to maintain fluidity. When an order for asphalt concrete is received, aggregates of varying sizes are added to a mixer where the asphalt is injected as a fine spray. The asphalt mixture is delivered to hot storage bins where it is kept until delivery to site.[xxiii] The processes involved in the placement of modern roads include roadway preparation, excavation and stabilization, base construction, the placement of asphalt or concrete in various ways, and finishing processes, such as line marking and maintenance. The removal of old roads requires both reclamation and disposal. The asphalt must be removed and reprocessed for recycling, which will involve crushing and reuse.

Road construction materials

Concrete is a mixture of cementitious material, aggregates, water and admixtures for workability. Concrete pavement is a strong structure designed to resist and dissipate the heavy dynamic loading of traffic, and it is often covered by a small layer of asphalt for noise control.[xxiv] The cementitious materials may consist of lime, blast furnace slag, flyash or a geopolymer material. Aggregates for concrete roads are quarried and crushed to various sizes for strength and durability. Asphalt pavement encompasses both bitumen and aggregates. Bitumen is a dark, cement-like semisolid, solid or viscous liquid produced by the non-destructive distillation of crude oil during petroleum refining, to which aggregates of varying size are added.[xxv] Sprayed seal (referred to as chip seal also) is a thin layer of binder sprayed onto a pavement surface with a layer of aggregate incorporated, and it is impervious to water.[xxvi]

The main aggregates used in road pavements on their own or in combination with a cementitious material are either natural rock materials, gravels and sands or slag aggregates. Natural rock aggregates are classified according to their method of origin (i.e. igneous, sedimentary and metamorphic), and then into categories based on their practical road making abilities (i.e. basalt, gabbro, granite and porphyry). Basalt aggregates are strong, although some may have high drying-shrinkage characteristics that can lead to problems when used in concrete. Granites are strong, though often acidic, while porphyries are considered to be good all round roads stones.[xxvii] Secondary aggregates are low-grade aggregates that have been sourced from the 'waste aggregates' of various industrial processes. They include blast furnace slag, pulverized fuel ash, furnace bottom ash, china clay waste and demolition and construction waste. The use of these secondary aggregates is primarily in the sub base or embankments.[xxviii]

Due to the large quantities of material required for roadbase construction, the transport of aggregate materials forms a significant part of the total greenhouse gas emissions from road building. Reducing this impact can be achieved in a number of ways, such as by reducing the total distance travelled by materials (using locally sourced or recycled materials) or using different modes of transport. Traditional aggregate materials used in the road base, such as natural rock, gravels and sands, can be replaced by recycled materials, repurposed waste, or alternative processes.

Reducing toxins and contaminants

The most significant introduction of toxins and contaminants through the road construction process occurs via stormwater runoff.[xxix] These contaminants may include hydrated ions, colliodial and gravitoidial particles and suspended matter. Heavy metals and organic compounds also pose problems due to their propensity to sorb to the clay, silt and sand commonly used for road and road bed.[xxx] Therefore, when considering the use of potentially contaminating materials, both the chemical composition and the placement of the road construction material is important. The ecological impacts of road construction materials currently used in road construction is well documented, and includes the effect of fill materials and non-fill material such as Portland cement and associated plasticizers,[xxxi] bitumen, asphalt[xxxii] and flyash.[xxxiii] Studies into the pollution of ground and surface water by existing road construction materials have found that it is occurring at an alarming rate, with high toxicity levels and a recognised need for mitigation strategies.[xxxiv,xxxv]

The use of recycled materials in road construction is becoming more prevalent and widely accepted due to growing shortages and rising costs of virgin materials. However, there is growing concern that waste materials negatively impact the runoff and soil quality, creating toxic leachate, contaminating soils and polluting nearby waterways.[xxxvi] The materials that have been the focus of most studies to date are bottom ash from the incineration of municipal wastes,[xxxvii] recycled tyre and crumb rubber,[xxxviii] steel slag[xxxix] and old asphalt pavement as fill.[xl] Studies into the use of these materials have found that, while in some cases there exists higher than normal contamination of the surrounding soil and groundwater, most contaminates are volatized, sorbed, degraded or retarded significantly in their transport through nearby soils and groundwaters,[xli,xlii,xliii] making them appropriate for use.

Aggrigate

Reducing energy in aggregate crushing

After rocks have been mined and transported from quarries, they must be crushed into smaller rocks, gravel or rock dust in order to be usable in road constructions. This process requires large amounts of energy. Improvements to the efficiency of rock crushing apparatus can significantly reduce the energy requirements of this process, as documented by Nenad Djordjevic at the University of Queensland in Brisbane, Australia, who identifies optimal pressure intensities for rock crushing. Resulting modifications to pressure and particle size distribution have resulted in energy savings of up to 40%.[xliv]

Alternatives to extracted aggregates

The benefit of repurposing waste materials is twofold. It reduces both the virgin materials used and the waste products directed to landfills. Macadam can be manufactured with up to 30% of the aggregate being replaced by crushed glass with no detrimental effects, as demonstrated in trials of this product, trade-named Glasphalt, at the Washwood Heath Depot in Birmingham, UK.[xlv] Other possible alternatives materials tested and quite commonly used are:

- Colliery spoil/ mining waste rock;
- Air cooled blast furnace slag, air;
- Ground granulated blast furnace slag;
- Steel slag (basic oxygen and electric arc furnace slag);
- Coal fly ash;
- Coal bottom ash;
- Building demolition by-product;
- Foundry sand;
- Municipal solid waste incinerator bottom ash.
- Rubber from tyres (Vic roads specification, 2006)
- Crushed glass (Vic roads specification, 2006)
- Red sand from bauxite residue (Alcoa and Curtin studies, 2010)
- Recycled crushed concrete and demolition waste (Collin Leek, 2011)

In-situ stabilization, or the process of stabilizing natural earth to strengthen and allow it to function as a pavement layer, is a technique that drastically reduces the amount of aggregates needed and therefore the amount of greenhouse emissions from a road project. This technique was demonstrated by the Queensland Department of Transport and Main Roads (DTMR) on the Cunningham Highway. The trial used higher quantities of lime than had previously been tested, resulting in exceptionally durable outcomes in the high heave soil, a process pioneered by Prof Dallas Little, Texas A&M University, US.[xlvi] DTMR also utilizes a foam bitumen process that has process excellent long-term results on Queensland roads (in the Border District, North and South Coast Hinterlands and Redland Shire). This process uses a hot bitumen mix to stabilize the pavement, replacing the traditional combinations of lime, cement and flyash. The trial has been extremely successful and was recently written into a main roads specification, which will enable efficient technology transfer to future projects.[xlvii] Other aggregate replacement techniques, such as the use of geopolymers pioneered by Alcoa[xlviii], are further reducing the need for virgin materials, and reducing the greenhouse gas footprint from road construction materials.

The process of recycling old or deteriorating flexible road pavements by cement stabilization has been employed in Australia for about 25 years. This process requires very little material to be removed from the site, thus reducing greenhouse gas emissions from the transport of unwanted materials. This is a proven technology, with roads in Brisbane, Australia, that were stabilized using this technique in the 1960s still in use today.[xlix] Old concrete highways in the US that have deteriorated and cracked due to poor maintenance and design are today being reused as recycled concrete aggregates for new road base. This practice is now in the second revolution, in which recycled roads are being recycled once more, and considerable progress is being made with recent advances in processing and construction materials technology. [l]

Performance of alternative materials

The use of bottom ash (the product remaining when municipal waste is incinerated) in roadbeds and embankments is a significant step towards reducing waste to landfill. One of the challenges involved with this technology is ensuring that there is no negative environmental impact through pollutant leachate. Tests of roadbeds in France, where the use of bottom ash is encouraged but strictly regulated with specific criteria and quality management, give encouraging results, showing that the use of bottom ash can be safe and have similar environmental impacts to roads constructed from natural materials.[li] Similar studies in Sweden are more cautious in their analysis, yet conclude that there are significant opportunities to reduce resource use and waste to landfill, if the environmental impact is carefully managed.[lii]

Two major European projects have attempted to solve the potential leachate problem. The first one named ALT MAT (Alternative Materials in Road Construction) proposes a different testing methodology for alternative aggregates. In1998, this project was launched in response to pressure in Europe to use alternatives road base materials, mainly due to expensive landfill taxes, taxes on natural aggregates in some cases and the huge amount of waste involved. However, the first step was to work out how to assess those alternative aggregate materials. The project demonstrated that the alternative materials performed better when used in roads than when tested in laboratory through the conventional method. Other research supports this.[liii] The project research showed that two types of MSWI bottom ash first used in France gave very high values in Los Angeles and Micro-Deval tests, indicating they were not suitable for high quality end uses, whereas, inspections of two existing roads in which MSWI ash had been used as unbound sub-base showed that they were giving satisfactory performance 20 years after construction. Moreover, no environmental problems were reported (Reid *et al.*, 2001). In order to determine if an alternative materials is suitable, the ALT MAT research defined, through laboratory tests and field behaviour, the methods that should be followed. Comments on the testing of mechanical properties, the leaching test and environmental impact, the hydrodynamic test and the mitigation methods are available on the project websites.

The second project, SAMARIS (Sustainable and Advanced Materials for Road InfraStructure), investigated methodologies to assess the engineering performance and environmental impact ofalternative road construction materials. This led to the construction of decision trees that indicate which environmental and mechanical tests have to be performed, and in which order, in order to assess the suitability of a material for a given function. The result is a technical guide to support and encourage the use of alternative materials in roads. This report seeks to ensure the the satisfactory environmental and functional performance of alternative materials by detailing not only how alternative materials should be tested, but also where and how they should be placed in the pavement structure.[liv]

Reducing energy in aggregate crushing

After rocks have been mined and transported from quarries, they must be crushed into smaller rocks, gravel or rock dust in order to be usable in road constructions. This process requires large amounts of energy. Improvements to the efficiency of rock crushing apparatus can significantly reduce the energy requirements of this process, as documented by Nenad Djordjevic at the University of Queensland in Brisbane, Australia, who identifies optimal pressure intensities for rock crushing. Resulting modifications to pressure and particle size distribution have resulted in energy savings of up to 40%.[lv]

Recycled Aggregate and Crushed Concrete

Concrete which utilises recycled materials as aggregates generates huge reductions in the need for virgin quarry materials. Recent research and testing has demonstrated that the use of construction and demolition waste is appropriate, especially in lower level applications, such as the base or sub-base layer. The source of recycled concrete aggregates is varied and can include recycled precast elements or demolished concrete buildings. Barriers to this technology include low industry confidence in the final product, the cost of disposal to the construction industry, and the attractiveness of dumping older concrete with low disposal fees.[lvi]

Asphalt

Asphalt Aggregate Alternatives

While there are successful examples of concrete roads, most roads in Australia are sealed with bitumen or asphalt, and so attention to concrete in this study has been limited to opportunities for the use of alternative aggregate materials and the use of cement alternatives. Processes that enable the storage of atmospheric carbon in concrete have also been identified. Asphalt is, according to the Austroads Glossary of Terms[lvii], a mixture of bituminous binder and aggregate with or without mineral filler, produced hot in a mixing plant, and delivered, spread and compacted while hot. The bituminous binder refers to materials that resembles or contain bitumen. However, as we will see later in this chapter, asphalt can be produced with warm, semi warm and cold processes.

In the same glossary bitumen is defined as a very viscous liquid or a solid, consisting essentially of hydrocarbons and their derivatives, which are soluble in carbon disulphide. It is substantially non-volatile and softens gradually when heated. It possesses waterproofing and adhesive properties. It is obtained from native asphalt or by processing the residue from the refining of naturally occurring crude petroleum. Hunter[lviii] in another definition explains that the derivatives correspond to a number of other structures containing hetero atoms, that is, atoms other than hydrogen and carbon, such as oxygen, sulphur and nitrogen. It is the complex arrangement of the hydrocarbon molecules and those molecules containing heteroatoms which gives bitumen its unique balance of properties. Hunter[lix] adds that only 100 out of 1500 types of crude oil are suitable to bitumen production, and the chapter on bitumen in this source also outlines how to replace oil or reduce its consumption in bitumen production. As explained in the definition asphalt is bituminous binder mixed with aggregates. Bituminous binder is currently mostly made of bitumen. The gTKP, the global Transport Knowledge Practice, in its report about Eco road building[lx] has identified 6 technology areas of potential interest in relation to the development of renewable locally sourced alternatives to conventional bitumen, asphalt and Portland cement based materials for low cost road building. Two of them deal with bitumen replacement: pine resin and tall oil; and oil, resin and biomaterial blends.

Municipal waste products can potentially be used as aggregate components of bitumen. This is demonstrated by the development of innovative projects that use plastic waste for roads in Southern India, where a kilometre long test track of road made of bitumen with 3-4% plastic waste has indicated that the durability of 'plastic roads' may be far above that of a normal road.[lxi] Bitumen aggregate replacements can also be made from those materials detailed in the materials section.

- Pine resin or tall oil, also called liquid rosin or tallol, is a viscous yellow-black odorous liquid obtained as a by-product of the Kraft process of wood pulp manufacture. Tall oil is a mixture of fatty acids and resins that tend to be separated into "tall oil rosin", "tall oil pitch" and tall oil fatty acids, and has been employed as a tar/bitumen substitute often in combination with other bio materials.
- The gTKP report presents this solution as the most promising option to replace bitumen. The use of pine pitch, rosin and vegetable oils to produce bituminous binder has been the subject of many patents, but recent innovations only started to attain commercial success as ecologically acceptable alternatives. The process is kept secret and the gTKP report assumes that more sophisticated control over polymerisation conditions using oxidation catalysts and various pre-treatments may have lead to this success. Products using this technology already exist; there are Vegecol from Colas or Ecopave from Australia. UNEP[lxii] gives details about the technology used by ecopave, noting that it is an invention that turns sugars (from sugar cane) and a wide range of other natural materials including tree resins and gums, vegetable oils, potato and rice starches, and molasses into road paving. The process is said to involve negligible levels of fumes during the laying and, unlike bitumen, which must be constantly heated at temperatures of 170 degrees C, the new material can be stored and transported at room temperature. A novel advantage is that the product can be pigmented to reflect heat and thus help to cool cities, the company claims. The main barriers to the wider use of these materials are the cost and appropriate technology implementation.

  From 2007 to 2010, the ECRPD - Energy Conservation in Road Pavement Design – project investigated how to lower energy consumption in pavement materials production and during pavement maintenance. The ECRPD report on existing and new pavement materials[lxiii] lists the solution available at the moment to replace bitumen. Some of these, known as Eco-friendly binders, are based on a similar technology to the product just described. Here, eco-friendly "fluxants" efficiently replace oil "fluxants" to reduce the viscosity of the bitumen used in surface layers and for maintenance. They are likely to replace bitumen but are nowadays more expensive.
- Polymer modified bitumen is supposed to last longer and therefore reduce oil consumption. Saunier et Associés[62] write that polymer bitumen improves the adhesion to the underlying surface and the aggregate used in a surface treatment. Polymer bitumen also decreases the risk of bleeding and stone loss. Hunter[lviii] notes that the addition of polymer reduces the temperature susceptibility of the pavement. Improvements in flexibility, workability, cohesion, ductility and toughness (Wardlaw and Schüler, 1992) may also occur, which leads to improved performance and service life. Hunter adds that different polymers have been

assessed and found to improve the performance of bitumen. Despite this, relatively few have been exploited commercially.

Warm and semi warm asphalt processes

The report from Saunier et Associés describes a hot mix asphalt (HMA). The HMA process was developed in the 1930s and is still in general use. Traditionally, asphalt is produced at temperatures of about 150-180°C. At these temperatures the bitumen can fully coat the dried aggregate. This ensures that the bitumen is fluid enough to be workable during mixing, laying and compaction, which normally take place at temperatures of between 140-170°C. 175 MJ is the energy required to heat one tonne of aggregate skeleton and greenhouse gas (GHG) emissions for a tonne of asphalt can be as much as 16 kg CO_2 equivalent. It generates this much greenhouse gas as a result ofthe heat and pressure required to refine the raw crude oil into useable products. Most new techniques developed to date are based on one of two properties: either additive based technology (where a proprietary additive is used to allow a reduction in energy usage) or alternative manufacturing techniques. This chapter details processes that consume less energy and less fuel than the traditional HMA.

From the same report cited above, Saunier et Associé, warm asphalt is described as a material manufactured between 80°C and 130°C with various mixing processes. It has the same performances as HMA as soon as it is applied: there is no development/waiting period as for cold mixes. There are two kinds of warm asphalt: those which are manufactured above the evaporation temperature of water (100°C), semi warm asphalt, and those under, warm mix asphalt (WMA). A significant amount of the energy consumed in coating is due to the latent heat required to evaporate water. For this reason asphalts manufactured under 100°C are interesting.

WMA has the same mechanical characteristics as HMA, saves energy and has other advantages:

- It reduces GHG emissions.
- As it is applied at a lower temperature than hot-mix asphalt, it cools faster and roads can be reopened more quickly. That increases productivity.
- Working conditions are improved, with increased safety, reduced health risks, no smell, fumes, gaseous emissions or dust, and reduced vapour emissions.
- The reduction of temperature limits the ageing of the binder and increases durability.

The report states that, considering the reduction in energy consumption, this kind of asphalt could come into general use in the medium term. It adds that, as the process is still new, it is not being adopted as widely as it might be because companies prefer to use familiar processes. Finally, it notes that there are many ways of making warm asphalt and each company has its own formula and manufacturing process. For a comparison of the products listed visit the reference. Research led by Diefenderfer and Hearon[lxiv] for the Virginia Transportation Research Council compares the performance of warm mix asphalt (WMA) and hot mix asphalt (HMA) two years after construction. The results show thatlxiv:

– Visual surveys indicated no significant distresses in either the WMA or HMA sections during the first two years in service.

- Evaluations of the core air-void contents indicated that generally the contents for the WMA and HMA were not significantly different in each trial. The air-void contents at different ages were significantly different in a few instances; however, no trends concerning air voids were observed.
- Permeability measurements did not indicate any trends concerning permeability over time.
- Performance grading of the recovered binder suggested that the WMA produced using Sasobit aged at a slightly reduced rate than the HMA, as indicated by decreased stiffening. No difference in performance grade was measured between the HMA and WMA produced using the Evotherm emulsion.
- Comparisons of historical data, core data, and ground-penetrating radar scans illustrated that each may indicate a slightly different pavement structure.

Regarding economic benefit, Diefenderfer and Hearon explain in their conclusion that "during the period from February through October 2009, VDOT let maintenance contracts using HMA surface mixtures valued at approximately $101 million. If, conservatively, one-tenth of these mixtures were replaced with WMA produced using technologies having beneficial aging characteristics and the apparent trend of a 1-year reduction in the rate of aging continued, resulting in a 1-year deferment of repaving, VDOT could realize a one-time cost savings of approximately $1.15 million."

Cold asphalt processes

The definition given by Saunier et Associés[62] of cold asphalt is a process where the manufacturing temperature is under 60°C. Their report emphasizes that, as for warm asphalt, working conditions are improved (safer work environment, less dust and fume emissions at the mixing plant and during the paving operation) and roads can be quickly reopened. The binder is heated less, which reduces the artificial ageing and hardening of the bitumen. Companies are still working to improve performances of cold mixes to use them in the wearing and base courses of the pavement. The company Eurovia (in the Czech Republic) has developed a new material: *Aspha-min® admixture.* It is a special admixture for bituminous mixtures which allows the temperature of the mixture during the placement process to be decreased by up to 30 degrees Celsius. Currently, it is mainly used for maintenance on low trafficked roads (rut). There are various processes of warm and cold mix asphalt processes listed in the Saunier et Associés report.

- *Foam mix bitumen*: Hunterlviii explains that foam bitumen is a method involving the controlled introduction of a small amount of water into hot bitumen. The foam produced has a very high surface area and extremely low viscosity, making it ideal for coating aggregate. Hunter adds that the foam mix process is not a new concept. Csanyi[lxv] originally developed it at Iowa State University in 1956, and the first trials were carried out in Iowa and Arizona between 1957 and 1960. Adoption of Csanyi's process was, however, limited due to its reliance on the injection of high pressure steam into hot bitumen to produce the foam. Mobil (Australia) refined the process by using cold water to generate the foam and was granted a patent in 1968. The foam mix process was originally developed as a means of stabilizing marginal aggregates but has since evolved into a widely accepted maintenance and construction technique. Hunter explains that there are several reasons for this. Firstly, the process is very adaptable as it can be used in static mixing plants or specially constructed “in situ” production units. There are also significant energy savings in comparison to conventional hot mix production as the aggregate does not require heating or drying. Mixed material can be stockpiled for a period before being used, which results in minimal wastage. Finally, Hunter notes that the foam mix process is equally applicable to the coating of virgin and recycled aggregates, which explains its increasing popularity for in situ recycling of roads. The process is also seen as being less susceptible to the effect of weather in its early life than other cold mix processes[lxvi,lxvii] However it is expensive.

– *Fulton Hogan*: In 2006, Fulton Hogan combined additive technology with plant and process modifications to create an asphalt that could be produced below 100ºC and placed at temperatures as low as 60ºC. The two major benefits resulting from this technology are a reduction in greenhouse gas emissions (by as much as 50%) and major improvements to field crew health and safety (mainly due to the considerable reduction in temperature). As a result, Fulton Hogan has produced over 6000 tones of ‘CoolPave’, which has been used on minor city streets, multi lane city arterials, airport taxiways and factory yards and car parks. Vigorous performance testing shows excellent compaction results and rutting levels comparable to that of hot mix asphalts, demonstrating that paving quality need not be compromised when using low emissions production techniques.
– *Greenpave:* The Greenpave technology, developed and trialed in Melbourne, Australia, is very similar to the cool pave technology found in Christchurch, New Zealand. Greenpave has been laid at 17 sites across metropolitan Melbourne and all sites have passed independent audits. The new asphalt production facility, situated in North Melbourne, meets tough European environmental standards and has reported gas and electricity consumption savings of 30%, noise and odour reduction, improved site drainage to reduce storm water contamination and asphalt recycling facilities.[lxviii]

Reclaimed Asphalt Pavement

In France, the maintenance of road surface layers generates approximately two millions tons of reclaimed asphalt pavement (RAP) a year of which less than 10% is recycled into road materials.[lxix] In the US, the Federal Highway Administration estimated that 100.1 million tons of hot mixed asphalt (HMA) is scrapped each year (Consentino, 2001). RAP is a blending of high quality, well graded aggregates coated with asphalt (RMRC, 2010) and its recycling represents environmental and economic benefits. As an example, Al-Qadi *et al,*[lxx] report that using reclaimed HMA provides savings ranging from 14 to 34% for a RAP content varying between 20 to 50%,[lxxi,lxxii] based on a cost of HMA at $11.90 per ton. However, the storage of RAP constitutes an environmental issue. Research by Norin and Strömvaix[lxxiii] emphasizes the risk of stockpiling RAP, due to potential leaching of semi volatile components. Norin and Strömvaix conclude that the concentrations and the cumulative amounts of semi-volatile organic contaminants are high in the leachates from temporary storage of RAP, especially from stockpiles with scarified asphalt. In addition, they highlight that for both unstored and stored scarified asphalt the concentrations of total PAH in the leachates exceeded the threshold as specified in Swedish recommendations for groundwater in polluted soils at petrol stations. In summary, they stress that these findings clearly show that the release of organic pollutants from asphalt storage can cause environmental problems.

There are different possibilities for the use of RAP. One of the objectives of the European project Re-Road[lxxiv] (2011) is to allow the re-use of the optimal proportion of RAP in new wearing courses, depending on the industrial means and the costs for recycling. The Re-Road project notes that most European countries are already using RAP in new bituminous bound courses (up to 40%), but the amount of RAP added to new wearing course is still low (10 to 20%). The reason for the difference is that there are higher demands on the road surface, and specifications for this are very high as the wearing course is in contact with tyres and subject to a wide range of weather events. The project aims to use up to 90% of RAP in new wearing courses. However, the use of RAP in new wearing courses requires that a range of problems be addressed. The main issue when using RAP in wearing courses is that its properties alter with aging. As Al-Qadi *et al* explain it, during service the blend of aggregates and binders undergoes various physical and rheological changes that have to be considered in the design process to ensure that HMA mixtures with RAP perform as well as HMA produced with virgin materials. There are two types of ageing:

– Short term ageing occurs during construction. This is due to exposure to hot air at temperatures ranging from 135^{o}C to 163^{o}C. It will cause a significant increase in viscosity and changes in the associated rheological and physiochemical properties such as complex shear modulus and adhesion.
– Long term ageing accurs during service life. This corresponds to a hardening of the material and is mostly due to six mechanisms: oxidation, volatilization, polymerization, thixotropy, syneresis and separation.
– In addition, the properties of RAP will also depend on moisture, void content, the level of damage to the pavement and stockpiling.

Considering these ageing impacts, problems to be solved if RAP is to be used are:

- The interaction between aged and virgin binders. One of the issues involved in mixing RAP with new binder that is still under investigation is the reaction between aged and virgin materials. This interaction between aged and virgin binder is important because the level of blending affects both the performance of the produced HMA and the economic competitiveness of the recycling process. To use an aged binder, you must either mix it with a recycling agent, a soft asphalt binder, a softening agent (which correspond to asphalt flux oil, lube stock and slurry oil, and will lower the viscosity of the aged binder) or a rejuvenating agent (that would restore the physical and chemical properties of the old binder of the old pavement. They consist of lubricating and extenders oils which contain a high proportion of maltene). It is known that blending occurs between aged and virgin binders, influenced by preheating.
- The interaction between an aged binder and old and new aggregates.

There are a lot of studies[lxxv,lxxvi,lxxvii] focused on the leaching probability of RAP when used as base, sub-base or construction fill material. Those studies show that RAP is not causing any significant environmental issue. However, there has been little research on the use of RAP in new wearing courses, as this practice is not very common. This is one of the tasks planned by the Re Road project.

Alternative cements

Innovative concrete products such as Wagners Earth Friendly Concrete (EFC), normal concrete with an alternative sustainable binder, are leading the way in the use of more sustainable concrete. Current research and development trials undertaken through a licensing agreement with Zeobond have produced over 1000m^3 of retaining walls, street pavement, bridge beams and water tanks for commercial and private projects throughout Brisbane, Australia. The concrete exhibits better strength, shrinkage and acid resistance characteristics while saving over 150 kg of CO_2 per m^3.[lxxviii]

Watersheds and Biodiversity

There are many facets of road building that have negative impact on nearby watersheds, ranging from hydrological effects on catchments (such as scour and altered flow paths and velocities) to problems resulting from extra sedimentation, toxic runoff and loss of biodiversity. A major concern for watersheds and their anadromous and fish habitats is that significant adverse impacts may be experienced kilometres downstream even when disruptive activities are confined to a relatively small area and have a seemingly small initial impact. Any action that results in changes to sediment production, water levels, toxins and temperature changes may produce off-site damage downstream due to the extremely sensitive nature of waterways systems.

Potential watershed damage control techniques

The Bureau of Land Management in Colorado, USA, has developed a comprehensive ‘Watershed Plan’, in which it identifies many concerns regarding the effect of road construction on watersheds. The report proposes a number of technical methods, some of which are already in practice and others that will require significant research and development to become feasible:

- Erosion and Sediment Structural Controls (Fibre rolls, earth dikes, drainage swales, gravel bag berms, straw bale barriers, silt fences, sediment sraps, water velocity dissipation devices),
- Erosion and Sediment Non- Structural Controls / Soil Stabilizers (Preservation of existing vegetation, streambank stabilization, straw mulch, hydraulic mulch, hydroseeding, geotextiles & mats, riprap, gradient terraces, soil roughening),
- Road Construction designs to mitigate storm water runoff impacts (Drainage dips, ditches, road crowning, ditch relief culverts, low-water crossings, culverts), and
- Materials Handling & Spill Prevention, Waste Management and General Pollution Prevention (Spill prevention and control, vehicle and equipment re-fueling, stockpile management, solid waste management, hazardous waste management, contaminated soil management, sanitary / septic waste management.)

(Watershed Working Group, 2007)

Consideration of Case Studies

In order to evaluate the practice of reducing environmental pressures in road project construction in Australia, two projects that were recently completed in Australia can be examined as the case studies: the Tullamarine Calder Interchange and Mickleham Road in Victoria.

Tullamarine Calder Interchange, Victoria

The Tullamarine Calder Interchange is a main arterial located north west of Melbourne, Victoria. The interchange is the intersection of Tullamarine and Calder freeways, adjacent to the Essendon Airport, Melbourne as shown below. The project length is approximately 2km long illustrated by the red stars in the figure.

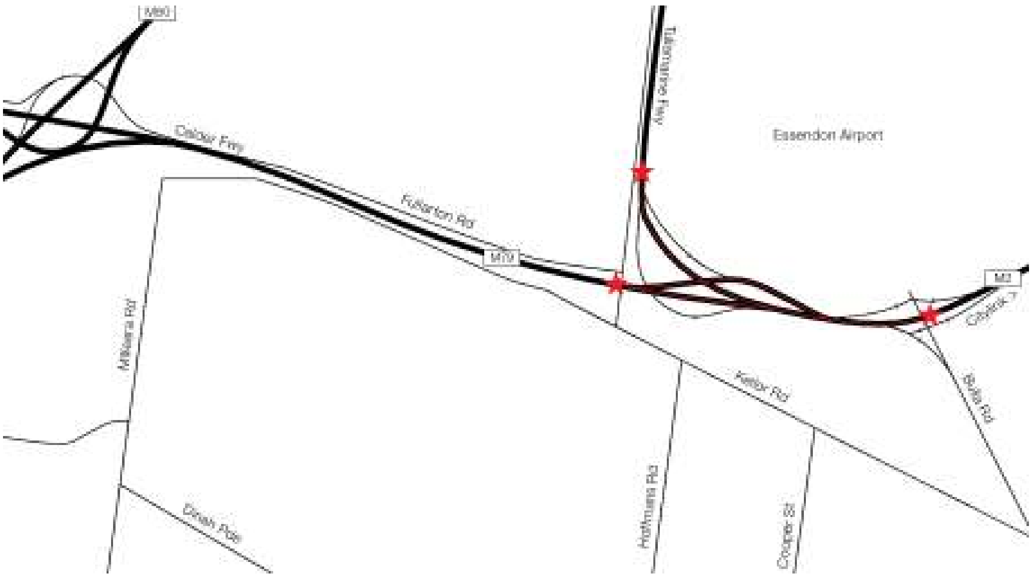

Figure 1: Location of Tullamarine Calder Interchange

The Tullamarine Calder Interchange was commissioned by VicRoads to enhance the existing link between the Tullamarine Highway and Calder Highway, as there had been more than 150 casualty accidents in the five years prior to the new interchange being built. The interchange was designed to carry 170,000 vehicles per day, as well as to contribute to a consistent travel time between the Melbourne CBD to the Melbourne Airport. The introduction of the new interchange allowed less traffic and congestion on local roads, and included safer signalised intersections at Bulla Road and Melrose Drive.[lxxix] The budget awarded for this project was $150 million, and the project commenced in October 2005 and ended in July 2007. The Tullamarine Calder Interchange was able to be finished five months ahead of schedule and $12 million under budget.[lxxx] Many important environmental options were implemented in this project to allow it to be under budget as discussed below. Through the application of these key options as well other innovative ideas, the Tullamarine Calder Interchange was awarded the National Award for Excellence in Major Capital Alliances and a finalist in the 2008 Banksia Foundation Environmental Awards.[lxxxi]

A number of sustainability initiatives helped reduce the environmental pressures caused by this project. For the road shoulders, instead of using the conventional concrete pipes, 100 percent recycled high density polyethylene (HDPE) pipes were used. This helped reduce overall cost, as well as reducing installation time by 25 percent. On site, up to 4 ML of stormwater was captured and used to suppress the dust around the work site in order to reduce the polluting of the surrounding area. VicRoads was also able to recycle 97 percent of construction waste and, with the use of recycled asphalt, was able to save 8500 tonnes of raw materials. Another key option was the construction of one of the biggest bio-retention basins, covering 500 m^2, to treat stormwater runoff from 3 ha of road.[lxxxii] In road construction, Portland cement is commonly used. With every tonne of Portland cement produced, one tonne of carbon dioxide is emitted. Fly ash was used as a substitute for cement and was able to save 200 tonnes of carbon. In addition, VicRoads incorporated the use of biodiesel in plant and equipment as an alternative to tradition diesel fuel.

Figure 2: Solar panels on noise walls, (Johnston 2007)

Noise walls were installed to reduce the amount of noise pollution in the surrounding area. Attached to the top of the noise walls were 210 solar panels at that generated 25 kw of power.[lxxxiii] As the solar panels are vertical and not on an incline, only 37 percent of power is lost.[lxxxiv] The amount of power produced was also maximised with the careful selection of light poles, as the shade produced from these objects would reduce the amount of power being generated from the solar panels. The electricity generated from the solar panels was then used to help power the CCTVs and lights in that area and this offset 10 percent of the annual free lighting power demand. From the careful placement of the light poles and the use of solar panels 70 tonnes of carbon emissions are saved annually.

A review of literature on the Tullamarine Calder Interchange project reveals the adoption of a range of innovative ideas that could also be adapted to future road infrastructure projects in Australia. By inspecting the various levels of road infrastructure it can be determined at which stages key options were applied. The Tullamarine Calder Interchange project has incorporated the remediation of roads. Rather than laying a new road to deal with traffic issues incorporated with this road prior to the improvement, the road has been remediated to better serve its original purpose.

In situ stabilization was used to save raw materials and this saved 8500 tonnes of asphalt. With the installation of noise walls, emissions will be able to be reduced by containing wind spray. The road design incorporated better and safer vertical and horizontal alignments that allow the driver to see further as a result of an enhanced curve radius. Many measures were taken to reduce environmental impacts. These include the use of captured stormwater to suppress dust around the site, the recycling of construction waste, and installation of the HDPE pipes.

Other key options that could have been employed but were not considered include the inclusion of helophyte filters and a maintenance plan. With a traffic count of 170,000 vehicles per day, a large number of harmful pollutants are emitted and run off to the side of the road. Due to the location of the project, there was no immediate threat to the soil but emissions could still build up in the road basin. Therefore, adding helophyte filters would have been beneficial. The inclusion of a maintenance plan would have helped regulate the amount of waste on the roads. Regular cleaning would not only clear the road of debris, but also minimise the waste entering key areas such as drainage systems and basins.

Mickleham Road Duplication

Mickleham Road Duplication is a sub arterial road located in Greenvale, Victoria, north of Melbourne. Mickleham Road is connected to the main arterial of Tullamarine Freeway which leads to Melbourne's CBD. The duplication of Mickleham Road lies between Barrymore and Somerton Roads as shown below.

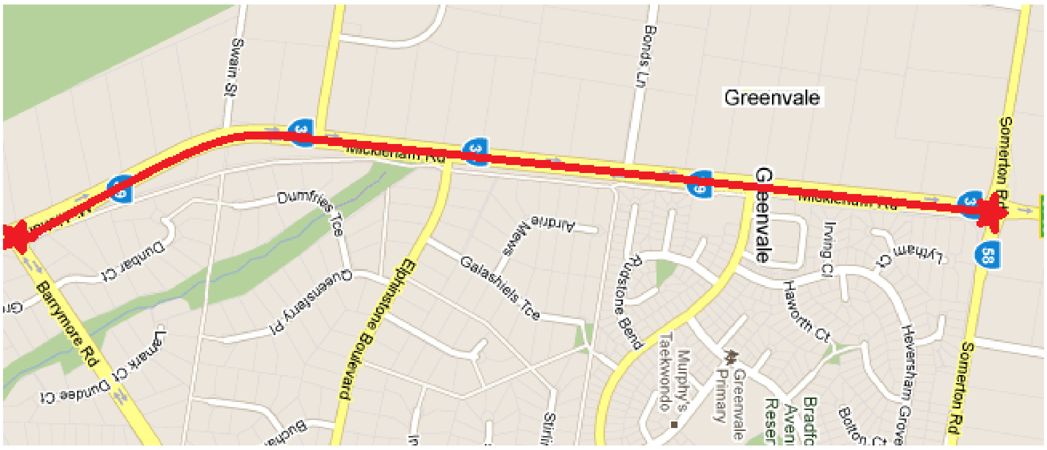

Figure 3: Location of Mickleham Road Duplication, (Google, 2011)

VicRoads constructed the Mickleham Road Duplication to upgrade the existing Mickleham Road as part of the Outer Metropolitan Arterial Roads Program. The main features of stage two of the duplication of Mickleham Road were the new and upgraded traffic signals, associated street lighting, service relocations and drainage. Other features included construction of off-road shared user paths and allowance for a future third lane in each direction. The road enhancement is designed to service the projected population growth of Greenvale, Victoria. The project cost $13.3 million, is over 2.4 kilometres long and was completed in February 2008.[lxxxv]

Mickleham Road Duplication was the first project to calculate the amount of greenhouse gases (GHG) it emitted during construction, including from materials used and associated transport . From this initiative VicRoads have developed a framework for future road infrastructure projects to enable them to calculate their own carbon footprint. In Appendix A VicRoads has identified in a concept map which processes emit greenhouse gases. For this initiative VicRoads in alliance with BMD Constructions was awarded the Earth Award of Excellence in 2008.

VicRoads were able identify and calculate all the elements of road infrastructure that were generating GHGs. All aspects of road infrastructure were considered, including fuel used to transport materials to and at the site, fuel used for on-site construction plant, on-site electricity and the embodied carbon in the materials used, such as steel, concrete and asphalt.[lxxxvi] Even with the selection and use of sustainable materials the total amount of GHGs from the Mickleham Road Duplication came to 1,751 tonnes or 730 tonnes per km of road built. Most of the GHGs came from the embodied carbon of materials (73 percent) and on-site transport (24 percent). The remaining GHGs came from the transport of materials to site (2 percent) and from on-site electricity (1 percent).[lxxxvii] VicRoads was able to determine the magnitude of embodied carbon in the materials used, and these were, from largest to smallest: concrete (37 percent), cement treated crushed rock (29 percent), aggregate/base (21 percent), asphalt (7 percent) and steel (6 percent).[lxxxviii]

VicRoads was able to eliminate the carbon footprint from the construction of the Mickleham Road Duplication by planting 7500 trees, thus offsetting 2002 tonnes of GHGs. This cost approximately $25,000, equivalent to 40 million black balloons filled with GHG, making Mickleham Road Duplication the first “carbon neutral project” in Australia.[lxxxix] Working with the Department of Sustainability and Environment and the City of Hume a wildlife corridor was created on the east side of Mickleham Road Duplication to improve the habitat for native species in the area. Through the enhancement the risk of fauna crossing the road was minimised. Various applications of key options were found from the literature review. As there was a risk to native fauna there would have been an environmental impact assessment (EIA) carried out, as well as a SEA for the construction phase of road infrastructure. With the reduced emissions resulting from the use of alternative materials, the overall elimination of a carbon footprint from the project’s construction, and the creation a framework to calculate GHGs, VicRoads has created a benchmark for future projects.

Other key options that could have been employed that were not considered include the inclusion of helophyte filters, noise walls and a maintenance plan. With Mickleham Road having soil at the edge of the road, emissions from the runoff from the pavement will affect the soil. This will cause a build-up of toxins. Therefore proper drainage should be implemented along with helophyte filters to filter out the toxins. A maintenance plan would help regulate the amount of waste on the roads. Regular cleaning would not only clear the road of debris but also minimise the waste entering key areas such as drainage systems and basins. VicRoads also recognized other key options that would have reduced environmental pressures in road infrastructure, but due to time constraints of the project they were not able to be implemented. The key options recognized were the sourcing of local products, using products and materials that contain a high recycled content, and using bio-fuels or blended fuels in the plant rather than traditional diesel fuel. Other options that may have been implemented included reducing the amount of import or export of fill with better balancing of cut and fill, and the reduction of imported aggregate by the crushing of rock on-site.[xc]

The Mickleham Road Duplication and the Tullamarine Calder Interchange demonstrate that our national road infrastructure is embarking on notable sustainable options to reducing environmental pressures on road infrastructure. With the emergence of a framework to calculate carbon footprint, such calculations can not only be made for future road projects in Australia; this framework can also be the starting point for a national rating scheme for road infrastructure, which would accelerate the adoption of sustainable road construction in this country. The case studies drawn from a review of literature show that Australia has implemented some key options to reduce environmental pressures from road construction. Through careful selection of materials used in each project, finite resources have been saved, along with a reduction in GHGs. Both case studies concentrate heavily on materials and only marginally address other sustainable options. Not surprisingly, they do not reduce carbon emissions or environmental pressures post road completion. Innovations include the application of new materials, design elements and procedures to reduce environmental pressures, for example, solar panels attached to the noise walls, the type of fuel used, and specific materials chosen, such as recycled asphalt and fly substituted for cement. With the introduction of a framework for calculating the amount of carbon in a project, and the implementation of Australia’s first carbon neutral project, progress is being made in the right direction.

Strategic Area 2: Evaluate the future pressures for roads (producing an environmental, economic and social framework)

Investigate the potential for adaptation to future pressures such as climate change and peak oil, and The project aims to develop of a base framework for a 'Sustainability Assessment Framework for Road Infrastructure' (SAFRI) model. The new model will be used to undertake a preliminary comparison of current national practices to identify opportunities for improvement. Project partners will be invited to nominate projects implement the assessment framework as part of its development. The framework will tie in closely with the AGIC framework. As part of the second stage of the project beginning in October 2012 the research team intends to expand SAFRI and undertake a comprehensive comparison of current national practices to identify opportunities for improvement to inform recommendations as to potential legislative and policy adjustments and to investigate potential impacts and benefits of such adjustments.

What will be the increasing pressures on the 'Future of Roads'?

In the coming decades the design, construction and maintenance of roads will face a range of new, interconnected environmental, social and economic challenges. In many ways these will bear little resemblance to the challenges previously faced, and will require a range of new approaches. Environmental pressures will include the impacts of climate change on rainfall patterns and temperature profiles. Economic pressure will result from shifting global economic balances and flows, and will include materials and resources shortages, along with predicted increases in energy and resource prices globally.[xci] Social pressures will include potential shifts to lighter vehicles, reduced use of cars due to higher fuel costs, and political pressure to respond to climate change.

When considering the impact on the world's economies of such pressures it is sobering to consider that the distance covered by roads around the world is more than 34 million kilometres,[xcii] nearly 90 times the distance from the Earth to the Moon. Given that roads typically have a design life of 20 to 40 years, with bridges being designed for up to 100 years, it is crucial that future environmental impacts, economic risks, and social trends associated with roads be properly considered in order to minimise associated costs and impacts. With this in mind a number of Australian state governments are investigating the likely influences on the future of roads and considering how a strategic response can be informed – the impetus for this project.

The SBEnrc '*Future of Roads*' project is a collaboration between academia, government and industry to combine world class research with operational understanding and policy experience to inform the consideration of the increasing pressures that will face roads in the future. A key step in the early stages of the research project has been a review ofliterature to ascertain advances in this area around the world. Both the impact on roads of the future pressures just identified and roads' contributions to such pressures represent a significant challenge and an exciting opportunity. The research project seeks to demonstrate that by embracing new technology and innovations effectively and strategically, governments can ensure that roads not only minimise their impact on the environment and contribution to climate change,[xciii,xciv] but also make significant contributions to society, including through the enhancement of Australia's efforts to mitigate and adapt to climate change.

Considering the case of climate change as a pressure on the future of roads, the most recent Intergovernmental Panel on Climate Change (IPCC) assessments suggest that '*warming of the climate system is unequivocal*', and will have significant impacts on the world's cities and infrastructure. Such impacts are increasingly being felt with Australia experiencing marked declines in regional precipitation levels along the eastern and western coasts in the early parts of the last decade.[xcv] These changes to precipitation levels will have impacts on the future of roads and will influence soil moisture contents, pavement moisture levels and design life, and design loads on storm water infrastructure associated with roads.

The environmental, financial, and social impacts of climate change represent one of the most pressing global issues, one which will directly and indirectly impact current and future road infrastructure. The solutions to such a challenge will need to be dynamic and flexible to successfully navigate the inevitable changes to the environment, society, and the economy. The unprecedented nature of the potential impacts from climate change on roads is such that the existing assessment and planning frameworks are likely to be insufficient and will need updating. Furthermore, the potential interaction of the many concurrent pressures and events mean that it is urgent that we better understand the future of roads within these contexts, and design appropriate assessment and planning frameworks to ensure that road design and construction is resilient and responsive to the future.

An Overview of Emerging Frameworks

Existing efforts to adapt road building practices to address the threats of climate change are being enhanced by a number of emerging rating schemes for infrastructure, in Australia and abroad. The research team is in the process of investigating a number of such schemes and tools, to support the development of an assessment framework, the '*Sustainability Assessment Framework for Road Infrastructure*' (SAFRI). Emerging schemes and tools are as follows:

The Australian Green Infrastructure Council (AGIC)

AGIC is preparing to release an assessment scheme to the industry in late 2011 applicable to many types of infrastructure, including roads.

In a recent industry workshop on the Future of Roads run by SBEnrc, participants were provided with a list of the preliminary themes from the Australian Green Infrastructure Council (AGIC) Rating Tool that is currently under development, as shown in Table 2.

Table 2: *Australian Green Infrastructure Council Rating Tool (Preliminary Themes)*

– Purchasing & Procurement – Reporting & Responsibilities – Making Decisions – Climate Change Adaptation – Knowledge Sharing & Capacity Building – Value For Money – Economic Life – Energy Use – Water – Materials Selection & Use – Greenhouse Gas Management – Discharges to Air Land & Water	– Land Management – Waste Management – Functioning Ecosystems – Enhanced Biodiversity – Participatory Processes – Positive Legacy – Urban & Landscape Design – Knowledge Sharing – Capacity Building – Increased Knowledge and Applied Sustainability and – Equity.

Note: Four sub-categories are yet to be decided and are currently under review.

Source: Australian Green Infrastructure Council.[xcvi]

VicRoads 'INVEST'

VicRoads have released 'INVEST' (Integrated VicRoads Environmental Sustainability Tool), a tool that enables assessment of sustainability considerations and practices included in road construction projects.[xcvii] The tool promotes projects that advance the state of sustainable transport solutions, and requires independent certification. Early outcomes of INVEST have been reported to be the driving the achievement of reductions in greenhouse gas emissions from road construction projects.

Roads Australia

Roads Australia, the national peak body for the road transport sector, has developed a Sustainability Chapter to emphasise and address sustainability in major road construction projects. This has resulted in a number of non-price based criteria to rate and rank the overall sustainability of complex road infrastructure projects.[xcviii]

Infrastructure Australia

Infrastructure Australia has developed a number of tools and reports related to improving infrastructure in Australia.

Greenroads (US)

In the US, the 'Greenroads' rating scheme is a sustainability rating system for road design and construction. The tool assesses both mandatory practices (i.e. minimum requirements for green roads) and 'voluntary credits', which may be predefined or created through individual projects. In this way, the Greenroads rating scheme is able to rank and rate projects and encourage new and innovative construction practices and paradigms.[xcix] Greenroads began in the University of Washington's Department of Civil and Environmental Engineering in 2007. Originally, it was a Masters thesis in the construction/transportation area of the department. In mid-2008 the university teamed up with CH2M HILL, a multi-national consultancy, to fully develop the Greenroads performance metric. Over the four years of development, Greenroads has been tested on over 50 design and construction projects of various scales and phases. Certification is now available in the US through the Greenroads Foundation (a non-profit organization) for a nominal fee. The categories listed below identifies the key elements required to be analysed and the sub-categories show the areas requiring innovation in road infrastructure.

Table 3: *Greenroads US categories*

– Project Requirements – Environment and Water – Access & Equity – Construction Activities	– Materials & Resources* – Pavement Technologies* – Custom Credits
Key sub-categories	–
Materials & Resources – Lifecycle Assessment – Pavement Reuse – Earthwork Balance – Recycled Materials – Regional Materials – Energy Efficiency	Pavement Technologies – Long-Life Pavement – Permeable Pavement – Warm Mix Asphalt – Cool Pavement – Quiet Pavement – Pavement Performance Tracking

Source: Greenroads US.[c]

GAIA Environmental Assessment Tool

Investigations revealed an environmental decision-making tool know as GAIA,[ci] developed by Euravia, a multi-national infrastructure company employing 40,000 people. Eurovia developed it to address new methods and materials for 21st Century roads. The contracting authorities use the software when evaluating technical solutions proposed by companies bidding on projects. The tool compares the environmental assessments of different construction solutions and theri implementation. The system then calculates the environmental impact of each solution using recognised, published European databases. The evaluation uses impact categories for construction materials (resource depletion, GHG emissions, atmospheric acidification etc. taken from the French NFP 01-010 standard) and bespoke impacts including but not limited to local road transport (tonnes/km) and excavated materials removed for recycling.

The GAIA environmental assessment tool provides users with criteria that can be used to support decision-making. It is said to enable both the roadworks company and the customer to ask the right questions in order to reduce environmental pressures on site. It makes possible a systems approach to global warming issues, and makes greenhouse gas emissions and resource conservation paramount questions in the road structure design process.

The Highway Sustainability Checklist

The Highway Sustainability Checklist was developed to support the integration of environmental stewardship into highway-related practices. Parsons Brinckerhoff, a US based global infrastructure consultancy, was named by the American Association of State Highway and

Transportation Officials (AASHTO) as the national winner for the 2007 World Road Association's (PIARC) International Competition. The checklist is a compendium of possible measures associated with phases of highway projects. It is said to enable highway improvements to incorporate elements that go beyond satisfying minimum functional criteria and address additional factors that contribute to sustainability of the natural, built, and social environment.[cii] The checklist is flexible and can be adapted to a more structured approach with criteria weightings, and it can be used as an agenda for project meetings. The checklist is intended to generate a sustainability-based frame of mind rather than a "mechanical" approach, by triggering criteria that might otherwise be overlooked. The intention is not simply to avoid or minimize harm (minimum standards) but rather to create net benefits that “transcend transportation functionality”, benefits that encompass the natural, built and social environments. Improving existing facilities provides a unique opportunity to achieve "better than before" outcomes in terms of sustainability and functionality.

Institute for Sustainable Infrastructure

The Institute for Sustainable Infrastructure (ISI) is a non-profit corporation delivering a civil engineering infrastructure sustainability rating currently undergoing public comment with a planned implementation in 2012.[ciii] ISI was formed by the American Society of Civil Engineers (ASCE), the American Council of Engineering Companies (ACEC), and the American Public Works Association (APWA) in 2010. Its voluntary civil infrastructure rating system, envision TM, is a framework that provides owners, agencies, engineers and others with a comprehensive approach for describing the features and performance of sustainable projects. The framework is focused on the needs of the United States and Canada, but the applications and benefits are readily transferable to other locations if the user applies discretion in adapting the criteria and performance measures to local conditions.

Energy Conservation in Road Pavement Design

The European Union project entitled Energy Conservation in Road Pavement Design (ECRPD), Maintenance and Utilisation, was completed in early 2010. The road pavement focused project looks at evaluating energy conservation in pavement manufacture and placement using JOULESAVE 2 software to identify benefits including:[civ]

- low energy pavement materials
- energy saving in road maintenance so as to save energy in vehicle use
- preserving road pavements in a condition that maximises the energy efficiency of vehicles using the road.

This software package evaluates the energy required to construct and carry out maintenance works on a road and also the energy used by vehicles over the course of the life of the road. The project has established that during construction the most energy-intensive process is the production of asphalt mixtures, which consumes about 92 percent of energy. Transport of materials and mixtures consumes about 6 percent of energy and processes of pavement laying consumes less than 2 percent of energy.

The software reveals that significant energy savings could be achieved in the following areas:

- Construction energy: savings of up to 47% (primarily due to 'low energy' material use)
- Operation energy: savings of up to 20% (primarily based on route selection)?
- Maintenance: savings of up to 30%.

These savings are significant and indicate that substantial reductions in energy use are possible if consideration is given to the materials being used. The use of 'low energy' materials is the primary factor in major construction energy savings.

A Focus on the AGIC Infrastructure Sustainability Assessment Categories

An Overview of AGIC

The Australian Green Infrastructure defines itself as: *"A member based industry association committed to the delivery of more sustainable outcomes from the design, construction and operation of Australia's infrastructure. AGIC was formed in 2008 by industry professionals from engineering, environmental, planning, legal, financial, and construction backgrounds working in both private and public organisations related to infrastructure."*[cv] The mission statement of AGIC is: *"AGIC will be the principal industry catalyst for advancing sustainability in the design, construction and operation of Australian infrastructure."*[cvi] There are seven assessment categories in the AGIC system. Each category is further subdivided into subcategories to make twenty-eight assessment areas. The categories and their associated subcategories are listed below:

1. Project Management & Governance
   - *1.1 Purchase & Procurement*
   - *1.2 Reporting & Responsibilities*
   - *1.3 Climate Change Vulnerability*
   - *1.4 Making Decisions*
   - *1.5 Knowledge Sharing & Capacity Building*
2. Economic Performance
   - *2.1 Value for Money*
   - *2.2 Due Diligence*
   - *2.3 Economic Life*
3. Using Resources
   - *3.1 Energy Use*
   - *3.2 Water*
   - *3.3 Material Selection & Use*
4. Emissions, Pollution & Waste
   - *4.1 Greenhouse Gas Management*

4.2 Discharges to Air, Water & Land

4.3 Land Management

4.4 Waste Management

5. Biodiversity

5.1 Functioning Ecosystems

5.2 Enhanced Biodiversity

6. People & Place

6.1 Health, Wellbeing, Safety

6.2 Natural & Cultural Heritage Values

6.3 Participatory Processes

6.4 Positive Legacy for Current & Future Generations

6.5 Enhanced Urban & Landscape Design & Aesthetics

6.6 Knowledge Sharing, Shared Intellectual Property

7. Workforce

7.1 Safety, Health & Wellbeing of Workforce

7.2 Capacity Building

7.3 Increased Knowledge of Applied Sustainability

7.4 Equity

The assessment tool has been developed for AGIC by several consultants though a tendering process, including Aurecon, Parsons Brinkerhoff, Institute of Sustainable Futures University of Technology, Smart Future, Snowy Mountains Engineering Corporation, Edge Environment, Worley Parsons, and Envisage. The tool is at the pilot trial stage and expressions of interest have been called for projects to be assessed. Round 1 of the pilot trial was limited to projects in Brisbane and Sydney. Expressions of Interest for Round 2 of the pilot trial will close on 1 August 2011. Expressions of Interest will be submitted for the three selected road projects for inclusion in Round 2.

According to AGIC, the primary purpose of road infrastructure is to facilitate resource exploitation, whether that resource is physical, agricultural or pastoral land, forests, mineral resources, water resources, residential, tourism or other leisure activities or human population. The secondary purpose of road infrastructure is to facilitate communication between population centres and distributed networks and provide amenity to those centres and distributed networks. The sustainability of the communities that rely on the road infrastructure depends on the sustainability of that infrastructure. A tool is required to assess whether the appropriate road infrastructure is being planned or has been constructed.

A resilient road may be considered to be one that serves the need of a community in the face of change whether that change is in population, traffic densities or the resources being exploited. A sustainable road may be considered as one that is able to be constructed and maintained with a minimal environmental impact locally and in a wider context through a significant lifetime.

There are two key areas to investigate, firstly whether the resources to maintain these roads are available and sustainable; and secondly whether road infrastructure is sustainable when the exploitable resources are exhausted or depleted. Further when considering the future of roads the following areas are important.

1. What is the right question to ask to determine whether the road infrastructure under investigation is sustainable?
    a) To whom ought the question be addressed?
    b) Who are the stakeholders in the provision of road infrastructure?
    c) For whom is the road infrastructure being created?
    d) Can sustainable road infrastructure have a defined lifespan (design life)?
2. Western Australian Infrastructure Context
    a) Are these projects building infrastructure that will create a more sustainable human society in Western Australia?
    b) How does road infrastructure contribute to the flourishing of human society in Western Australia?
    c) What are the social impacts of changing resource availability or suitability and the degradation of the road infrastructure that has been created to service what was the initial resource?
    d) What are the social impacts of developing and redeveloping of road infrastructure?
    e) What is the impact of resource depletion on the prosperity of Perth?
3. AGIC's Infrastructure Sustainability Rating Scheme
    a) Is the link between resilience and sustainability clearly defined or is it a complex relationship with multiple variables?
    b) What method of measurement can be used to determine the effectiveness of a sustainability plan?
    c) Is the Australian Green Infrastructure Council's Infrastructure Sustainability Rating Scheme adequate in assessing the sustainability of roads or does it need enhancing?
    d) Does it adequately define what a sustainable road is?
    e) Does the road infrastructure drive development or is development the driver of infrastructure creation?
    f) Does a sustainable road develop perverse resilience as resource depletion progresses?
4. Policy implications
    a) Can a decision making topograghy be developed as a continuity diagram to guide policy towards more sustainable road infrastructure?
    b) Are the current government and agency sustainability policies appropriate for the creation of sustainable infrastructure?

c) Do the current sustainability policies seek to create a sustainable human society in Western Australia?

Case Studies

Three case studies in Western Australia are proposed for the assessment of the AGIC Infrastructure Sustainability Assessment Categories using the AGIC Assessment Tool, namely the Great Eastern Highway – Roe Highway Interchange, Great Eastern Highway – Kooyong Road to Tonkin Highway and the Gateway WA. An Expression of Interest for inclusion in the AGIC pilot trial of their Assessment Tool will be submitted for each of the projects. MRWA are interested in the having other projects included in the pilot trial. Two additional expressions of interest will be submitted, namely James Price Point and Wheatbelt ISA.

Great Eastern Highway – Roe Highway Interchange

The Great Eastern Highway – Roe Highway Interchange is currently under construction with a date for completion of May 2012. The project will create a grade separated interchange between the Great Eastern Highway and the Roe Highway at Midland, an eastern suburb of Perth.

"Once complete, it will enable Roe Highway traffic to flow freely over Great Eastern Highway via a bridge and efficiently and safely integrate connecting traffic in all directions. It will also:

- *Improve safety by reducing the number and severity of accidents, in particular rear end collisions;*
- *Reduce road user costs and vehicle emissions as a result of delays;*
- *Improve the efficiency and sustainability of the transport system;*
- *Reduce the likelihood of neighbouring areas being used as 'rat runs';*
- *Improve the approach to Great Eastern Highway for heavy vehicles; and*
- *Improve the level of service of Roe Highway.*
- *This project has been jointly funded by the Federal and State Government."*[cvii]

MRWA has developed the design of the interchange and associated modifications to the local road network through extensive consultation with the local community and transport industry.

Great Eastern Highway – Kooyong Road to Tonkin Highway

The Great Eastern Highway upgrade project between Kooyong Road, Rivervale to the Tonkin Highway, Redcliffe will widen the Great Eastern Highway from four to six lanes over a distance of 4.1km. The project is in the preconstruction phase with construction scheduled for commencement in 2011 and completion in 2013. A central median will be constructed to limit the number of conflicting movements to increase road safety. All major intersections will have dedicated turn pockets and allow U-turns. Parallel walk phases will be installed at all signalled intersections. Bus priority will be included in all major intersections to improve public transport travel times to make public transport more attractive through this area. More pedestrian and cycle friendly facilities will be included to all safe crossing of the highway. A pedestrian crossing near Abernethy Road will improve access to the Swan River and its foreshore and connect to the existing recreational path.

Gateway WA

The project covers the section of Tonkin Highway between Great Eastern Highway and Roe Highway, as well as Leach Highway from Orrong Road to Perth Airport. The primary objective is to provide safe and efficient access for all road users that will enhance social, economic and regional. The project is currently in the planning phase. Early planning has identified possible road and bridge improvements:

- *Upgrade Tonkin Highway between Roe Highway and Great Eastern Highway;*
- *Major freeway to freeway interchange at Leach Highway/Tonkin Highway, including new primary access road to consolidated airport terminals;*
- *Planning for a new interchange at Tonkin Highway - Boud Avenue;*
- *Diamond, grade-separated interchange at intersection of Horrie Miller Drive/Kewdale Road-Tonkin Highway;*
- *Intersection upgrade at Leach Highway/Abernethy Road;*
- *Upgraded interchange at Tonkin Highway/Roe Highway; and*
- *Upgrade and control of access along Leach Highway between Orrong Road and Tonkin Highway.*

Other key objectives include:

- *Improved connectivity between industrial areas and the primary road network for freight vehicles;*
- *Improved access to the Perth Airport for domestic, national and international travel and freight;*
- *Improved efficiency of the road network with grade-separation and extra lanes - resulting in reduced congestion, travel times, freight costs, fuel consumption and emissions;*
- *Provision of infrastructure and traffic management systems to manage congestion and capacity on the road links servicing Perth Airport and the Kewdale Intermodal Facility;*
- *Improved safety and efficiency of the road transport links surrounding the Perth Airport and Kewdale area, resulting in less crashes, reduced crash costs and less delays;*
- *Maximised economic potential of airport growth to WA and enhanced productivity, sustainability and liveability of the region;*
- *Enhanced economic potential of commercial land development in the Kewdale/Forrestfield area through improved connectivity with intermodal facilities and the regional road network;*
- *Assurance the road network does not constrain the capacity of the Perth Airport to deliver aviation services required for regional development and economic growth;*
- *Complements the major investment in aviation infrastructure that will result in consolidation of all large-scale air services into the current International precinct of Perth Airport; and*
- *Improved visitors' impressions of Perth by creating a more direct route to the city from the airport, via the Leach Highway/Orrong Road route.* cviii

James Price Point

MRWA, in consultation with the Department of State Development, is responsible for constructing a new 19 km fully sealed, all weather access road from the Broome – Cape Leveque Road to the proposed Browse LNG Precinct Site, an area just south of James Price Point approximately 60km north of Broome. At least two LNG projects are proposed for the site. The project will also include the reconstruction of 25km of the existing Broome - Cape Leveque Road from the Broome Highway and compliment the plans to seal the remaining 90km of unsealed section. The project aims to foster economic growth in the Kimberley Region by providing safe access for the provision of goods and services on the Dampier Peninsula, increase State Revenue and provide employment and training opportunities for local workers and businesses.

Wheatbelt ISA

The Wheatbelt Integrated Service Arrangement has been formed to provide road infrastructure maintenance services for the Wheatbelt North and Wheatbelt South Regions. The operational phase of the road network is the critical phase of the life of the asset. It will test how effective the tool is for an existing large piece of infrastructure. The Wheatbelt ISA manages 3445km of national and state roads.

Strategic Area 3: Build strategies for implementing the roads of the future (utilising scenario planning strategies)

Investigate the opportunity for utilising road areas to contribute to the mitigation of climate change and strengthening infrastructure and economic resilience, the project aims to develop an 'Innovative Scenarios for Sustainable Road Infrastructure' (ISSRI) scenario planning methodology. Using the ISSRI scenario planning methodology will be used to interrogate a range of innovative scenarios to consider the availability, reliability and cost of existing and emerging options, considering the likelihood of adoption and appropriateness of each scenario in the context of various socio-economic and environmental conditions. As part of the second stage of the project beginning in October 2012 the research team intends to expand ISSRI to consider a wider range of potential scenarios in collaboration with partners.

This part of the literature review looks at various scenario planning methodologies to inform the development of an 'Innovative Scenarios for Sustainable Road Infrastructure' (ISSRI) scenario planning methodology, drawing on outcomes from the stakeholder engagement workshop that was held. The review focuses not on the content of the scenarios but rather on how they are developed. The primary disciplines investigated include futures research, resource management and business, and sustainability based methods.

The Development of Scenario Planning

The scenario planning methods commonly used today started primarily in the 1970s, with the Royal Dutch Shell (Shell) organization. Shell was concerned about how increasing oil prices and other uncertainties resulting from the formation of the Organization of Petroleum Exporting Countries (OPEC) would impact on their business. In order to help reduce some of the possible risks they developed a scenario plan addressing how they might respond. Thus, when the oil price did rise in October 1973 Shell was prepared. Its scenario planning forms the basis for many of the current methods used today, and is described below. Scenarios are stories of the future. They are not predictions. Rather, they are narratives aimed at developing constructive thinking about the future;[cix] 'a means of exploring a variety of long-range alternatives'.[cx] '[W]hile we cannot know what will be, we can tell plausible and interesting stories about what could be'.[cxi] Scenarios need to represent a range of alternatives, not just the best and worst outcomes, and their reliability is less important than the conversations, learnings and decisions introduced to the discussions. The common generic types of scenarios are:

Inductive scenarios: These are stories about the future based on the critical uncertainties developed from discussion and exploration of drivers and trends.

Deductive scenarios: These are scenarios created using two or more critical uncertainties to structure scenarios.

Incremental scenarios: These are scenarios developed from one 'official' future and two plausible alternatives.

Normative scenarios: These are visioning futures: they are the futures we want to happen.[cxii,cxiii,cxiv]

The process of developing scenarios, usually conducted in a workshop setting lasting one to three days, is as important as the final scenarios themselves. The process, through active and interdisciplinary learning, allows for the deconstructing of preconceived ideas about the future, and of biases and cultural or institutional norms. The process, therefore, enables positive, practical and proactive strategies to be developed, rather than 'reactive decision making'.[cxv] Scenarios provide support for informed decision making, enabling analysis of decisions, the understanding of relationships between issues, and the challenging of cultural norms and assumptions. They enable strategies and plans to develop that combat risk and incorporate necessary and positive changes. They are part art and part science.[cxvi,cxvii]

Scenarios revolve around driving forces and critical uncertainties. These are the 'on-going forces that help to shape the future' and the acronym STEEP identifies key aspects of scenarios: social, technological, economic, environmental and political.[cxviii] Driving forces can be predetermined, and certain or uncertain. The critical uncertainties are may be key driving forces. These can be used to develop and shape the scenario. Critical uncertainties do not have to be catastrophic events, although this is often the case, with scenarios revolving around risk management or large-scale environmental or economic disasters. There is a growing trend for scenarios concerned with global futures, particularly around issues of climate change, population growth and the depletion of natural resources. These scenarios usually depict alternative futures, offering either pessimistic or hopeful worlds.[cxix]

As stressed through the scenario planning literature it is important to remember that scenarios are not predictions or the only possible alternatives, and should not be presented as such.[cxx] The value of scenarios lies in the underlying dynamics and the challenges and opportunities they present. Shell International, which provide the basis of many scenario planning methodologies, stresses in its scenario planning description that scenarios are to help raise issues and challenge people to think about the future in a constructive fashion. Therefore, in scenario development it is important to avoid providing very detailed descriptions of events and timings, as 'precise details can seem misleadingly like predictions' and 'scenarios are intended to describe a context. They are not meant to instruct their users on how to respond to different circumstances, but to provide sufficient information for the recipients to imagine being in a particular future, and to think about how they might behave in it'.[cxxi] In addition, scenarios are unable to act as predictions because we can be surprised and lack knowledge about the future.[cxxii]

An Overview of Scenario Planning Methodologies

A basic scenario planning framework could be considered to consist of the following steps:[cxxiii]

1. Define a scenario question/problem/statement/focal issue.
2. Define a timeframe.
3. Determine current trends. From these, determine the driving forces and the critical uncertainties, and any relationships between these.

4. Work through the critical uncertainties and develop a basic scenario structure (sometimes called mini-scenarios) for each scenario. This step can use various structuring elements such as 2x2 matrix[cxxiv] or the matrix used by the Millennium Project.[cxxv]
5. Test the scenario structure outcomes against the current trends, making sure the scenarios are valid, internally consistent, relevant, and different enough from each other to provoke useful dialogue.
6. Develop the scenario details into a coherent story.
7. Construct a powerful title/metaphor for each scenario.

This basic framework can be varied depending on the purpose of the scenarios. The principle variation is in how the critical uncertainties are developed into a scenario framework. This can be clearly seen through the scenario examples below. Many of the current scenario planning methods have been developed (or built upon) from the Royal Dutch Shell (Shell) scenario planning methods.[cxxvi]

Royal Dutch Shell (Shell) Scenario Planning Method

Shell's scenario planning methods form the basis for many current scenario planning frameworks. Shell uses a relatively qualitative technique designed to include various decision makers and enable them to see beyond their preconceived ideas of the future when developing possible scenarios. This technique develops a small number of scenarios (usually 2 or 4) from a set of critical uncertainties or key trends. The Shell scenario planning process is conducted using a workshop format that includes diverse stakeholders, disciplines and perspectives, and follows these steps:

1. *Conduct an orientation workshop.* This workshop informs stakeholders on all of the research conducted so far. The research is compiled into themes that then are merged into sets of key research themes.
2. *Identify critical uncertainties within each theme.* Identify which of the driving forces in each theme are certain or uncertain. Then identify the critical uncertainties within each theme by determining the driving forces, addressing how these driving forces may change and how they relate to each other and to the themes. Think about what the outcomes of both the certain and the uncertain driving forces are likely to be, particularly any extreme outcomes. Identify which driving forces are most challenging and/or relevant.
3. *Develop a scenario structure plan*. Develop a structure plan that 'comprises one or more focal questions' and 'a branching point with two or more branches for each critical uncertainty'. This provides the scenario outline. The focal question is a 'broad definition of the major challenge(s) that the primary recipients of the scenario will face within the set timeframe. This focal question must be framed in a way that allows for exploration of critical uncertainties. Branches are the different directions that a critical uncertainty can move, with each branch leading to possible future branches. By following these branches the scenarios play out in different ways, developing different directions and results. The

scenario outline is the story created by following different paths through the alternative branches.[cxxvii]

4. *Developing the scenario structure plan to create outlined scenarios.* This step involves choosing an approach, from the following, to developing the scenario:
   a. *Deductive*: Choose two critical uncertainties and describe the extremes on a matrix. Develop storylines for the paths in each segment of the matrix and develop descriptions of how the stories could shift from one quadrant to another.
   b. *Inductive*: Start with different chains of events (no less than 3 events per chain) and construct a conceivable storyline from each. This description enables the development of a scenario structure, which can lead to alternative scenarios and help to frame a focal question.
   c. *Normative*: This approach is used when you are choosing a future you want to occur. Start with a set of characteristics that describe this future at the end of the timeframe, and 'work backwards to see what it would take to get there and whether it is plausible'. This will highlight the critical uncertainties that can be taken through the branches and the focal question, and how these uncertainties can be negotiated.[cxxviii]

   At this stage possible scenario structures can be combined as appropriate.
5. *Develop the scenarios into stories*. Once the scenario structure and themes are established, then the scenarios can to be developed into an interesting and creative story. This is generally done around themes.
6. *Present the scenarios*. Present the scenarios to the team of stakeholders. At this stage, test the scenarios for plausibility, challenge, relevance and clarity. This will determine if any further work is needed. It is important to remember that this stage does not add any new information, rather it is about making sure the scenarios are plausible and communicable.[cxxix]

Shell International (2008) stresses that, although there method provides a linear framework, the development of scenarios is not nearly as linear or mechanical as this process implies. Therefore it is important to use judgment and intuition in the development of scenarios. In addition, Shell International warn against the use of probabilities when constructing scenarios as the point is to incorporate variations into scenarios, rather than 'collapse differences into a single quantifiable and comparable value'.[cxxx]

The Shell method is very well known, widely adopted and thus forms the basis of many scenario planning methodologies. It is adaptable and provides a solid basic scenario planning framework. An example of a scenario planning framework developed from the Shell process in an Australian context is given later in 3.1.1.

Case Study: National Strategic Workshop on Genomics and Gene Technology

The method described here is from a scenario planning process conducted by the John Curtin International Institute (JCII) for the Australian Research Council (ARC) and the Rural Research and Development Corporations (RDCs).[cxxxi] It was conducted in a workshop situation using a method based on Shell's scenario planning tools. The steps used were:

1. *Undertake preparation.*
    (a) Conduct interviews with a wide range of stakeholders, using Shell's scenario planning questions.
    (b) Develop an overview of current issues, trends, emerging technologies, innovations and investments in the field.
2. *Identify the key factors.* Identify what the key factors are, including the range of concerns, the trends and any other relevant issues.
3. *Identify the timeline*. Determine the appropriate timeframe(s). Timeframes can be staged also (for example: two years and ten years).
4. *Display the key factor summaries*. This step is concerned with ensuring that all participants understand the key factors. This particular workshop displayed the key factors on an Idon (a visual display that enables manipulation of large amounts of data). However, other methods could be used.
5. *Identify the inevitables*. Identify any factors that are certain or predetermined, meaning they will apply regardless of what the scenario is, identify the uncertainties (these are what will drive the scenarios) and any driving forces.
6. *Group the key factors*. Group the key factors according to how they impact on the primary issue. The grouping used here consisted of:
    a. Global. These are factors that will 'impact society as a whole and are beyond the ability of one organisation or industry to control'. These will act as drivers in the scenarios.
    b. External. These are factors that are external to the industry. It will impact the whole industry and 'are beyond the ability of one organisation to control'.
    c. Internal. These are factors that are internal to the industry or organisation.
7. *Rank the drivers (factors).* Rank the drivers into two overlapping groups: 1. those drivers that are uncertain; and 2. those drivers that are influential. The drivers that occur most frequently in both groups become the parameters. Some of these drivers will affect all scenarios, some will only affect some.
8. *Assign the drivers a parameter. The identified drivers (factors) are then given a parameter or a broad range of effects, for example in this case the parameters were: enabling, unclear, absent and restrictive. Parameters must be broad to enable the 'greatest possible divergence in scenarios'.*
9. *Create a scenario framework. Place the chosen driving forces down the left-hand side and the columns for scenarios placed along the top (see Table 4.). The driving force parameters are then assigned to the scenarios looking at an appropriate range. This table produces the overall parameters for the skeletal scenarios.*

Table 4: Scenario planning framework.

Drivers	Scenario A	Scenario B
Driver A (i.e. Economy)	Strong (impacts all scenarios)	Strong
Driver B (i.e. Government policy)	Enabling	Restrictive
Driver C (i.e. Environmental issue)	Unclear	High cost

10. Develop 'what ifs'. Brainstorm a series of external, unpredictable factors that could impact dramatically on the future. These can provide possible storylines for the scenarios.
11. *Develop the scenarios*. In groups, develop the outline narrative of a scenario using the scenario framework as a guide. When doing this it is important to determine if any of the internal and external factors can help develop the scenario plot, along with any of the what ifs. Name the scenario based on the major driving factor that shapes it. It can help at this stage to think of the end timeframe and work backwards. At this step it is important to make sure your scenario addresses the key issue and is relevant. Finally present your scenario back to the group.
12. *Identify positives and negatives*. Identify the key elements of each scenario and evaluate their potential impact in terms of positive and negative.
13. *Identify strategies and action plans for each scenario*. Determine the possible strategic opportunities and barriers embedded in each scenario, and develop action plans. This step looks at how the scenarios can be implemented and developed, including the implications of each action.[cxxxii]

This method is comprehensive. It is very workshop and stakeholder focused and has the potential to produce scenarios that are appropriate to the group. This process is aimed at arriving 'at several parallel hypotheses about the future which can be held at the same time'.[cxxxiii]

The 2x2 Matrix 'Double Uncertainty' Method

The 2x2 matrix or double uncertainty method is used to develop four scenarios that generate challenging questions. It is a useful method for organisational or community based scenarios and provides a snap-shot of the future with a clear audit trail.[cxxxiv] The method follows a problem solving structure. This method is commonly used and well known.[cxxxv] The steps involved in this method includes:

1. *Determine driving forces*. Analyse and determine the driving forces.
2. *Identify the critical uncertainties*. The critical uncertainties can be identified by prioritizing the driving forces identified in the previous step according to their importance (with

regard to the focal issue) and how uncertain they are. The driving forces that are most important to the focal issue and most uncertain thus determine the critical uncertainties.

3. *Construct the matrix*. The matrix is constructed using the critical uncertainties (see Table 5.). These become the axes of the matrix. It is important that these drivers do not influence each other, as the interface between the two (how they play off each other) is what creates the scenarios. These axes can be viewed as conceptual poles encompassing what is possible within the timeframe, or in other words 'continuum of possibilities ranging between two extremes.'[cxxxvi]

Table 5: Example of the 2x2 matrix framework.

Scenario A (continuum) Driver 1	**B**
(i.e. more, strong) Driver 2 **C**	(less, weak) **Scenario D**

Scenario A A world with a strong social safety net, perhaps less devolution of social services, and a narrowing income gap Driver 2: Strong economy	Driver 1: More government **B** Weak economy
C	very inward-looking environment with a crumbling infrastructure for social services; it could also mean a world of innovation at the local level driven by economic necessity Less government **Scenario D**

Source: Example compiled and constructed from Global Business Network (2004).[cxxxvii]

4. *Create scenarios*. Combine the different uncertainties in the matrix to develop four scenarios.

Reviews on this method suggests that the 2x2 matrix method provides a clear and logical structure from which to develop scenarios, but it is very dependent on the chosen axes, is based within current ideologies without allowing much room for critical thinking or the incorporation of varying standpoints, and the scenarios created often offer little in the way of surprise.[cxxxviii] Curry and Schultz (2009) in their applications of this method maintain that 'the 2x2 matrix generated coherent, cohesive scenarios that offered enough difference from the present to generate strategic insights, but were not different enough to startle or provoke: they didn't generate any big questions about transformations in deep structures'.[cxxxix] Some of these issues can be overcome by incorporating other methods into the 2x2 matrix framework, particularly the Manoa method of creating a futures wheel (see below).

Causal Layered Analysis (CLA)

The causal layered analysis (CLA), or post-structural participation approach, was developed by Sohail Inayatullah in 2004. It is an integrative approach, developed to overcome some of the limitations of other scenario approaches, particularly the 2x2 matrix method, and is used mainly in Australia and Asia.[cxl] It is highly workshop based and takes a lot of preparation to develop shared perspectives of the present and future and to determine the possible drivers. The method used in CLA divides knowledge into four layers: litany (how trends are presented in the public domain, for example: 'Globalisation will erode the local colour in our organisation'); systems ('causal understanding-ideology'); worldview; and metaphor.[cxli] The metaphor stage introduces a challenging metaphor aimed at introducing a change in direction. The layers are all equal and represent different ways of viewing the world, enabling different scenarios to emerge. There are two stages to this scenario planning framework (outline in Figure 4):

1. *Analysis phase*: This phase involves working through the layers from litany to metaphor with litany provides the initial 'story'.
2. *Inflection phase.* This phase occurs at the metaphor layer and involves modifying or changing the story. The metaphor layer is a challenging perspective which is then worked into the story.

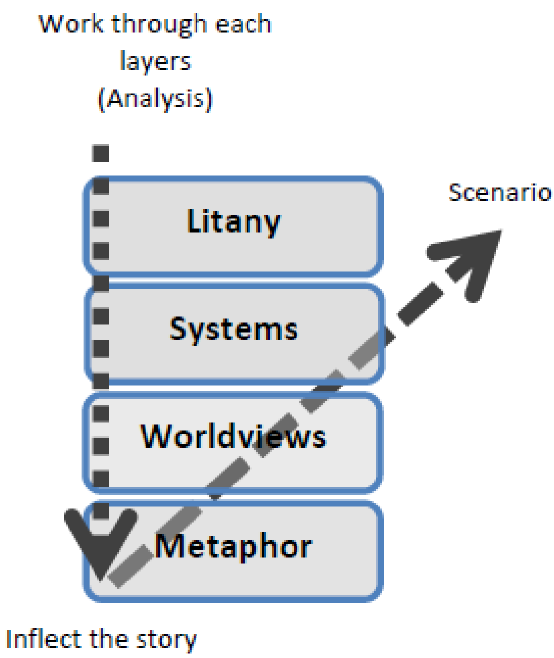

Figure 4: CLA approach to scenario planning. Source: Redrawn and altered from Curry & Schultz (2009).[cxlii]

The CLA approach results in a wide variety of scenarios. This is both positive and negative, with widely differing scenarios able to create new insights and challenging assumptions but also making policy and strategic insight hard to determine.

The Manoa Approach

The Manoa approach creates scenarios based on the intersection of multiple emerging trends and their interplay.[cxliii] This approach requires at least three emerging drivers and is focused on the development of long range scenarios, working best for 25 plus year scenarios, or the timeframe of approximately one generation. The purpose of this scenario method is to develop surprising scenarios that challenge current thinking and provide insight into how the future might develop. This scenario is conducted in a workshop setting. The steps in this process include:

1. *Determine emerging issues*. Choose 3-5 significant emerging issues of change (or weak ‘emerging’ uncertainties). These are the drivers of change that are only just becoming noticeable but would have great impact in the long term, and are called 'weak signals'. This step can be done by reviewing potential drivers and choosing those that are the ‘newest’ if the emerging drivers of change are unclear.
2. *Determine the scenarios*. From these emerging issues develop scenarios. (Note: the idea is to create futures and then embedded your topic in them)
    a. *Brainstorm scenarios.* Brainstorm or mindmap the potential impact cascades (primary, secondary and resulting) of each uncertainty, working through each one individually. This creates a futures wheel.
    b. *Determine cross impacts of scenarios*. Determine and question the cross-impacts arising from 3-5 of the drivers and how their impacts work together. Where these cross-impacts meet is what determines the final scenario.
    c. *Test the scenario*. Check the scenario for depth of detail using an ethnographic inventory (exploration of deep social structures and cultural and belief systems).
3. *Embed your topic in the scenarios*. Check the scenarios against your topic or question by embedding your topic within the developed scenarios
4. *Title your scenario*. Develop a summary ‘metaphor’ or title.

The scenarios that develop out of the Manoa process are creative and serve to challenge current thinking. The use of emerging issues of change or 'weak signals' distinguishes this from the other scenarios, which focus on the current major uncertainties.

The Millennium Project

The Millennium Project produces many scenarios particularly focused on global futures. Many of their scenario developments follow on from Shell’s techniques.[cxliv] A futures technique explored by the Millennium Project in developing scenarios is the use of the cross impact of trends. This can be done in a matrix (see Table 6.) and can be incorporated within the structure of other scenario planning methods.

Table 6: Matrix of the cross impact of trends. Developed from Glenn (2008).

	THEME 1	THEME 2	THEME 3
THEME 1			
THEME 2			
THEME 3			

The Landscape Scenario Method, CSIRO Sustainable Ecosystems

The landscape scenario method is a 'framework for developing alternative landscape scenarios with the aim of helping policy makers design evidence-based, long-term policy in the face of different sources of uncertainty'.[cxlv] This method builds on the scenario planning methods of Shell and Schwartz (1996) combining it with an analytical simulation model, and it is sometimes referred to as the *story-and-simulation* method. This approach is similar to the Millennium Project (2011) global scenario method described above. The steps used in this method are:

1. *Determine the focal Issue*. Determine and clearly define what the focal issue is.
2. *Brainstorm the key drivers*. Identify all drivers (external and internal). This process needs to be multi-disciplinary to incorporate a wide range of information and issues. Cluster and rank the drivers according to their impact on the focal issue and their ease of predictability.
3. *Identify the critical uncertainties*. Differentiate between fixed or predicable drivers (things that cannot change, will happen regardless of decisions and are common to all scenarios) and those drivers that are unpredictable (the critical uncertainties).
4. *Determine the scenario logic*. Determine how the uncertainties work with the predictable trends to develop a scenario structure. This can involve combining uncertainties or seeing how they interact with each other.
5. *Develop the scenario*. From the previous step, work through the uncertainties and certainties to develop two to four coherent scenarios relevant to the focal issue. These should be challenging but plausible to the stakeholders.
6. *Model the scenarios*. This framework uses the Australian Stocks and Flows Framework (ASFF) modelling platform.
7. *Return to the focal issue*. Test the final scenarios against the focal issue, asking whether it addresses the focal issue.[cxlvi]

The landscape scenario method offers some real possibilities to the development of a scenario planning methodology. The use of the ASFF model requires further investigation.

Business Based Scenario Planning, Schoemaker

Paul Schoemaker is an international strategic thinking expert and author on many books in strategic planning and scenario planning. He has developed a comprehensive scenario planning methodology for managers and businesses to help with strategic planning. The scenario planning methodology steps Schoemaker describes are as follows:

1. *Define the scope*. Determine the scope of analysis (for example: geographic area and technologies). For this step think about what knowledge would be of greatest value. Determine the timeframe. Determine the major stakeholders.
2. *Identify the basic trends*. Briefly explain each trend, including how it influences the scope. This step can be done with the use of an influence diagram (a list diagram) which rates the trends into positive, negative and uncertain. Separate the key trends into those that are certain (confident) and those that are uncertain or unknowable (unconfident).
3. *Identify key uncertainties*. From the identified uncertain trends in step 2, identify which are key to the scenario development. Identify any relationships between these key uncertainties. This identification can help to rule out any implausible outcomes. Then for each of these key uncertainties, determine simple possible outcomes. This is the ingredients for your scenarios.
4. *Construct initial scenario themes*. Construct initial scenarios. This can be done by two possible ways:
    a. Identify extremes. Put all positive critical uncertainties relative to current strategy in one scenario and all the negative critical uncertainties into another. This helps to identify surprises.
    b. Group around themes. Group or cluster the various critical uncertainties into themes (for example: the top two uncertainties, uncertainties that have continuity, uncertainties that we are prepared for, uncertainties that would create turmoil etc.).
5. *Check for consistency and plausibility*. Check the initial scenarios for consistency and plausibility. This can be done by asking:
    a. Are the trends compatible within time-frames?
    b. Do the scenarios combine outside uncertainties that indeed go together?
    c. Are the major stakeholders placed in positions they do not like and can change? (For example: oil companies changing oil prices when they are not in their favour).
6. *Develop learning scenarios*. From the above step, identify any major themes that emerge. From that step it should be possible to arrange and weight the possible outcomes and trends for importance in scenarios and for the original goal. These themes and outcomes can be arranged into learning scenarios. Give these scenarios a name. The scenarios at this stage are tools research rather than decision making tools.
7. *Identify further research needs*. Conduct further research into the uncertainties and trends that have been uncovered by the learning scenarios. Re-examine any internal inconsistencies of the scenarios.
8. *Develop quantitative models.* Determine whether any of the interactions in the scenarios can be formalised via a quantitative model, and whether this would be helpful.

9. *Converge towards decision scenarios*. Retrace steps here to check for any inconsistencies, lack of focus and/or other issues in the learning scenarios. In addition, think about any other emerging issues that need to be included and factor these in. The scenarios that emerge from this test phase or judgment step become your decision scenarios.

   Some possible questions to think about at this stage include:

   a. Is the scenario relevant?

   b. Does the scenario connect directly to the mental maps and concerns of users?

   c. Is the scenario internally consistent, and is it perceived as consistent?

   d. Are the scenarios archetypal (do they describe different futures, rather than just variations on the one theme)?

   e. Is the period of time for the scenario realistic? Each scenario should describe an equilibrium or a state in which the system might exist for some time, rather than a highly transient state for which companies and organizations cannot prepare.[cxlvii]

This scenario planning methodology provides a broad view of the future and an easy-to-follow, logical structure for developing scenarios.

Perspective-Based Scenario Analysis

The perspective-based scenario analysis (PBSA) framework is based on the analytic hierarchy process (AHP) developed by Tom Saaty in the 1970s. The framework uses pair comparisons and a matrix to identify which criteria are important to the development of the scenario. These important criteria are then weighted against each other. The methodology used is as follows:

1. *State the objective.* Determine what the objective or goal is.

2. *Define the criteria.* Break the problem into a hierarchy. This involves:

   a. Identifying the elements of the problem.

   b. Grouping the elements into consistent sets.

   c. Arranging the sets of elements into different levels of relevance, with the primary goal of the decision analysis always at the top.

   d. List the relative roles of each of the elements (variable, criteria). Group these into major categories.

   e. Rank these categories to form a hierarchy.

3. *Prioritize the hierarchy elements*. This is done using a pairwise comparison—comparing two criteria at a time using the hierarchy created in step 1 and then applying weights to the criteria using a matrix. For example: start with the top level elements, compare each top level element to the others, in relation to the criterion's importance to the stated goal. The weights use a scale ranging from 1 to 9 where a 9 signifies that X is much more important in meeting the decision goal than Y is, while 1 represents equal importance

between X and Y. From these weightings per criterion, a normalised value (average value and a percentage of relative priority) per category can be determined.

4. *Select alternatives*. Create the priorities to create an evaluation of alternatives.
5. *Evaluate the alternatives*. Evaluate each of the alternatives based on these weights.[cxlviii] [cxlix]

The perspective-based scenario analysis enables different key trends and drivers to be weighted against each other, resulting in a complete analysis of the importance of varying trends. The process described, here, however, seems a little esoteric for use in a workshop style scenario planning process, and requires further investigation to deem whether it is suitable.

Common Drivers of Change used in Scenario Planning

There are common drivers (key trends) of change that emerge in many scenario planning frameworks that worth consideration in the development of the critical uncertainties for scenario development within the future of roads.

Some important ones include:

- *Economics*. How will the economy change?
- *Leadership*. Is there appropriate leadership that can drive the changes needed?
- *Governance*. What are the current governance structures? Are they likely to change? What changes are needed here?
- *Employment*. What are the employment rates and models?
- *Demographics and Population*. What are the current population trends?
- *Social and cultural Issues*. What are the current social trends? What are the current cultural barriers, norms and requirements? Are there gender, poverty and/or equality issues?
- *Environment*. What are the current environmental barriers? What are the trends in environmental policy? What is the forest area? What areas of land need to be protected?
- *Air Quality*. What are the air pollution rates? What are the trends in air pollution regulation policies? What are the CO_2 levels? What are the CO_2 reduction policies, mitigation requirements and targets?
- *Water*. What is the cost of water infrastructure per unit measured (for example: per person, per household, per road kilometre)? What are the water saving measures? What are the water policies? What is the water stress? What are the water reuse technologies and trends?
- *Energy*. What are the energy use trends? What are the energy policies? What are the energy requirements? What are the trends in energy provision?
- *Infrastructure costs*. What are the infrastructure costs? What are the projected changes in infrastructure costs? What are the timings of infrastructure costs?
- *Infrastructure maintenance*. What are the timings of infrastructure maintenance?

- *Housing*. What is the growth rate for housing?
- *Transportation*. What are the trends in transportation (for example: mode share splits, vehicle miles travelled per year, railway boardings, delay times of peak traffic.). What are the transportation investment trends?
- *Land use*. What is the density? What are the percentages of different land uses? What are the land use trends?
- *Technology*. What are the current relevant technology trends?

Future Research Needs and Directions

This literature review has identified some future research directions. These include:

The use of models

Increasingly the use of models is being incorporated into the development of scenarios. Modelling is particularly helpful when looking at scenarios dealing with changes in population and the corresponding changes in consumption (ecological footprints) and water use. In addition models are often used in conservation to track the changes of vegetation and when investigating the possible impacts of climate change, particularly sea level rise. Some examples of model tools include:

- *CSIRO Scenario Planning and Investment Framework (SPIF) tool*. This tool is used by CSIRO to develop frameworks for forestry planning.
- *Australian Stocks and Flows Framework (ASFF) modelling platform.* This tool is an interactive model looking at physical economies developed by CSIRO and Whatif? Technologies.

This is a growing area of research and requires integration with most scenario planning literature focusing solely on creating qualitative narratives rather than on quantitative modelling. This is a growing area of scenario planning.[cl]

The use of Collective Intelligence

The use of scenario planning with Collective Intelligence (CI) is an emerging field. CI creates intelligence from synergies between data, information and software/hardware. It continually learns from feedback and produces just-in-time knowledge. An example of CI would be Wikipedia. CI is being explored by the Millennium Project, and possibly could create synergies in developing scenarios.

The use of Delphi

The use of Delphi, particularly conventional Delphi, in the development of scenarios would involve using a series of sequential questionnaires to develop scenarios.[cli]

Scenarios provide a shared language in which decision makers and stakeholders can develop and discuss strategies for the future. They are not predictions. The scenario planning methods described here aim to provide a basis for the development of an ‘Innovative Scenarios for Sustainable Road Infrastructure’ (ISSRI) scenario planning methodology. The purpose of this literature review is to determine the best possible scenario development structure for the project when looking at possible contributions of roads to the mitigation of climate change, and the impact of climate change on roads. This review focuses not on what the scenarios consist of but rather on how they can be developed. To do this the research has investigated a wide range of literature from varying disciplines, reflecting the changing needs of scenario planning within sustainability research. The review has identified gaps in some of the current scenario planning methodologies and has identified possible future areas of research.

Potential Areas for Scenario Planning

A major deliverable of this section is the development of an 'Innovative Scenarios for Sustainable Road Infrastructure' scenario planning methodology. As discussed previously, there is a range of scenario planning methodologies that have been investigated and assessed for relevance to the Future of Roads project. The subject matter and contexts of these scenarios will emerge in the context of stakeholder engagement workshops and interviews. 'The Contribution of Road Areas to the Mitigation of Climate Change' strategic area will identify the opportunity for utilising road areas to contribute to the mitigation of climate change and strengthening infrastructure resilience. The development of scenarios is a key tool that will enable the strategic and visionary planning necessary for roads to mitigate and react to a changing climate while providing significant environmental, social and economic benefits.

The current literature suggests that there is enormous breadth of opportunities for roads to reduce negative environmental pressures. These opportunities may involve road construction processes, for example, the sequestration of carbon in road base and pavement layers, or enable road surfaces to become generators of electricity through the capture of solar or kinetic energy. Other opportunities may arise from a reassessment of the fundamental assumptions underlying the use and construction of roads, by encouraging sustainable transport decisions and reducing road areas. Some of the key trends for these areas of opportunity have been summarized below.

Road construction Innovations

Road construction is an enormous industry and any innovation which enables road construction to efficiently mitigate climate change will have a substantial and far reaching impact. Processes are appearing that enable roads to act as repositories for industrial, municipal and agricultural waste. These reduce the need for virgin materials in road construction while also decreasing the amount of waste going to landfill and helping to encourage 'cradle to cradle' development. Some examples of these innovations are plastic roads in India[clii] and the development of Glasphalt, a product that uses waste glass, in the UK.[cliii] Other innovative groups such as CarbonLoc[TM][cliv] and Calera Technology[clv] are creating products (mainly concrete) that allow significant amounts of carbon to be stored within roads and road furniture.

Generation of Renewable Energy

While still very much in the early stages of development, the literature suggests that the use of roads as generators of renewable energy may be a viable technology. Solar Roadways, constructed by incorporating solar panels into the road surface, are being investigated, although have questionable viability as a mainstream technology.[clvi] Road Energy Systems (RES) has developed Thermal Energy Asphalt Pavements, which are embedded with tubes that carry energy from solar radiation absorbed by roads to nearby buildings.[clvii] Other potential technologies include the collection of motion power (kinetic energy), the use of electro-kinetic generators and the creation of piezoelectric materials. However much of this technology is still in its infancy and will not be industrialized for many years.

Improving the Efficiency of Existing Roads

There are many existing programs to encourage individual road users to use the road more efficiently. Behavior change programs in European countries like Sweden have been enormously successful in promoting sustainable transport and reducing car dependence, which is now being studied and adopted in other countries.[clviii] Other initiatives, such as managed lanes (T2/T3 lanes, HOT and HOV lanes), Quickchange Moveable Barriers, UK road agencies shifting road marking to reduce lane ruts, and bus rapid transport, are producing effective results in improving the efficiency of existing roads and encouraging behaviour change.

Freight Alternatives

The freight task in Australia's eight capital cities is expected to grow by 70 percent between the years 2003 and 2020 (BTRE 2007). Increasing congestion on urban roads means that as freight continues to compete with other traffic, productivity declines.[clix] This is particularly important for the productivity of businesses. Solutions to support functional shifts of road use are being examined in order to reduce pavement degradation due to excessive loads, and to target fossil fuel reduction. According to Zerocarbon Australia (2010) moving road freight to rail in can begin to address these issues by 2020.[clx]

Retrofitting Roads

As infrastructure ages and communities are becoming more active, the discussion of urban highways and mobility continues with the development of a fairly recent phenomenon: urban freeway removal. According to analysis by the Massachusetts Institute of Technology, freeway removal will only take place when:

- there are concerns about structural integrity and safety,
- a freeway removal alternative gains legitimacy,
- the value of mobility is lower than other objectives such as economic development and the quality of life for citizens; and
- powerbrokers value other benefits like whole system design and sustainability, more than traditional freeway infrastructure benefits.

Within North America, MIT identified six cases of freeway removal: Portland's Harbor Drive, San Francisco's Embarcadero and Central Freeways, Milwaukee's Park East Freeway, New York City's Westside Highway, and Toronto's Gardiner Expressway.[clxi] The restoration of the Cheonggyecheon River in Seoul, South Korea, is the most famous highway retrofitting project. It required the removal of an elevated expressway that was constructed between 1967 and 1971 to solve paralyzing congestion in the city CBD. The infrastructure showed signs of serious degradation in 1990 and after extensive planning and feasibility studies, the motorway was taken down and the river restored. Extensive bus services replaced the need for the motorway and a complete urban renewal transformation occurred.[clxii] Retrofitting road infrastructure and private vehicle facilities in order invest in public spaces has been shown to raise commercial activity for metropolitan areas.

Gehl Architects, global design experts, reveal that Copenhagen's city centre has converted 22 public parking locations and entire streets in to public space since the 1960s. This greatly increased the amount of public space for citizens and 30 years of detailed studies show how a gradual expansion of the city's public spaces has led to a surge in the number of people using public spaces.[clxiii]

[i] Preston, B. and Jones, R. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change**,** CSIRO, Canberra, Australian Capital Territory.
[ii] Preston, B. & Jones, R. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change**,** CSIRO, Canberra, Australian Capital Territory.
[iii] Goodyear, T. (Ed) (2009) *Innovative Practices for Greener Roads*, International Road Federation Geneva Programme Centre, Geneva, Switzerland.
[iv] Forum of European National Highway Research Laboratories (2008) *New Road Construction Concepts: Towards reliable, green safe and smart and human infrastructure in Europe*, FEHRL.
[v] Solsby, J. (2010) 'Earth Day "Green & Clean" Publication Highlights Transportation Infrastructure Project Environmental Success Stories', *American Road and Transportation Builders Association*, 22 April, www.artba.org/article/earth-day-green--clean-publication-highlights-transportation-infrastructure-project-environmental-success-stories/, accessed 20 July 2011.
[vi] Sustainable Built Environment national research centre (2011) 'Greening the Built Environment - Future of Roads', SBEnrc Fact Sheet, Australia.
[vii] Worldmeters.Info (n.d.) 'Cars produced in the world International Organization of Motor Vehicle Manufacturers (OICA)', *Worldmeters.Info* [website], www.worldmeters.info/cars, accessed 20 July 2011.
[viii] Australian Bureau of Statistics (2010) 'Yearbook, Construction Activity', *Australian Bureau of Statistics* [website], www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/EE3D1C74D28C102BCA25773700169CD5, accessed 20 July 2011.
[ix] InterAcademy Council (2007) 'Transportation Energy Efficiency', *Lighting the Way: Toward a Sustainable Energy*, InterAcademy Council.
[x] Preston, B.L. & Jones, R.N. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change, CSIRO, Canberra, Australian Capital Territory.
[xi] Preston, B.L. & Jones, R.N. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change, CSIRO, Canberra, Australian Capital Territory.
[xii] Preston, B.L. & Jones, R.N. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change**,** CSIRO, Canberra, Australian Capital Territory.
[xiii] Preston, B.L. & Jones, R.N. (2006) Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions, A consultancy report for the Australian Business Roundtable on Climate Change, CSIRO, Canberra, Australian Capital Territory.
[xiv] Preston, B.L. & Jones, R.N. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change, CSIRO, Canberra, Australian Capital Territory.
[xv] Bureau of Infrastructure, Transport and Regional Economics (2009) *Transport Statistics Yearbook*, Australian Government, Department of Infrastructure and Transport, Canberra.
[xvi] BIS Shrapnel (n.d.) 'Infrastructure and Mining', Road Maintenance in Australia 2010-2025, www.bis.com.au/reports/rma_r.html, accessed 5 April, 2011.
[xvii] Ausroads (2004) *The Impact of Climate Change on Road Infrastructure*, National Library of Australia, AP-R243/04, Sydney, p.97
[xviii] Lay, M.G. (2009) Handbook of Road Technology, Taylor and Francis.
[xix] Queensland Department of Main Roads (2009). *Pavement Design Manual. Queensland*, Queensland Government.
[xx] Queensland Department of Main Roads (2009). *Pavement Design Manual. Queensland*, Queensland Government.
[xxi] Smith, M. R., Collis, L., *et al*. (2001). *Aggregates: sand, gravel and crushed rock aggregates for construction purposes*, Geological Society.
[xxii] Kett, I. (1998) Asphalt materials and mix design manual, Noyes.
[xxiii] Zapata, P. & Gambatese J. A. (2005). 'Energy consumption of asphalt and reinforced concrete pavement materials and construction', *Journal of Infrastructure Systems*, vol 11, p.9.
[xxiv] Austroads (2010). *Austroads Glossary of Terms*. Austroads, Sydney, Australia.
[xxv] Inter-Organization Programme for the Sound Management of Chemicals (IOMC) (2004) 'International Program on Chemical Safety (IPCS)–Ashphalt'. *Inter-Organization Programme for the Sound Management of Chemicals (IOMC)*, World Health Organization, Geneva.
[xxvi] Austroads (2010) *Austroads Glossary of Terms*. Austroads, Sydney, Australia.
[xxvii] O'Flaherty, C. A. (2002) Highways: the location, design, construction and maintenance of road pavements, Butterworth-Heinemann.
[xxviii] O'Flaherty, C. A. (2002). Highways: the location, design, construction and maintenance of road pavements, Butterworth-Heinemann. Butterworth-Heinemann.
[xxix] Coffin, A. W. (2007) 'From roadkill to road ecology: a review of the ecological effects of roads', *Journal of Transport Geography,* Vol 15, Iss, 5, pp.396-406.
[xxx] Coffin, A. W. (2007) 'From roadkill to road ecology: a review of the ecological effects of roads', *Journal of Transport Geography,* Vol 15, Iss, 5, pp.396-406.
[xxxi] Azizian, M., Nelson, P., *et al*. (2005) 'Environmental Impacts of Leachate from Portland Cement Concrete (PCC) with and without Plasticizer in Highway Construction', *Water Pollution*, pp. 43-60.
[xxxii] Brantley, A. S. & Townsend, T. G. (1999) 'Leaching of pollutants from reclaimed asphalt pavement', *Environmental Engineering Science*, Vol 16, Iss 2, pp.105-116.

[xxxiii] Polic, P., Ilic, M., *et al*. (2005) 'Environmental Impact Assessment of Lignite Fly Ash and Its Utilization Products as Recycled Hazardous Wastes on Surface and Ground Water Quality', *Water Pollution*, pp.61-110.
[xxxiv] Polic, P., Ilic, M., *et al*. (2005) 'Environmental Impact Assessment of Lignite Fly Ash and Its Utilization Products as Recycled Hazardous Wastes on Surface and Ground Water Quality', *Water Pollution*, pp.61-110.
[xxxv] Azizian, M., Nelson, P., *et al*. (2005) 'Environmental Impacts of Leachate from Portland Cement Concrete (PCC) with and without Plasticizer in Highway Construction', *Water Pollution*, pp. 43-60.
[xxxvi] Coffin, A. W. (2007) 'From roadkill to road ecology: a review of the ecological effects of roads', *Journal of Transport Geography,* Vol 15, Iss, 5, pp.396-406.
[xxxvii] Olsson, S., Karrman, E., *et al*. (2006) 'Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction', *Resources, Conservation and Recycling,* Vol 48, Iss 1, pp.26-40.
[xxxviii] Azizian, M., Nelson, P., *et al*. (2003) 'Environmental impact of highway construction and repair materials on surface and ground waters:: Case study: crumb rubber asphalt concrete,' *Waste Management*, Vol 23, Iss 8, pp.719-728.
[xxxix] Bruder-Hubscher, V., Lagarde, L., *et al*. (2001) 'Utilisation of bottom ash in road construction: evaluation of the environmental impact', *Waste Management & Research*, Vol 19, Iss 6, p.545.
[xl] Brantley, A. S. & Townsend, T. G. (1999) 'Leaching of pollutants from reclaimed asphalt pavement,' *Environmental Engineering Science*, Vol 16, Iss 2, pp. 105-116.
[xli] Azizian, M., Nelson, P., *et al*. (2003) 'Environmental impact of highway construction and repair materials on surface and ground waters:: Case study: crumb rubber asphalt concrete,' *Waste Management*, Vol 23, Iss 8, pp.719-728.
[xlii] Bruder-Hubscher, V., Lagarde, L., *et al*. (2001) 'Utilisation of bottom ash in road construction: evaluation of the environmental impact', *Waste Management & Research*, Vol 19, Iss 6, p.545.
[xliii] Olsson, S., Karrman, E., *et al*. (2006) 'Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction', *Resources, Conservation and Recycling,* Vol 48, Iss 1, pp.26-40.
[xliv] Djordjevic, J. (2010), 'Improvement of energy efficiency of rock comminution through reduction of thermal losses', *Minerals Engineering*, Vol 23, Iss 15, December 2010, pp.1237-1244.
[xlv] Balkema, A.A. pp.197-210, in Zoorob, S. E., Collop, A. C., *et al*. (2002) *Performance of bituminous and hydraulic materials in pavements: proceedings of the Fourth European Symposium on Performance of Bituminous and Hydraulic Materials in Pavements*, 11-12 April, Bitmat 4, Nottingham, United Kingdom.
[xlvi] Personal communication, Peter Evans, DTMR
[xlvii] Main Roads Specifications (2010). *Insitu Stabilization using Foam Bitumen*. Queensland Government, Brisbane.
[xlviii] Drechsler, M. & Graham, A. (2005) 'Innovative Materials Technologies: Bringing Resource Sustainability to Construction and Mining Industries', *48th Institute of Quarrying Conference*, Adelaide, South Australia.
[xlix] Hodgkinson, J. (1991) Long-term performance of Local Government road pavements recycled by cement stabilisation. *6th National Local Government Engineering Conference,* Hobart, AustSTAB.
[l] Telford, T, in Dhir, R. K. & Jappy T. G. (1999), Exploiting wastes in concrete: proceedings of the international seminar held at the University of Dundee, Scotland, United Kingdom ,7 September 1999, pp151-160.
[li] Bruder-Hubscher, V., Lagarde, L., *et al*. (2001) 'Utilisation of bottom ash in road construction: evaluation of the environmental impact', *Waste Management & Research*, Vol 19, Iss 6, p.545..
[lii] Olsson, S., Karrman, E., *et al*. (2006) 'Environmental systems analysis of the use of bottom ash from incineration of municipal waste for road construction', *Resources, Conservation and Recycling,* Vol 48, Iss 1, pp.26-40.
[liii] Schouenborg B., Aurstad J. & Pétursson P. (2004) 'Test methods adapted to alternatives aggregates', *SP-Swedish National Testing and Research Institute*, p.9.
[liv] SAMARIS (2006) 'Final Report Summary', *SAMARIS - Sustainable and Advanced Materials for Road Infrastructure*, p.140.
[lv] Djordjevic, J. (2010), 'Improvement of energy efficiency of rock comminution through reduction of thermal losses', *Minerals Engineering*, Vol 23, Iss 15, December 2010, pp.1237-1244.
[lvi] Rao, A., Jha, K. N., *et al*. (2007) 'Use of aggregates from recycled construction and demolition waste in concrete', *Resources, Conservation and Recycling,* Vol 50, Iss 1, pp.71-81.
[lvii] Milne, P., Sharp, K., & Ungers, B. (2010) *Austroads Glossary of Terms*, 4th edition, Austroads Ltd Publication, No: AP-C87/10 p.165.
[lviii] Hunter R.N., (2000) 'Asphalt in road construction', Thomas Telford, p.563.
[lix] Hunter R.N., (2000), 'Asphalt in road construction', Thomas Telford, p.563.
[lx] Lennox R. and MacKenzi M. for Global Transport Knowledge Partnership (2008) 'Eco-Road Building for Emerging Economies: An Initial Scan for Promising Alternative Technologies', *DFID Department for International Development*, p.20.
[lxi] Verma, S. (2008) 'Roads from plastic waste', *The Indian Concrete Journal,* pp.43-47.
[lxii] UNEP (2006, 5 February) '9th Special Session of UNEP Governing Council/Global Ministerial Environment Forum', *UNEP*, Dubai/Nairobi, http://www.unep.org/Documents.Multilingual/Default.asp?DocumentID=469&ArticleID=5132&l=en, accessed 26 August, 2011
[lxiii] Saunier et Associes (2007) 'Existing and new road pavement materials', *ECRPD-Energy Conservation in Road Pavement Design*, p.55.
[lxiv] Diefenderfer S.D. & Hearon, A.J., (2010) 'Performance of Virginia's Warm-Mix Asphalt Trial Sections', *Virginia Transportation Research Council*, p.46.
[lxv] Csansy L. H., (1960) 'Bituminous Mixes Prepared with foamed Asphalt', Iowa State University, Iowa, p.189.
[lxvi] County Surveyors' Society (1997) 'Permanent Cold Lay Bituminous Materials, Overview Report', CSS ENG, pp.1-97.
[lxvii] Brown D.C., (1997) 'Wisconsin Demo Explores In Place Asphalt Rehabilitation, Roads and Bridges', Road and Bridges Online, p.28.
[lxviii] CityWide (2009) 'Citywide Greenpave' CityWide Service Solutions Pty Ltd, Melbourne, www.citywide.com.au, accessed 26 August, 2011.
[lxix] Mathias V., Sedran T. % de Larrard F., (2004) 'Recycling reclaimed asphalt pavement in concrete roads', *Barcelona Conference*, LCPC Centre de Nantes, p.11.

lxx Al-Qadi I.L., Elseifi M. & Carpenter S. H., (2007), 'Reclaimed Asphalt Pavement, A Literature Review', *Civil Engineering Studies* Illinois Centre for Transportation Series, No. 07-001, UILU-ENG-2007-2014, pp.25.
lxxi Kandhal P. S. & Mallick, R. B. (1997) 'Pavement Recycling Guidelines for State and Local Governments–Participant's Reference Book', *National Centre for Asphalt Technology*, Auburn, AL, Report No. FHWA-SA-98-042.
lxxii Page G. C. & Murphy, K. H. (1987) 'Hot-Mix Recycling Saves Florida DOT $38 Million", *Asphalt*, Vol. 1, No.1.
lxxiii Norin N. & Strömvaix A-M., (2004) 'Leaching of organic contaminants from storage of reclaimed asphalt pavement', *Environmental Technology*, Vol 25, Iss 3, pp323-340.
lxxiv Re-Road (2011) Re-Road Project [website], http://re-road.fehrl.org/, accessed 26 August, 2011
lxxv American Society of Civil Engineers (1998) 'Asphalt Tests Show Little Leachate', *Civil Engineering*, Vol 68, No 11. p 32.
lxxvi Townsend T.G., (1998) 'Leaching Characteristics of Asphalt Road Waste', State University System of Florida, Centre for solid and hazardous waste management, Report 98-2
lxxvii Brantley A.S.& Townsend T. G., (1999) 'Leaching of Pollutants from Reclaimed Asphalt Pavement', *Environmental Engineering Science*, Vol. 16, No. 2, pp 105-116.
lxxviii Wagner, T. (n.d.) *AGIC Breakfast Symposium Presentation*, http://www.agic.net.au/agic_bfast_-_wagners_presentation.pdf, accessed 26 August, 2006.
lxxix Tullamarine Calder Interchange Alliance (2008). *Pioneering the way*, Tullamarine Calder Interchange Alliance, www.misheye.com/pdf/tcibook.pdf, accessed 13 May 2011.
lxxx Baulderstone (2005). *Tullamarine Calder Interchange Alliance*. Press release, Issued 2 May 2005
lxxxi Baulderstone (2005). *Tullamarine Calder Interchange Alliance*. Press release, issued 2 May 2005
lxxxii Parsons Brinckerhoff. (n.d.) 'Tullamarine Calder Interchange', Parsons Brinkerhoff, http://www.pb.com.au/PBAU/Projects/Tullamarine%E2%80%93Calder+Interchange/ accessed 27 May, 2011.
lxxxiii Edgoose, J. (2007) 'Renewable Energy Support Fund', *Sustainability Victoria Renewable Energy and Regional Australia Conference,* 17 September, 2007 http://www.efa.com.au/Library/RESFPresentation.pdf, accessed 26 August, 2011.
lxxxiv Johnston, W. (2007) 'Case Studies: PV Noise Barrier for the Tullamarine-Calder Interchange'. *Going Solar Projects.*
lxxxv Maguire, A. (2009). Calculating the Carbon Footprint of Road Construction, *2009 National Local Government Asset Management and Public Works Engineering Conference*, 28-29 April, 2009,The Melbourne Convention Centre, Melbourne.
lxxxvi Maguire, A. (2009). Calculating the Carbon Footprint of Road Construction, *2009 National Local Government Asset Management and Public Works Engineering Conference*, 28-29 April, 2009,The Melbourne Convention Centre, Melbourne.
lxxxvii Humphrys, T. (2006) *Victoria's first carbon neutral road construction project–VicRoads*, http://www.ipwea.com/Microsoft%20Word%20%20Carbon%20footprint%20of%20road%20construction%20-%20060308.pdf accessed May 6, 2011.
lxxxviii Maguire, A. (2009). Calculating the Carbon Footprint of Road Construction, *2009 National Local Government Asset Management and Public Works Engineering Conference*, 28-29 April, 2009,The Melbourne Convention Centre, Melbourne.
lxxxix Humphrys, T. (2006) *Victoria's first carbon neutral road construction project–VicRoads*, http://www.ipwea.com/Microsoft%20Word%20%20Carbon%20footprint%20of%20road%20construction%20-%20060308.pdf accessed May 6, 2011.
xc Humphrys, T. (2006) *Victoria's first carbon neutral road construction project–VicRoads*, http://www.ipwea.com/Microsoft%20Word%20%20Carbon%20footprint%20of%20road%20construction%20-%20060308.pdf accessed May 6, 2011.
xci Preston, B. & Jones, R. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change**,** CSIRO, Canberra, Australian Capital Territory.
xcii International Road Federation (2010) 'World Road Statistics 2010, Data 2003 – 2008', *World Road Statistics WBS2010*, IRF, Geneva.
xciii Goodyear, T. (Ed) (2009) *Innovative Practices for Greener Roads*, International Road Federation Geneva Programme Centre, Geneva, Switzerland.
xciv Forum of European National Highway Research Laboratories (2008) *New Road Construction Concepts: Towards reliable, green safe and smart and human infrastructure in Europe*, FEHRL.
xcv Preston, B. & Jones, R. (2006) *Climate Change Impacts on Australia and the Benefits of Early Action to Reduce Global Greenhouse Gas Emissions*, A consultancy report for the Australian Business Roundtable on Climate Change**,** CSIRO, Canberra, Australian Capital Territory.
xcvi Australian Green Infrastructure Council (n.d.) 'Rating Tool Theme Overviews', *Australian Green Infrastructure Council*, www.agic.net.au/Tool.htm, accessed 20 July 2011.
xcvii Roads Australia (2010) 'Thiess' Hunter Expressway Contract Finalised at $825 Million', *Roads Australia Insider*, 30 August, www.roads.org.au/news/show-arf-insider/95, accessed 20 July 2011.
xcviii Roads Australia (2010) 'Draft RA Reliability Policy Released for Comment', Roads Australia Insider, 13 August, www.roads.org.au/news/show-arf-insider/94, accessed 20 July 2011.
xcix Greenroads (n.d.) 'The Greenroads Rating System-Overview', *Greenroads* [website], www.greenroads.us/18/55/overview.html, accessed 20 July 2011.
c Greenroads (n.d.) 'The Greenroads Rating System-Overview', *Greenroads* [website], www.greenroads.us/18/55/overview.html, accessed 20 July 2011.
ci International Road Federation (IRF) (2009) 'Innovative Practices for Greener Roads', *IRF*, IRF Geneva Programme Center, Geneva, Switzerland, http://www.irfnet.ch/files-upload/pdf-files/IRF_BP_Environment_Web.pdf 2009, accessed 26 August, 2011.
cii AASHTO's Center for Environmental Excellence and spreadsheet may be accessed at: http://environment.transportation.org/pdf/waste_manage_recyc/PBChecklistV7.zip
ciii Institute for Sustainable Infrastructure (2011) 'Envision[TM]', *Institute for Sustainable Infrastructure* [website], www.sustainableinfrastructure.org/index.cfm, accessed July 2011.

[civ] Energy Conservation in Road Pavement Design, Maintenance and Utilisation (ECRPD) (2010) *Energy Conservation in Road Pavement Design, Maintenance and Utilisation* [website], http://www.ecrpd.eu/, accessed 26 August, 2011
[cv] Australian Green Infrastructure Council http://www.agic.net.au/ at 29 May 2011
[cvi] AGIC above n1
[cvii] Main Roads Western Australia http://www.mainroads.wa.gov.au/BuildingRoads/Projects/UrbanProjects/GEHRoe/Pages/GEHRoe.aspx#overview at 31 May 2011
[cviii] Main Roads Western Australia http://www.mainroads.wa.gov.au/BuildingRoads/Projects/UrbanProjects/Pages/GatewayWA.aspx#scope at 31 May 2011
[cix] Schwartz, P. (1996) *The Art of the Long View: Planning for the Future*. Currency Doubleday, New York.
[cx] Raskin, P., Banuri, T., Gallopín, G., Gutman, P., Hammond, A., Kates, R. & Swart, R., (2002) *Great Transition: The Promise and Lure of the Times Ahead*. A report of the Global Scenario Group. Stockholm Environment Institute, Boston, p.14.
[cxi] Raskin, P., Banuri, T., Gallopín, G., Gutman, P., Hammond, A., Kates, R. & Swart, R., (2002) *Great Transition: The Promise and Lure of the Times Ahead*. A report of the Global Scenario Group. Stockholm Environment Institute, Boston, p.14.
[cxii] Davis, G. (2002) *Scenarios as a Tool for the 21st Century*, Shell International, The Hague.
[cxiii] Scearce, D., Fulton, K., & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank.
[cxiv] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague.
[cxv] Dunlop, M (2001) 'A Scenario Planning Framework for Australian Landscapes, CSIRO Sustainable Ecosystems', Paper presented at *Landscape Futures: Social and Institutional Dimensions*, 2nd International Symposium on Landscape Futures, 4-6 December 2001, Institute for Rural Futures, Armidale, p.5.
[cxvi] Ringland, G. (2006) *Scenario Planning: Managing for the Future*, John Wiley & Sons Ltd, Chinchester.
[cxvii] Schoemaker, P. (1995) 'Scenario Planning: A Tool for Strategic Thinking', *Sloan Management Review,* Vol Winter 36, Iss 2, pp.25-40.
[cxviii] Commonwealth of Australia (2000) 'National Strategic Workshop on Genomics and Gene Technology – An Alliance for the Future, March 2000, Australian Research Council (ARC) and Rural Research and Development Corporations (RDCs)', Commonwealth of Australia, Canberra, p.13.
[cxix] Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., & Meyer L.A. (Eds.) (2007) 'Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', *IPCC*, Cambridge University Press, Cambridge and New York.
[cxx] See for example: Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60; Davis, G. (2002) *Scenarios as a Tool for the 21st Century*, Shell International, The Hague; Glenn, J.C. (2008) 'Overview of Millennium Project Scenarios Process'; Millennium Project, The (2011) *The Millennium Project* [website], http://www.millennium-project.org/, accessed 23 August, 2011; Pesonen, H., Ekvall, T., *et al*. (2000) 'Framework for scenario development in LCA', *The International Journal of Life Cycle Assessment*, Vol 5, Iss 1, pp. 21-30; Raskin P,. Banuri, T, *et al*. (2002) *Great Transition: The Promise and Lure of the Times Ahead*. A report of the Global Scenario Group. Stockholm Environment Institute, Boston; Scearce, D., Fulton, K. & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank; Schwartz, P (1996) *The Art of the Long View: Planning for the Future*. Currency Doubleday, New York; Schoemaker, P. (1995) 'Scenario Planning: A Tool for Strategic Thinking', *Sloan Management Review,* Vol Winter 36, Iss 2, pp.25-40; and Shell International (2008) 'An Explorer's Guide', Shell International, The Hague.
[cxxi] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague, p.56.
[cxxii] Raskin P,. Banuri, T, *et al*. (2002) *Great Transition: The Promise and Lure of the Times Ahead*. A report of the Global Scenario Group. Stockholm Environment Institute, Boston.
[cxxiii] The key reference that informed this list are: Business Council of Australia (2004) 'Aspire Australia 2025', Business Council of Australia, Melbourne; Davis, G. (2002) *Scenarios as a Tool for the 21st Century*, Shell International, The Hague; Dunlop, M. (2001) 'A Scenario Planning Framework for Australian Landscapes, CSIRO Sustainable Ecosystems', Paper presented at *Landscape Futures: Social and Institutional Dimensions*, 2nd International Symposium on Landscape Futures, 4-6 December 2001, Institute for Rural Futures, Armidale; Ellyard, P. (2011) 'Designing 2050: Imagining and Building a Global Sustainable Society', *Journal of Futures Studies*, Vol 15, Iss 3, pp.175–190; Peterson, D.G., Cumming, G.S. & Carpenter S.R., (2003) 'Scenario Planning: a Tool for Conservation in an Uncertain World', *Conservation Biology*, Vol 17, Iss 2, pp.358–366; Raskin P,. Banuri, T, *et al.* (2002) *Great Transition: The Promise and Lure of the Times Ahead*. A report of the Global Scenario Group. Stockholm Environment Institute, Boston; Ringland, G. (2006) *Scenario Planning: Managing for the Future*, John Wiley & Sons Ltd, Chinchester; Saul, P. (2010) 'Australia 2025: Three Global Scenarios: A Framework for Analysing Australia's Possible Future Workplaces and Workforce Development Requirements', *Journal of Futures Studies*, Vol 14, Iss 3, pp.129-146; Scearce, D., Fulton, K., & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank; Shell International (2008) 'An Explorer's Guide', Shell International, The Hague; Schoemaker, P. (1995) 'Scenario Planning: A Tool for Strategic Thinking', *Sloan Management Review,* Vol Winter 36, Iss 2, pp.25-40; and Schwartz, P. (1996) *The Art of the Long View: Planning for the Future*. Currency Doubleday, New York; amongst others.
[cxxiv] See for example: Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60; Ringland, G. (2006) *Scenario Planning: Managing for the Future*, John Wiley & Sons Ltd, Chinchester; and Schwartz, P. (1996) *The Art of the Long View: Planning for the Future*. Currency Doubleday, New York.
[cxxv] See for example: Glenn, J.C. (2008) 'Overview of Millennium Project Scenarios Process', The Millennium Project; and the Millennium Project, The (2011) *The Millennium Project* [website], http://www.millennium-project.org/, accessed 23 August, 2011.
[cxxvi] See for example: Dunlop, M (2001) 'A Scenario Planning Framework for Australian Landscapes, CSIRO Sustainable Ecosystems', Paper presented at *Landscape Futures: Social and Institutional Dimensions*, 2nd International Symposium on Landscape Futures, 4-6 December 2001, Institute for Rural Futures, Armidale; Peterson, D.G., Cumming, G.S. & Carpenter S.R., (2003) 'Scenario Planning: a Tool for Conservation in an Uncertain World', *Conservation Biology*, Vol 17, Iss 2, pp.358–366; Saul, P. (2010) 'Australia 2025: Three Global Scenarios: A Framework for Analysing Australia's Possible Future Workplaces and

Workforce Development Requirements', *Journal of Futures Studies*, Vol 14, Iss 3, pp.129-146; and the example given below in 3.1.1.

[cxxvii] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague, p.44.

[cxxviii] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague, p.46.

[cxxix] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague.

[cxxx] Shell International (2008) 'An Explorer's Guide', Shell International, The Hague, p.44.

[cxxxi] Commonwealth of Australia (2000) 'National Strategic Workshop on Genomics and Gene Technology – An Alliance for the Future, March 2000, Australian Research Council (ARC) and Rural Research and Development Corporations (RDCs)', Commonwealth of Australia, Canberra.

[cxxxii] Commonwealth of Australia (2000) 'National Strategic Workshop on Genomics and Gene Technology – An Alliance for the Future, March 2000, Australian Research Council (ARC) and Rural Research and Development Corporations (RDCs)', Commonwealth of Australia, Canberra, pp.11-17.

[cxxxiii] Commonwealth of Australia (2000) 'National Strategic Workshop on Genomics and Gene Technology – An Alliance for the Future, March 2000, Australian Research Council (ARC) and Rural Research and Development Corporations (RDCs)', Commonwealth of Australia, Canberra, p.9.

[cxxxiv] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60.

[cxxxv] See for example: Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60; Ringland, G. (2006) *Scenario Planning: Managing for the Future*, John Wiley & Sons Ltd, Chinchester; and Schwartz, P. (1996) *The Art of the Long View: Planning for the Future*. Currency Doubleday, New York.

[cxxxvi] Scearce, D., Fulton, K. & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank, p.28.

[cxxxvii] Scearce, D., Fulton, K. & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank.

[cxxxviii] See for example: Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60; and Scearce, D., Fulton, K., & Global Business Network community (2004) 'What if: The art of scenario thinking for nonprofits', Global Business Network Think Tank.

[cxxxix] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, p.56.

[cxl] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60.

[cxli] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60.

[cxlii] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60.

[cxliii] Curry, A. & Schultz, W. (2009) 'Roads Less Travelled: Different Methods, Different Futures', *Journal of Futures Studies*, Vol 13, Iss 4, pp. 35-60.

[cxliv] Millennium Project, The (2011) *The Millennium Project* [website], http://www.millennium-project.org/, accessed 23 August, 2011.

[cxlv] Dunlop, M. (2001) 'A Scenario Planning Framework for Australian Landscapes, CSIRO Sustainable Ecosystems', Paper presented at *Landscape Futures: Social and Institutional Dimensions*, 2nd International Symposium on Landscape Futures, 4-6 December 2001, Institute for Rural Futures, Armidale, p.1.

[cxlvi] Dunlop, M. (2001) 'A Scenario Planning Framework for Australian Landscapes, CSIRO Sustainable Ecosystems', Paper presented at *Landscape Futures: Social and Institutional Dimensions*, 2nd International Symposium on Landscape Futures, 4-6 December 2001, Institute for Rural Futures, Armidale, pp.7-8.

[cxlvii] Schoemaker, P (1995) 'Scenario Planning: A Tool for Strategic Thinking', *Sloan Management Review,* Vol Winter 36, Iss 2, pp.25-40.

[cxlviii] Saaty, T (1995) 'Transport planning with multiple criteria: The analytic hierarchy process applications and progress review', *Journal of Advanced Transportation,* Vol 29, Iss 1, pp.81–126.

[cxlix] Winebrake, J.J. & Creswick, B.P. (2003) 'The future of hydrogen fueling systems for transportation: An application of perspective-based scenario analysis using the analytic hierarchy process', *Technological Forecasting and Social Change*, Vol 70, Iss 4, pp.359-384.

[cl] Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., & L.A. Meyer (eds.) (2007) 'Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', *IPCC*, Cambridge University Press, Cambridge and New York.

[cli] Metz, B., Davidson, O.R., Bosch, P.R., Dave, R., & L.A. Meyer (eds.) (2007) 'Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change', *IPCC*, Cambridge University Press, Cambridge and New York.

[clii] Verma, S. (2008) 'Roads from plastic waste', *The Indian Concrete Journal*, pp. 43-47.

[cliii] Zoorob, S. E., Collop, A. C, *et al.* (2002) 'Performance of bituminous and hydraulic materials in pavements', *Proceedings of the Fourth European Symposium on Performance of Bituminous and Hydraulic Materials in Pavements*, Bitmat 4, Nottingham, United Kingdom, 11-12 April 2002, A.A. Balkema pp.197-210

[cliv] LOC Composites (n.d.) 'New CarbonLoc[TM] Material Technology', *LOC Composites* [website], http://loklite.com.au/New_carbon.htm, accessed 26 August, 2011.

[clv] Calera (n.d.) *Caleria* [website], http://www.calera.com/, accessed 26 August, 2011.

[clvi] Zyga, L. (2009) 'Solar Roadways Awarded DOT Contract to Pave Roads with Solar Cells', *Physorg.com*, News, September 7, 2009, http://www.physorg.com/news171545860.html, accessed 26 August, 2011.

[clvii] International Road Federation (2009) *Innovative Practices for Greener Roads,* IRF Geneva Programme Center, Geneva.

[clviii] Thynella, M., Mohanb, D. & Tiwarib, G. (2010) 'Sustainable transport and the modernisation of urban transport in Delhi and Stockholm', *Cities*, Vol 27, Iss 6, pp.421-429.
[clix] Bureau of Transport and Regional Economics (BTRE) (2007) *Estimating urban traffic and congestion cost trends for Australian cities, Working Paper 71,* BTRE, Canberra.
[clx] Beyond Zero Emissions (2011) 'Beyond Zero Emissions: Transport Plan'. *Beyond Zero Emission* [website] http://beyondzeroemissions.org/zero-carbon-australia-2020/transport-plan, accessed 26 August, 2011.
[clxi] Napolitan, F. & Zegras, P.C. (2007) *Shifting Urban Priorities: The Removal of Inner City Freeways in the United States*, http://web.mit.edu/czegras/www/Napolitan_Zegras_FreewayRemoval_Final.pdf, accessed 26 August, 2011.
[clxii] Shin, J. Lee, I. & Gye, C. (2006) 'Cheon restoration in Seoul, Korea', *Proceedings of the ICE-Civil Engineering*, Vol 159, Iss 4, pp. 162–170.
[clxiii] Gehl Architects (2009) 'A people Oriented Vision for Brisbane' Gehl Architects, Copenhagen.