Reducing the environmental impact of road construction

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

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Executive Summary

The practice of road construction and maintenance is inherently lean and efficient; a result of the economic benefits that are gained by minimizing wasted resources. In this age of conservation and environmental management, the inbuilt sustainability of existing road construction practices is being developed and extended to produce variety of environmentally sustainable options. A new concept of a "sustainable road" has emerged through both academia and industry, and is defined to be a road that is:

- constructed to reduce environmental impacts;
- designed to optimise the alignment (vertical and horizontal including considerations of ecological constraints and operational use by vehicles);
- resilient to future environmental and economic pressures (e.g. climate change and resource scarcity);
- adaptable to changing uses including increased travel volumes, greater demand for public and active (cycling and walking) transport; and
- able to harvest the energy to power itself.

Early efforts to create sustainable roads focused on reducing the ecological footprint of new roads by optimising route alignment, managing storm water runoff and controlling erosion. Best practice in sustainable road construction has now moved into a second generation of initiatives, where road networks are entering a new chapter in formation and function. This next "wave of innovation" in sustainable road construction centres around energy and resource efficient materials and methodologies. Such a shift in focus is imperative and urgently needed to give road authorities time to create road networks that will be resilient to significant environmental and resource related challenges in future.

To date, innovations in sustainable road construction practices in Australia have been given little incentive by government and industry, with research investments focused primarily on engineering design for rapid construction, speed and safety of roads. However, in an increasingly resource and energy constrained world, governments have clearly seen the value in investing in research and development for sustainable roads, evidenced by a host of new initiatives ranging from new standards for recycled materials to the recently released AGIC rating scheme that adds an economic value to sustainable roads.

Innovative road builders now see resource efficiency and carbon neutrality as paramount to the success of their projects. Through this literature review, cutting-edge projects focusing on innovative sustainable solutions to road construction and maintenance have been identified. These include projects that use plant based bitumen alternatives, radical energy and cost reductions by implementing new lighting and signal technology, roadbases that reuse previous pavement layers as a resource material rather than virgin quarries and road surfaces constructed using scrap tyres and plastic bags as durable wearing surfaces. As the first phase of the "Future of Roads" project, this literature review looks at the next wave of innovations inroad infrastructure maintenance and provision. This research reveals that road construction activities and research across the world are advancing well beyond the traditional construction practices to achieve further cost savings,

improvements in performance and risk mitigation. Furthermore these innovations are capitalising on opportunities.

The strategic areas identified by this research as important in reducing the environmental impacts of road infrastructure include:

1. Design
2. Materials
3. Asphalt
4. Cement
5. Lighting and Signals

Of these strategic areas, materials and lighting and signals have the greatest environmental impact in road infrastructure (excluding vehicle use). This review provides a range of successful examples that address the use of materials and road lighting and signals. The environmental impacts of these strategic areas are coupled with the future pressures of resource scarcity (particularly the access and availability of crushed rock aggregate) and rising electricity costs. As such, these two strategic areas should be considered the low hanging fruit for road agencies to target immediately.

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Introduction

The “Future of Roads” project (as shown below in Figure 1 and 2) is focused on supporting Australian governments and industry to respond to issues and risks related to climate change, availability of natural resources, and issues related to energy especially oil. As such it is important that the outputs of the program are relevant and timely. In order to do so the project team is working in close consultation with government, industry and university stakeholders. Informed by a comprehensive literature review the research team has evolved the original scope of the project in-line with stakeholders needs and by learning lessons from other similar efforts. This paper outlines the key findings from the literature review.

The document reveals the results of a global literature review with research investigations targeting information that is applicable to Australia’s circumstances. An audience familiar with the road industry is the intended reader for this document considering they have an established understanding of road infrastructure. However this is not a technical report. It is presented for an audience that is considering a strategic approach to reducing the environmental impacts of road construction when considering the future of roads.

This document presents the output for the first part of the project. It is a report on the options for reducing the environmental pressure of roads with a focus on suitability to Queensland and Western Australia. The report will systematically work through the various options and present the findings of investigations to inform considerations around their adoption (such as aggregates security and potential alternatives). This includes:

- design improvements;
- materials (alternative aggregates, in-situ stabilisation, water);
- asphalt (alternative aggregates, bitumen substitute, manufacturing processes, mix design);
- cement alternatives; and
- lighting and signals.

Project partners

The project is supported by the state departments of Main Roads Western Australia, Queensland Department of Transport and Main Roads, in addition to industry partners Parsons Brinckerhoff, John Holland Group, and supported in-kind by the Australia Green Infrastructure Council (AGIC).

Key Contacts for Project Partners:

MRWA	Louis Bettini, Ed Nieman
DTMR QLD	Ross Guppy, Jon Oxford, John Spathonis

Workshops facilitated by Charlie Hargroves, Cheryl Desha and Luke Whistler were undertaken to engage with partners and stakeholders enabling them to provide direct input into the research directions of the project. The first round of workshops were held in July and September (MRWA 12 July, TMR 9 September). In the first quarter of 2012 second round of workshops explored the progress on the assessment framework and seek contributions from both agencies and key stakeholders to build strategies for dealing with likely scenarios to be faced by agencies in future.

The imperative to plan for the future of roads in Australia

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.[1] Leading efforts around the world are now showing how such challenges can now be met with creativity and innovation across many aspects of roads.[2,3,4] 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,[5] 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.

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.[6] Road infrastructure also supports vehicles that combust 310 000 barrels of oil every day in Australia and emit 17 per cent of Australia’s greenhouse gases, in turn threatening global climatic stability, local ecology and agricultural industries.[7] Recent history clearly shows that roads are a cornerstone of economic activity. Improved road transport has contributed to six per cent 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 per cent of global carbon dioxide emissions.[8]

Definition of sustainable roads

A sustainable road is:

- constructed to reduce environmental impacts and designed to optimise the alignment (considering ecological constraints and operational use by vehicles);
- resilient to future pressures e.g. climate change, resource scarcity; and
- adaptable to changing uses including increased travel volumes, changes in demand for public transport, cycling and walking. It will power vehicles, harvest energy and measure its own performance.

It is worth highlighting that road construction is inherently an efficient practice that seeks to minimise costs related to construction and maintenance. Such practices include:

- balancing earthworks to optimise cut and fill;
- utilising local sources to minimise the import of materials;
- stablilising additives to adapt local marginal materials;
- ensuring impacts on the local environment and biodiversity are appropriately managed and revegetated;
- road water runoff capture and treatment;
- optimising pavement thickness for anticipated conditions and loads; and
- effective scheduling of associated capital expenditure and rapid delivery.

These lean construction 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 future pressures.

Life cycle impacts of roads – construction, operation and maintenance impacts

During the course of this literature review, the very idea of reducing the environmental impact of roads through innovations in road construction processes was questioned many times. Stakeholders frequently expressed their belief that the emissions caused by the vehicular and operational use of roads were far greater than those produced during the construction phase. The research team acknowledges that the emissions caused by the vehicular and operational use of roads are extremely significant. However, given the sheer size and scale of road construction projects currently occurring throughout Australia and the world, there is a clear imperative to investigate measures that reduce the environmental impact of the road construction phase.

Hence, while acknowledging that the use of roads by freight and passenger vehicles does indeed contribute the most significant greenhouse gas (GHG) emission costs of roads, the construction, operation and maintenance phases of a road's life-cycle all have substantial GHG emissions in their own right (note that operational costs in this context excludes vehicular emissions). Of these three, generally road construction is considered the most important. However a report by the Transport Authorities Greenhouse Group Australia and New Zealand (TAGG) suggests that over the course of a road's life-cycle (40 plus years), the GHG emissions caused by road operations become important. The operation phase contributes approximately half of all GHG emissions, which is approximately equal to those produced during the road construction phase. Furthermore, TAGG also determined that the GHG emissions produced during the maintenance phase, while not as significant as those produced during the construction and operational phases, are also important.

Road infrastructure in Australia

Roads in Australia 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.[9]

Currently, the responsibility for planning, funding, constructing, maintaining and operating road infrastructure is shared between the three levels of Australian government (for example, federal, state and local). Generally, stakeholders within various levels of government report good collaborative arrangements with other levels of governments within their respective jurisdictions.[10] However, the complex intergovernmental arrangements for road infrastructure management does create the potential for a number of issues, including difficulties for transport operators to access roads, sub-optimal design of the network, a lack of integration between roads and other transport infrastructure and a growing backlog of road infrastructure maintenance projects.

The allocation of responsibilities between levels of government depends on the type of road based upon definitions of road classes (broadly, either arterial or local roads). State governments generally own the arterial road network while local governments generally own the local road network, and both the state and local receive financial contributions from the Commonwealth government for the road networks that they own. Within each level of government there are a number of bodies that have responsibilities for various section of the road network. Figure 1 below summarises the roles and processes governing these bodies.

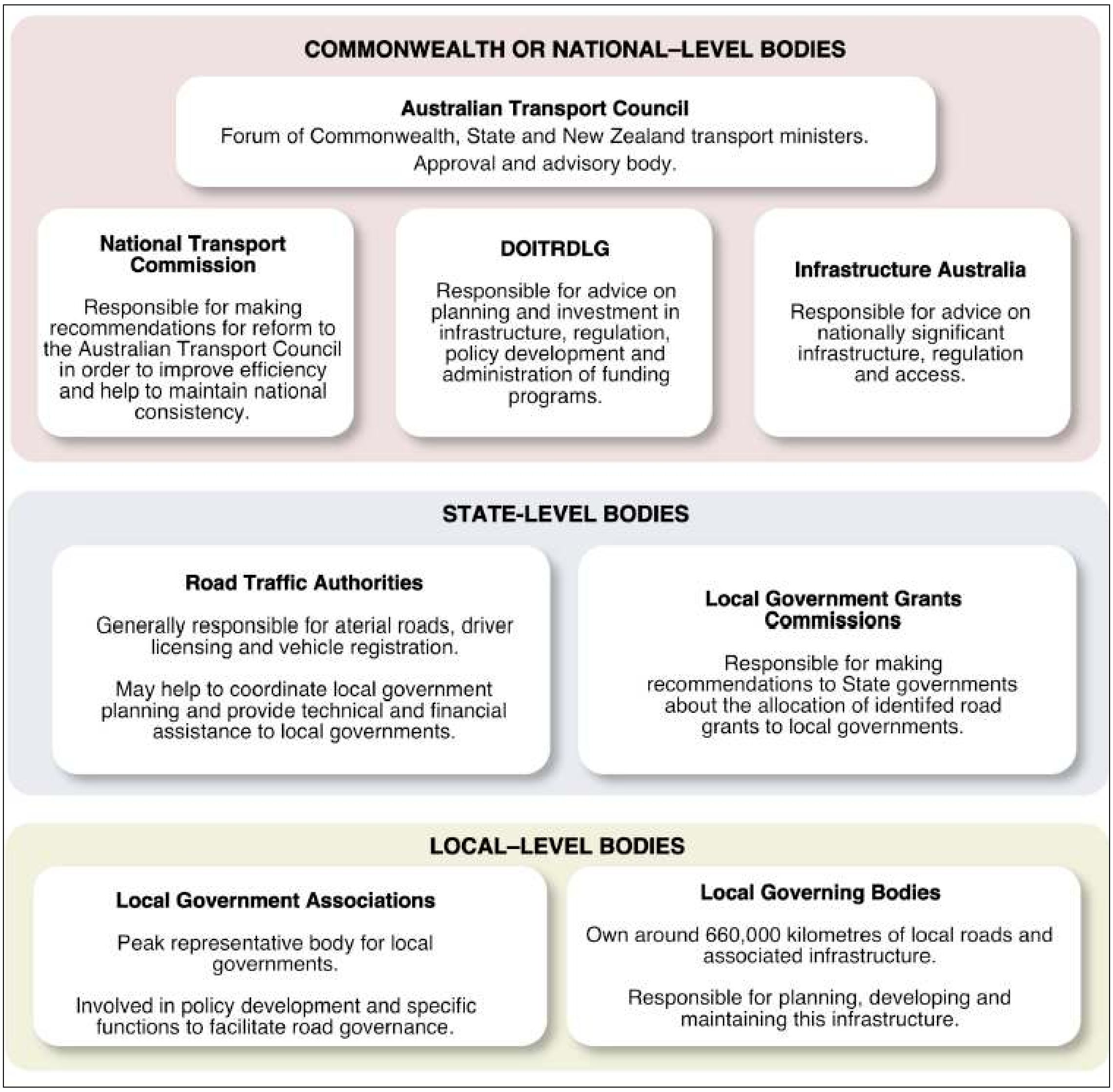

Figure 1 *Bodies within each level of governance with responsibilities to the road network of Australia*

Source: The Allen Consulting Group (2009)[10]

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.[11] 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, stabilised 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.[11]

Although many different materials may be used in road construction, the general order of layers includes:

- The **natural subgrade**, which is the lowest layer of a road and can consist of remnants that have been left from old roads or may be the natural soil that is unearthed for new road building.
- The ***sub-base***, which consists of compacted gravel, stone or sand and is the first layer that the road builder puts down on the natural subgrade. Primarily, this layer contributes to the strength of the road, but also provides a platform for operating the machinery.
- The ***roadbase***, made of graded mineral aggregates, is considered the main working layer of the road and provides strength and flexibility. The mixture may contain bitumen if the load bearing requirements are high.
- The ***base course***, comprised of aggregates and bitumen, is an even surface foundation for the top layer and further strengthens the road.
- The ***wearing course***, usually made of a finely textured mixture of aggregate and bitumen, must be able to resist the abrasion of traffic and provide a smooth surface for vehicles to travel. It must be weather-proof and capable of dispersing water effectively so as to minimise dangerous incidences such as skidding.
- A ***tack coat*** of bitumen may also be applied between layers to ensure they adhere appropriately to each other.[12]

According to Transport Authorities Greenhouse Group Australia and New Zealand (TAGG), the pavement types and material depths (as shown below in Figure 2) dominate in the Australian and New Zealand context.

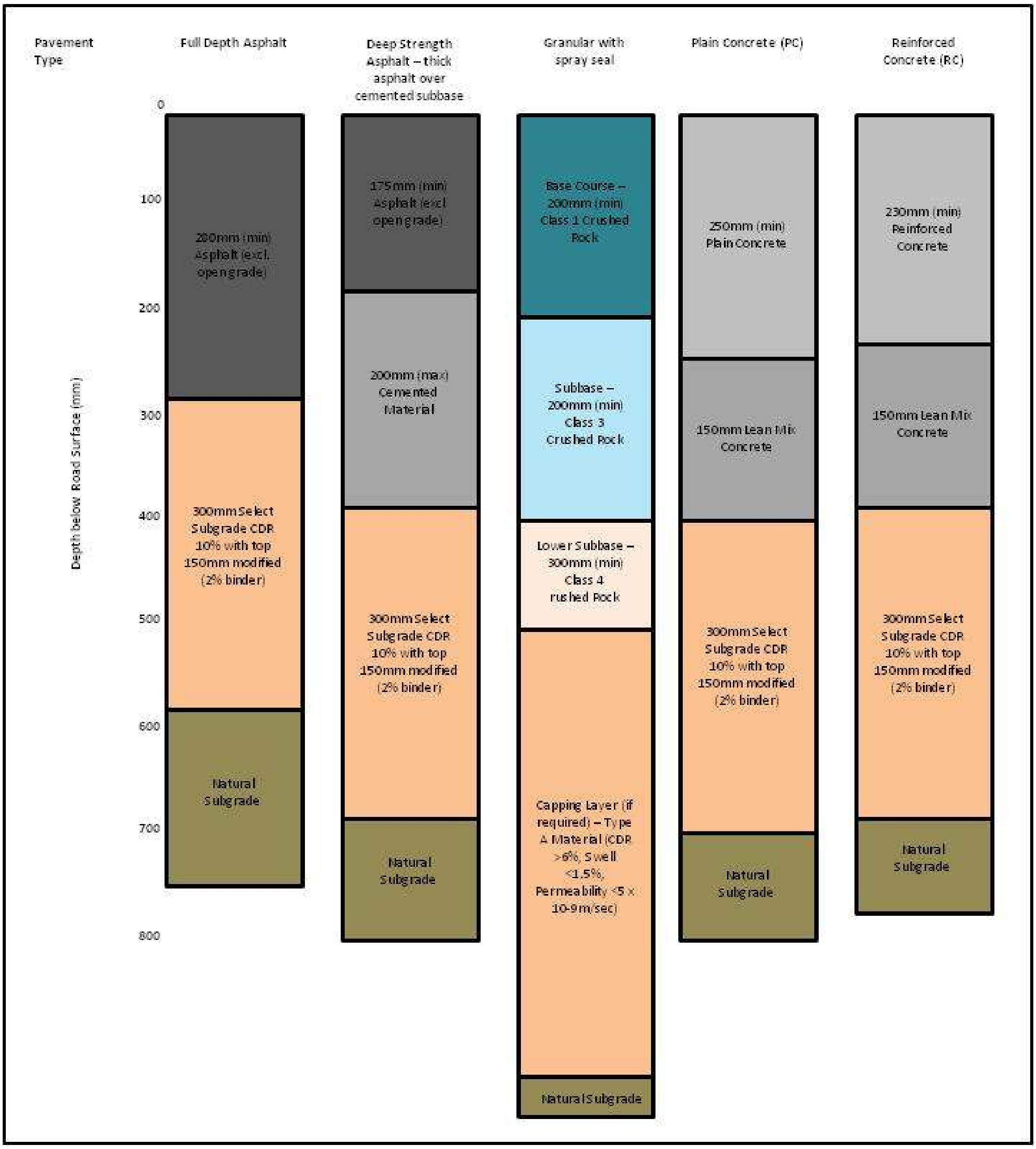

Figure 2 Adapted from *Pavement types and material depths*
Source: Dilger, A. (2011)[13]

Road delivery

Road design process

In Australia, the road design process is documented through an AUSTROADs publication, “Guide to Road Design: Process and Documentation”. This publication provides detailed guidance on all phases of the design process. The design of road infrastructure is a complex and iterative process tailored to meet the needs of current and future generations. A professional and experienced project team is often used to integrate many factors including user safety, workplace safety, environmental protection, social advancement and economic prosperity.

Road design includes a number of phases to ensure activity interfaces are appropriately managed:

- Phase 1 Establish the preferred solution – Concept Design
- Phase 2 Further develop the solution – Preliminary Design
- Phase 3 Design for construction – Detail Design, and
- Phase 4 Delivery – delivery mechanism is dependent on the depth of design detail achieved in Phase 3. Delivery options include construct only (C), design and construct (D&C) and maintain (DCM), early contractor involvement (ECI) and alliance.[14]

The design process combines complex technical elements that require the project team to apply sound judgment and experience in reaching the appropriate design. Traditional elements covered in road design include:

- pavement design and material specifications
- intersections, interchanges and modal interfaces
- geometric design including coordinated road alignments, adequate cross sectionsn and sight distances
- environmental constraints and the impact of the road on the environment, both physically and operationally
- drainage design including storm water runoff
- roadside design including median strips, road furniture, lighting and signals, pedestrian and bicycle facilities, landscaping and noise barriers
- geotechnical design such as earthworks design, construction materials and environment issues.[15]

Road construction process

Road construction introduces huge quantities of foreign material to the natural environment and disrupts the soil conditions and runoff behaviour for hundreds of kilometres. Consequently, the road construction process is paramount 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 stabilisation 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.[16] 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).[17] 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.[18] The processes involved in the placement of modern roads include roadway preparation, excavation and stabilisation, 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.[19] 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.[20] 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.[19]

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 (for example, igneous, sedimentary and metamorphic), and then into categories based on their practical road making abilities (for example, 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.[21] Secondary aggregates are low-grade aggregates that have been sourced from the "waste aggregates" of various industrial processes. They include blast furnace slag, pulverised 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.[21]

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 roadbase, such as natural rock, gravels and sands, can be replaced by recycled materials, repurposed waste, or alternative processes.

Strategic Area 1 – Reducing environmental impacts through improved design

Route design

Decisions made in the design phase of a road construction project can have an enormous effect on the overall environmental impact of a road. Small adjustments to horizontal alignments can avoid sensitive ecological areas and minimise the amount of raw materials required to complete the project. The vertical alignment of a road has huge implications for vehicle efficiency and small changes made during the design phase can result in enormous energy savings over the life of a roadway.

Developed in 2006, JOULESAVE[22] is a widely used European software that allows the road designer to rapidly quantify the energy requirements for all phases of road construction and to compare different options based on energy use. JOULESAVE also has the functionality to interact with a Swedish designed program, VETO,[23] which allows each route option to be assessed in terms of the fuel usage of vehicles using the road. In this way, roads can be designed not only to reduce the energy requirements of the construction phase, but also to reduce the operational (including vehicular use throughout the life of the road) impact of the road throughout the design life.

The JOULESAVE software is now in its second generation with the release JOULESAVE2,[22] which has undergone significant testing to ensure consistency and features additional capabilities to allow the user to choose low energy materials, incorporate road deterioration and to measure rolling resistance of the road under evaluation.

The use of software such as JOULESAVE enables energy to be one of the main criteria for route selection, alongside more traditional criteria such as the impact of a route on ecologically sensitive or heritage listed areas. To date, the software has shown that energy savings of up to 47 per cent in road construction, up to 20 per cent in the operational life of a road and up to 30 per cent in maintenance are possible in many road construction projects. For road agencies, the use of such software is extremely beneficial in order to rapidly identify the most energy efficient route design from a number of otherwise equally viable alternatives.

Pavement design

There are many factors to consider when selecting a wearing course for a road. The availability of materials, the type of road, the economics of the project, the composition of the surface layers and the climactic conditions all currently influence the eventual choice of road surface. However, a new compelling principle is emerging that threatens to overtake all other considerations for major road surfaces: pavement smoothness. Recent research is increasingly confirming the role of pavement smoothness in reducing the emissions and fuel consumption of the vehicles that use the road.

The Asphalt Pavement Alliance (APA) in the US has identified three major pavement characteristics that are being explored in an effort to reduce vehicle fuel consumption: pavement-tyre rolling resistance, pavement stiffness and pavement texture or smoothness. Of the three, it appears the pavement-tyre rolling resistance and pavement texture are the only real viable options to decrease the fuel consumption of vehicles on the road. A full scale field study conducted by the

Federal Highway Administration at the WesTrack pavement in Nevada showed that trucks running on slightly smoother pavements could reduce fuel consumption by 4.5 per cent.[24] Smoother pavements are also proven to last longer due to less deterioration caused by less bouncing of truck and car tyres, resulting in pavements that last up to ten per cent longer than ordinary pavements.[24]

Perpetual pavement is another innovative pavement design methodology that is reducing the environmental impact of new road construction. Perpetual pavements are designed to last indefinitely with just the top 25-30mm wearing course needing to be replaced every 20 years or so, significantly reducing both the maintenance and construction costs and the need for new materials. This technology is based on experience both in Australia and overseas showing that there is a limiting pavement layer thickness, past which there is no increase in strength. While not currently recognised in Austroads standards (which are still based in finite element analysis theory), the perpetual pavement methodology is gaining traction within the Australian Asphalt and Pavement Association (AAPA).

Material specifications, policy and knowledge transfer

The amount of aggregates required for road construction can be significantly reduced by substituting the raw materials with recycled or repurposed waste from a variety of sources. However, this practice has traditionally been impeded by a lack of knowledge about the availability and performance of these aggregate waste materials. Material specifications guidelines often prohibit the use of recycled materials in order to ensure consistency and safety, even though many of the materials may be adequate for use. Another major barrier to the use of recycled materials is the lack of knowledge about how they might perform as aggregates and roadbase in the long term.

Research programs

There are a number of international research programs funded by **Forum of European National Highway Research Laboratories (FEHRL)**. FEHRL was formed in 1989 to provide a coordinated platform for conveying the research of over thirty national research and technical centres from Europe. It collaborates with associated institutes from around the world, on topics covering safety, materials, environmental issues, telematics and economic evaluation.[25] Detailed below are some relevant projects, including SAMARIS (Sustainable and Advanced Materials for Road Infrastructure) and ALT-MAT (Alternative Materials in Road Construction) that have attempted to encourage the use of recycled materials through new testing procedures and guidelines.

SAMARIS

The SAMARIS Project[26] aimed to define a methodology to assess the structural performance, safety and environmental impact of alternative materials in road construction. Materials investigated include mining waste rocks, blast furnace slag, coal fly and bottom ash, crushed concrete, reclaimed concrete pavement, municipal solid waste incinerator ash and scrap tyres. The project, begun in 2002 for the European Commission, produced mechanical models and test methods that led to the first performance-based specifications for recycled materials. Additionally, the project also created technical guides and recommendations for proper recycling techniques in road construction projects.

ALT-MAT

The ALT-MAT research project[27] has taken different approach towards encouraging the use of alternative materials. While SAMARIS had a definite technical and laboratory component, the ALT-MAT project aimed to provide road agencies with the information to bridge the gap between laboratory tests and field behaviour of alternative materials. Methods to evaluate the suitability of alternative road constructions materials to a variety of potential applications were defined, and as a result, there are now technical guidelines for selecting appropriate alternative road construction materials.

DIRECT-MAT

DIRECT-MAT (Dismantling and RECycling Techniques for road MATerials) is a coordination and support project from the FEHRL. The project, running from 2009 to 2011, aims to share European experiences on dismantling and recycling of road materials into new roads. Specifically, the project will build a web database and draft Best Practice Guides. The project aims to support the daily work of practitioners, researchers and standardisation bodies, to actively contribute to reducing the waste disposal associated with roads.[28]

RE-ROAD

The RE-ROAD project, supported by FEHRL, aims to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt pavements. This significant project has a $EU3.2 million budget being carried out from 2009 to late 2012. There is a considerable technical component, with laboratory and field trials being conducted to complement and inform the knowledge transfer part of the project. The project is grounded in life cycle analysis, which is being introduced into European waste policy.[29]

NR2C

New Road Construction Concepts (NR2C) is a large innovation project that has emerged as a result of increasing concerns about the future of the European road system. It aims to develop long term visions of the best possible road system that might be possible and actively seeks ways to link these long term visions and ideas to practical short term actions. At the core of the project lies four concepts – reliable, green, safe and smart, and human – through which critical research gaps and directions can be identified. Once these gaps are identified, NR2C enables specific research projects that work towards creating the best possible future for the European road system.

After developing new concepts for the roads of the future, the NR2C project will develop innovations under three broad categories – urban infrastructure, interurban infrastructure and civil engineering structures (specifically bridges). Specific innovations have already been identified, such as:

- new design models for the development of new multi-modal streets;
- road underlayers with a high percentage of recycled products;
- crack free semi rigid pavements that utilise industrial by-products;
- new road maintenance projects that can be completed under all weather conditions;
- new lightweight bridges that are easily prefabricated and allow for rapid installation; and
- developing infra-red technology to improve drivers' vision under bad weather conditions.

The NR2C project has already delivered a number of significant reports to FEHRL, including a paper entitled "New Road Construction Concepts: Vision 2040" and a planning document called "Facing the Future – Developments Required" which outline some of the future research areas identified through the project.

Specifications

In Australia, there are a number of new specifications that are helping to promote the use of recycled materials including:

- In 2010, the Queensland Department of Main Roads released MRS35 – Recycled Materials for Pavements. The specification clearly defines stringent requirements that suppliers must consistently meet before providing recycled roadbase. Compliance with this specification ensures that end users can use the products with confidence;
- In Western Australia (WA) the Pavement Specification 501 has undergone a revision during 2010/11 to include the use and management of recycled materials for the construction of roads. It states that recycled materials such as recycled crushed concrete and crushed glass can be used as long as it passes an inspection criterion that is equivalent to crushed rock aggregates;
- The New South Wales Government claims to be at the forefront of many initiatives, and in 2001 contracted the Institute of Public Works Engineering Australia to create the first industry wide specification for the use of recycled materials in NSW road infrastructure. Since this time, a number of revisions have occurred to account for significant developments in the science of materials recycling as well as major changes to the legal environment in which recycling takes place;
- In June 2011 road construction specifications for Tasmania went through a large overhaul of their publications to incorporate the use of recycled materials in the production process of asphalt and aggregates. The use of recycled materials has its own specification criteria to ensure the materials are free from hazardous compounds.
- VicRoads has begun incorporating the use of recycled materials into the construction of roads. This includes the use of; alternative aggregates, asphalt and the use of recycled wastewater. The document "Sustainable Procurement Guidelines", published in August 2011, specifies

where and the recycled materials are sourced from and the quality it must be in order to be used.

- As of September 2008 in the Northern Territory, road construction specifications stated only quarried rock materials may be used as aggregates in the construction of roads. Further information on the status of this is unknown due to limited information provided on official websites.
- Road construction specifications in South Australia in 2008 stated that recycled materials may not be used as asphalt aggregates in the construction of roads. It is of note that the specifications do not state clearly about the use of crushed glass and indicates that in the future these may be amended to allow further use of recycled materials.
- Austroads guide to pavement technology part 4E: recycled materials.

Local and appropriate technologies (OR Marginal Materials and Local technologies)

Using local resources to build infrastructure is integral to developing countries creating a network of rural roads but equally appealing to geographically isolated road construction typical in Queensland and Western Australia. Known as "local and appropriate technology" the concept of using local resources is not new, however it has a renewed focus when focusing on reducing environmental impacts in road construction.

Local technology implies construction methods that utilise local resources whether that involves local borrow pits for extracting crushed rock aggregate, strengthening in-situ materials using stabilising additive or resources that are simple to extract and exist in abundance.

Case Study – Chile

2000kms of Salt Roads – Caminos Básicos

The "Caminos Básicos 5 000" programme has improved 5 000 km of low traffic roads using low-cost construction techniques. In particular 2 000 km of roads have been made with readily available salt (magnesium and calcium chlorides) in the northern regions of the country. This salt construction method has delivered inexpensive roads at the same time as generating local skills and providing employment. The techniques carried out on the "Caminos Básicos 5 000" are now being repeated in similar circumstances across Mexico, Bolivia, Peru and Argentina. There is also a history of salt road construction techniques in Botswana and Namibia.[30]

The use of local resources has been an integral component of the traditionally lean methods of road construction. Identification of local borrow pits for road construction aggregates is an important investigation activity in the design phase and repeated by the construction contractor when determining their earthworks strategy. These lean construction methods are increasingly challenged as we complicate infrastructure delivery with homogenous material specifications, rigid contractual structures, rapid delivery timelines and new quarry site processes. Is the industry losing sight of good practices in a bid to roll out huge contracts and deliver Government promises? For example, the 2011 Roads and Highways conference in Malaysia presented a project by the Indian Government. The Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was a tremendous success in rapidly delivering 4 million kilometres of rural roads (single lane with shoulder) across the country. However the extensive project did not demonstrate any local and appropriate technologies including the oversight of local maintenance mechanisms.[31]

Case Study – Vietnam

Clay Brick Roads and Nuptials – Ministry of Transport Vietnam

Vietnam has a traditional of building brick roads. When a girl was married to a boy from another village, the boy's family had to provide payment of 1 000 bricks to the girl's village. This traditional custom existed in many communities until 1945 and is now less common. In addition to the bricks contributed by the groom's family, the villagers paid for complimentary materials including lime, sand and a team of builders to construct a section of village roadway. Over history, this contribution has been integral to the development of permanent community infrastructure. The Ministry of Transport of Viet Nam with the support of international donors are investigating the possibility of building rural brick roads in line with this marriage tradition. Particular attention is being paid to the Mekong and Red rivers delta where there is plenty of clay for bricks but limited stone.[32]

Appropriate technologies are construction methods that support the social context of the project and how it is placed in the local environment. This ensures technologies are easy to implement and repeated without depending on third party involvement or specialised machinery. Using appropriate technology ensures construction can be repeated readily for more infrastructure and maintenance carried out locally at a minimum cost. Appropriate technology is known to deliver more affordable construction solutions in rural areas and empower the local population.

Case Study – Uzbekistan

Caravan roads to highways – Uzbekistan Engineers

Engineers in Uzbekistan are transforming rough caravan roads into highways with pavements constructed from local natural stone bound with local crude oil. The gradual development of the road network has optimised local resources and conditions within tight budget constraints. Traditional tracks and transport routes were upgraded quickly using local building materials with small investments to provide the largest possible network across the country. The sub-base, culverts and bridges were constructed to international standards, however the pavement construction relied local stone bound with local crude oil. Under increasing traffic loads the surface has been upgraded with concrete and bitumen products depending on the local circumstances and elevation. This method ensured the delivery of 5 500 km of roads per year in Uzbekistan and resulted in Uzbek engineers opening 250 km of roads on critical mountainous routes like the Osh – Irkeshtam Road between Kyrgyzstan and China.[30]

Locally available road pavement materials, particularly rural or geographically isolated areas are often of marginal quality. Best performance may not be achieved due to the limited technical knowledge of the material being used. An understanding of appropriate construction techniques and expected performance of such materials under traffic loading are important factors in achieving an optimal result. Local knowledge is often paramount. Restructuring in Local Government and State Road Authorities, increased mobility of public service personnel and national construction contractors result in a diminished degree of local knowledge required.

Appropriate technology in the Australian context

In order to address this issue a partnership was established between the Australian Road and Research Board (ARRB) and the Institute of Engineers Australia introducing “guidelines for making better use of local materials”.[33] The guidelines reveal how 50 soil types perform across Australia with information gathered from practical, local experiences, laboratory testing and case studies. The Guidelines draw extensively upon information gathered for a national materials register prior to 1991 by the Queensland road agency.[34] Low cost methods are described on how to test soils to arrive at a better understanding of their performance as a pavement material. Guidance is given on how to treat a soil for particular use as a sub-base, base course and as a wearing course in the case of unsealed roads.

Local pavement materials are typically naturally-occurring weathered rocks, ridge gravels, stream gravels, sands and clays which are close to site and can be won and placed by readily available construction equipment. They can be ripped in place without special methods (for example, drilling and blasting, as distinct from fine crushed rock aggregate which is produced in a hard rock quarry with fixed crushing and screening equipment).

In Australia, a vast road network of local roads have been built at relatively low cost and adequate service performance without sophisticated testing regimes, using materials which do not meet the current specifications for major road pavements. The guidelines highlight that an extensive “variety of materials, loams, soft sandstones, natural gravel, decomposed rock and industrial residuals have been and are being successfully used where traffic is not too heavy, the environment is understood and properly taken into account, where design, construction and maintenance is appropriate to the circumstances and quality control is adequate”.[35]

Strategic Area 2 – Reducing environmental impacts through AGGREGATES in road construction

Studies exploring extractive resource availability in Australia estimate that current resources approved for extraction (including rock, sand, gravel, loam and other materials from a pit or quarry) may be depleted in the near future. Comparing demand estimates from 2005 to 2026 with extractive material currently available in SEQ, the GHD report predicts that current resources that are approved for extraction will be depleted by the year 2015, and that there will be a shortfall of 509 million tonnes of resources available for extraction by 2026.

Revising a previous study by GHD in 2005, an additional report was commissioned by Cement, Concrete and Aggregates Australia (CCAA) to estimate the extent of extractive resources available in Southeast Queensland (SEQ) following the introduction of new state environmental policy and legislation in 2006. The report estimates that there are 1 656 million tonnes of resources available for extraction, of which approximately half (855 million tonnes) are not currently approved for industry development.[36]

From a different perspective, a 2011 study commissioned by the Chamber of Commerce and Industry Western Australia (CCIWA) sought to forecast supply and demand information of basic raw materials into the future with a view to establishing state environmental policy and legislation ensuring a sustainable supply of such resources. As a result, Landvision recommended localised town planning provisions for resource protection, predominantly in the form of managing Special Control Areas (SCA).[37]

The methodology for mitigating the risks associated with resource scarcity focus on the business case for alternative materials in road construction. A study commissioned by Zero Waste South Australia in 2010[38] aimed to increase the market acceptance of recycled aggregates for use by the construction sector. The report revealed that the use of recycled aggregates results in GHG emission reductions of 22-46 per cent, when compared with equivalent quarried or primary aggregate products. This represents an emission saving of 4 kg CO_2 equivalent per tonne (based on the investigation data). The findings correlate with US studies that reveal recycled aggregate to have 30 per cent less embodied carbon emissions than primary aggregates.

A software tool created by the research team at Zero Waste South Australia can be used to compare the sustainability of materials choices for a range of road construction activities. The replacement of 50 per cent of primary aggregates with recycled aggregates could reduce the embodied energy and GHG emissions of the materials component of the road construction by around 23 per cent.

The report concludes that in order to advance the market acceptance of recycled aggregates in the construction sector, future data collection needs to quantify offsite environmental and social impacts of quarrying, recycling and landfill operations.

The use of recycled aggregates and the process of repurposing waste brings substantial environmental gains in the form of:

- reductions in resource consumption;
- diversion of waste materials from landfill;

- reduced quarrying; and
- reduced GHG emissions – recycled aggregates can have lower embodied energy in addition to the reduced transport emissions where recycled materials are reused close to their original location.

A review of global literature reveals a number of key materials that are applicable to Australia.

Alternative aggregate materials

MATERIAL 1. Recycled construction and demolition materials

In Australia, over 43.8 million tonnes of waste is generated each year[39] with the construction and demolition sector responsible for 38 per cent of this. Waste material from the demolition of buildings and pavements, including concrete, brick, rubble, asphalt, metals, timber and other building materials, can be used as a substitute for virgin aggregates in most crushed rock aggregate material applications. Commonly the primary constituent is crushed demolition concrete with up to 20 per cent supplementary materials such as brick and asphalt. Whilst recycled materials are generally not as strong as rock or gravel, they are still generally capable of meeting most road specifications, especially for medium or heavily trafficked flexible base course and sub-base. Logistically, the use of recycled construction and demolition materials tends to present major problems in road construction projects. The costs involved in the separation and transportation of construction and demolition waste aggregates are often prohibitively expensive for many smaller road building projects. Thus, the locality of the facility is critical, and specifications need to allow for the inclusion of alternative materials.

However, there are a number of agencies and companies that have championed projects involving recycled construction and demolition waste. In Queensland, the Alex Fraser Group has emerged as an industry leader and innovator, and was recognised for this as a finalist in the inaugural Queensland Premier's Sustainability Award in 2010. Its entry focused on the use of recycled materials in the construction of Brisbane's Clem 7 Tunnel and the reduction in greenhouse gas emissions this created. The Alex Fraser Group were also concerned to reduce the amount of material going to landfill, and this could occur through the use of recycled materials as roadbase. Thus, the firm calculates that in the Clem 7 Tunnel the use of recycled materials achieved several environmental benefits such as:

- a saving of over 1 000 tonnes of CO_2 emissions;
- diversion 100 000 tonnes of waste from landfill sites;
- a 120 000 tonne reduction in natural resources depleted;
- a saving of 725 truck movements (45 000 km of road travel); and
- a 20 per cent reduction in material costs from savings in transport and sourcing.

The recycling of aggregates and concrete continues to expand, and this is reflected in the recently announced AUD$45 million Western Metropolitan Recycling Facility, owned and operated by the Alex Fraser Group. It will bring together some of the best design and innovation technology to deliver a massive boost to C&D (construction and demolition) recycling capacity in Victoria.[40]

Case Study – Western Australia

Saving Landfill, Building Roads – Kwinana Local Government [41,42]

In 1995, the Town of Kwinana, Western Australia faced an AUD$1 million bill to clay line its landfill. In an unprecedented move, the Council decided to send its general waste elsewhere and convert the tip to an inert landfill site. When seeking expressions of interest to operate the site, the Council strongly emphasised the recycling of incoming waste materials.

Waste Stream Management was chosen to operate the site, a company that attracts a large proportion of the demolition and building waste from the Perth metropolitan region and has a strong commitment to recycling as much as possible into useable products. Since commencing at the Thomas Road site in 1997, the Company has stockpiled clean concrete for eventual use in road building. It has also recycled steel, aluminium and top soil.

To efficiently facilitate the waste being recycled at the site, Waste Stream Management, in partnership with the Town of Kwinana and Main Roads WA, constructed a road using recycled concrete aggregate (RCA) on a one kilometre stretch of Gilmore Avenue. The road was subject to Main Roads WA testing over an extended period, and was used regularly by passenger and heavy freight vehicles. The testing revealed that this road performed better than a control road nearby made from non-recycled materials. The control road already appears degraded whilst the road using the recycled materials has remained in good condition.

Whilst the test road itself proved a structural success, the resulting partnership between Main Roads WA and Waste Stream Management and the general incorporation of RCA into road projects was not as positive. As reported by Cardno, Waste Stream Management appeared to be reluctant to import fines into the mix at Main Roads' request, while Main Roads were slow to respond to the new technology. During the trial, the price of landfill also fell, reducing the availability of waste material to be recycled.

Waste Stream Management was subsequently forced to sell the AUD$1 million crushing equipment imported from Germany. However, in a positive outcome for the project, Main Roads WA is now updating its pavement specifications to include alternate materials such as RCA for road construction. Ultimately, the project proved that recycled concrete aggregate can be used successfully in sub-base and base course as a viable alternative to extracted materials.

Case Study – Victoria

Recycled Crushed Concrete Aggregates – ARRB [43]

A Melbourne industrial estate's road was scheduled to be redeveloped. Normally this would be done with traditional bitumen and virgin quarried rocks sourced from areas around Victoria, but it was the ideal situation to trial the performance of Recycled Crushed Concretes (RCC) as an aggregate alternative to quarried rocks.

The ARRB Group and another partner undertook road construction operations using crushed rock aggregates in one road section and recycled crushed concrete (RCC) in another, followed by rigorous testing and analysis. ARRB conducted falling weight deflectometer tests at 16 different sites to compare the life expectancy and material strength of each section.

The tests concluded that at the time of the tests the life expectancy of the virgin rocks was 5 years and that of the RCC was 441 years. The strength of quarried rock was recorded as being 270 MPa whereas the strength of the RCC was 13 times greater at 3 500 MPa.

Case Study – Western Australia

95 per cent of Road Construction Waste Recycled – Main Roads WA[44]

The Great Eastern Highway is a major connection between the metropolis of Perth and the nearby city of Kalgoorlie. It is also a key freight connection to the wheatbelt and goldfields. Recent upgrades to the highway necessitated the demolition and removal of a number of buildings in Midvale. Previously, this waste would have been sent to landfill, but Main Roads WA were able to seize the opportunity to reuse much of the construction waste in other projects. Main Roads engaged local business All Earth Group for this work, and 95 per cent of the waste was recycled in various ways – in a new carpark for the Perth Airport, in steel recycling plants and for garden and farming mulch. This project is a significant step in the process of encouraging recycling of construction and demolition waste in Western Australia, which has traditionally fallen behind other Australian states in its recycling programs. Indeed, most recycling companies in WA now find that the demand for recycled products far outstrips the supply of material sent to them rather than dumped in landfill. Hopefully, with Main Roads WA leading the recycling way, other companies will soon follow, and thus help to reduce the huge amount of waste sent to landfill every year in Western Australia.

Case Study – Western Australia

Specifications for RCD material use on local government road pavements – City of Canning[45,46]

Because the term “waste” is broadly understood to mean items of no value, it is difficult to convince local councils and other parties to begin using recycled aggregates. For example, the City of Canning, Western Australia, was initially reluctant to use recycled materials because of this perception of waste and because the City did not believe it would meet quality standards.

However, during 2007 C&D Recycling persuaded Canning to use recycled materials after an inspection of such materials proved that there were no contaminants and confirmed it was a viable resource. The Welshpool Road project was thus undertaken and, after it was completed and opened to traffic, extensive tests by the City showed equivalent performance to crushed rock aggregate road construction.

Similar demonstrations of this magnitude have occurred throughout Western Australia, such as in Gilmore Avenue, Kwinana, from January to April 2003 (discussed earlier), and Warton Road, Gosnells during March 2009. All three projects have concluded that the use of recycled materials in Western Australia is a viable resource and will pave the way for further use in future construction.

The 860 metre Welshpool Road project trialed different recycled material combinations and compared them to a control section of conventional roadbase. The pavement of this four-lane undivided road was widened by 4.5 m on each side. The road carries 8 000 vehicles per day with 15 per cent of the vehicles being trucks, and is designed to carry traffic loads of 20 million standard axles over a 30 year design life. The heavy traffic includes road trains serving livestock feed manufacturers and heavy engineering construction companies.

Construction commenced in 2007, when the road verge and footpath were boxed out with an excavator and all concrete products (kerbs, paths, driveways) separated from the subgrade on site. This was carted to C&D Recycling in Hazelmere, where crushed roadbase manufactured from recycled demolition materials was back-loaded to the job site. When placed and compacted the crushed comingled recycled concrete material was of such a high quality that the City felt confident enough to extend the trial to include the recycled material as a base course in lieu of conventional crushed granite roadbase. Four different pavement profiles were constructed using combinations of recycled material and conventional crushed rock aggregates.

Importantly, it was observed during construction that the RCD material was able to withstand heavy turning traffic for an extended period without an asphalt surface. Conventional materials typically are unable to survive this harsh treatment.

The Welshpool Road project demonstrated that RCD materials perform better than conventional crushed granite roadbase. The RCD material is highly stable at varying moisture contents, it is easily spread and compacted during construction, and it withstands the effects of turning traffic. It is not clear whether the tendency of RCD materials to re-cement with time will be a benefit or not to the pavement's survivability. It may be possible to utilise this property to provide additional pavement life, an area that Curtin University plans to research.

The aim of this investigation was to develop a specification for use on local government road pavements in Western Australia. It has established that high density foreign materials in the recycled concrete material are clay brick and tile, sand, milled asphalt, and crushed glass less than 4 mm in size. The major component of the product will be concrete and this may be from structural and non-structural sources. The maximum percentage of high density foreign material is recommended as 20 per cent for low traffic base course, 30 per cent for sub-base and 40 per cent for select fill.

MATERIAL 2. Glass

Crushed glass is most often employed as an aggregate for the asphalt pavement layer of modern roads, but it can also be used as part of the admissible foreign material component of roadbase and sub-base. The glass is generally sourced from recycled glass bottles, glass factories and building demolition. VicRoads specification (Section 821 – Cementitiously Treated Crushed Concrete for Pavement Sub-base) allows for foreign material to be present, including up to 3 per cent glass. Handling risks related to cuts from sharp edges may be avoided with the modern crushing processes that reduce the angularity of shapes.

The Municipal Association of Victoria is promoting the use of recycled materials in the construction of roads throughout Victoria. In particular it is planning to extend the recommended amount of materials used in the construction blend from 3 per cent to 15-25 per cent. A trial by Swinburne

University has proven that blends containing up to 30 per cent recycled material are equal in performance to, or exceed, blends using quarried rocks as aggregate.

The use of virgin quarried rocks for aggregates is becoming less and less efficient and economical due to sourcing difficulties throughout Victoria, and crushed glass, crushed used concrete and brick work are acceptable alternatives.

United Kingdom, United States, Europe and New Zealand have also begun to use recycled materials, in particular crushed glass, in the construction of roads. Glass accounts for one-quarter of recycled material generated in Victoria for use in construction and there is thus a viable supply of glass for this purpose. A 2008 study by RMIT and the Alex Fraser Group[47] confirmed that the use of recycled materials in road construction can lead to a reduction in carbon emissions of up to 65 per cent. (Details of this commercial report were not publicly available at the time of publishing.)

Case Study – New Zealand

Crushed Glass Aggregates – Fulton Hogan and Nelson City Council[48]

Nelson is a city of approximately 50 000 people located at the top of the South Island of New Zealand. Its geographic location makes road transport expensive, and this is exacerbated by the lack of a rail link. The city collects between 2 000 to 3 000 tonnes of recycled glass per annum – glass which has become extremely expensive to sort and transport around New Zealand for reprocessing.

In 2005, Fulton Hogan and Nelson City Council agreed to undertake a trial of recycled glass aggregate in a city street. The costs and benefits of the process are summarised below.

Benefits	Costs
- reduced cost of transporting glass to landfill or distant reprocessing site; - reduced use of landfill air space; - less virgin aggregate being consumed; and - improved environmental awareness and attitudes.	- kerbside collection (though this is likely to be carried out anyway); - crushing glass; and - mixing with base course.

After a business case determined the exercise was economically feasible, a glass crushing process was added to a separate base course crushing operation and this generated a product consistent with Transport New Zealand specifications. A visual assessment of the performance of the trial road to date shows no difference between the sections of road constructed with recycled glass and the virgin aggregate sections, and neither exhibit any rutting or distress. Further technical investigations support these observations.

The results from the trial of crushed glass in base course aggregate show that this is an excellent initiative to promote sustainable practices in road construction. Despite some minor difficulties with stockpiling and crushing, the product is a feasible alternative to virgin aggregate at the current specification levels (five per cent). The in situ performance of the trial road suggests that the use of recycled glass is a structurally feasible option.

From a sustainability point of view, the reduction in carbon emissions resulting from transporting the glass long distances (for example, Nelson to Auckland) for recycling, or to increasingly more isolated landfill sites, is a clear benefit. However, it is the extension of the life of both landfills and quarries that really make this sustainability initiative worthy to raise one's glass to!

Case Study – NSW and Victoria

Mayors support recycled glass as a sustainable alternative in road construction – Australian Food and Grocery Council[49]

In July 2010 the councils of Bondi in NSW and Manningham in Victoria became among the first local councils to use recycled glass in road and path construction. The projects are funded and supported by the Packaging Stewardship Forum of the Australian Food and Grocery Council. Together, these organisations and councils have diverted almost 100 tonnes of recycled glass from landfill.

In Manningham, a new bicycle and pedestrian path was laid using a 100 per cent recycled mix of crushed glass and rock, with 15 tonnes of crushed recycled glass and crushed rock used over the 240 metres of pathway. The two projects demonstrate to local governments across Australia that there are practical and sustainable ways to reduce the use of virgin materials whilst still producing high quality infrastructure. This work is supported by the continual development of new standards and policies to encourage such measures.

MATERIAL 3. Recycled vehicle tyres

In 2009-10, the National Waste Policy[50] identified the need to address the environmental issue of tyres going to landfill. At this time it was estimated that around 29 million waste tyres or 230 000 tonnes of material were generated in Australia each year. Most of these tyres are left with tyre dealers or retailers, who replace them with new or retreaded tyres. This practice means that waste tyres are generated over a vast area and, given their typical weight of 8 kilograms and inherent bulk, they are difficult to sort, collect, transport, store and finally dispose of or recycle. Disposal to landfill is still the most common end for waste tyres in Australia, with 60 per cent disposed of this way, while 30 per cent are recycled and an estimated 10 per cent are dumped illegally.[51]

Tyres are generally made from rubber, steel and textiles, and the facilities required to recycle them are limited in Australia. Currently the nation has about 4 000 tyre retailers, about 30 licensed and operating tyre disposal organisations and less than 10 recyclers.[52] Rubber material that is recycled is turned into a product known as "crumb", and all steel is recycled in a concurrent process. In August 2011, Tyres Stewardship Australia was formed by the Government to address product life-cycle waste issues and foster further opportunities to use waste tyres in:

- the manufacture of new rubber products;
- surface materials such as artificial turf, sporting field and playground surfaces, and conveyor belts;
- alternative fuel for industries including producers of energy and cement, and a diesel substitute in explosives manufacturing;
- asphalt pavement for road construction; and

- infrastructure for embankment stabilisation and lightweight fill.

Recycling road tyres for road construction purposes generally entails use of the rubber crumb product in the asphalt pavement layer, although this involves technical hurdles. The rubber crumb tends to melt when exposed to the high temperatures in the bitumen, and the process of cutting the tyres into a crumb is extremely energy intensive. However, there are newer techniques that use whole tyres as part of the roadbase, in embankments or as scour protection.

Ecoflex is an Australian company that provides a range of engineered systems involving the removal of the sidewall of used tyres to create a structural unit or container.[53] The container void is then filled with crushed rock, gravel, sand or soil, thus forming a structural building block that acts almost as a very large aggregate unit. This unique tyre foundation structure was patented in 2003.[54] One system that employs these tyres, E-Pave, is a permeable road construction system typically used in areas with poor soil conditions.[55] A high strength sub-base is constructed from a single or double layer of car or truck tyres, filled with crushed rock or sand. This unique system is able to spread the load far better than traditional road building materials can.

E-Pave has been trialled in underground mine roads in the Hunter Valley. The wet, soft sub-grades present in mines are susceptible to degradation under heavy equipment and relocation of longwall equipment. The results from the trial are extremely encouraging, with improvements to the drainage and erosions problems which have plagued roads in the area.

According to Ecoflex, the E-Pave system has the following advantages:

- High structural load: in underground mine roads E-Pave serves mine bulldozers weighing in excess of 100 tonnes;
- High drainage: the Ecoflex system allows water to drain naturally without affecting the strength of the overall structure; and
- Immediate use: E-Pave can be laid over virtually any surface, wet or dry, and the technology allows roads to be built as you move forward, in a similar way to the laying of railway tracks.

MATERIAL 4. Bauxite residue – red sand and red mud

Australia plays a significant global role in supplying minerals and natural resources for global markets. The corresponding challenge of this fortuitous market strength is the need to treat, reuse, recycle or store industrial by-products and toxins. This typically involves mine tailings and process residues. The generally accepted response in Australia is to place the tailings and residues in engineered storage facilities, requiring long-term, active management. However many countries, such as Sweden, Germany and Denmark, are setting precedents by achieving high rates of reuse of their industrial wastes.

Australia produces 40 per cent of the world's alumina with many alumina refineries located near population centres (as are power stations, steel mills and their potentially useful by-products). Australia currently stores:

- 40 million tonnes per annum of bauxite residue from the alumina industry;[56] and
- 14 million tonnes per annum of ash from coal fired power stations.[57]

Depending on the grade of the bauxite resource, for every tonne of alumina produced, 0.5 to 3 tonnes of bauxite residue may be produced. The global average is 1.0-1.6 tonnes of bauxite residue per tonne of alumina processed, with around 145 million tonnes of bauxite residue produced annually.[58] The bauxite residue is derived from the residual soil components of the raw materials source, and is generally about half sand and half mud. Opportunities exist, particularly within road construction, to use these residues for large volume applications in infrastructure projects such as civil engineering and soil amendment, and to use recycled materials as substitutes for natural aggregates.[59] Some of the identified possible uses of the bauxite residue are as a colouring agent, as a building material (e.g., for bricks), and as a glaze for ceramics.[59]

The Bauxite Residue Program at the Centre for Sustainable Resource Processing (CSRP) in Western Australia was established under the Cooperative Research Centres Program of the Department of Innovation, Industry, Science and Research. The program aims to utilise the various components of the by-product derived from alumina production. CSRP's objective is to re-direct large volumes of existing by-products from the minerals and energy sectors to beneficial uses in the construction, agricultural and environmental sectors. The objectives fit closely into the Federal Government's National Waste Policy Framework November 2009 (less waste, more resources), a framework that addresses significant long-term environmental challenges faced by industry and the community.

This research initiative has partnered with Alcoa of Australia Limited to create a specification detailing the recovery of sand from mineral residues in order to use it as a practical roadbase material.[60,61] Alcoa is a major producer of aluminium from two smelters in Victoria and is the world's leading producer of alumina from three refineries in Western Australia. The use of sand from mineral residues as a roadbase material has a range of potential benefits including:

- replacement of increasingly scarce supplies of quarry sand;
- reduction in the clearing of natural bushland for sand quarries; and
- reduction in the demand for expensive waste residue containment facilities.

Case Study – Western Australia

"ReSand" Bauxite Residue in Road Construction – Curtin University, Alcoa, MRWA[62]

The Centre for Sustainable Resource Processing (CSRP) in Western Australia has developed a concept called ReSand® where sand sourced from recovered bauxite residue is used in place of conventionally sourced quarry sand with equivalent performance. CSRP undertook a demonstration project with Main Roads Western Australia, consisting of several hundred metres of sub-base for one lane of a new link road from Pinjarra connecting with the Perth to Bunbury Highway.

Research carried out by Curtin University and Alcoa identified a separation process for using the coarse component, quartz, in ReSand®. Laboratory testing in 2006 showed that ReSand® could provide commercial bulk fill and pavement material for the civil construction industry, replacing the commonly used virgin mined sand and limestone. A pilot plant of 10 tonnes per hour capacity was installed by Alcoa and produced several thousand tonnes of sand suitable for road making trials in 2009. The pilot plant successfully demonstrated the separation, washing and carbonation processes.

Early in the investigations, the physical properties of the sand were reviewed by Main Roads and the results determined its location in the road profile – in this project case the sand was used in place of crushed limestone in the sub-base layer. The construction trial involved the University of Queensland, WML Consultants and Southern Roads Services, the contractor responsible for delivering all maintenance and minor construction works in the state road network for the south west region of Western Australia. The contractor reported that the ReSand® was easy to work and compact.

ReSand® met all standard industry specifications for roadbase applications. It has little if any dust, has great drainage and wetting properties, requires only light grading, and compacts well. The performance of the roadway is currently being monitored by Main Roads in order to assess:

- the impact (if any) on surface drainage water;
- the comparative performance of the ReSand® road section and a standard road section with regard to surface and ground water;
- up-stream and down-stream monitoring comparisons in light of water regulations; and
- comparative assessments of performance, and identification of future trials.

In addition to the ReSand® trial, the Southern Gateway Alliance constructing the Perth Bunbury Highway trialled a further use of bauxite residue using a "nutrient trap" process to improve the quality of water collected in a constructed wetland beside roadworks and agricultural land. The nutrient trap collects water run-off and removes nutrients, that is, phosphates and nitrates, to prevent algal blooms in the surrounding waterways. The filter has been effective in removing phosphorus nutrients and in fostering increased confidence in and acceptance of bauxite residue use. The investigations attracted a wide cross-section of stakeholders including the Department of Agriculture and Food WA (DAFWA), Alcoa, Main Roads WA, Wallis Water, Peel Harvey Catchment Council and the Conservation Council of WA.

Aluminum of Greece, in partnership with the Laboratory of Highway Engineering at Greece's Aristotle University of Thessaloniki, has successfully demonstrated the re-use potential of bauxite in road construction.[59] The partners are monitoring roads built using different mixes of natural materials and red mud as a stabilising material. This project included two major steps. The first one was to study the physico-chemical properties of red mud (1993-1995), and the study's results show some strengthening properties of this material, specifically, the bearing capacity of the soil structure seems to be up to three times greater. The second phase was to build an experimental embankment (2001-2004), and the results of this are shown in the case study below. The reuse of bauxite residue as a construction material provides a sustainable option for the road building industry.

<u>Case Study – Greece</u>

<u>Bauxite residue reuse – Aristotle University of Thessaloniki</u>

This project[59], introduced above, involved the design and construction of an experimental embankment using bauxite residue. The embankment, which enabled testing of the material under real conditions, was composed of three segments made of different mixtures, two of which contained bauxite residue.

The project was undertaken in March-April 2003 and took 40 days, following conventional construction methods. The material exhibits excellent performance in earthwork construction and constitutes an effective solution in projects where borrow-pits are rare and other local materials prove inapplicable. However, the study also determined that "the by-product presents a time-hardening behaviour as a result of binding internal stresses developing after laying" and that "special care must be given, in the case of earth-work construction, to the water tightness of the earth-structure to prevent erosion or inflow which might produce instability".

In-situ stabilisation

In-situ stabilisation, or the process of stabilising natural earth to strengthen and allow it to function as a pavement layer, is a technique that drastically reduces the amount of aggregates needed for roadbase construction. There are a number of techniques, such as foamed bitumen, cement stabilisation and the use of geopolymers that are all variations of the key principles involved in in-situ stabilisation.

The Queensland Department of Transport and Main Roads (DTMR) has successfully demonstrated in-situ stabilisation using foamed bitumen on the Cunningham Highway west of Brisbane, and the results were reproduced in a larger trail on the New England Highway (see case study below). The New England highway 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 from Texas A&M University.[63] The foam bitumen procedure has now produced excellent long-term results on many Queensland roads (in the Border District, North and South Coast Hinterlands and Redland Shire). The process uses a hot bitumen mix to stabilise the pavement, replacing the traditional combinations of lime, cement and fly ash. The trial has been extremely successful and was recently written into a main roads specification that will enable efficient technology transfer to future projects.[64]

The process of reusing material from old or deteriorating flexible road pavements for the roadbase of new roads through cement stabilisation has been employed in Australia for about 50 years. The advantage of this process is that it requires very little material to be removed from site, reducing the greenhouse gas emissions associated with the transport of unwanted materials. It is a proven technology, with roads in Brisbane that were stabilised using this technique in the 1960s still in use today.[65] 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 roadbase. This practice is now in the second revolution, with recycled roads being recycled once more, and considerable progress is being made with recent advances in processing and construction materials technology.[66]

Case Study – Queensland

Foamed Bitumen – Department of Transport and Main Roads

In 1997 a 1.6 km section of the Cunningham Highway was the site of the first foamed bitumen trial, and it also included the replacement of cement in the bitumen blend. Smaller tests had been conducted in Australia but none were conducted on this magnitude. This trial concluded that the use of foamed bitumen in the construction of roads allowed traffic to use the road earlier than in conventional methods, and the long term use of foamed bitumen was deemed feasible.

The foamed bitumen process uses a mixture of air, water and bitumen. Cold water is added to and the mixture is then combined with the bitumen and cement particles to form a usable base for road construction as shown below in Figure 3.

Figure 3 *Foamed Bitumen on the Cunningham*
Source: Evans, P (2011)[63]

The Cunningham Highway trial showed no signs of distress from road use. The road was later lightly sealed and continued to operate. After two years of service it showed minor signs of distress but was considered acceptable for continued operation. The results of this trial support further use of foamed bitumen throughout Queensland.

Given the success of the 1997 Cunningham project it was decided to implement this technique on a larger scale project, and so in 1999 a 17 kilometre section of the New England Highway between Warwick and Toowoomba was replaced using foamed bitumen stabilisation.

The blend used was adjusted from the Cunningham project to take into account differences of scale, weather and climate. This blend was 3.5 per cent bitumen and 1.5 per cent quicklime. After 3 years of service 1 per cent of the road was showing signs of distress, which was considered normal, and the road is still in service today after 12 years.

Case Study – Saudi Arabia[67]

Foamed bitumen stabilisation – University of Petroleum and Minerals, Dhahran

Throughout eastern Saudi Arabia, there is an extreme shortage of quality road construction materials. The use of stabilisers is an efficient way of stretching limited high quality resources and improving the performance of marginal building materials. As a result, there has been significant testing of various stabilisation methods. This knowledge can easily be transferred to other roads agencies throughout the world, to encourage a reduction in the need for raw aggregate for road building.

Recycling and treating old roadbase materials on site is a cost effective, resource efficient method of producing a base that is of equal or superior quality to traditional base construction materials. The first use of foamed asphalt in Saudi Arabia was in 1997 on the Shaybah oilfield road. The road was tested and monitored and the foamed asphalt was found to perform exceptionally well. It has consequently exceeded its original design life as a construction access road, but certain places show significant deterioration of the slurry sealed surface. The practice of foam stabilisation fell into disuse for a number of years and many local roads were built using various forms of marginal aggregates. Most of these roads now need major maintenance and researchers at the University of Petroleum and Minerals, Dhahran, Saudi Arabia have undertaken laboratory tests to compare the performance of roads with foam stablisation layers to those with conventional aggregate layers.

Results of the significant testing confirmed the effectiveness of foamed stabilisation as a replacement for much of the conventional aggregate base course. Roads constructed with foamed bitumen sub-base were found to have equivalent levels of resilience and levels of permanent deformations, and outperformed the aggregate base course roads under soaked conditions. The results of these significant laboratory tests confirm the place of foamed bitumen as a successful alternative to natural or virgin aggregates under even the most extreme of conditions in the Saudi Arabian desert.

Stabilising aids

Various stabilising aids have been utilised around the world. Some of these products include ECOroads® (discussed in the box below) and PolyCom and O.F.B Soil Binder™:

- PolyCom Stabilising Aid is an Australian product that strengthens the subgrade on both sealed and unsealed roads.[68] It is a powder that is mixed with water and then can be used to strengthen sub grade. This aid has been used in road building around Australia including projects by Transport and Main Roads on Wondai-Proston Road Queensland and Main Roads Western Australia in shoulder stabilisation.
- O.F.B Soil Binder™ is a liquid latex (renewable natural rubber source) based soil additive that is mixed with water and used in stabilisation, water loss retention and in dust control. Testing on this product demonstrates comparable results as cement stabilization. Furthermore the product can be used in combination with cold in-place recycling O.F.B. Soil Binder™ mixed with the recycled flexible pavements to create a more durable base. It has successfully applied as a soil binder in South East Queensland and South Australia with the business owners targeting the remote and isolated road construction.[69]

Case Study – North America

Global application of Liquid Stabilising Aids – ECOroads®

ECOroads® is stabilising aid composed of "a complex non-bacterial, concentrated, multi-enzymatic formulation" along with "additional organic compounds".[70] This liquid product is mixed with water and then with the road subgrade material prior to compaction, and increases. The mixture increases the strength and durability of the road by hardening the subgrade material (soil) to create a hard sub-base, eliminating the amount of aggregates needed to construct the road. Furthermore the product accelerates the bonding of ionic, charged soil particles "promoting a closer binding of soil particles" enhancing the durability of the base earth layer of the road, preventing water penetration, rutting and other maintenance issues.[71]

Testing of ECOroads® has found:

- That it can reduce the cost of road building by 20 – 40%.
- That it can save up to 50% of the cost of ongoing road maintenance.

ECOroads® has been approved for use in projects around the world including in states in the US such as California (Caltrans), New York (on the approved soil stabilizer materials list), Utah (approved for soil stabilization and dust abatement), and Washington (approved for dust abatement), and by the governments of Kazakhstan, Romania, Morocco, Venezuela and Thailand.

Water

Whilst water and storm-water quality is an integral part of most modern road construction projects, the idea of water as a road building material is often overlooked. Water is mainly used for dust control on road construction sites, but is also a necessary component of concrete and asphalt mixes. With increasing water shortages across Australia, the efficient use of water is an important part of sustainable construction.

This use of water in the context of efficient resource use has been highlighted in the recently released AGIC rating scheme.[72] While there is currently no national regulation or reporting on water use in Australia, the scheme aims to showcase those organisations that use water efficiently in road construction projects. Literature reviews by the AGIC team show that the preconstruction and construction phases of a project require the most water, while the end use varies according to the specific project, and includes use as a dust suppressant and for ablutions, sub-grade stabilisation and wash down or cleaning.

The vision for the AGIC rating scheme is to encourage a greater level of water efficiency across a project's lifecycle. This requires that measurement, monitoring and reporting of water use becomes the norm instead of the exception. In turn, this practice will establish the typical water usage footprint, against which other projects can be compared. An AGIC rating scheme would minimise the volume of water used and encourage locally appropriate alternative water sources as substitutes for potable water. As such, the tool has been created with a focus on additional water use, not on the use of storm (or waste) water or the embodied water in road construction materials.

Data on water consumption in a road project during the construction phase is currently difficult to find. However, a recent life cycle analysis of AGIC's pilot project,[73] the Eastern Busway in Brisbane, was able to quantify water used by the project, and uses the National Greenhouse Energy Reporting Scheme (NGERS) functional unit (for example, one month of construction). The analysis found that during a typical month of construction the project required over 1.2 ML of water. As more and more projects are analysed and the reporting of water becomes more common, road construction agencies will be encouraged to use water more efficiently and innovatively.

Case Study – Western Australia

Saline Water in Road Construction – The Great Northern Highway Alliance[74]

During the upgrade of The Great Northern Highway located in Western Australia the use of saline water in the construction process was trialled. The use of saline water in is a relatively new concept and is approached with much hesitation due to the corrosive properties of salt. This trial was conducted because of the geographic location of the construction operation and the lack of supply of fresh potable water. A trial section was constructed along the highway and preliminary inspection of the site showed no immediate road quality issues. This section is still operational and indicates that the use of saline water in road construction offers triple bottom line benefits. The Great Northern Highway Alliance was formed between Brierty, AECOM and Main Roads Western Roads (MRWA) in 2006.

Case Study – Victoria and NSW

Sustainable Water Management on the Hume Highway – Southern Alliance[75]

During 2006 work began on a large scale operation to duplicate a 67 Km section of The Hume Highway linking Melbourne to Sydney. The purpose of this project is to reduce the stress currently being experienced by the highway due to single lane access in either direction. The highway is an important aspect in the transportation of freight and people throughout eastern Australia.

The scale of this project involves extensive earthworks to be undertaken as well as other environmental concerns such as; biodiversity corridors to be evaluated, water management and heritage assessments. The number of issues that have to be assessed and solved for this project required are numerous and extensive. This project constructed two alliances comprised of several road construction companies and agencies to address all these issues.

The two alliances formed were the Northern Alliance and the Southern Alliance. The Southern Alliance was comprised of NSW Road and Traffic Authority (RTA), Sinclair Knight Merz (SKM) and Abigroup. Focusing the companies to work in an alliance framework allowed certain connections to form and created innovation among each group to solve the relevant environmental concern. One such outcome for the Southern Alliance was sustainable water management. Water is a key material in the construction of roads being used for a variety of operations. Investigations relieved that there was a shortage of water supplies in close proximity to the location of the site.

Norse Skog mill, which is located 10km from the construction site, was identified as having a large reserve of recycled potable water which can be used in the construction of roads. The Southern

Alliance constructed a pipeline from the mill to the site and using existing pumps at the mill supplied 50 per cent of the water needed for the project thus reducing the stress on Lake Hume.

This project proved that working in an alliance framework can allow multiple companies from different backgrounds and specialities to cooperate together and achieve sustainable outcomes. This was evident in the innovative management of the water usage by the Hume Highway Southern Alliance.

Strategic Area 3 – Reducing environmental impacts through ASPHALT in road construction

Asphalt, according to the Austroads Glossary of Terms,[76] is 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. Bitumen itself is a very viscous liquid or a solid, consisting essentially of hydrocarbons and their derivatives. In order to avoid confusion, the term "asphalt" as used in this document is in accord with Australian and European convention and refers to a mixture of bitumen and mineral aggregate designed for specific paving applications. The global asphalt market (including bitumen) is expected to reach 124 million metric tons in 2011 representing an estimated turnover of AUD$74.4 billion. Prices of bitumen were AUD$115 per metric tonne delivered at the refinery in 1999 and topped AUD$200 in 2005 rising to more than AUD$600 in the summer of 2011.[77]

Asphalt pavement material is typically 95 per cent mineral aggregates mixed with 5 per cent bitumen, with bitumen functioning as the glue binding the aggregates in a cohesive mix. The production of asphalt includes the following phases: extraction by distillation and cooling during the petroleum refining, transportation, storage and final processing at the hot mix asphalt (HMA) plant. The HMA plant heats the bitumen to ensure fluidity and proper coating of the aggregates. The aggregates are conveyed from stockpiles to dryers where they are heated to a temperature between 150 and 180 °C. The aggregates are then mixed with bitumen to create the hot asphalt. This asphalt product is delivered to trucks or stored in hot storage bins prior to transportation to a construction site.

While there are successful examples of concrete roads, most roads in Australia are sealed with bitumen or asphalt. The following section is a detailed exploration of the myriad of opportunities to reduce the environmental impact of roads by improving the production of asphalt. These options are extremely varied and include the use of recycled aggregates, alternative processes to produce bitumen, methodology changes and emerging proprietary products.

Case Study – ACT

Improving the sustainability of asphalt production – The Downer Group[78]

The Downer Group has just unveiled their newest production facility in Hume, ACT. This facility is equipped with the latest sustainable processes and technology to ensure a cleaner, greener production environment. Added to these technologies is the certified laboratory and workshop to design, test and ultimately manufacture new innovative ways for a sustainable asphalt production. The main purpose of this facility is to push forward to the sustainable production of asphalt.

Alternative Asphalt Aggregates

MATERIAL 1. Reclaimed asphalt pavement

Recycled asphalt pavement is of particular importance in Australia at present, as currently any reclaimed asphalt that is not reused is regarded by the industry as waste. In the US almost all reclaimed asphalt is reused, amounting to between 75-95 million tonnes of RAP is used every year.[79] According to Australian Asphalt Pavement Association CEO John Lambert, industry in Australia should be aiming to use 100 per cent of all recycled asphalt pavement produced. The ability to use asphalt over and over again reaffirms its place as a viable and useful asphalt aggregate substitute.

Recent investigations in the United States has shown the use of RAP in pavement base and sub-base layers can:

- reduce global warming potential (20 per cent);
- energy consumption (16 per cent);
- water consumption (11 per cent);
- waste generation (11 per cent); and
- life cycle costs (21 per cent).[80]

The use of RAP and incorporation of road material alternatives in pavement layers are important in reducing the impacts of road construction.

Case Study – Japan

Pavement recycling reaches 98 per cent

Road related activities account for two per cent of Japan's total emissions (2005).[81] To help combat this Japan has been exploring various technologies, including the recycling of asphalt pavement, referred to as asphaltic concrete in Japan, the use of warm mix asphalt and cool pavement technologies.[82]

Warm mix asphalt (WAM) has been determined to be one of the most practical measures to reduce the CO_2 emissions during pavement construction. This process drops the mixing temperature to 130°C, from 160°C. This results in a reduction of CO_2 by 10-15 per cent through the reduced fuel consumption. The Japanese Road Contractors Association determined that the use of WAM would produce the following financial benefits:

- A reduction of CO_2 emission = 85 million yen;
- A reduction of fuel cost at asphalt plant = 1 275 million yen; and
- A reduction of traffic jams caused by construction work = 16 382 million yen.

However, the increase of the price of the asphalt mixture would also result in a cost of 12 140 million yen. Furthermore, the use of WAM would enable the reduction in the number of asphalt plants, due to the lower temperature enabling the mixture to be transported further, and to increase the efficiency of the plants.

Japan has been recycling reclaimed asphaltic concrete, or reclaimed asphalt pavement (RAP), since the 1970s, with a recycling rate of over 98 per cent. This provides a long history for examination of the technology. They two primary ways of recycling this material: on site and at a stationary mixing plant. Plant recycling is the most popular, and in 2009, was able to achieve a ratio of almost 70 per cent recycled asphalt. This means that, given a renewal cycle for asphalt pavement of ten years, more than half of the RAP produced in Japan after 2008 will be recycled at least once.[83] Furthermore the RAP component is increasing (ration of RAP in recycled hot mix asphalt). This can have implications due to the deterioration of repeatedly recycled asphalt in RAP. Tests in Japan have determined that the softening point becomes higher as the rate of recycling increases, estimating that "asphalt that has been repeatedly reclaimed with rejuvenators becomes brittle". Furthermore, "oxidation tends to become larger as the number of times of recycling increases, proving that oxides accumulate due to repetitive recycling" and that "oxides are more easily accumulated in the case of recycling with rejuvenators.' These studies conclude that 'the use of rejuvenators with large paraffin constituent should be avoided, and straight asphalt should be used chosen instead".

On-site recycling involves crushing the existing asphalt and mixing it with a granular base material and a stabilising agent (e.g. cement) and then compact this to form a base course.[83] This process is popular on local roads. Japan also conducts on-site surface recycling, which involves heating the existing asphalt mixture, scarifying it to loosen the material and then adding new asphalt or rejuvenators, if necessary. This technique, although it reduces CO_2 emissions from transport significantly, it requires pre-heated, hot air which causes a large amount of emissions and is not possible when using drainage asphalt pavement. Furthermore, the heating process has localised environmental problems. Kubo determines that reusing reclaimed asphalt can reduce total CO_2 emissions more than warm mix asphalt.

Along with recycled asphalt, Japan also utilises cool pavement technologies such as water retention pavement and heat shield pavement. These technologies have been found to reduce the heat island impact of roads. Water retention pavement is porous asphalt pavement with water-retaining materials. The water causes evaporation which draws heat from the surrounding materials and cools the temperature by about 10°C. This effect lasts as long as water is retained within the road surface: two to three days in Japan. Heat shield pavements increase the reflection of infrared rays, reducing the heat absorbed by the road. This technology can be applied to existing roads, however the longevity of the technology has not yet been determined.

MATERIAL 2. Glass

The use of recycled glass in road construction occurs most significantly in asphalt pavement, and this practice dates back to 1970's. Today, commercial products which feature up to 30 per cent crushed glass by weight are now commonly available on the asphalt market. Cemex, a UK based pavement supplier manufactures a product which claims to provide the same level of performance and durability as regular asphalts, but features a high recycled content.[84] It should be noted that asphalts with recycled glass content are never suitable for a surface course as they are unable to provide the necessary level of skid resistance. Fortunately, there is adequate demand for this product in the base and binder course.

Case Study – United Kingdom

Glasphalt on the M6 Highway – Aggregate Industries[85]

The first large scale use of Glasphalt occurred over a four km, four lane section of the M6 highway in Cheshire, England. The scheme, undertaken by Aggregate Industries UK, was developed as a way of utilising the huge quantities of recycled glass, replacing the aggregates in the layers below the road surface with up to 30 per cent crushed glass. The amount of glass used over the life of the project was equivalent to 14 million empty bottles, all sourced from nearby bottle recycling refuses.

MATERIAL 3. Crumb Rubber Modifier (CRM)

The primary use for scrap tyres in road construction occurs as an additive (either as an aggregate or modifier) in asphalt paving mixtures. The rubber is generally granulated and referred to in literature as crumb rubber modifier (CRM).

Prior to its use as CRM, scrap tyre rubber must be recycled by granulating it into small particles. This can be achieved through a wide range of recycling techniques, ranging from simple mechanical processes that simply cut and compress the rubber to extremely complex mechano-chemical or thermal treatments.

The CRM is then used in enhanced hot mix asphalt mixtures, either through a “wet” or “dry” process. The wet process utilises a blended and partially reacted version of CRM with asphalt cement, a process which creates “rubber modified bitumen” that is then used as a binder in conventional hot mix asphalt production. By contrast, the dry process adds the CRM to the aggregate of a conventional hot mix, allowing some of the CRM to react with the asphalt bitumen while the coarser particles replace part of the mineral aggregate. The wet process is already available through a number of patented technologies.

While the use of crumb rubber as an asphalt additive is widely accepted as an excellent use of scrap tyres, the process is inherently energy intensive. This does pose a significant barrier to the uptake of this recycling technology. However, with increasing landfill costs for scrap tyres, their use as CRM in asphalt pavements will become increasing economically beneficial.

Case Study – South Africa

Crumb Rubber Exports – Wadeville[86]

A plant located in Wadeville, South Africa for several years has been granulating old tyres into rubber crumbs which are shipped to Europe for the use of road construction. The use of recycled tyres as aggregate replacement is a fairly new concept yet the results are proving to indicate that they produce a higher quality road surface than quarried rocks.

The rubber crumbs in the roadbase reduce the level of noise created by traffic flow and they increase the durability of the road structure creating a stronger road. The rubber crumbs also increases the braking efficiency of tyres from motor vehicles as they drive on the road therefore creating a safer environment.

Due to lack of funding and legislation the use of recycled tyres as aggregate replacement is limited throughout South Africa. Several projects and services are campaigning to receive funding and change waste legislation to allow larger scale production of rubber crumbs from recycled tyres.

Case Study – South America

Crumb Rubber Asphalt – Respol YPF

In 1990 and 2003 two large scale demonstrations were conducted in USA and Argentina respectively. Both projects resulted in positive conclusions indicating that crumb rubber asphalt is a viable alternative to traditional methods.

During 1990 a trial in Arizona, USA was conducted to test the effectiveness of crumb rubber as asphalt not just aggregates along a highway. This test concluded that not only did the highway work as effectively as bitumen but resulted in a higher quality road. As impressive as this trial may be it does not represent an alternative for poorer nations due to the fact that the USA is a highly developed nation which has the resources and expenditure for such tests.

Thirteen years later in 2003 a company in Argentina (Respol-YPF) conducted a similar test to the 1990 Arizona test on a high traffic road.[87] This test incorporated four sections each with different mixes varying from crumb rubber asphalt and standard asphalt cement. All sections were layered at the same time and mixed on site. Each section was submitted to extensive testing for several months. The results concluded that all sections performed effectively and suitably.[88] This test proves that not only waste tyres can be used as an asphalt but they can be used in developing nations.

MATERIAL 4. Recycled concrete

The use of crushed recycled concrete as a source of aggregates for asphalt pavement layers is currently being investigated as both a viable depository for demolished concrete elements and as a potential replacement for virgin aggregate. The primary concern with the use of recycled concrete is the cement paste that remains attached to the surface of the original natural aggregates after they are crushed and recycled. This paste is porous and variable in quantity, leading to aggregates with a lower particle density, higher porosity and higher water absorption.

Significant testing by researchers at RMIT in Melbourne, Australia has been undertaken to determine the performance of asphalt concrete with recycled concrete aggregates compared with virgin aggregates.[89] Comprehensive experiments that examined the volumetric properties, resiliency and creep properties of the asphalt concretes were conducted. The results showed that all the volumetric properties, the creep values and the resilient modulus for asphalt concrete with recycled aggregates were lower than the values for asphalts with virgin aggregates. These results are encouraging and hopefully will lead to further progress on specification of an asphalt pavement that contains recycled concrete aggregates.

Alternative processes

Traditional asphalt manufacture

Asphalt represents a small fraction of the total mixture that acts as a viso-elastic binder between various aggregate particles (detailed above). Traditional asphalt productions occurs at temperatures between 150º and 180º, while spreading and compaction occurs at only marginally lower temperatures, between 130º and 160º. Working at these temperatures enables the bitumen to properly coat the mineral aggregate particles and to make the total mixture fluid enough to all for enough workability during mixing, laying and compaction.[90]

Many innovations that attempt to lower the environmental impact of asphalt production centre on reducing the production temperature. However this reduction inevitably results in an unwanted reduction in asphalt mixture quality and has significant negative impacts on the workability of the final product. Any new process that operates a lower temperature, be it warm or half-warm mix applications, or processes that occur at ambient temperatures, must strike a delicate balance between low viscosities, good workabilities and acceptable curing times in order to gain acceptance within the roads agencies.

Warm mix asphalt

Warm mix asphalts are generally made by introducing emulsions to the mix that act to reduce the viscosity, known as "additive based systems". Less commonly, warm mixes can also be manufactured through alternative manufacturing techniques. Warm mixes have many benefits over hot mix asphalt. The obvious factor is the reduction in energy (and consequently fuel) that is traditionally required to heat both the binder and the aggregates to the high temperatures needed. They also allow for simplified hot mix plants and allow for on-site production in mobile plants. Warm mix asphalts are more storable, with longer working lives, and are proven to considerably reduced fume exposure and emissions for construction workers.[90] Interestingly, the use of warm mix allows for increased use of RAP, and this is where large greenhouse (and material) savings are made.[79]

Case Study – Victoria

Warm Asphalt Validation Project, AAPA, Austroads, VicRoads[91]

The Hume Hwy WMA validation project is an ongoing investigation to test the quality performance of different blends of WMA by AAPA, Austroads and VicRoads. This project began in April 2010 and testing is continuing today. The results of this project are crucial to the future of warm mix asphalt in the construction of Australian roads.

Currently Austroads are conducting a validation project to determine the effectiveness of warm mix asphalt (WMA) in comparison to hot mix asphalt (HMA). This project is being undertaken on the Hume Hwy, Vic and began in April 2010 with testing continuing today. The test involves the use of HMA on three sections of the highway and 19 WMA of various blends along several sections.

To date the project shows no sign of difference between the HMA mixes and the WMA mixes and several road agencies have begun to change legislation to allow extended use of WMA. The final results of the validation test are not concluded yet and further testing is underway.

This test has also shown that the energy cost difference between the manufacturing of WMA and HMA are not significantly different and this alone cannot promote the use of WMA on a large scale. The major advantage of using WMA is the higher levels of reused aggregate pavements (RAP) which will reduce GHG emissions significantly.

Case Study - Victoria

Introducing Greenpave Technology – Citywide[92]

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 per cent, noise and odour reduction, improved site drainage to reduce storm water contamination and asphalt recycling facilities.[92]

Greenpave was introduced several years ago by Citywide as an alternative to Hot Mix Asphalt (HMA). The product was instantly recognised as a potential alternative with great environmental benefits. Product only needs to be heated at 110°C instead of 170°C which classifies it as a warm mix asphalt product. Greenpave also has less fume emissions, less energy required to produce and can be mixed on site.

Several townships and councils in Victoria have trialled Greenpave in the past and more are trialing it currently. An early trial was conducted by Yarra City Council on Bell St. The results showed that not only does Greenpave perform the same level of quality as HMA but more than one tonne of carbon emissions were reduced in comparison to HMA.

All the trials that were conducted within the Victorian region have concluded that Greenpave is a safe, clean and effective alternative to HMA. Due to the lower temperature it allows work crews to work longer and also allows laying of roads to be conducted in summer which reduces the risk of health concerns.

Greenpave has helped several towns around the Victorian region enter an age where environmentally sustainable roads are becoming more demanding by the public and has allowed them to promote reducing GHG emissions. Since the products first introduction it is estimated to reducing GHG emissions by 83 884.65kg.

Half warm mix applications

Following on from the warm ashalt mix innovations of the 1990’s, more recent advances have further reduced production temperatures, further reducing fuel usages and emissions from asphalts. These asphalts have even lower production temperatures and are hence known as “half warm mixes”. A European process, licensed worldwide, combines the use of additives with plant and process modifications which has resulted in asphalt production temperatures of well under 100ºC and placement temperatures as low as 60ºC.

According to Fulton Hogan, a leading New Zealand asphalt company, the half warm mix process is significantly different to warm mix design, involving a patented system and required some modification to asphalt plants. Reductions in burner fuel usage of up to 50 per cent have been recorded, as well as the elimination of “blue smoke” fumes that are emitted by traditional and warm mix asphalt production and handling.[93]

Case Study – New Zealand

CoolPave at Christchurch International Airport – Fulton Hogan

Fulton Hogan has created asphalt with decreased temperature needed to produce a workable product than regular asphalt. This asphalt is named “CoolPave” and is currently in use in New Zealand around the country along minor roads. There are several benefits to using this product from reduction of GHG emissions to earlier use of roads after construction. Coolpave has been tested on several trial sites one of which was the Christchurch international Airport. The results of this trial concluded that Coolpave is as stable and durable than conventional bitumen.

The Christchurch International Airport taxiways went under renovation during 2008 and 2009, during these renovations the use of CoolPave was trailed for alternative to hot mix asphalt (HMA) on a high impact road construction. In 2008 taxiway A was designated a small scale trial area for the use of Coolpave the results from this trial concluded that was as stable and strong as the HMA tarmacs currently on the airfield.

In February 2009 Christchurch International Airport Limited (CIAL) in conjunction with Fulton Hogan conducted a larger scale field trial on Taxiway F. this trial was considerably larger using 2 745m² of Coolpave instead of 598m² from the Taxiway A trial. The results were similar to the taxiway A trial showing stability and strength parity to HMA. Handling and manufacturing of Coolpave is also proving to be safer and easier for the laying crew.

Bitumen alternatives

There are a number of proprietary products that are able to perform the role of the aggregate binder in the asphalt layer of a road. While these products are currently operating in a relatively small market, it is expected they will become both more prevalent and also more economically attractive as the price of oil continues to rise.

Pine resin of tall oil (Vegecol and Ecopave)

Pine resin or tall oil, also called liquid rosin, is a viscous yellow-black odorous liquid obtained as a by-product 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 use of pine pitch, rosin and vegetable oils to produce bituminous binder is the subject of many patents, but only the most recent innovations have attained any level of commercial success as ecologically acceptable alternatives. Examples of these products include there are Vegecol from Colas or Ecopave from Australia.

Ecopave,[94] is a product manufactured through a process 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 can be stored and transported at room temperature. The main barriers to the wider use of these materials are the cost and appropriate technology implementation. Ecopave has experienced significant patent problems that unfortunately are threatening to slow down the production of this viable bitumen alternative.

Propritary products – asphalt innovations

Case Study – Louisiana, USA

Photocatalytic Pavements, air purifying asphalt – PURETI INC[95,96]

At the Louisiana State University (LSU) a team of engineers in association with PURETI Inc (a world leader in air-purifying road treatments) has developed an air purifying asphalt. This technology uses a process called photocatalysis which accelerates the biodegradation of organic materials in the air thus increasing the purity of the air. This technology was applied on small low traffic roads around the LSU campus in Louisiana which is still being tested. Application of the products is shown to be sprayed on the watering surface of the pavement and is suitable for concrete also.

Dr Marwa Hassan, the project leader, explains that this technology will be able to purify outdoor air from harmful toxins such as nitrogen oxide, volatile organic compounds and sulphur dioxide which all a produced by traffic movement along the road. Laboratory testing has already been conducted by the team at LSU with results indicating a 70 per cent decrease in the levels of NOx produced.

This project began in early 2010 and ran for one year while extensive testing was conducted throughout the project's life time. Results are already looking promising with indications that this is a viable product. The results were finalised in January 2011 and all tests indicate promising results so far.

Case Study – New Zealand

Rehabilitation of Road Surfaces using Ultra High Pressure water cutting[97]

Ultra High Pressure (UHP) water cutting was introduced as a viable alternative for road resurfacing since the ban of burning excess bitumen in 2000. UHP water cutting has proven to be a viable alternative with minor draw backs. The process has been trialed extensively along the northern Hwy in Christchurch, New Zealand and other locations around the world which has produced remarkable results.

Prior to 2000 roads were burnt to reduce the amount of excess bitumen to reduce the skid resistance (as shown below in Figure 4). Reducing the skid resistance of roads is an important and proficient maintenance process to decrease the chances of traffic incidents along the road. In 2000 this process was banned due to the damaging effects it caused the environment. An alternative process had to be developed.

Figure 4 *Burning excess bitumen from a flushed chipseal*
Source: Pidwerbesky, Beuzenberg & De Bono (2009)[93]

As an alternative to burning bitumen Ultra High Pressure (UHP) water cutting was being tested in June 2000. UHP water cutting is the process to use high pressurised water to remove the excess aggregates along withered roads to reduce skid resistance. This process was currently used to clean roads for redeveloped but not for regular maintenance purposes.

A large scale trial was conducted along sections of the Northern Hwy in Christchurch, New Zealand. Two sections were treated using UHP water cutting and a 3rd was left untreated as a control section. The two sections that were treated had their life expectancy increased by four years longer than that of the controlled section.

After the success of the trial ten more tests sites around the world were also chosen and tested upon. Each test site's environment was unique and varied from climate to rainfall to level of traffic flow. Obviously the results from these trials were various and dependent upon the location of the testing however the results indicated that UHP water cutting was definitely a viable process for resurfacing.

Case Study – India

Asphalt and plastic bags: Improvement pavement durability – R.V College of Engineering[98]

In 1997 engineers from the R.V College of Engineering, Bangalore began testing the effectiveness of using plastic waste from PET bottles, plastic bags and cups in the blend of asphalt. At the conclusion of this test it was shown that the use of plastic waste in roads strengthens the road created by a stronger mix. A kilometre long section of road in southern India was replaced using this plastic waste mix to test its practical application. The durability of this road is above that of normal roads.

Various forms of plastic waste bi-products can be used in the construction of roads as quarried rock for aggregates replacement. In Southern India a kilometre long test track of road was constructed using three to four per cent plastic waste and extensively tested and concluded that the durability of the “plastic road” may be above that of a “traditional” road.

The reason behind this extra durability and strength of “plastics roads” is due to the higher melting point of which is created from the plastic additives. Not only does it increase the melting point but also the elasticity of the road. In the turbulent climate of India roads are severely treated and cause an extensively large drain on the natural resources to maintain. The higher elasticity of the “plastic roads” will be able to survive harsher treatment which will reduce the maintenance costs.

This project, which is being spearheaded by K.K Plastic Waste Management, has not only helped the environment by clearing waste but also the social community by creating employment. The project has already layered over 1 200 kilometres of road using 3 500m² of plastic waste mostly in Bangalore.

Strategic Area 4 – Reducing environmental impacts through CONCRETE in road construction

The global annual production of cement is 2.8 billion tonnes, creating 11 billion tonnes of concrete. This giant industry is underpinned by rapid growth in developing nations, with increases in demand predicted to rise at 4.1 per cent annually through to 2013.[99] Cement is commonly produced from limestone, clay and sand, providing the four key ingredients: lime, silica, alumina and iron. Combining these materials and exposing them to intense heat causes chemical reactions that convert the partially molten raw materials into pellets called clinker (as shown below in Figure 5). The kiln reaches about 2 000°C, heating the materials to around 1 500°C. After adding gypsum and other minerals, the mixture is ground to form cement, a fine grey powder.

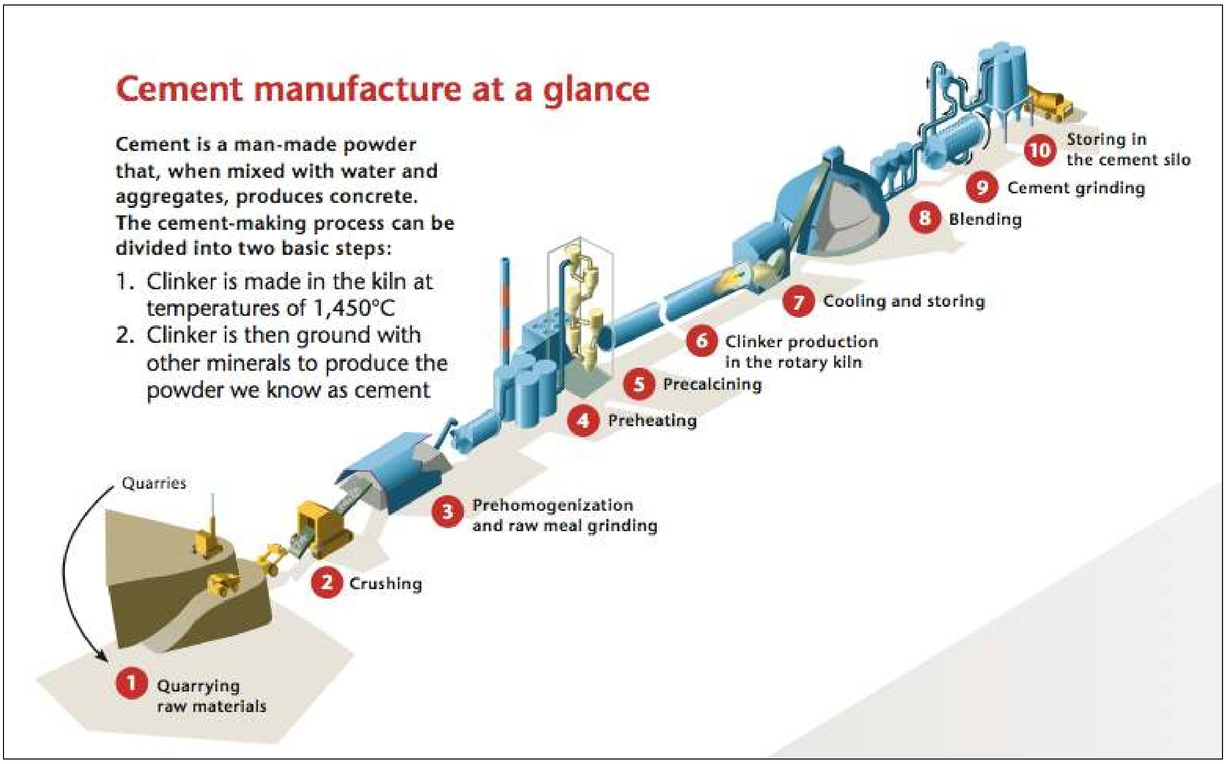

Figure 5 *Cement manufacture*
Source: World Business Council for Sustainable Development & International Energy Agency (2009)[104]

The cement industry is responsible for a range of environmental impacts, including significant consumption of natural resources and greenhouse gas (GHG) emissions primarily from cement kilns. Cement manufacturing produces five to eight per cent of global anthropogenic GHG emissions. China alone is accountable for over 45 per cent of all global cement production, while India, the second-largest producer, accounts for only 6 per cent of global cement production.[100]

The market is dominated by Portland cement (OPC) based concretes, grounded in 200 years of research and development. The production of Portland cement generates an average of around 0.82 tonnes of CO_2 for every tonne of cement produced.[101] It is a highly energy intensive process, and energy accounts for 20-40 per cent of total production costs.

The purpose of this research is to show how the environmental impacts of road construction can be reduced through the use of concrete alternatives, primarily alternative forms of cement. Concrete products used in roads include pavement, pathways, road furniture and auxiliary structures like pipes and pits. It is not common for Australian states to build concrete “rigid pavements”, as there is a preference for thin, flexible pavements of asphalt that are easier to maintain and are constructed at a lower capital cost.[102] The most significant way to reduce greenhouse gas emissions from the use of concrete in road production is to use an alternative cement source. These cement alternatives are helping to create low carbon concrete in the ways described below.

Case Study – Britain

“2012 Mix” reduces carbon footprint by 43 per cent, London Olympic Games

The construction of facilities for the 2012 London Olympic Games has a strong focus on sustainability and has already delivered innovative processes and technology that reduce environmental impacts. As part of this the Olympic Delivery Authority decided to reduce the level of carbon in the construction and use of concrete. One year prior to needing any material, they approached the concrete industry with key tender conditions stipulating that carbon footprint reductions would account for 25 per cent of the tender evaluation. From this focus came a new concrete mix, the “2012 Mix”, which uses a large proportion of recycled materials and is also claimed to have a carbon content 43 per cent lower than traditional mixes.[103] Commercial obligations limit the availability of data on the technology but they are likely to be released after the Olympics.

The reuse of concrete products in road construction, which primarily involves the use of recycled construction and demolition (RCD) materials, is discussed in Strategic Area 2 – Reducing environmental impacts through AGGREGATES in road construction. Also, while bridges are typically concrete structures, innovations in this field are beyond the scope of this research. It is however acknowledged that there are advances being made in bridge technology, including the Queensland-developed bio-composite material Carbonlock™ is intended to improve the sustainability of construction materials by using polymers from waste streams that can store carbon.

Case Study – Global

Cement Sustainability Initiative (CSI) reveals life cycle impacts – WBCSD

A decade ago the World Business Council for Sustainable development (WBSCD) created a voluntary business initiative known as CSI to address climate change issues. While there are known negative environmental impacts from cement manufacture there are also clear benefits from the use of concrete. It is able to endure for centuries with only limited maintenance or repairs, and at the end of its life it is recyclable into aggregates. A well-designed concrete building may consumes 5-15 per cent less heat than an equivalent building of lightweight construction, and it requires less mechanical temperature control internally. Concrete also absorbs CO_2 from the air during its lifecycle, and it has a high albedo effect – that is, it reflects back a high proportion of the sun's rays landing on it – thus limiting the amount of heat absorbed and reducing the "urban heat island" effect. The CSI is currently working to understand the impact of cement's whole life cycle – its use in concrete and recycled aggregates – and a potential next step is the development of a technology roadmap considering this.[104]

Cement alternatives – low carbon concrete

MATERIAL 1. Geoploymers – alkali activation (Australia)

Geopolymer concrete is an alternative technology that can demonstrate significant reductions in carbon emissions compared to a Portland cement (OPC) product. It utilises waste materials, including fly ash and bottom ash from power stations, blast-furnace slag from iron-making plants, and concrete waste, to make alkali-activated cements. It demonstrates strong engineering performance, comparable to that of OPC based concrete in structural applications. Geological resources for the feedstock are available on all continents, and recent studies of its use in the 1960s and 1970s in Ukraine and Russian buildings reveal it has better durability than OPC.[105] The manufacture of alkali activated binders omits the need for the bulk of the material to be processed in a kiln, thus greatly reducing GHG emissions. Only the silicate activator component (typically less than ten per cent of the binder mix) is super-heated in kilns, and a high proportion of industrial by-products, including fly ash and metallurgical slags, are added to complete the binder mix.

Case Study – Queensland

Earth Friendly Concrete, Wagners Pty Ltd

In February 2011, Queensland based Wagners CFT Manufacturing Pty Ltd introduced an innovative premixed concrete product, containing a cement additive, that has very low carbon emissions and embodied energy. Known as Earth Friendly Concrete, or EFC, it utilises geopolymer binder technology. Basically, EFC is traditional concrete that uses no ordinary Portland cement, and it represents a giant leap towards low carbon concrete.

To use an everyday example of its CO_2 emissions reduction potential, consider the slab and footings of a typical 300 m_2 house. If EFC is used in place of normal concrete, 9 tonnes of CO_2 emissions are avoided. Use of EFC in house slabs built in Queensland would save a massive 274 428 tonnes of CO_2 per year.

EFC has been trialled throughout Queensland in various projects with positive results. It has been used in several projects in Toowoomba and they are all performing better than traditional Portland cement. Clients at the Port of Brisbane and Toowoomba Shire Council have been very satisfied with EFC, and its applications include driveway pavement, footpaths, structural bridge beams, precast retaining walls and boat jetties.

Geopolymer concrete produces 45-80 per cent less greenhouse gas than concrete made from Portland cement.[106] The CSIRO found that this technology results in a five-fold energy efficiency improvement (Factor 5), reducing greenhouse gas emissions by 80 per cent, and it does this by avoiding the high-temperature calcining (ore breakdown) process.[107] The large range in GHG emissions reductions is being further investigated by industry as it considers in more detail the lifecycle "cradle to gate" impact of the product. Sodium silicate forms the bulk of the alkaline activator material used in geopolymer concrete. However, different methods of sodium silicate production exist, and obsolete methods have a significant impact on the emissions and energy profile of this material. Sodium silicate is a synthetic chemical which is commonly produced by heating sodium carbonate and silica sand to produce a glass. This is then either crushed and sold as a solid, or dissolved in warm water to produce a liquid sodium silicate. The heating is done via a kiln or hydrothermal process, and different methods of heating can mean a two-fold or three-fold difference in CO_2 emissions, and up to an eight-fold difference in some other emission categories.

The industry in Australia received a confidence boost with the release of a state of the art document from the Concrete Institute of Australia in which it recommends the use of geopolymer concrete by the construction industry.[108] This document was developed with industry and university collaboration to provide up-to-date information to the marketplace on geopolymer concrete. In addition, advocates of the technology are aiming to accelerate its commercialisation through an Australian Research Council (ARC) Linkage Grant in 2012. The research project seeks to address the issue of standards, which has been identified as a major barrier to the commercialisation of geopolymer materials. The US Federal Highway Administration have recently reported that "the production of versatile, cost effective geopolymer cements that can be mixed and hardened essentially like Portland cement would represent a game changing advancement".[109]

Case Study – Victoria

E-crete – Zeobond Pty Ltd[110]

Australia is now among the world leaders in research and commercialisation of geopolymer cement. After two decades developing the technology, University of Melbourne researchers formed Zeobond Pty Ltd in 2006 to commercialise it. They have created a new product called E-Crete that forms at room temperature, requires no kiln and uses industrial by-products as the main feedstock. The product looks similar to and performs in the same ways as concrete. It can also be used in most cases where concrete is used today, such as in ready-mix applications including house slabs, footpaths and driveways, and in pre-cast products such as bricks, blocks, pavers and panels.

Zeobond laid the first test slab of E-Crete in 2006 and the company continues to grow with a solid track record of success. Users of the product include VicRoads, local councils and large housing developers. According to Zeobond Business Manager, Peter Duxson, at the existing small commercial scale Zeobond can make geopolymer products that are only ten per cent more expensive than Portland cement, using existing supply chains.

"That is like saying someone in a small factory in the western suburbs of Melbourne can make a plug-in hybrid car, and all the parts, and it will only cost just over a couple of thousand more than any car produced by the big global car manufacturers", Duxson says.

"As the scale of commercialisation is increased and more is invested in the supply chains, we expect the costs of making geopolymer cements to come down significantly".

According to the Massachusetts Institute of Technology, if carbon dioxide emissions in the world's cement manufacturing sector can be reduced by even 10 per cent, that would accomplish one-fifth of the Kyoto Protocol 2012 goal of an average 5.2 per cent reduction in developed country carbon dioxide emissions from 1990 levels.

Zeobond's success shows that Australian research and development is on its way to creating world-changing eco-innovations.

MATERIAL 2. Magnesium oxide and Novacem (United Kingdom)

British company Novacem has developed a new cement based on magnesium oxide (MgO) and selected mineral additives in its effort to reduce carbon emissions. Novacem aimed to produce a carbon negative cement, that is, a cement substitute that absorbs more CO_2 than it emits, with the same costs and performance as OPC. The process involves converting magnesium silicates to magnesium oxide at much lower temperatures than occur in traditional cement methods, in the region of 700°C. This innovative production technology uses a variety of non-carbonate-based feedstocks and a novel cement composition that accelerates the absorption of CO_2 from the environment by the manufactured construction products.

According to the company's recent estimates, across the globe there are known to be vast magnesium silicates reserves that have a high magnesium content and are located where open pit mining methods are feasible. Novacem has set up a pilot plant that operates continuously in order to solve a number of operational and reliability issues.

MATERIAL 3. Flash calcining technology by Calix (Australia)

Australian company Calix has developed flash calciner technology that uses steam as a catalyst, heat-source and solid transport medium to heat material to 300-500°C. Material is forced through the process by the steam and calcines in a matter of seconds. Not only does the process occur at a lower temperature than in traditional methods, it results in products with very high surface areas and produces waste CO_2 that is 98 per cent pure. This CO_2 can either be condensed and sold to industry or reincorporated into the process to enable carbon neutral materials to be produced. The company claims it can be used to calcine dolomite, magnesite or limestone, and its trial plant in Bacchus Marsh, Victoria, Australia, currently produces 20 000t/yr of the material. Calix plans to increase this to 80 000t/yr by the end of 2011.[111]

Catalytic Flash Calcination has a significant role to play in the future of the cement industry. At the Future Cement Conference in London 2011, Calix claimed the technology has the ability to:

- capture CO_2;
- minimise CO_2 and NOx emissions;
- be rapidly distributed in the market;
- reduce energy consumption;

- ensure consistent product quality and environmental controls; and
- augment Portland cement.

MATERIAL 4. Phosphogypsum (Portugal)

A Portuguese university, Universidade Nova de Lisboa, is researching Phosphogypsum as an alternative raw material for Portland cement production. Phosphogypsum is an industrial by-product of phosphoric acid production, and it represents a potential solution as a clinker extender in OPC.

Investigations to date include techniques using thermogravimetric analysis, differential scanning calorimetry and the use of micrographs. These reveal that the inclusion of 5 per cent phosphogypsum in OPC improves mechanical strengths. In addition, lab results show that these improved material strengths can be formed using a temperature up to 10 per cent cooler than standard techniques (a 150°C reduction). These preliminary results, revealed at the 2011 Future Cement Conference in London, suggest that Phosphogypsum may play a role in a low-carbon concrete in the coming decade.[111]

MATERIAL 5. Bio-based cements and "self-healing" concrete (Netherlands)

Recently the Dutch Organisation for Technological Sciences (STW) funded a research program at Delft University of Technology on "Bio-based Geo and Civil Engineering for a Sustainable Society" (BioGeoCivil). This research focuses on how bio-based materials and construction processes can provide major breakthroughs in engineering practices.[112]

There are two key parts of the project. In the first, "BioCement" uses bacteria to cement weak, unconsolidated soils, offering an alternative to cement or other chemicals in ground improvement, while in the second, "BioConcrete" uses bacteria as an additive in concrete to extend its life and reduce maintenance by giving it self-healing properties to repair structural weaknesses in concrete constructions.

The "BioCement" is the more relevant to road infrastructure. This biological ground improvement system treats unstable ground by first applying urea and calcium chloride, and then using bacteria to convert these into calcium carbonate, thus binding the ground together, be it sand, shale, rubble or otherwise. Following increasingly large laboratory tests, which culminated in researchers producing 40m^3 of "sandstone", the group was approached by a construction company looking to lay a pipeline under a river, and the technology enabled the ground to be sufficiently stabilised to satisfy the project objectives. The process is now being refined to reduce its high costs by removing the need for specific bacteria and addressing issues surrounding calcium chloride.

Strategic Area 5 – Reducing environmental impacts through road LIGHTING and SIGNALS

Street lighting and traffic signal lighting result in a large amount of indirect greenhouse emissions due to the consumption of electricity. This electricity is often, particularly in urban areas, produced offsite and beyond the control of the road agency. Road agencies can however, reduce their consumption of electricity and their greenhouse gas emissions through their lighting choices. When considering the greenhouse gas emissions from lighting, the amount (or number) of lights, the type of lights used, the wattage of the lamps (bulbs) used and the operating hours of the lights all need to be considered. To reduce consumption of electricity and greenhouse gas emissions many road authorities worldwide are exploring and implementing changes to their lighting and traffic signal provision. These changes include switching light bulbs to lower wattage bulbs, installing Light Emitting Diode (LED) lights, dimming lights or switching off lights in certain areas.

The energy use and greenhouse gas emissions from lighting are significant. In the operation phase of a road, lighting is the dominant energy consuming activity. In a Swedish study looking at greenhouse gas emissions produced during road construction, operation and maintenance, the operation phase accounted for approximately half of the energy use of the road, and of that, street and traffic signal lighting accounted for nearly all of the energy consumed, approximately 12 terajoules (TJ) over the 40 year study.[113] Main Roads Western Australia (MRWA) spends AUD$1.7 million per year in power costs resulting from street lighting and it comprises one third of the emissions (9 200 tonnes of CO-e) associated with direct activity. The Transport Authorities Greenhouse Group Australia and New Zealand (TAGG) developed a “Greenhouse Gas Assessment Workbook for Road Projects”, which looked at the various greenhouse gas producing elements of roads.[113] They calculate that:

> *Over a 50 year period, typical arterial roads and freeway ramps (250W HPS lamps) lighting would consume 640 kWh/m of road lit by street lighting (assuming that the lighting operates 12 hours a day and is spaced 86m apart). Assuming that lighting is on both sides of the carriageway and that the pavement is 20m wide this equates to 64 kWh/m2 or 0.014-0.088 t CO2-e/m2 of pavement depending on the state/region that the project is in.*[113]

Furthermore, looking at traffic signal lighting specifically, TAGG calculate:

> *Over a 50 year period, an intersection on an undivided road is estimated to consume 1 346 000 kWh if incandescent lighting is used or 208 000 kWh if LED lighting is used. This equates to 310 – 1 840 t CO2-e for incandescent lighting and 50 – 280 t CO2-e for LED lighting.*[113]

These are significant emissions.

The emissions produced from lighting is generally considered during the operational phase of roads, however even though small, the lighting use during construction should also be considered, particularly for tunnel building. TAGG calculated that lighting during the construction phase does not account for more than 1 per cent of the construction emissions.[114]

Case Study – USA

Traffic Signal and Low Wattage Lighting – New York City Department of Transportation

The New York City Department of Transportation (NYCDOT) maintains approximately 300 000 lights, with 262 000 located on streets, bridges and underpasses, and 26 000 in highway lighting. Overall the City annually uses 4.32 billion kWh, with street lighting accounting for approximately six per cent of total municipal energy use (based on 2009 figures).[115] NYDOT have started using LEDs in their traffic signals and testing the use of low wattage bulbs in there street lights. In 1999, NYCDOT began replacing the high pressure sodium (HPS) light fixtures and metal halide light fixtures in their "cobra head street lights" with lower wattage HPS luminaires[115] As of May 2009, they had replaced over 80 000 250 and 150 watt cobra head lights with 150 and 100 watt heads (respectively). This replacement has resulted in financial and environmental benefits. The pilot trials in New York reveal that converting the 250 watt heads to 150 watt heads yields a 45 per cent reduction in energy use and the conversion of the 150 watt heads to 100 watt heads yields a 35 per cent reduction in energy use. This results in significant greenhouse gas emission and in financial savings. The conversion has also been deemed to reduce upward lighting and glare.

NYCDOT are also switching the lighting in their traffic signals to LED. Between 2001 and 2009, NYCDOT converted nearly all of their traffic signals to LED. This conversion has resulted in an annual energy savings of 81 per cent and energy and maintenance cost savings of approximately US$6.3 million a year. They conclude that while the LED traffic signals have a higher initial capital cost than the incandescent lights, they have a longer life expectancy, and therefore the lower maintenance needs, and have lower energy consumption. The conversion has resulted in significant energy cost and emission savings (shown below in Figure 6, Figure 7 and Figure 8) and the capital costs of the conversion were recovered in less than five years.

Table 2: Incandescent vs LED Traffic Signals

Signal Type	Wattage	Infrastructure Costs	Maintenance Costs	Annual Energy Use	Annual Energy Costs
Incandescent traffic*	67	$.65	$13	587kwh	$70.44
Incandescent pedestrian*	67	$.65	$13	570kwh	$68.40
LED 8 inch traffic	9	$75	$10.50	79kwh	$9.48
LED 12 inch traffic	14	$165	$10.50	123kwh	$14.76
LED pedestrian	12	$200	$35	96kwh	$11.52

*The difference in annual energy use for incandescent traffic and pedestrian signals is due to the flashing time of the pedestrian signal.

Figure 6 *Incandescent traffic signals versus LED Traffic Signals in New York City*
Source: New York City Department of Transport (2009)[115]

Table 1: Cost Comparison of Various Street Light Options (costs per fixture)						
Luminaire	Lamping	Wattage	Fixture Costs	Maintenance Costs	Annual Energy Use	Annual Energy Costs
Cobra head/standard with electonic ballasts	HPS	150W/ 100W	$160	$100 per year	672.4kWh/ 475.6kWh	$102.52/ $72.51
Historic (i.e. shielded teardrop)	HPS	250W	$950	$100 per year	1,230kWh	$187.53
Optional (i.e. Helm contemporary, see page 5	HPS	150W/ 100W	$950	$100 per year	1,230kWh	$187.53
LED/standard pole or under deck	LED	108W/ 90W	$1,050	$0 per year*	442.80kWh/ 369 kWh	$67.51/ $56.26
Central Park LED/"Type B" pole	LED	90W	$1,650	$0 per year*	369 kWh	$56.26

*The LED components are covered under a 7 year manufacturer's warranty. General maintenance required for the lights related to the non-LED components are covered by the street lighting general contract which is not included as maintenance costs.

Figure 7 *Cost Comparison of Various Street Lighting Options in New York City*
Source: New York City Department of Transport (2009)[115]

Table 3: Comparison of Wattage Reduction Effort with LED Deployment Cobra Head Wattage Reduction					
Location	Net GHG Savings (tons CO2)	Net kWh Savings	Net Energy Cost Savings	Net Maintenance Cost Savings	Contruction Cost per ton of GHG Reduction
Phase 1 - BK & QN	18,558.45	35,723,681	$4,644,078.57	$0	$983.39
Phase 2 - MN, BX, SI	19,337.72	37,223,720	$4,839,083.55	$0	$1,204.95
Phase 3 - Misc Other	17,148.06	33,008,772	$4,291,140.36	$0	$1,398.96
Phase 4 - High-ways	869.02	1,672,800	$217,464.00	$0	$1,299.39
TOTAL	**55,913.25**	**107,628,973**	**$13,991,766.48**	**$0**	**$1,192.38 (avg)**
LED Lighting Projects					
Belt Parkway (BK and QN)	350.34	675,024	$101,254.00	$149,352	$7,997.36
Central Park	327.70	631,400	$94,710.00	$88,900	$8,031.82
Eastern Parkway	146.29	281,875	$42,281.25	$39,687	$8,031.82
FDR (arterial and under deck)	238.32	459,200	$68,880.00	$101,600	$7,007.24
TOTAL	**1,062.65**	**2,047,499**	**$307,125.25**	**$379,539**	**$7,790.67 (avg)**
Non-Lighting Energy Efficiency Projects					
Bicycle Lanes	15,664.13	-	-	-	$2,234
Car Sharing	85.00	-	-	-	$8,552

Figure 8 *The Wattage Reduction of LED Deployment New York City*
Source: New York City Department of Transport (2009)[115]

Case Study – Western Australia

"Brown Out" Trial, Main Roads Western Australia

Main Roads Western Australia (MRWA) conducted a pilot study looking at reducing the energy use and emissions as a result of street lighting whilst maintaining road safety along major roads in the Perth Metropolitan Region from 2008 to 2011. This pilot involved switching off selected street lights, a "brown out", between intersections along selected segments of major roads between the hours of 1 am and 5 am. The trial determined that over the three years the reduced street lighting resulted in AUD$560 000 in power cost-savings and approximately an 8 500 tonne reduction in carbon emissions and had no significant crash risks. From the results of this study, MRWA is now undertaking a review of their Lighting Policy.[116]

Case Study – Western Australia

Northern Alliance for Greenhouse Action – Street lighting

The Northern Alliance for Greenhouse Action (NAGA) was formed in 2002 to network, share and coordinate GHG emissions throughout Victoria. The Melbourne based alliance now have several companies, agencies and township councils apart of its network and continues to grow throughout Australia. Its latest initiatives are projects and campaigns to change road and street lighting from high energy consumption mercury based lamps to energy saving lights.[117]

So far this campaign has positive feedback and most associated members of NAGA are committing to the projects. If all members of the network and surrounding areas change their street lights there will be a significant decrease in the amount of GHG emissions produced by Victoria.

Traffic signals

Case Study – Western Australia

LED Traffic Signal conversion – Main Roads Western Australia[74]

There is currently a shift from using signal lamps to installing light emitting diodes (LED) throughout Western Australia. This project is being managed by Main Roads Western Australia (MRWA) and is the beginning of a larger project to convert all existing lights to LEDs and all future installations are already required to use LEDs. This project is expected to prevent the release of 2 000 tonnes of GHG emissions annually once the whole state has been converted. With the conversion to LED lights throughout main roads the level of energy required will decrease significantly thus reduce the strain on the power grid and reduce overheads.

Appendices

Road Infrastructure Projects - Sustainability Case Studies

In order to evaluate the practice of reducing environmental pressures in road project construction in Australia, four projects that were recently completed in Australia can be examined as the case studies:

- Appendix A: Eastern Busway – Queensland;
- Appendix B: Tullamarine Interchange – Victoria;
- Appendix C: Mickleham Road Duplication – Victoria; and
- Appendix D: Coopernook to Heron Creek – New South Wales.

Appendix A: Eastern Busway – Queensland

The Eastern Busway in Brisbane, Queensland is a major infrastructure project that provides rapid bus transit between the eastern suburbs of Brisbane, the central business district and the University of Queensland. In 2009, the design and construction of the 1.05km Buranda to Main Avenue section of the Eastern Busway was awarded to the Alliance team, consisting of the Department of Transport and Main Roads Queensland (TMR), Leighton Contractors, SKM and AECOM. The Alliance delivered the project at a cost of AUD$45.81 million and successfully provided the community with a significant number of environmental, financial and social benefits.[118]

Sustainability initiatives

The concept of sustainability was financially incentivised to emphasise it as a key result area to all members of the alliance. This was manifested with the presence of a full time sustainability consultant for the life of the project and monthly status and progress reports regarding sustainability metrics. The project also became the first pilot trial of the AGIC ratings scheme.

Innovative and deliberate design was undertaken to reduce the energy consumption of the busway by decreasing the demand for street lighting (reducing tunnels and using natural lighting). Other innovations like grid connected solar panels and LED lighting was also included. Waste reduction by recycling materials was achieved through many facets of the project including the upgrade of an existing pedestrian bridge and the reuse of houses that were initially slated for demolition.[118]

Key sustainability outcomes

The use of the AGIC ratings scheme directly and indirectly lifted the sustainability performance of the Eastern Busway project in a number of significant ways. It also led to the beginnings of a significant body of knowledge in ways to encourage and embed sustainability into large infrastructure projects.[119]

Tangible changes resulting from the AGIC trial and the inclusion of sustainability as a key performance area included a reduction in busway grades to save fuel, the lifting of bus stations to prevent flooding, the incorporation of water sensitive urban design, the removal of houses prior to demolition, and significant reduction in lighting and operation costs due to improved design.

Less visible sustainability measures made a significant contribution towards establishing greener construction practices. These measures included setting recycling targets for demolition waste, the top down construction of the tunnel to minimise community disruption, trails for alternative materials and methods and an increased sustainability awareness and understanding throughout the alliance team.

Sustainability management

The Alliance team developed and used a number of innovative methods to quantify and track the progress of sustainability throughout the life of the project. Sustainability became a *key result area*, sitting alongside traditional project management indicators such as cost, quality and safety (as shown below in Figure 9). Each key result area brought with it a number of *key performance indicators (KPI).* Under sustainability were three indicators: S1 – Decision Making Criteria, S2 – Greenhouse Gas Emissions and Resource Efficiency and S3 – Awareness of Sustainability.

These indicators were then tracked and reported to the alliance team, which enabled consistent and reliable progress to be made towards ensuring the sustainability goals could be met throughout the life of the project.

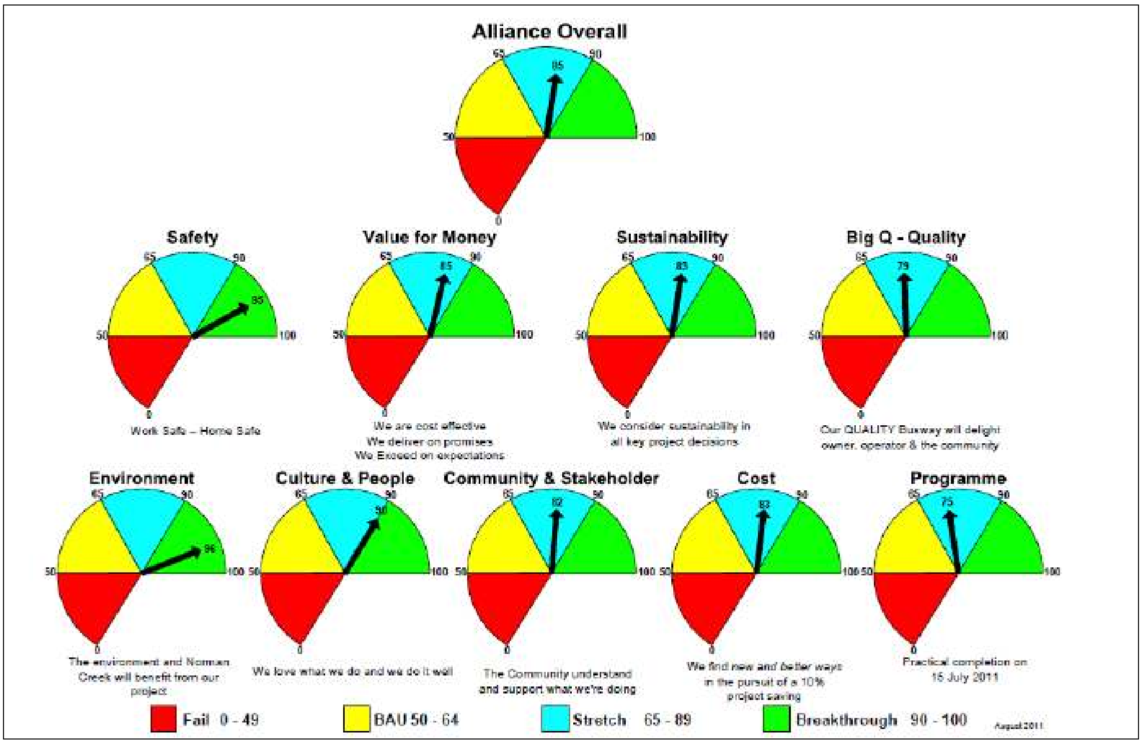

Figure 9 *Key Result Areas for the Eastern Busway Alliance Project Team, Brisbane, Queensland*
Source: White, G. (2011)[119]

To further embed sustainable principles into the design of the Eastern Busway, the project became one of the first two projects to undergo pilot testing of the AGIC rating scheme. The project was assessed under three overarching AGIC themes:

1. Discharges to air, water and the land;
2. Land Management; and
3. Waste Management.

Table 1 below describes the specific areas covered by the rating scheme and some adopted practices to reduce environmental impacts.

Table 1 *Practices Adopted as a result of the AGIC pilot trial for the Eastern Busway, Brisbane, Queensland*

AGIC Rating Scheme – Adopted Practices		
Discharges to Air, Water and the Land	Land Management	Waste Management
Water Quality - Existing creek and water table studies undertaken - Environmental Management Plan - KPI specifically related to Water Quality Noise - Baseline monitoring & operations predications - Construction mitigation measures & monitoring - Limited working hours Vibration - Construction methodology reviewed to determine monitoring requirements - Condition Surveys - More than just buildings and structures Air Quality - During Construction & Operation - Addressing Community Concerns Light Pollution - Construction methodology - Alternate lighting solutions	Site Selection and Route - consideration of designs that are economically and environmentally optimal Conservation of site resources - 80% topsoil removed due to fire ants - Imported topsoil – specification compliance issues - > 30,000m3 excavated material re-used on site Contamination / Remediation - Removed off site to approved waste facilities - > 80% materials were recovered for other uses Flooding Design - Hydrology & Hydraulic modelling - Adjacent properties - Busway operations - Climate Change considerations	Waste Minimisation – Didn't undertake predications Waste Tracking - Tracked & reported Monthly - Waste Subcontractor well set up Waste Management - Re-use non hazardous Clearing of Alignment - 48 houses removed - 96% demolition waste recycled Unused Material - Concrete discharged on site Qld Recyclers Reused Components - Pedestrian Bridges

Source: adapted from White, G. (2011)[119]

Appendix B: Tullamarine 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 Figure 10 below.

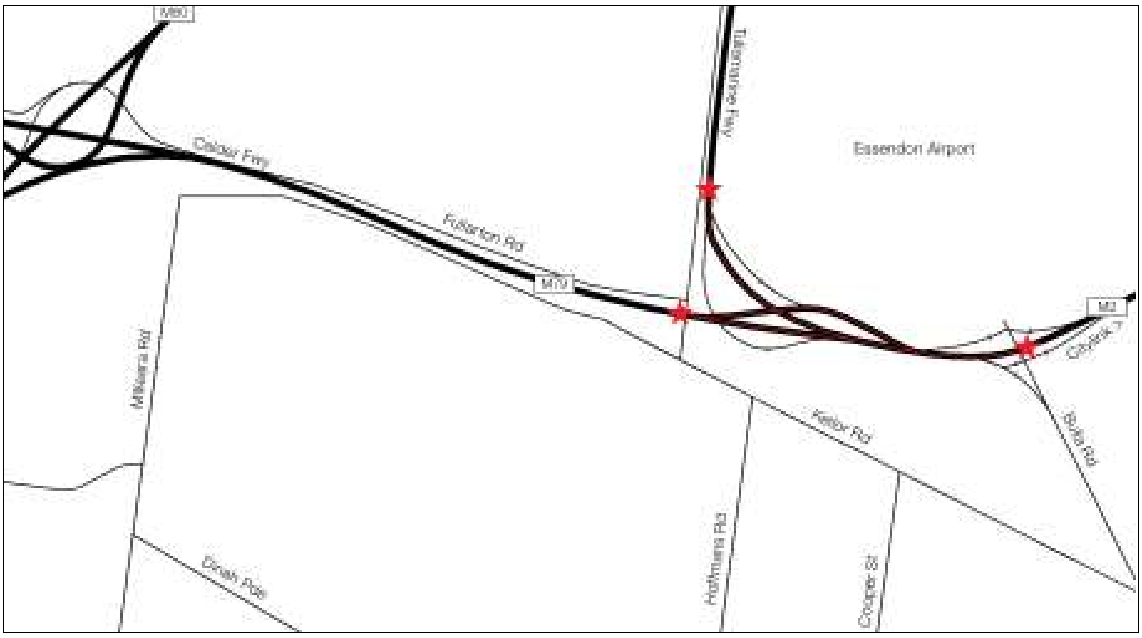

Figure 10 *Location of Tullamarine Calder Interchange*
Source: RoadTrip (2011)[120]

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.[121] The budget awarded for this project was AUD$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 AUD$12 million under budget.[122] 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.[122]

Sustainability initiatives

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 per cent recycled high density polyethylene (HDPE) pipes were used. This helped reduce overall cost, as well as reducing installation time by 25 per cent. 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 per cent of construction waste and, with the use of recycled asphalt, was able to save 8 500 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.[123] 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.

Noise walls were installed (as shown below in Figure 11) to reduce the amount of noise pollution in the surrounding area.

Figure 11 *Solar panels on noise walls*
Source: Johnston, W. (2007)[125]

Attached to the top of the noise walls were 210 solar panels at that generated 25 kw of power.[124] As the solar panels are vertical and not on an incline, only 37 per cent of power is lost.[125] 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 ten per cent 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 stabilisation was used to save raw materials and this saved 8 500 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.

Appendix C: Mickleham Road Duplication – Victoria

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 in Figure 12.

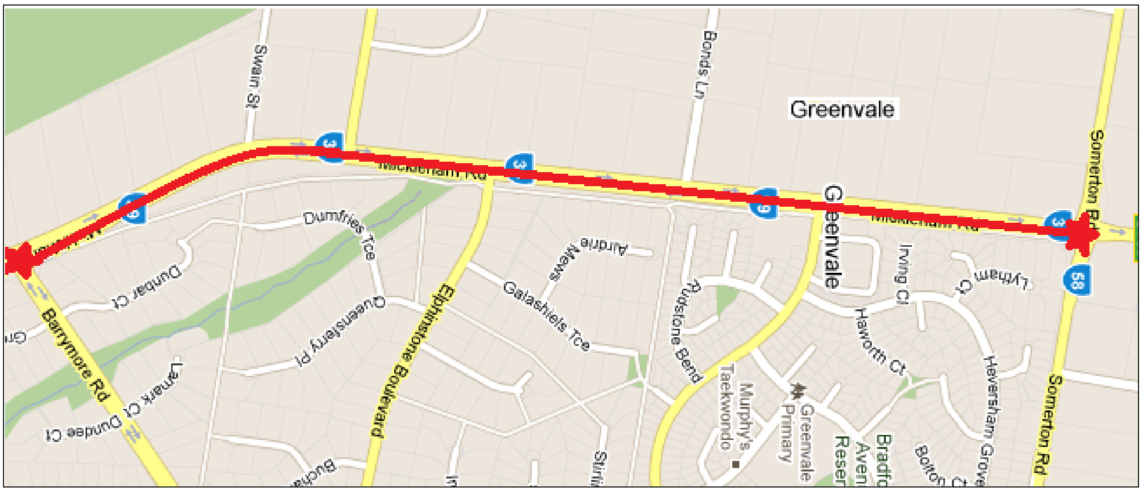

Figure 12 *Location of Mickleham Road Duplication*
Source: (Google, 2011)

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 AUD$13.3 million, is over 2.4 kilometres long and was completed in February 2008.[126]

Sustainability initiatives

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. 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 as shown below in Figure 13.[126]

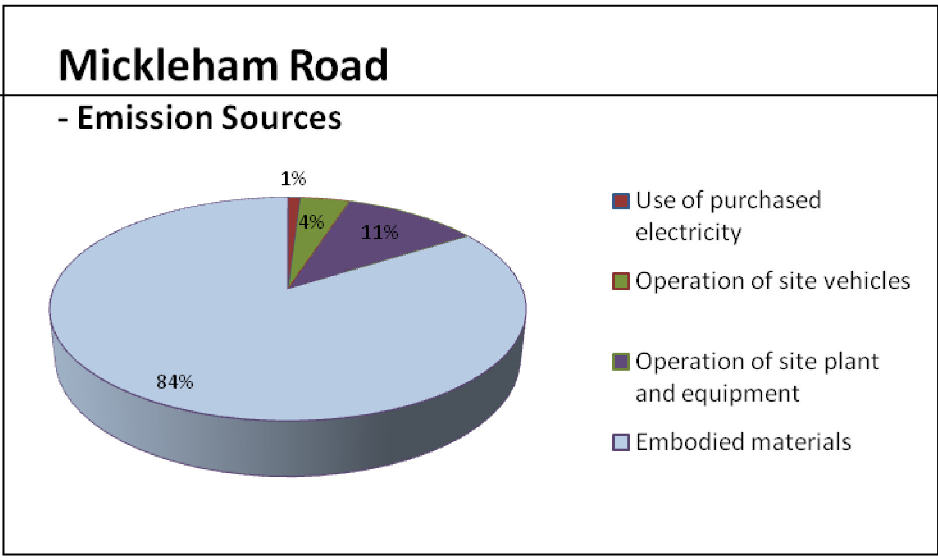

Figure 13 *Emission sources of Mickleham Road Duplication*
Source: Dilger, A. (2011)[13]

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 per cent) and on-site transport (24 per cent). The remaining GHGs came from the transport of materials to site (2 per cent) and from on-site electricity (1 per cent).[127] VicRoads was able to determine the magnitude of embodied carbon in the materials used as shown below in Figure 14, and these were, from largest to smallest: concrete (37 per cent), cement treated crushed rock (29 per cent), aggregate/base (21 per cent), asphalt (7 per cent) and steel (6 per cent).[126]

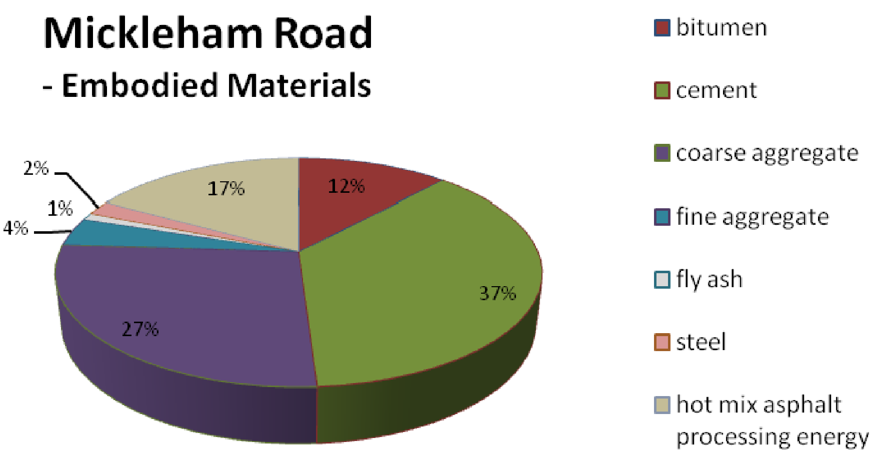

Figure 14 *Emissions from embodied materials of Mickleham Road Duplication*
Source: Dilger, A. (2011)[13]

Key sustainable outcomes

VicRoads was able to eliminate the carbon footprint from the construction of the Mickleham Road Duplication by planting 7 500 trees, thus offsetting 2002 tonnes of GHGs. This cost approximately AUD$25 000, equivalent to 40 million black balloons filled with GHG, making Mickleham Road Duplication the first "carbon neutral project" in Australia.[127] 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 recognised 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 recognised 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.[127]

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.

Appendix D: Coopernook to Heron Creek – New South Wales

The Pacific Highway is a large highway that connects many regional centers along the east coast of Australia. The Coopernook to Herons Creek (C2HC) Project required the upgrade of a 33 kilometre stretch of the Highway between Taree and Port Macquarie on the mid North Coast of NSW. The project passes through national parks, endangered ecology areas, heritage sites and many river and creek crossings. These areas presented many challenges and required the project team (the C2HC Project Alliance, consisting of the Road Transport Authority, Thiess and Parsons Brinkerhoff)[128] to innovate and unconventional construction methods.

Project-specific challenges

The AUD$453 million C2HC Project faced a number of challenges both in the design and construction stages. Much of the bushland affected by the project is listed as an "endangered ecological community", requiring significant planning to minimise the environmental disruption. The project traverses steep terrains, posing huge problems regarding slope stability. The project causes huge disturbances to large and sensitive catchments with highly dispersive soils and requires over 45 waterway crossings. Scour was identified early as a potentially huge problem, which proved correct when the project continued through flooding rains that broke a ten year drought across the region.

Sustainability initiatives

The C2HC project took significant steps towards the sustainable management of scour and erosion problems, with investments into innovative scour protection methods that are slated to become industry standard measure.[129] This work was recognised internationally, with the project reaching the finals of the 2008/2009 Award for Environmental Excellence in the International Erosion Control Association for Australia and New Zealand. The project's commitment to ecological protection of the surrounding environment is also highly commendable.[128]

However, there is little evidence of an overarching sustainable design process that is able to holistically incorporate the project from the feasibility to the rehabilitation stage. The current evolution of sustainable construction is able to reach deeper than surface mitigation measures and tackle issues such as the use of huge quantities of recycled materials and major design changes that reflect sustainable outcomes. For such a large and costly project, it did appear that the concept of sustainability had not been completely embedded from the outset of the works.

Fortunately, the sustainability initiatives that were implemented (scour and erosion control, flora and fauna fences and an active rehabilitation process) are innovative, unconventional and successful.[129] It could also be noted that many of these initiatives appeared to improve the quality of the design and construction process and reduce the level of risk on this large construction project. This fact illustrates the notion that sustainability is a productive and economically beneficial area in which to invest considerable time and resources, ideally from the very outset of a project's life.

Innovative measures

There are a significant number of innovative practices that have been well documented and quantified by the C2HC Project Alliance team. These project metrics have been summarised in Table 2.

Table 2 *Project Metrics resulting from innovative practices on the C2HC Project, NSW, Australia*

Total project budget	AUD$453 million
Total length	33 km
Project design commenced	April 2007
Consultation commenced	November 2007
Seedlings planted	187 000 which resulted in the abatement of approximately 5 400 tCO_2 or 1 265 cars off the highway
Abatement of CO_2 emissions by Green Power	100% Green Power which equates to approximately 1 926 t CO_2e-
Amount of water captured in rainwater tanks and concrete batch plants	XX million litres used for ablutions and wash-down
Total energy usage	256 247 KWh
Fuel consumption by Hino Hybrid Trucks	30% reduction of fuel consumption
Power poles re-used as fauna crossing poles in culverts	150 abandoned power poles re-used on-site
Frog fencing installed	1.3 kilometres
Fauna fencing installed	9 kilometres
Reduction in clearing footprint of individual 60% scour inlets	60%

Source: de los Rios La Rosa, D. (2011)[128]

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