Quantifying the benefits of waste minimisation

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Abbreviations and acronyms

AADT:	Annual average daily traffic
CO_2:	Carbon dioxide
EEM:	Economic Evaluation Manual
GWPI:	Global warming potential index
LTNZ:	Land Transport New Zealand
MfE:	Ministry for the Environment
NCHRP:	National Cooperative Highway Research Program
NZTA:	NZ Transport Agency
P10:	Particles less than 10 microns in size
RAP:	Recycled asphalt pavement
RCA:	Road Controlling Authority
VOC:	Vehicle operating cost
vkm:	vehicle-kilometres
WRAP:	Waste and Resources Action Programme

Contents

Executive summary

A methodology was developed in 2006–2009 to quantify the benefits of waste minimisation in road construction. The methodology uses the costs detailed in the NZ Transport Agency's *Economic evaluation manual* but also allows users to input costs for other benefits, eg resource depletion.

The methodology makes estimates of the following:

- energy and emissions associated with
  - material manufacture
  - transport to site
  - construction
  - transport to waste
- quantities of raw and recycled materials used
- vehicle operating costs associated with traffic delays
- energy associated with traffic delay
- emissions associated with traffic delay
- traffic delay costs.

The methodology uses estimates of the energy used in all the operations. To convert this to emissions such as carbon dioxide (CO_2), the energy has been assumed to be consumed as diesel or electricity. In New Zealand, a significant proportion of electricity is generated in hydroelectric power stations and thus the emission levels for fixed plant, such as those for aggregate crushing, is significantly lower than if they were diesel powered. The methodology is flexible and allows the comparison of non-standard techniques, although the user needs to have knowledge of construction methods and equipment requirements.

Three examples are given and it is demonstrated that the major area where waste could be minimised is associated with using construction methods that minimise traffic delays. The travel delay costs (waste of time and fuel) tend to be an order of magnitude larger than the costs associated with other aspects of construction. The examples illustrate the environmental gains that can be made in terms of CO_2 emissions and resource depletion through using recycling techniques.

The methodology as described does not take life cycle costs directly into account. These are routinely calculated by roading engineers in comparing treatments by following the methods in the EEM. The benefits developed in the methodology given in this report can be directly inputted into calculating present worth value where the lives of the treatments are different.

It is considered that the methodology is a useful tool to enable road controlling authorities to decide on the merits of using a waste minimising technique and to compare the benefits with the costs associated with implementing the policy.

Abstract

A methodology was developed in 2006–2009 to quantify the benefits of waste minimisation in road construction. The methodology uses estimates of the energy and emissions involved in all operations, raw and recycled materials used, and the costs, energy use and emissions associated with traffic delay. A spreadsheet was developed as a tool for road controlling authorities to decide on the merits of using a waste minimising technique, and to compare the associated benefits and costs.

1. Introduction

1.1 Previous research

As part of the research project on recycling materials for more sustainable road construction initially set up by Transfund[1], an Industry Working Group was convened in 2003 to identify the main reasons for the failure of the roading industry to adopt waste minimisation strategies (including recycling). The Working Group concluded that reasons included:

- a lack of clear direction in the specifications current at that time
- a lack of experience and confidence in the use and performance of the technologies in a New Zealand context
- no methodology to quantify the benefits (Bailey 2001).

Since the initial research, the specifications have been reviewed to reduce or remove any barriers to using waste minimisation techniques. This has led to basecourse specifications that allow the incorporation of crushed glass, slag or recycled concrete. A report published by Land Transport New Zealand (LTNZ) also conducted research on trial pavement sections which were constructed using recycled asphalt and rubber crumb from tyres (Patrick 2006).

This project, which was undertaken in 2006–2009, addresses the need for a methodology for quantifying the benefits of recycling materials and aims to develop a tool for road controlling authorities (RCAs) to make informed decisions on whether to adopt waste minimisation strategies in their area.

Benefits can be direct in terms of cost savings by using a lower cost technique or reducing the quantity of material going to a landfill. More indirectly, benefits can be gained by reducing the materials and energy required, or the emissions produced.

This research is aimed at developing a matrix of these benefits that can be used with waste minimisation techniques which will enable RCAs to input their own values to assist in determining which techniques would be used in their area.

The research consisted of a number of tasks:

- International literature was reviewed to determine how the benefits from waste minimisation, as related to roading construction and maintenance, are quantified internationally.
- The development of a matrix of benefits attributable to waste minimisation techniques as identified in the literature review. This matrix includes both quantitative and qualitative benefits. Benefits can be further divided into two groups
  - those of direct benefit to the RCA, such as the reduction of waste to a council-operated landfill or the use of aggregate from river management

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[1] Transfund is now part of the NZ Transport Agency (NZTA), which was established in August 2008 when Land Transport New Zealand and Transit New Zealand merged.

  - those of more indirect or intangible benefits, such as reductions in carbon dioxide (CO_2) emissions or reductions in traffic delays. The benefits are then quantified using data from the *Economic evaluation manual* (EEM) (NZTA 2010). A methodology is given and structured so that users can enter their local cost structure and the benefits will be apparent. Flow diagrams and the like are used to make the methodology as clear and simple as possible.

- The draft methodology has been be trialled by examining two waste recycling techniques and a pavement recycling method.

1.2 The New Zealand Waste Strategy

The Ministry for the Environment prepared the New Zealand Waste Strategy in partnership with Local Government New Zealand (Ministry for the Environment (MfE) 2003) covering solid, liquid, gaseous and hazardous waste. The Strategy is designed to help reduce waste, recover resources and manage residual waste better in New Zealand.

The strategy has three core goals:

- to lower the social costs and risks of waste
- to reduce the damage to the environment from waste generation and disposal
- to increase economic benefit by more efficient use of materials.

1.3 Definition of waste minimisation

Waste is any material, solid, liquid or gas, which is unwanted and/or unvalued, and discarded or discharged by its owner (MfE 2003).

Waste minimisation can be defined as a chain of measures developed to prevent or reduce waste discharges through strict avoidance, reduction at source, reuse, recycling and recovery. In broader definition, waste minimisation includes three measures:

Strict avoidance prevents waste being generated during the road construction or maintenance process by avoiding the use of waste-generating technologies and materials, and replacing them with environmentally clean materials and modern technologies. As result of these measures, wastes are not discarded or discharged into the environment.

Waste reduction at source is a measure to reduce waste during the road construction and maintenance process. Waste reduction can be achieved by more efficient use of raw materials.

Recycling reduces the discharge of wastes and the use of raw materials. Implementing this measure involves processing used building materials for re-use. For the roading industry, recycling reduces the need for new building materials such as gravel, sand, clay and limestone that are used as a basecourse layer. Recycling is a means to avoid disposing used materials into landfills.

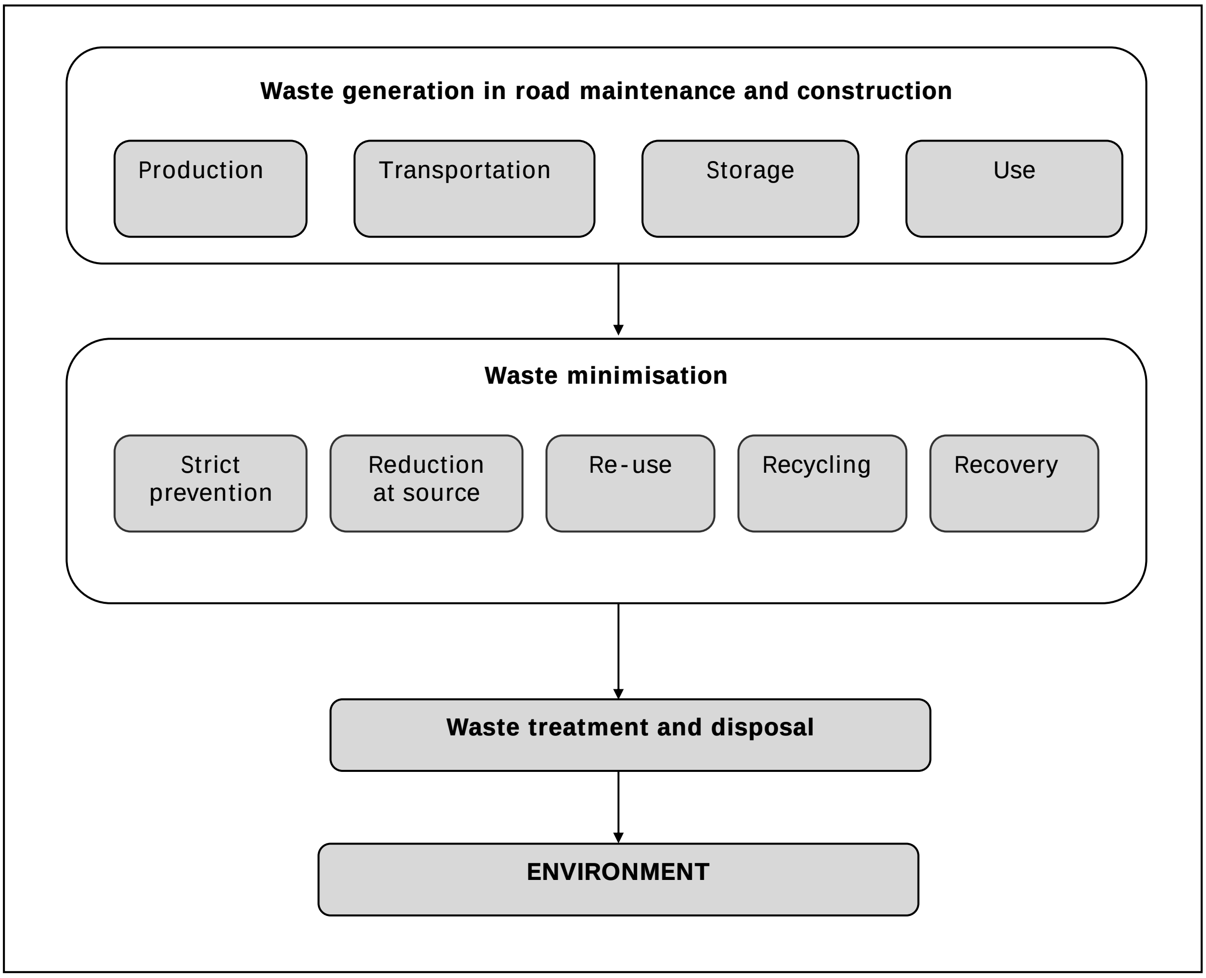
Reuse involves finding a beneficial purpose for recovered waste. Three factors are considered when determining for the potential reuse:

- the chemical composition of the waste and its effect on the reuse process

- the economic value of the reuse waste and whether this justifies modifying a process to accommodate it
- the availability and consistency of the reused waste
- energy recovery.

Figure 1.1 illustrates these principles as they could be applied in the road construction and maintenance industry.

Figure 1.1 Waste generation and waste minimisation in road maintenance and construction



2. Literature review

2.1 Overview

A literature review was undertaken in this study to collect the information on the benefits of waste minimisation practices in road construction and maintenance projects. The information gathered in this review has been grouped into two topics:

- waste minimisation internationally
- the New Zealand experience.

Specifically, this search focused on methods applicable for quantifying economic costs and benefits (including environmental) which result from waste minimisation programmes in the roading industry.

2.2 Waste minimisation in road construction and maintenance – international practice

2.2.1 Waste minimisation

A range of literature supports the desirability of waste minimisation, especially recycling.

In a study of post-consumer waste, namely glass, plastic, rubber tyres, paper and cardboard waste, Gupta (1998) uses a cost-effective analysis of waste recycling for highway construction. Arguing for their use, Gupta illustrates how the high cost of using recycled waste materials is still lower than the 'societal cost' of using virgin construction materials in highway construction by factoring in landfill costs as well as disamenity costs for disposal into the overall materials costs.

Examples of documents that bring together 'best practice,' include the British Transport and Road Research Laboratory publication *Recycling in transport infrastructure* (Reid and Chandler 2001), and the Highways Agency's *Building better roads towards sustainable construction* (2003). Reid concluded that 'the UK Landfill Tax, the EU Landfill Directive and Government initiatives to support sustainable construction have encouraged the use of recycled materials in transport infrastructure.' However, concern still remained regarding some of the practical problems associated with the durability and specification of recycled materials.

In the USA, the Federal Highway Administration promotes recycling, stating the following (Wright 2006):

> *The FHWA policy is:*
>
> 1. *Recycling and reuse can offer engineering, economic and environmental benefits.*
> 2. *Recycled materials should get first consideration in materials selection.*
> 3. *Determination of the use of recycled materials should include an initial review of engineering and environmental suitability.*

4. *An assessment of economic benefits should follow in the selection process.*
5. *Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications.*

The National Cooperative Highway Research Program (NCHRP) developed the *User guidelines for waste and by-product materials* (1997).

Waste minimisation initiatives have been incorporated into the number of roading projects throughout Australia. A case study demonstrating the benefits in using recycled materials in Victoria on the Western Ring Road (onSITE 1997) project has been reported. Also, the Australian Stabilisation Industry Association has actively promoted road recycling (Wilmot and Vorobieff 1997). The benefits of stabilisation have also been highlighted by Smith and Vorobieff (2007), who listed the environmental benefits as savings on:

- trucking materials off-site
- excavation of the existing materials
- dumping or disposal of excavated materials which still have a real asset value
- possible landfill usage
- quarrying replacement materials, which are in themselves finite resources
- trucking replacement materials to the site
- energy usage on the activities mentioned above
- gas emissions related to these activities.

However, Smith and Vorobieff (2007) made no attempt to quantify these benefits or assign them a monetary value.

The present central governing Australian body, the National Environmental Protection Council, does not have any national waste minimisation strategy similar to the New Zealand Waste Strategy (MfE 2003). However, a number of waste minimisation initiatives were addressed in different state government documents such as the New South Wales Waste Minimisation and Management Act 1995 (New South Wales Government 1995) or Victoria Waste Minimisation (Department of Sustainability and Environment 2005).

Less information, however, is available on initiatives to quantify waste minimisation. In the USA, Hyman and Johnson (2000) developed a decision-support tool to quantify the benefits of reusing waste material. His model is based on an Excel spreadsheet and is designed to quantify the benefits over a 20-year period rather than on a site-by-site basis. The spreadsheet quantifies the construction costs. Benefits are in terms of construction cost savings, including landfill savings. However, they do not account for externalities such as road user costs, energy and emissions.

An estimator designed for quantifying CO_2 emissions has been developed by the Waste and Resources Action Programme (WRAP) for British conditions. This Excel spreadsheet is very comprehensive in allowing the comparison of energy and CO_2 emissions of pavement construction techniques used in Britain. The developers of the tool performed an extensive review of European data related to the energy requirements of different plant and construction techniques. The output is designed to compare CO_2 emissions of the construction process and does not take traffic emissions related to the roadworks into account.

2.2.2 Energy and emissions

Waste minimisation is not solely related to conservation of materials. Energy and emissions, as related to energy consumption, are also relevant. The WRAP system described above gives details of energy use. Other studies include that of Zapata and Gambatese (2005), who compared the energy consumed during construction using asphalt and using reinforced concrete. They concluded that concrete consumed more energy in construction, but that uncertainty over the expected life of a concrete pavement compared with an asphalt pavement, and the associated maintenance requirements, did not allow a definitive conclusion.

The USA Transportation Research Board published a synthesis of highway practice in 1981 which gave details of the energy involved in construction. This includes the energy required to manufacture materials as well as consumed during pavement construction (Halstead 1981).

The Canadian Construction Authority (2005) also published data on the energy consumption related to road building and developed a guide for associated energy reduction. Their emphasis was on the efficient use of the machinery used in construction and transportation, and they conclude that the contracting industry has the potential to reduce both energy and costs in road rehabilitation.

The data used in the Canadian research has been expanded in a report (Meil 2006) comparing the embodied energy and global warming potential of concrete and asphalt pavements. This report has details of the energy required in construction and the CO_2 emissions from this. It uses the International Panel on Climate Change's 100-year time horizon factors as a basis for converting emissions to equivalent CO_2 equivalence. A Global Warming Potential Index (GWPI) is used as shown in equation 2.1.

$$GWPI\ (kg) = CO_2 kg + (CH_4 kg \times 23) + (N_2) kg \times 296) \qquad \text{(Equation 2.1)}$$

This relationship converts the CH_4 and N_2O into equivalent weight (in kg) of CO_2.

Reid and Chandler (2001) developed a list of issues relating to British use of recycled materials in roading, summarised as follows:

- Some material and methods are excluded from existing specifications.
- Test methods already in use that were developed for natural materials may not be suitable for some alternative materials.
- Alternative materials are perceived as being highly variable, so reliability and quality control is a concern.
- Potential long-term leaching of contaminants is an environmental concern.
- It is unclear whether alternative materials are subject to waste material regulations or whether they are considered to be construction materials.
- Some forms of construction may create an environment which gives no incentive for innovation. For example, partnering clauses may discriminate against novel materials or methods.

- It can be difficult to obtain planning permission for recycling.
- Matching supply and demand for some materials could be difficult.
- Alternative materials and methods may be more expensive.
- Many individuals and organisations may be unaware of the potential uses of alternative materials.

2.3 New Zealand practice

Techniques that can be used for recycling in the New Zealand context have been summarised in Bailey (2001). Removing barriers to their use have been researched by Peploe (2006), Peploe and Dawson (2006), Herrington et al (2006), Patrick et al (2006), and Vuong and Arnold (2006) in previous LTNZ sponsored research

New Zealand has a history of using cement and lime stabilisation which allows for more marginal aggregates in roading. Existing road materials are reused because the stabilisation process is often performed in situ. This is often a very cost-effective treatment, especially where good aggregate is scarce, such as in Hawkes Bay, for example.

Other recycled materials, such as asphalt, or used tyres and glass, are seldom used in roading, although nothing prevents this from happening.

The environmental benefits of using different road building techniques have been highlighted by Slaughter (2004) in a study comparing cutback bitumen and bitumen emulsion for chipsealing. Ferry (1998) presented a paper describing how, on low volume roads, the unsealed option could give a more sustainable outcome than chipsealing.

The benefits of stabilisation have been highlighted and discussed in a paper by Kett et al (2005). Using a project in Auckland as an example, the study found that the benefits in terms of the EEM were mainly associated with the shorter construction time that the stabilised alternative had in affecting vehicle operating costs (VOCs). The authors recommended 'that for project evaluation the environmental and social benefits are considered in addition to the economical benefits as required by the New Zealand Resource Management Act.'

The energy required for the typical New Zealand road construction (chipseal over a granular base) was developed by Hawthorne and published in the National Roads Board *Newsletter no. 55* (Hawthorne 1975). These energy requirements were based on work published by the USA Asphalt Institute and adapted to New Zealand construction practices.

The EEM is a comprehensive manual that suggests methods for considering the impact of various (positive or negative) benefits on a roading project such as:

- VOCs
- travel time
- crashes
- noise
- vehicle emissions

- vibrations
- water quality
- ecological impacts
- visual impacts
- community severance
- overshadowing
- isolation.

Not all cases have had a monetary value assigned, and the direct application to construction process may not be applicable. For example, the valuation of traffic noise is based on the perceived effect on property prices. However, the value of noise for a road construction or rehabilitation project would be more associated with the short-term annoyance given to residents.

In summary, information is available in the literature to allow us to estimate a range of benefits that accrue from using waste minimisation techniques, although these need adapting to the New Zealand environment.

Although waste is available, often the ratepayer needs to subsidise its collection. The following quote from the Auckland City Council (2006) illustrates this point:

> *More than 230 tonnes of glass a week are collected from Auckland city blue bins. New Zealand's good record in recycling means the country's sole recycling plant, ACI Glass Packaging New Zealand, in Auckland, currently has access to more than enough. This is compounded by glass imports, which make up over 36 per cent of glass consumed in New Zealand – much of it less suitable for recycling – and glass importers are being lobbied to take more responsibility for it once it has been used.*
>
> *Mr Jaine says that while the city's glass collection contractor gets the revenue for glass from ACI, ratepayers receive a direct benefit through a reduced price for the recovery service.*
>
> *'To maintain this service we have agreed to an interim arrangement with the contractor to partly subsidise the loss in revenue.*
>
> *If the losses continue over a one year period it will cost each ratepayer around $2 a year, or 5c a week.'*

3. Matrix development

Table 3.1 summarises key issues and concerned parties associated with a road project that includes waste minimisation.

Table 3.1 Key issues and concerned parties associated with a roading project

RCAs	Road users and society	Contractor
Waste collection/sorting	VOCs	Transportation
Waste transportation	Travel time	Raw materials
Total cost to RCA	Vehicle emissions	Material processing
	Resource depletion	Construction costs
	Energy	Traffic control
	Resident frustration	

Factors listed in the EEM but not considered in table 3.1 include:

- water quality
- ecological impacts
- visual impacts
- community severance
- overshadowing
- isolation
- dust
- noise
- vibrations.

The objective of this research is to develop a methodology for comparing construction techniques. Therefore, it is assumed that the project has been ‘approved’, and that water and ecological impacts will be the same for all alternatives. It is also assumed that any waste minimising technique will perform equally well as the conventional equivalent. Equal performance of a pavement using recycled materials means not only pavement life but also equivalent performance in terms of other factors such as roughness, noise, rolling resistance and skid resistance.

Although dust, noise and vibrations associated with construction can be considered, it is assumed that they are kept within the requirements of the RCA and are therefore captured in any costs associated with residents’ frustration. Values would vary according to differences in construction times and methods.

Similarly, crash costs associated with roadworks could be considered where construction times for the conventional and the waste-minimising technique are significantly different. Kett et al (2005) offer a method of estimating costs based on converting the annual cost of crashes to a daily cost experienced in New Zealand. They did not, however, factor in the number of roadwork sites per year and therefore this method has not been adopted. At this stage, crash costs have not been included.

As the EEM points out, one has to be careful to avoid double-counting costs or benefits. Therefore, some of the benefits that have been proposed for waste minimisation have not been included. These include the following:

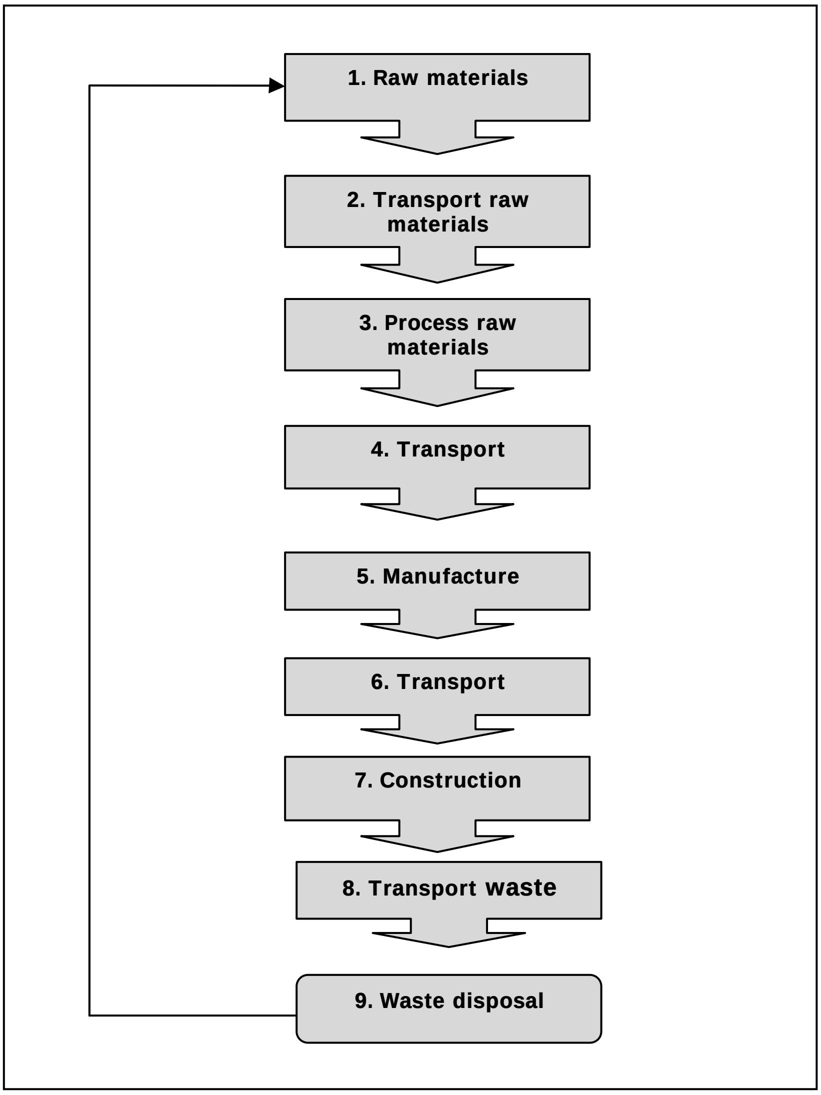
- **Road wear:** The decrease in heavy construction traffic occurs when techniques like in situ stabilisation are used. This has not been included, because road user charges imposed on heavy vehicles are designed to reflect road damage. Therefore, the 'benefits' should be captured in the contractor's cost calculations.
- **Landfill:** At present, local authorities are required to charge landfill fees that cover the cost of operation and provide for developing future landfills. The benefits of reduced material to the landfill from roading operations should therefore also be captured in the contractor's costs. In many cases, the waste from road building operations is classed as hardfill and is thus not charged at the same rate. In other cases, such as asphalt millings, the contractor can sell this material for constructing low traffic areas such as farmers' drives. Therefore, the 'waste' has considerable value and is, in fact, recycled. For other non-roading materials, such as glass, the cost of landfill disposal will be reflected in the costs determined by the 'owner' of the glass.
- **Job creation:** Job creation has been advocated as a benefit of recycling. However, the value placed on job creation in order to reduce recycling costs needs to be treated with caution. The use of recycled materials could reduce the demand for raw materials and thus reduce employment in other industry sectors.

4. Construction process flow diagrams

Road construction and maintenance are complex processes consisting of sub-components such as formation construction, sub-base and basecourse, and paving. It is essential to identify all process steps within these sub-components, and to show the input and output for each process. Insofar as the number of inputs and outputs is significant, flow diagrams for each sub-component should be considered separately.

A generalised flow diagram of the construction process is given in figure 4.1.

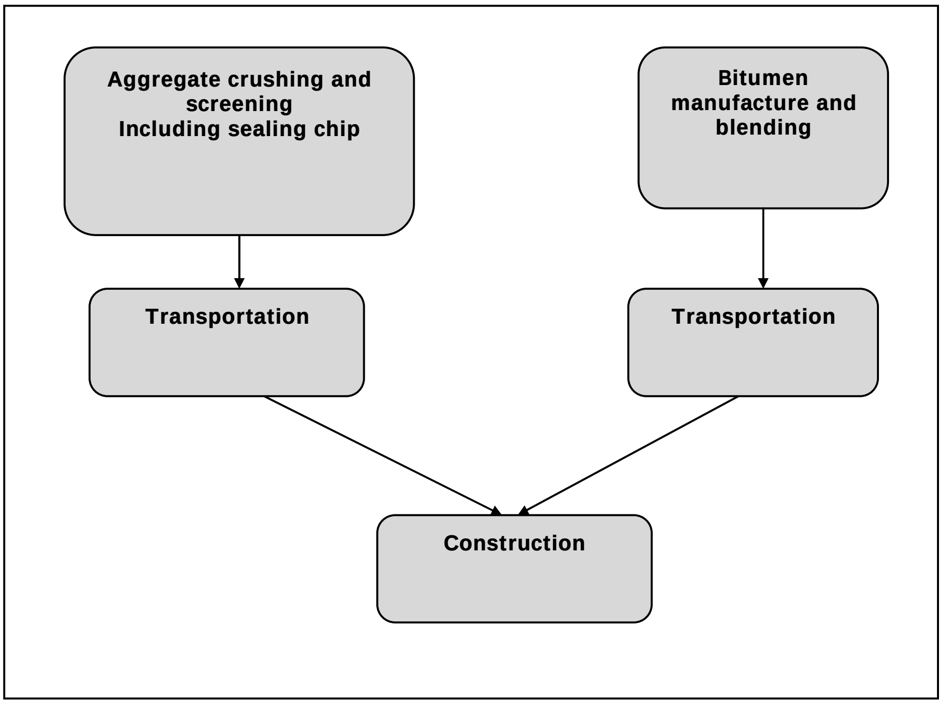
Figure 4.1 Generalised road construction process outline



For each stage of the process, energy is being consumed, emissions are produced and materials are often used. Waste minimisation techniques can be applied at all of the steps.

Not all of the steps are used for different aspects of construction. Three examples of methods of strengthening a pavement are given below. The methods all result in pavements that perform equally well, but they use other materials or in situ materials to minimise the use of aggregate. The traditional strengthening technique has been to overlay an existing pavement with new aggregate. The process diagram would be as shown in figure 4.2.

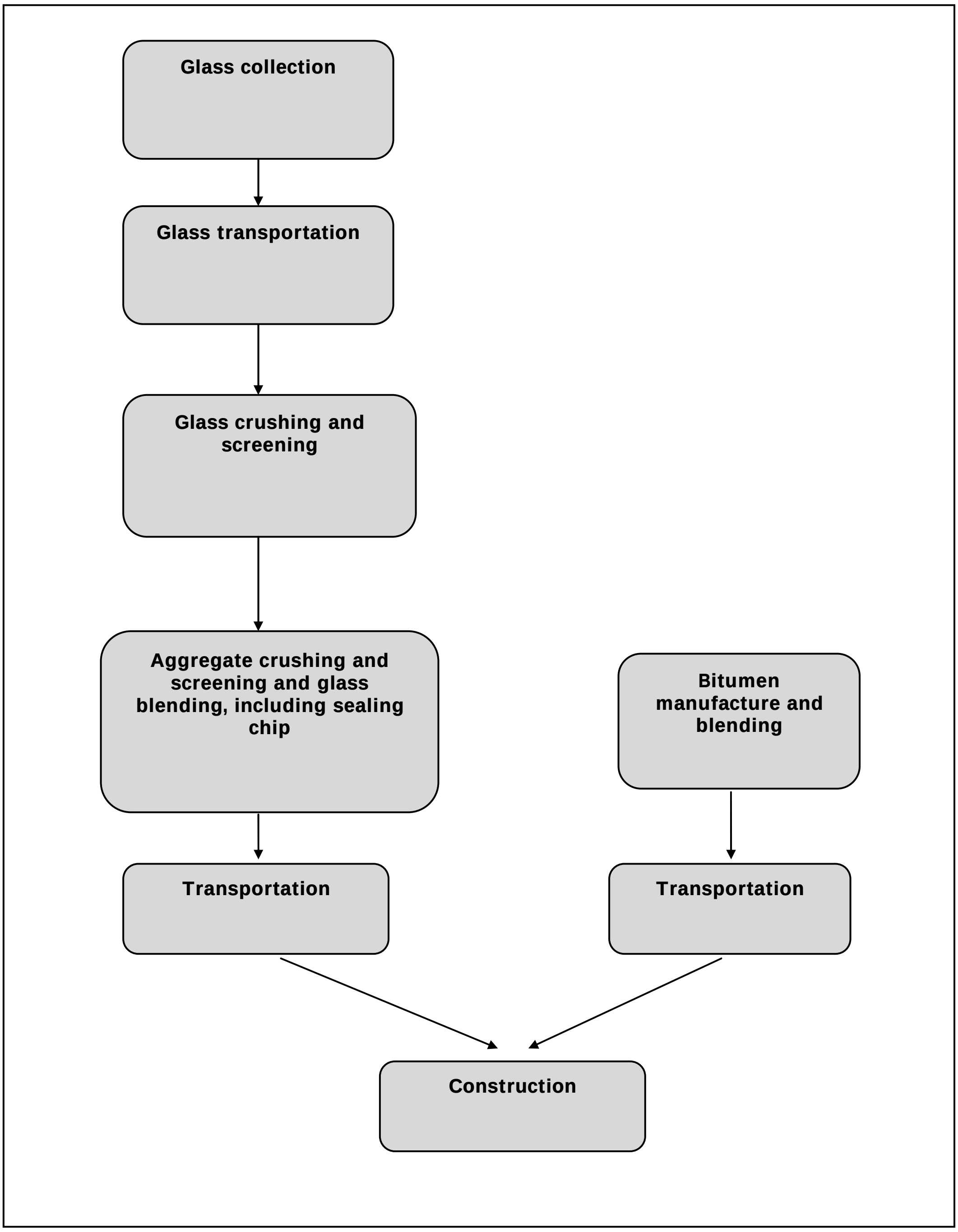
Figure 4.2 Flow diagram of the aggregate overlay strengthening method



In this first example, the aggregate is processed in the quarry and thus does not require raw material to be transported. No waste is generated because the new aggregate is laid on top of the old pavement.

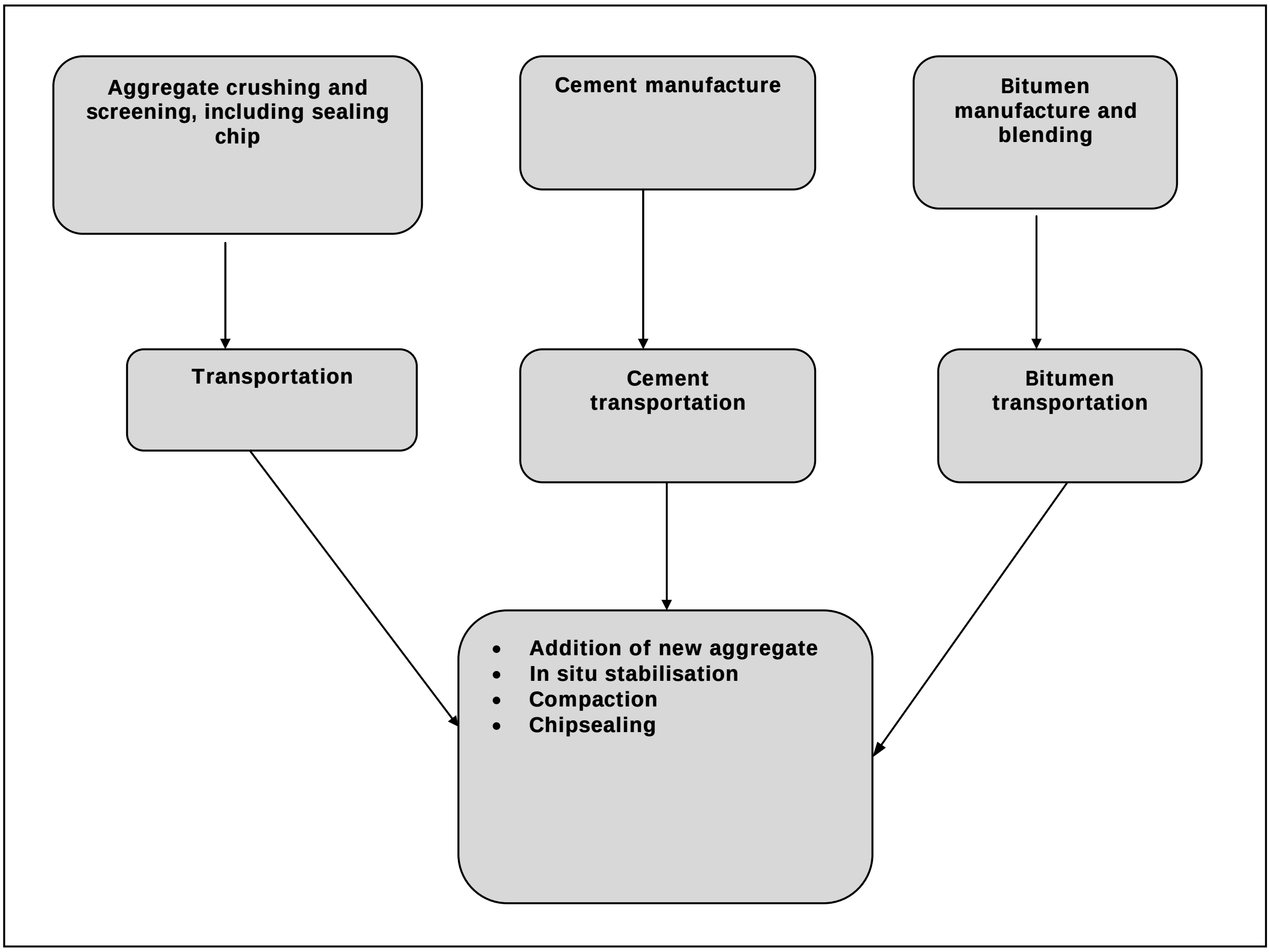
If the incorporation of waste glass was being considered as an alternative strengthening option, and if the construction sequence was the same as in figure 4.1, then the flow diagram would be similar to figure 4.3.

Figure 4.3 Flow diagram of the process of incorporating waste glass for strengthening a pavement



The third example uses a common treatment in New Zealand based on in situ recycling of the existing pavement with the addition of new aggregate to enhance pavement strength. In this case, the flow diagram would be similar to figure 4.4.

Figure 4.4 In situ stabilisation of a pavement with additional new aggregate



5. Basis of calculations

5.1 Objectives

A spreadsheet has been developed to calculate and compare the benefits associated of using any waste minimisation techniques. The objective was not to develop a project-specific tool but rather a tool to assist an RCA in developing a policy for the use of a technique within their jurisdiction.

The methodology developed includes the input of data that helps a user to compare the methods of constructing a pavement, and gives an output summary. Details of the assumptions and values proposed for the methodology are given in section 5.2.

5.2 Energy

The energy used in different forms of construction has been estimated from the literature, mostly from Hawthorne (1975). This data was based on USA Asphalt Institute publications and was a very topical subject during the oil crisis that occurred about that time. The data used in this project is given in table 5.1.

Table 5.1 Energy equivalents for different processed and materials used in pavement construction (taken from Hawthorne (1975))

Component	Value to be used	Unit
Petrol	34,800	kJ/L
Kerosene	37,600	kJ/L
Diesel	38,700	kJ/L
Bitumen	700,000	kJ/tonne
64% C emulsion	585	kJ/L
Cement	6,900,000	kJ/tonne
Lime	7,000,000	kJ/tonne
Crushed aggregate	80,000	kJ/tonne
Natural aggregate	19,000	kJ/tonne
Hot mix manufacture	478,000	kJ/tonne
Hot mix laying and compaction	56,000	kJ/tonne
Basecourse laying and compaction	65,800	kJ/tonne
Cartage (return trip)	2700	kJ/tonne/km
Brooming, loading, spreading and rolling chip	3000	kJ/m^2
Gang sprayer	165,000	kJ/tonne
Stabilisation static plant and loader	19,200	kJ/tonne
In situ stabiliser	10,450	kJ/tonne

Hawthorne's (1975) data has been used in this project as the first estimate of energy requirements as it was based on typical New Zealand operations, including chipsealing. It is recognised that the efficiency of construction has improved over time and thus the information has been compared with more recent information that was revealed in the literature survey.

The applicability of the data was checked against other research and this is summarised in table 5.2.

Table 5.2 Comparison of the Hawthorne (1975) energy equivalent values and those given by other researchers

Component	Unit	Research					
		Hawthorne (1975)	(Halstead 1981)	Zapata and Gambatese 2005	WRAP*	Alcorn (2003)	Meil (2006)
Petrol	kJ/L	3.48E+04	–	–	–	–	3.58E+04
Diesel	kJ/L	3.87E+04	–	–	–	–	4.26E+04
Bitumen manufacture	kJ/tonne	7.00E+06	6.83E+05	6.00E+06	1,73E+05	4.40E+07	4.68E+06
Cement manufacture	kJ/tonne	6.90E+06	8.41E+06	6.30E+07	4.78E+06	7.80E+06	5.50E+06
Crushed aggregate	kJ/tonne	8.00E+04	6.76E+04	5.30E+04	3.8E+04	4.00E+04	5.00E+04
Natural aggregate	kJ/tonne	1.90E+04	1.74E+04	2.40E+04	2.7E+04	2.00E+04	–
Hot mix manufacture	kJ/tonne	4.78E+05	2.30E+04	3.50E+05	3.72E+05	3.40E+06	4.80E+05
Hot mix construction	kJ/tonne	5.60E+04	1.94E+04	1.34E+04	–	–	–
Cartage (return trip)	kJ/tonne/km	2.70E+03	2.89E+03	–	1.0E+03	1.35E+03	–
In situ stabiliser	kJ/tonne	1.05E+04	–	–	1.23E+04	–	–

* Centre for Sustainability 2006

One of the difficulties in comparing the values is associated with the definition of energy used. The energy equivalents given in the literature often do not make it clear whether factors such as transport of the material has been included. Some researchers have used 'embodied' energy, which can be defined as including the energy in the material if it was used as a fuel and not the energy to manufacture it, eg the calorific value of bitumen if it had been used as a fuel. The capital equipment energy can also be included (Alcorn 2003). The energy recommended for use in comparing different construction methodologies is that required for the manufacture or operation of the material or plant, without including the embodied energy.

Some of the values are significantly different, especially in the manufacture of bitumen, which has a range of two orders of magnitude. The high value given by Alcorn (2003) may include a large transportation factor for importing crude oil, which would not be as large in overseas countries. Without further investigation into the appropriate value to be used, it is suggested that a value of 6×10^6 kJ/tonne, which is on the higher side of the published figures, be used.

The difference between estimates for cement is not as large.

For the asphalt manufacture, Halstead (1981) has a value lower than the energy needed to crush aggregate. The value has therefore been assumed not to cover aggregate manufacture but only the heating and mixing of the aggregate and bitumen.

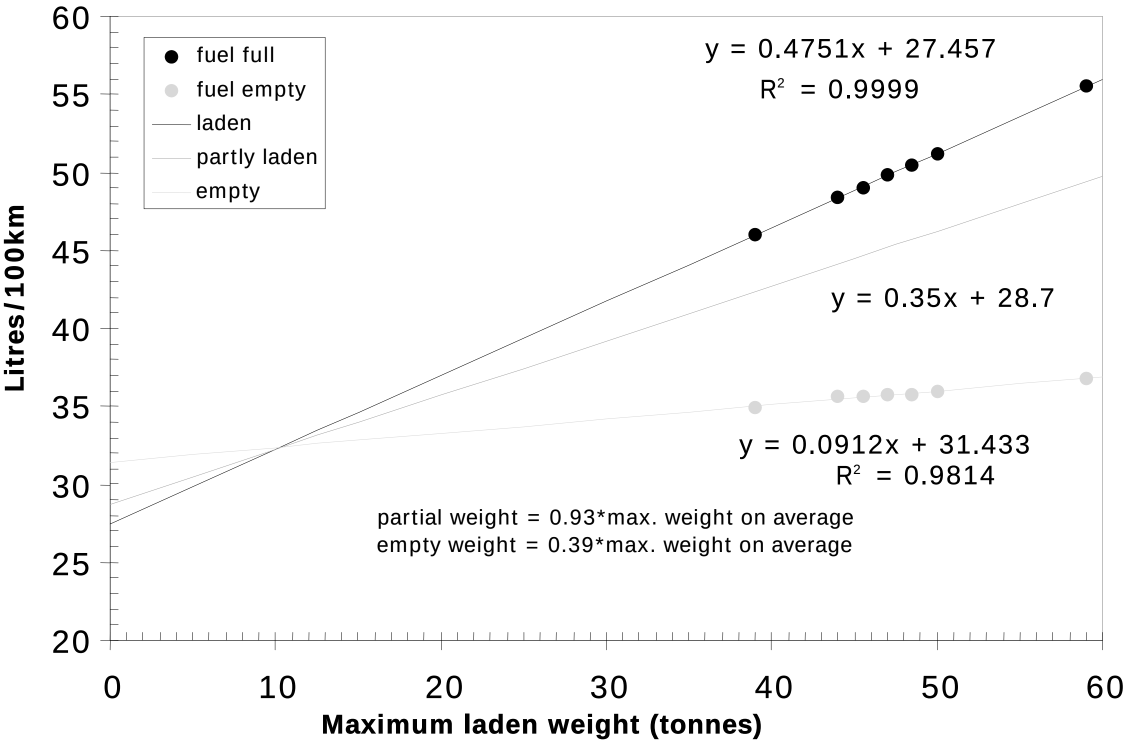
Figure 4.1 showed that transport was a key component of the construction process. The transport of the materials to the sites of manufacture, construction and waste is a significant component in the analysis.

The literature proposes a range of values. The WRAP project (Centre for Sustainability 2006) recommends the energy use for a long distance transport (32 metric tonne load) for a maximum load plus an empty return trip to be 13,340kJ/vehicle-kilometres (vkm) which equates to 416kJ/tonne/km.

For a ‘distribution’ truck carrying 14 tonnes, WRAP quotes a value of 12,000–13,000 kJ/vkm, which equates to approximately 890kJ/tonne/km. This is double the energy use of the long distance 32-tonne loads.

Dravitzki et al (2004) derived fuel consumption figures in New Zealand, shown in figure 5.1. For a 32-tonne load (maximum load; empty return), the fuel consumption equates to 77L/100km. This is equivalent to 930kJ/tonne/km. For a 14-tonne load, the energy is equivalent to 66L/100km, equalling 1825 kJ/tonne/km. Dravitzki et al’s figures are comparable with the WRAP in that the energy per tonne-km is approximately double for a 14-tonne load compared with a 32-tonne load.

Figure 5.1 Truck fuel consumption versus maximum weight (from Dravitzki et al 2004)



Differences in transportation energy can be significant in some cases and it is recommended that the appropriate values be used where transport differences between options are significantly different.

Suggested values for all components of the construction process to be used in any analysis are given in table 5.3.

Table 5.3 Suggested energy values for all components of the construction process

Component	Suggested value	Unit
Petrol	3.50E+04	kJ/L
Kerosene	3.76E+04	kJ/L
Diesel	3.87E+04	kJ/L
Bitumen	6.00E+06	kJ/tonne
64% C emulsion	5.85E+02	kJ/L
Cement	7.00E+06	kJ/tonne
Lime	7.00E+06	kJ/tonne
Crushed aggregate	5.00E+04	kJ/tonne
Natural aggregate	2.00E+04	kJ/tonne
Hot mix manufacture	3.00E+05	kJ/tonne
Hot mix laying and compaction	2.00E+04	kJ/tonne
Basecourse laying and compaction	6.58E+04	kJ/tonne
Cartage (return trip) large truck	9.00E+02	kJ/tonne/km
Cartage (return trip) medium truck	1.80E+03	kJ/tonne/km
Brooming, loading, spreading and rolling chip	3.00E+03	kJ/m^2
Gang sprayer	1.65E+05	kJ/tonne
Stabilisation static plant and loader	1.92E+04	kJ/tonne
In situ stabiliser	1.05E+04	kJ/tonne

5.3 Waste

Besides the energy and associated emissions associated with typical construction, the use of waste material also has an energy component in its collection and processing. This should be included in any calculation.

Where the construction method leads to dumping the waste, then the transport of this from the construction to a dump site needs to be included.

5.4 Traffic delay

5.4.1 VOCs

The user costs of roadwork delay can be substantial on higher traffic volume roads. The EEM has procedures to estimate the VOCs. The EEM calculates the total VOCs using equation 5.1.

$$VOC = BRC + R + ST + PED + C + B + SSC \qquad \text{(Equation 5.1)}$$

Where:

- BRC = base running costs by speed and gradient
- R = road roughness costs
- ST = road surface texture costs
- PED = pavement elastic deflection costs
- C = congestion costs
- B = bottleneck costs
- SCC = speed change cycle costs

When roadworks disrupt traffic flow, the speeds of the vehicles change, and thus the VOCs associated with speed are appropriate to consider.

As the objective of this research is to develop a tool to compare different treatments, it is assumed that the roughness of the site during construction is the same for each treatment and that therefore traffic speeds are low. Therefore, roughness costs have not been included.

Road surface texture and elastic deflection costs have not been included, based on the same principles as for roughness.

Congestion VOCs are associated with decreased speed etc through congestion. These can be estimated from the change in speed caused by the roadworks and would be considered by determining the change in base running costs.

Bottleneck delay is associated with vehicles stopped and idling. This cost should be included.

Speed change cycles associated with slowing and accelerating from roadworks should be included. The EEM has procedures to calculate speed change cycles based on relationships for different vehicle classes. It also has typical values for four different road categories. These are:

- urban arterial
- urban other
- rural strategic
- rural other.

It is considered that this classification is accurate enough to compare different treatment methods.

To calculate the total VOC, the traffic volume in (annual average daily traffic (AADT), vehicle speed through the construction site (in km/h), vehicle speed before the construction site (km/h) and stopping time (in minutes) should be estimated for the morning and evening peaks, and for the daytime off-peak.

5.4.2 Travel time

The traffic delay also has a significant cost associated with travel time. This data is also contained in the EEM. The calculation procedure is similar to that for VOCs, with costs for travel time again being based on road categories. The costs are given in table 5.4. Where one method of pavement construction is significantly shorter than another, then these costs can be very significant. They have been included in the methodology.

Table 5.4 Composite values of travel time in $/h (July 2002 values), combining occupant time, vehicle time and freight time (taken from the EEM)

Time	Road			
	Urban		Rural	
	Arterial	Other	Strategic	Other
Morning peak	15.13	16.23	23.25	22.72
Off-peak	17.95	16.23	23.25	22.72
Afternoon peak	14.96	16.23	23.25	22.72

In many cases, the benefits of minimising the ‘waste of time’ will be the major benefit when comparing options.

5.5 Emissions

Energy for transport of materials and construction of the pavement is assumed to be in the form of diesel and this has been converted to an equivalent CO_2 by assuming that 1 litre of diesel is equivalent to 2.7kg of CO_2, as recommended by the EEM.

The conversion of all energy components to their diesel equivalent would be conservative, especially as in New Zealand, over 60% of the electricity generated is derived from hydroelectric power. The energy equivalent of a litre of diesel is taken as being 38,700kJ/L. Therefore, the CO_2 emission factor for diesel is 0.07grams/kJ. Alcorn (2003) estimated the CO_2 emission factor for the generation of electricity in New Zealand based on the following proportions:

- gas = 23.3%
- coal = 3.9%
- geothermal = 6.4%
- hydro = 63.2%

His overall total was 0.016g of CO_2 per kJ, which is approximately four times lower than if the electricity was derived from diesel.

This difference can be significant in operations such as aggregate crushing. Where a fixed plant is at a quarry, the main power used will be electricity, with diesel being used to power trucks and loaders. However, if the crushing is done in a mobile plant which could be used to crush, say, concrete then the power used is more likely to be diesel. In the comparison of different construction techniques, the percentage of the manufacturing that is powered by electricity can have a significant effect on the estimation of the CO_2 emissions and needs to be included in any analysis.

The production of asphalt, where diesel or natural gas is used for heating, the energy has been assumed to be equivalent to diesel.

The GWPI described in chapter 2 was considered to increase the equivalent CO_2 emissions for diesel by approximately 6%. This is considered to be well within the errors associated with the energy estimation and thus this extension was not used. The cost of CO_2 has been assigned as \$40/kg according to the EEM.

Based on the traffic volume and construction time, the total VOCs can be calculated as described in section 5.3. The VOC calculations have the consumption of fuel as part of their basis. The EEM allows these VOCs to be converted to equivalent CO_2 kilograms by using equation 5.2.

$$CO_2\ equivalent = VOC \times 0.0015 \qquad \text{(Equation 5.2)}$$

The emission of carbon monoxide, particles less than 10 microns in size (known as P10), nitrous oxides and volatile organic compounds can also be estimated from the EEM. The calculation is based on the average traffic speed and traffic mix. For the calculation of these emissions, it is recommended that the traffic mix given in the EEM, reproduced in table 5.5, be used.

Table 5.5 Typical traffic mix (in percent) for calculating traffic emissions (other than CO_2)

Traffic mix	Urban		Rural	
	Arterial	Other	Strategic	Other
Car + LCV[a]	95	94	88	90
MCV[b] + HCV[c]	5	6	12	10

Notes to table 5.5:

a light commercial vehicle

b medium commercial vehicle

c heavy commercial vehicle (class 1 and 2)

Although the emission rate in terms of kg can be calculated, the effects on health etc are expressed in terms of concentration per cubic metre of air. The dispersion of the emissions is dependent on site geography and weather conditions.

At this stage, no attempt has been made to assign a value to carbon monoxide, nitrous oxides or volatile organic compounds. For the P10, the EEM recommends using, in urban areas, a value of NZ\$0.01 per kilometre for light vehicles and NZ\$0.2/km for heavy vehicles travelling at 40km/h, based on an estimation of the health effects of the particulates. No recommendation is given for rural areas, as the health effects will be significantly lower than in urban areas. It does not differentiate between moving and stationary vehicles. Therefore, as these emissions caused by disruption to the traffic flow by the roadworks cannot be directly quantified by the EEM, their value has not been included in the methodology.

For construction, the extra traffic can be included. It is recommended that, where the construction is in an urban area, all the transport from the plant to the site is urban running and therefore the cost of NZ$0.2/km can be included. To simplify the calculations, it can be assumed that the truck can carry 10 tonnes and therefore the cost is NZ$.02/tonne/km.

5.6 Resource depletion

The volume of the materials used in construction can be estimated. It is therefore possible to apply a cost to the depletion of the material. Again, care is required because material supply costs will reflect the value of the resource, and as the resource decreases, the costs to the contractor will rise. The value of aggregate is reflected in the costs in various parts of New Zealand. In Auckland, where aggregate resources are depleting, and in Hawke’s Bay, where premium aggregate is scarce, the cost of the material is much greater than in parts of the South Island, where good aggregate is more plentiful.

The quantities of materials have been reported but a resource cost not included. In Britain, a tax has been imposed equivalent to £1.60/tonne (approximately NZ$4.00/tonne). This fund has raised approximately £300 million per year in Britain (Department for the Environment, Food and Rural Affairs 2009).

The option of including a value for resource depletion associated with aggregate and bitumen should be included in any comparison methodology.

6. Using the matrix

6.1 The spreadsheet

A spreadsheet matrix was developed to perform the calculations. The data input and calculations follow the general flow diagram given in figure 4.1. It also makes provisions for the input of data associated with the traffic using the site, and calculates the delay costs and emissions.

The spreadsheet is relatively self-explanatory but does presume that the user has knowledge of road construction. As the number of combinations of construction techniques is vast, not all can be included. Users will need to determine an appropriate energy and emissions framework for some of the techniques that they wish to explore. For example, the energy and emissions associated with foam bitumen stabilisation are not specifically included.

The user also needs to make assessments of the operations involved in the construction and also needs to estimate the delays associated with roadworks under different traffic conditions.

The basis of the calculation is in square metres.

The energy spreadsheet has five main input areas:

- **Materials and plant manufacture:** This requires layer thickness for a range of materials to be put into the spreadsheet. The spreadsheet converts this to a mass based on a density that the user can modify. This is then converted to MJ of energy based on the energy values discussed in chapter 5. The total energy, based on materials and processing for a user-defined combination of materials, is then calculated.
- **Transport to site:** The energy required in transportation is then calculated based on a user-defined distance. The assumption is that the energy in transport is calculated on a loaded vehicle in one direction and an unloaded return; the user inputs the distance only to the site in kilometres.
- **Construction:** Construction energy is calculated based on the energy values in table 5.3. The user can vary these values and derive appropriate values for construction techniques that are not given. Values for energy from the WRAP project are given in appendix A.
- **Transport to waste: T**he distance to waste is inputted and the energy calculated. Again, the energy calculation is based on a loaded/unloaded cycle. The user inputs the one-way distance only.
- **Intangibles:** The input required to calculate the intangibles are summarised in sections 5.3 to 5.6. The user needs to have an estimate of the traffic volumes and the expected delay.

An example of the spreadsheet is shown in appendix B.

6.2 Example 1: recycled asphalt pavement

The first example is the reuse of asphalt that is milled from the surface. This is commonly referred to recycled asphalt pavement (RAP).

A local city council uses approximately 13,000 tonnes per year of new asphalt and mills off approximately 1200 tonnes per year. The RAP currently can be used as a driveway material (especially for farmers), and thus is reused and not dumped. The material does contain bitumen at a similar quantity as new hot mix. The Transit New Zealand Specification M/10 (Transit New Zealand 2005) for hot mix asphalt allows the use of up to 15% RAP with no special requirements regarding design.

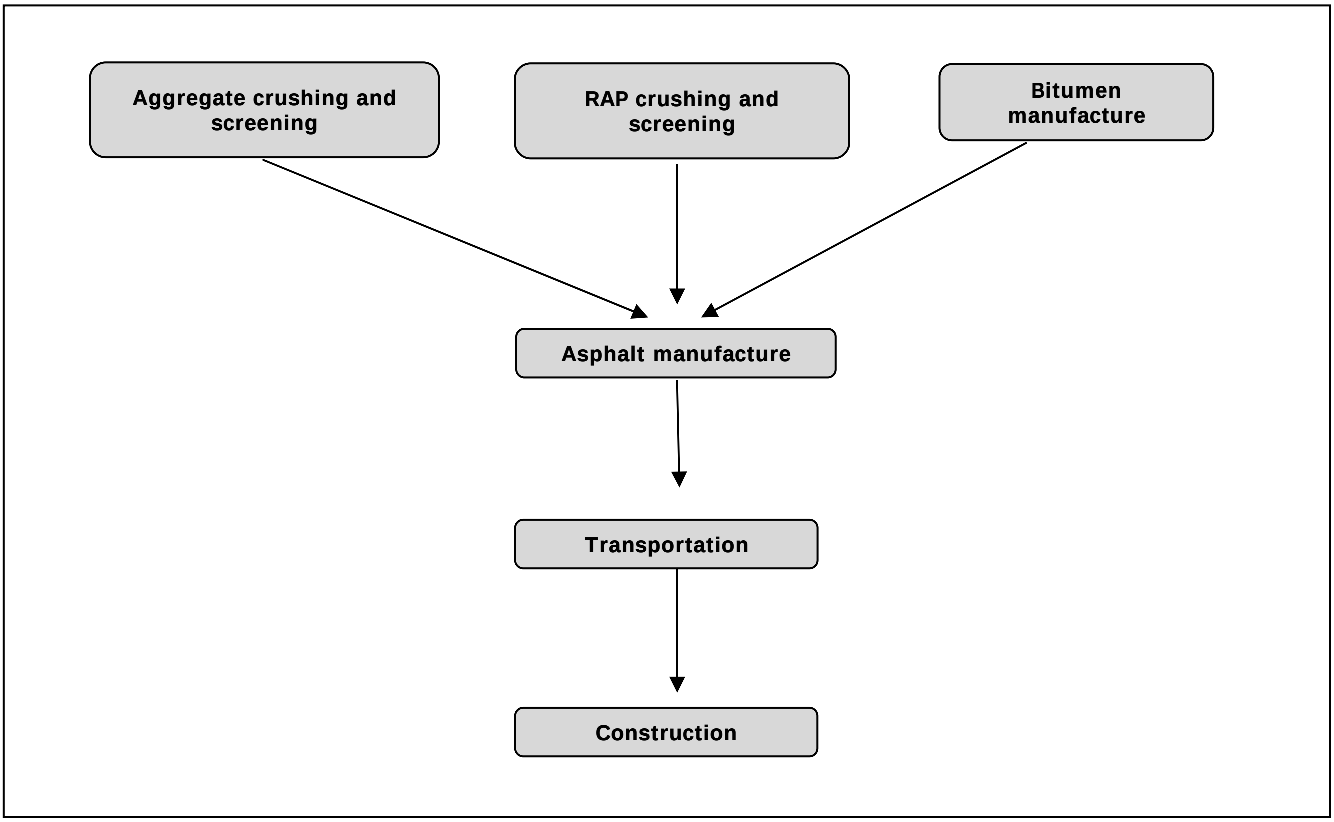
The main benefits associated with using RAP in the new asphalt rather than ‘cold’ in driveways would appear to be the reduced use of bitumen and premium aggregate. The 1200 tonnes of RAP at 15% addition will be able to be added to 8000 tonnes of hot mix. It is obvious that if more RAP was generated, it could easily be used. Including 15% RAP in 13,000 tonnes of hot mix means that the hot mix could use nearly 2000 tonnes of RAP per year in this local authority’s hot mix construction.

When comparing the benefits, it is assumed that the milling of the asphalt was necessary and that it was available at the asphalt plant. The RAP would need to be processed (screened and crushed) and this has been assumed to be equivalent in energy use to processing natural aggregate. Stockpiling and handling are assumed to be equivalent to normal aggregate, so no allowance for any difference has been made. The aggregate production was also presumed to be at the quarry, which is quite common in New Zealand. The energy to process the aggregate was presumed to be 80% electricity.

The transportation and construction inputs will be the same with and without RAP, as will the time required to construct the pavement; therefore, these inputs have not been calculated in this example.

A flow diagram of this process is given in figure 6.1. The traditional method would not include the RAP crushing and screening. The incorporation of RAP would result in less raw bitumen and aggregate being used.

Figure 6.1 Flow diagram showing the process of including RAP in hot mix construction



For the present situation, where the RAP is used at 15% concentration for 8000 tonnes of hot mix, the results of the calculations are illustrated in tables 6.1 to 6.4 and figures 6.2 to 6.5.

The results indicate that this local authority could easily recycle the RAP generated in the roading programme. The savings in bitumen would be in the order of 81 tonnes/year, which, at a current cost of approximately $1000/tonne, is $81,000. The contractor will, however, wish to cover the cost of processing and handling the material, and the savings to the council therefore will not be so great.

Table 6.1 CO_2 emissions (tonnes) for hot mix construction with and without RAP

Manufacturing method	Emissions
No RAP	277
15% RAP	238
Difference	39
Difference %	14.1

Table 6.2 Energy use in terms of litres of diesel for hot mix construction with and without RAP

Manufacturing method	Energy use
No RAP	88,200
15% RAP	75,700
Difference	12,500
Difference %	14.2

Table 6.3 Intangible costs (in $NZ) for hot mix construction with and without RAP

Manufacturing method	Intangible costs
No RAP	$11,098
15% RAP	$9,518
Difference	$1580
Difference %	14.2

Table 6.4 Raw materials used (in tonnes) for hot mix construction with and without RAP

Manufacturing method	New aggregate	Bitumen
No RAP	7476	524
15% RAP	6270	443
Difference	1206	81
Difference %	16.1	15.5

Figure 6.2 CO_2 emissions for hot mix construction with and without RAP

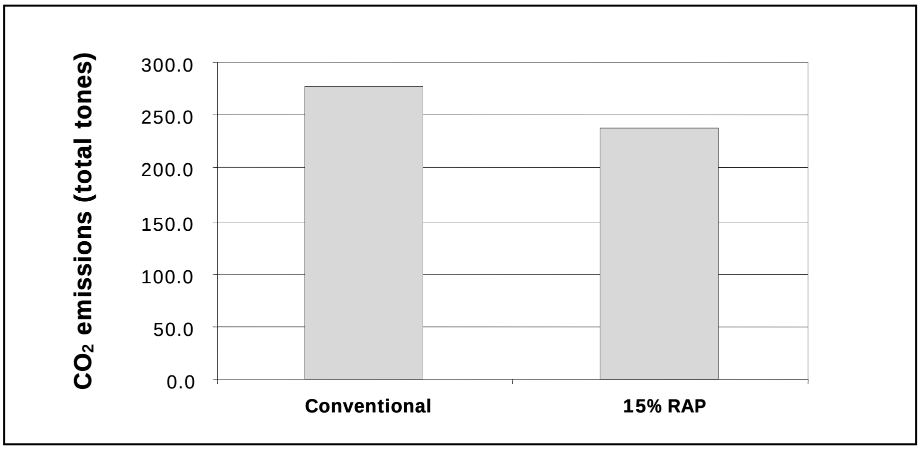


Figure 6.3 Energy use (in litres of diesel equivalent) for hot mix construction with and without RAP

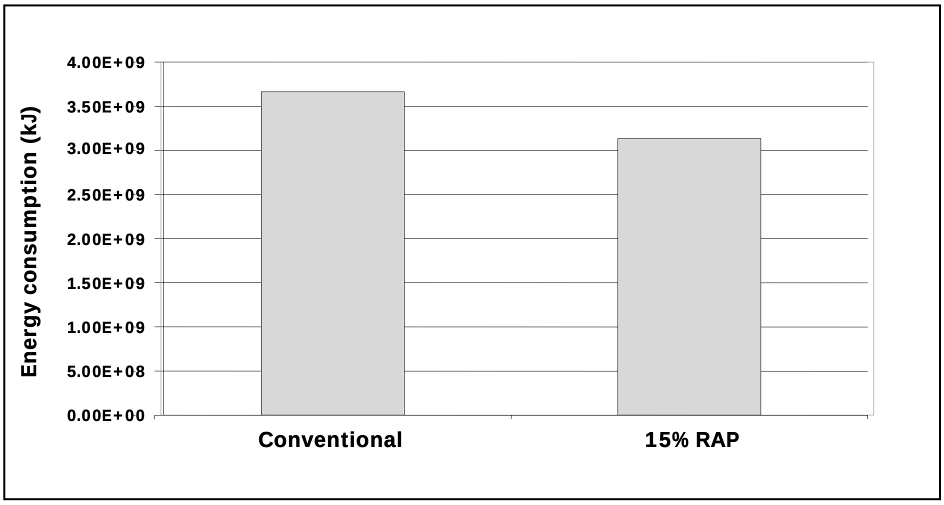


Figure 6.4 CO_2 emissions costs ($) for hot mix construction with and without RAP

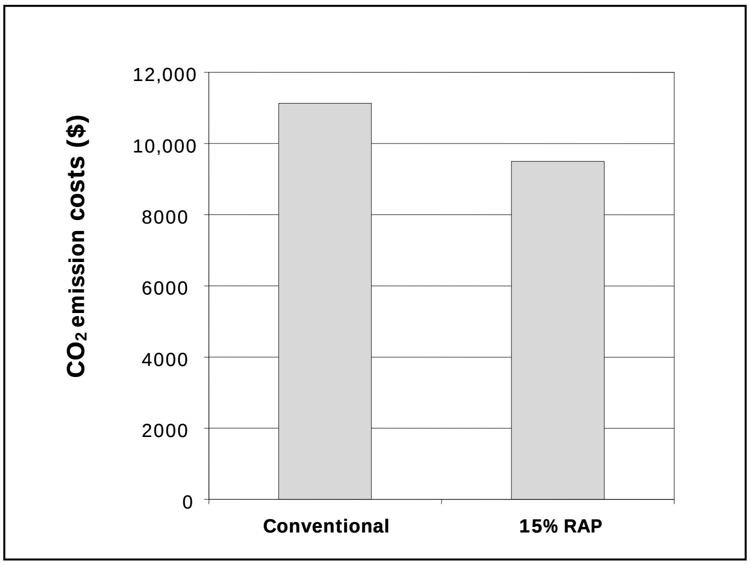
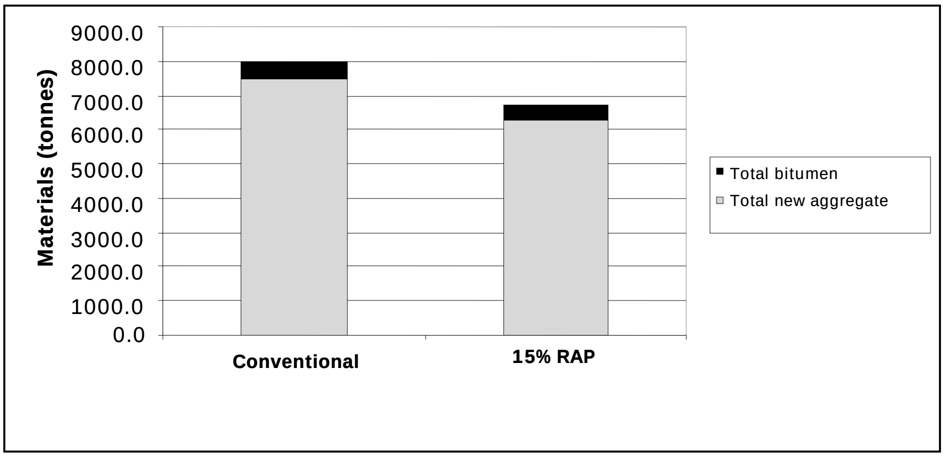


Figure 6.5 Raw materials used (tonnes) in hot mix construction with and without RAP



6.3 Example 2: glass

In the first example, the RAP is a by-product from the road construction. The material has to be milled off so that the total height of the road does not result in excess camber etc. If the RAP was not taken to be recycled, it would be reused or dumped. However, for recycling glass into basecourse, the local authority needs to take the energy in collection, etc, into account. They have the choice either to collect the waste glass or to allow it to go directly to the landfill. The flow diagram for this process was given in figure 4.3.

In 2002, a waste survey was undertaken in the Wellington region (MfE 2007). The quantities of glass collected are shown in table 6.5.

Table 6.5 Estimate of tonnes of glass landfilled or recovered in the Wellington region in 2002

City	Landfilled	Recovered
Wellington	5921	3300
Hutt Valley	2274	2270
Porirua	1246	1058
TOTAL	**9441**	**6628**

If the glass recovered was used in basecourse at a 5% concentration, as currently permitted in the M/4 specification for basecourse (Transit New Zealand 2006), 6628/.05 =132,500 tonnes of basecourse would need to be used in the area.

An industry estimate of the quantity of basecourse used in the area is 120,000 tonnes/year. Therefore the waste glass could nearly all be used in basecourse within the region.

The local authorities that collect the glass, however, are not large users of basecourse. NZTA network statistics show that the Wellington local authorities completed 2.8km of area-wide treatment and no pavement reconstruction. Based on a pavement width of 8m and a basecourse thickness of 150mm, the total quantity of basecourse being used is approximately 7500 tonnes per year.

Therefore, in the assessment of costs, the local authority has to consider that only about 7% of the benefits accrue to them and the rest to other users of basecourse, eg subdivision development.

The alternative is to use the glass as clean landfill. At present, Wellington City Council will charge $4/tonne (when required) for sending glass to the landfill compared to over $90/tonne for other rubbish.

The energy required in collecting is difficult to estimate. It could be argued that collection would occur whether the glass is to be recycled or put in the landfill. Based on this argument, the transport distance from the collection centre to the quarry has been included, not the energy involved in the collection itself. A distance of 25km has been assumed.

Tables 6.6 to 6.8 and figures 6.6 to 6.9 give the results of the analysis.

Table 6.6 CO_2 emissions (in tonnes) for basecourse constructed with and without recovered glass

	Manufacture	Transport	Grand total
New aggregate	709		709
5% glass	728	17	745
Difference			36
Difference (%)			5.1

Table 6.7 Energy use (in MJ) for basecourse constructed with and without recovered glass

	Manufacture	Transport	Grand total
New aggregate	6.0×10^6	?	6.0×10^6
5% glass	6.03×10^6	2.37×10^5	6.27×10^6
Difference			0.27×10^6
Difference (%)			4.5

Table 6.8 CO_2 costs (NZ$) for basecourse constructed with and without recovered glass

	Manufacture emissions	Transport emissions	Total
New aggregate	$28,352	?	$28,352
5% glass	$29,117	$663	$29,780
Difference	-$765	-$663	-$1438
Difference (%)			-5.1

Figure 6.6 CO_2 emissions for basecourse construction with and without recovered glass

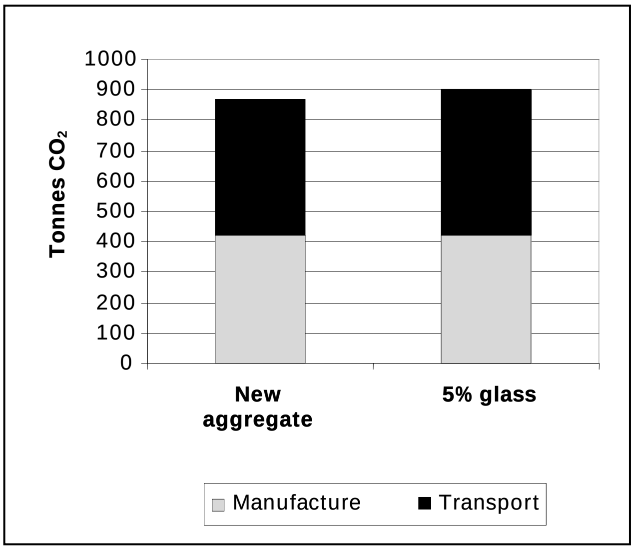


Figure 6.7 Energy consumption (in litres of diesel equivalent) for basecourse construction with and without recovered glass

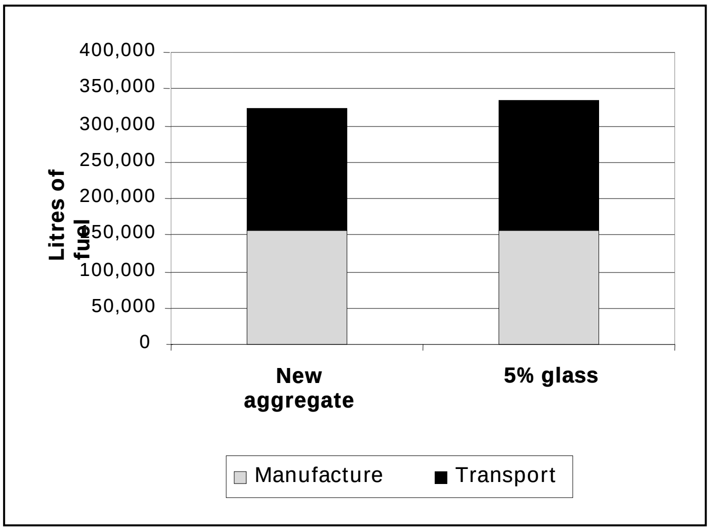


Figure 6.8 Intangible costs for basecourse constructed with and without recovered glass

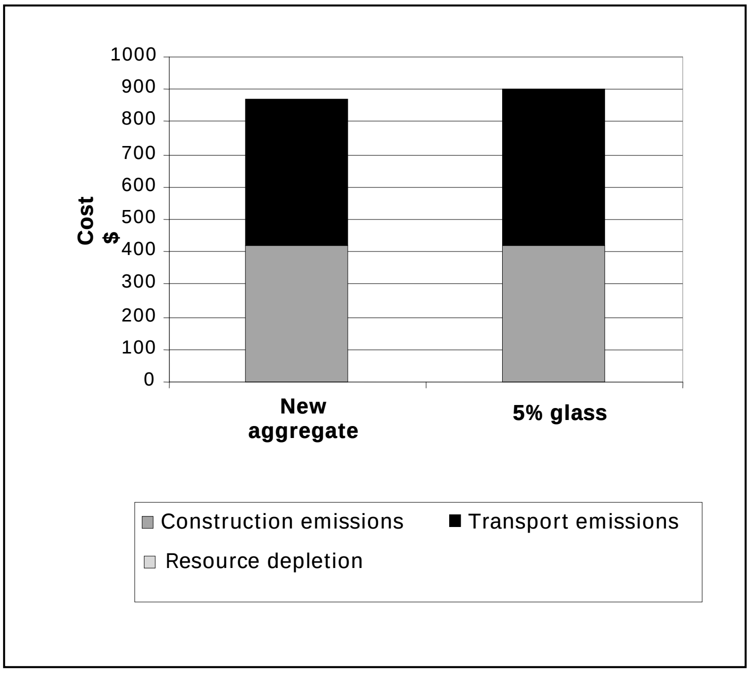
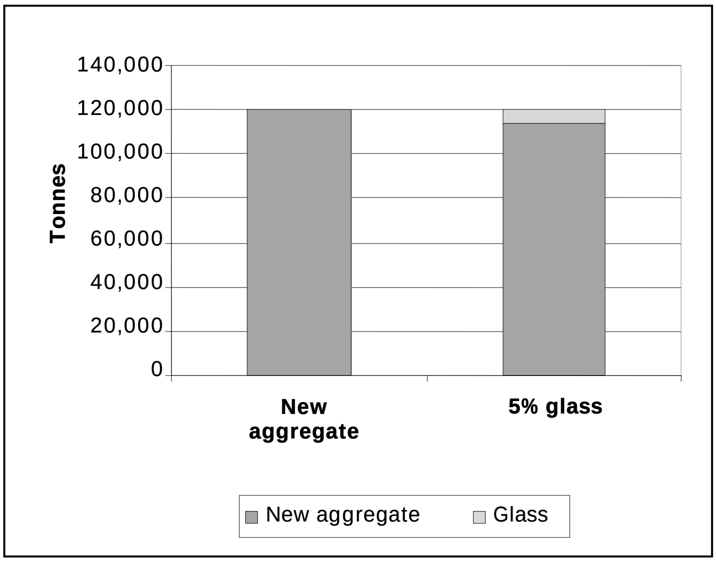


Figure 6.9 Raw materials used for basecourse with and without recovered glass



From this analysis, it can be seen that the use of recycled glass in Wellington basecourse would increase the CO_2 emissions by 36 tonnes or 5.1%. In terms of the cost of CO_2 at $40/tonne, this is only equivalent to $1400.

To justify the extra intangible cost, a value of $0.01/tonne of aggregate for resource depletion would be required. The cost of buying the basecourse will be higher than buying new aggregate, as the transport and mixing costs need to be considered even if the crushing costs are the same. Therefore, the value that society places on the aggregate resource is critical to the decision on the use of recycled glass. Even if the British aggregate tax (see section 5.5) of approx $4/tonne was imposed, it is doubtful if this would cover the producers' extra costs of crushing and blending the glass.

In contrast to the first example, where the high cost of bitumen should make the use of RAP economic, the aggregate producer has no incentive to incorporate glass into the basecourse even if raw glass is given free of charge.

6.4 Example 3: in situ stabilisation

The use of in situ stabilisation has the potential not just to minimise the use of raw materials but also to reduce construction time. In situ stabilisation consists of breaking up the existing pavement and then mixing in a small quantity of cement, lime or bitumen to correct deficiencies in the 'old' aggregate, and then relaying the pavement. If significant strengthening is required then some new aggregate can be added. The 'traditional' option would be to remove the old pavement materials and rebuild the pavement with new aggregate, or to overlay the existing pavement with new aggregate. This form of construction is generally has a reduced construction time, which results in significant reduction in traffic VOCs and emissions.

Many combinations of stabilisation are possible. In this example, the relatively extreme case of removing the existing pavement to a dump site has been assumed. The assumed inputs for a rural highway are given in tables 6.9 and 6.10.

Table 6.9 Site characteristics of a typical rural highway

Characteristic	Details	
Length	500m	
Width	10m	
AADT	15,000	
Morning peak vehicles Off-peak vehicles Evening peak vehicles	3000 9000 3000	
Electricity % in processing aggregate	80%	
Aggregate crushed or screened	All crushed	
Transport distance plant to site	20km	
Distance to dump	30km	
	Conventional	Stabilised
Construction time	15 days	10 days
Basecourse thickness	150mm	150mm
Sub-base	300mm	–
Stabilised in situ	–	250mm
Additive	–	1.5% cement
Excavated to waste	450mm	150mm
Surface	Chipseal	Chipseal

Table 6.10 Distribution of traffic and the speed through the roadworks on a rural highway

	Morning peak	Daytime off-peak	Afternoon peak
Traffic volume (AADT) =	3000	9000	3000
Speed during construction (km/h)	30	30	30
Speed before construction (km/h)	100	100	100
Stopping time (min)	0.5	0.2	0.5

The results are given in tables 6.11 to 6.14 and illustrated in figures 6.10 to 6.13. It can be seen that the intangible costs associated with travel time delays swamp all other costs. Furthermore, the reduction in manufacturing emissions of approximately 20 tonnes has the largest effect on emissions.

Table 6.11 CO_2 emissions (tonnes) for traditional and stabilised pavements

	Manufacture	Transport	Construction	Waste	Intangibles	Grand total
Traditional	31.4	6	24	16	1.1	**125**
In situ stabilised	11.7	2	9	5	0.9	**45**
Difference	19.7	4	15	11	0	**80**
Difference (%)	63	66	64	67	20	**61**

Table 6.12 Energy use (MJ) for traditional and stabilised pavements

	Manufacture	Transport	Construction	Waste	Grand total
Traditional	2.98E+05	9.07E+04	3.45E+05	2.30E+05	7.33E+05
In situ stabilised	1.31E+05	3.08E+04	1.26E+05	7.66E+04	2.88E+05
Difference	1.67E+05	5.99E+04	2.19E+05	1.53E+05	4.46E+05
Difference (%)	56	66	64	67	61

Table 6.13 Intangible costs (NZ$) for traditional and stabilised pavements

	Manufacture	Transport	Construction	Transport to waste	Vehicle CO_2 emissions	Travel delay + VOC	Total
Traditional	3113	253	963	641	46	116,376	**121,392**
In situ stabilised	1120	86	351	214	37	75,931	**77,739**
Difference	1993	167	611	427	9	40,445	**43,653**
Difference ($)	64	66	64	67	20	35	**36**

Table 6.14 Raw materials used (tonnes) for traditional and stabilised pavements

	New aggregate	Waste	Bitumen	Cement	Total
Traditional	5040	4995	7.7	0.0	**10,042.5**
In situ stabilised	1453	1665	7.7	41.6	**3167.6**
Difference	3586	3330	0	-42	**6875**
Difference ()%	71	67	0		**68**

Figure 6.10 CO_2 emissions for traditional and stabilised pavements

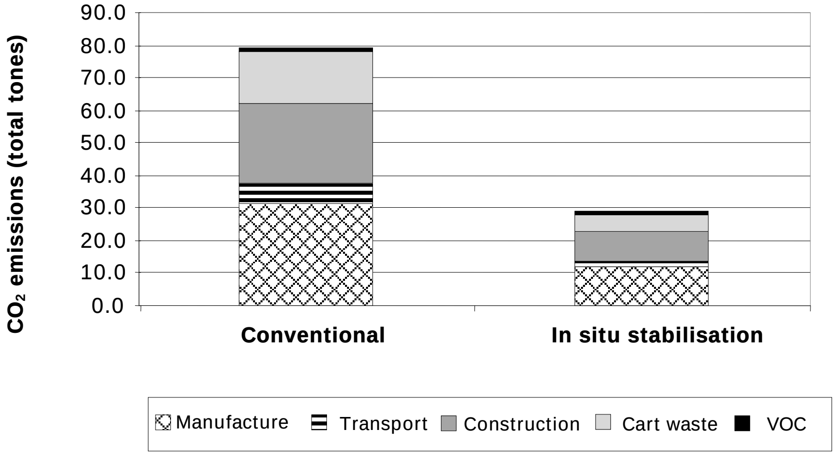


Figure 6.11 Energy consumption for traditional and stabilised pavements

Figure 6.12 Intangible costs for traditional and stabilised pavements

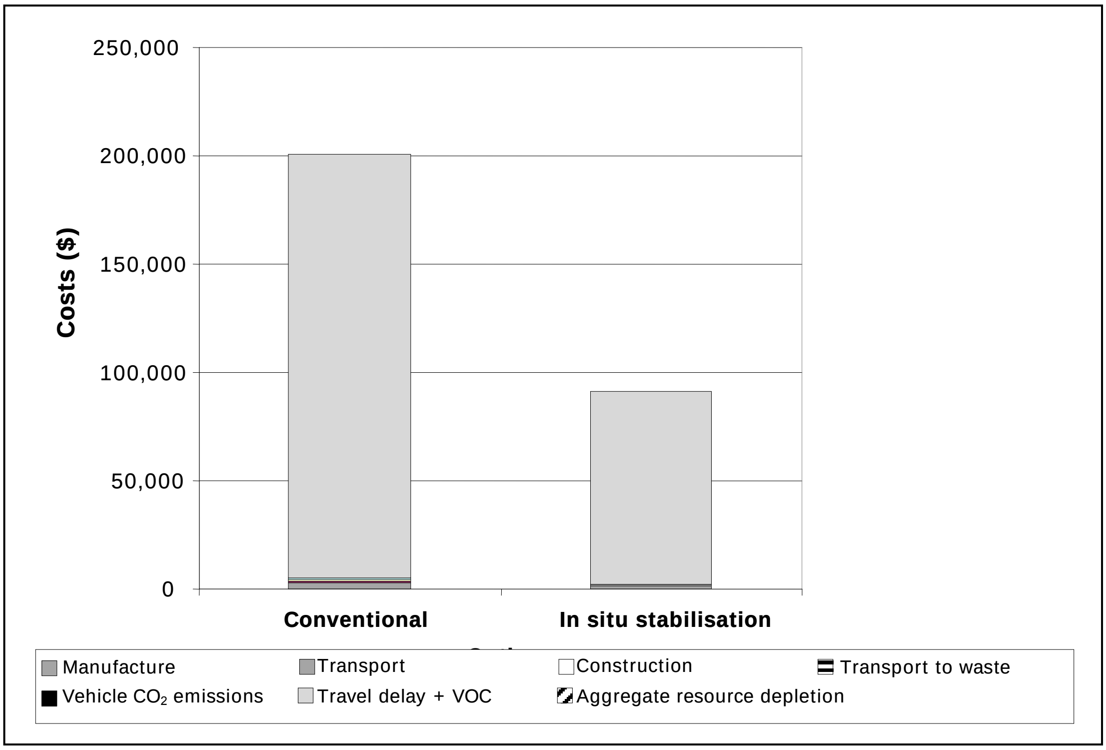
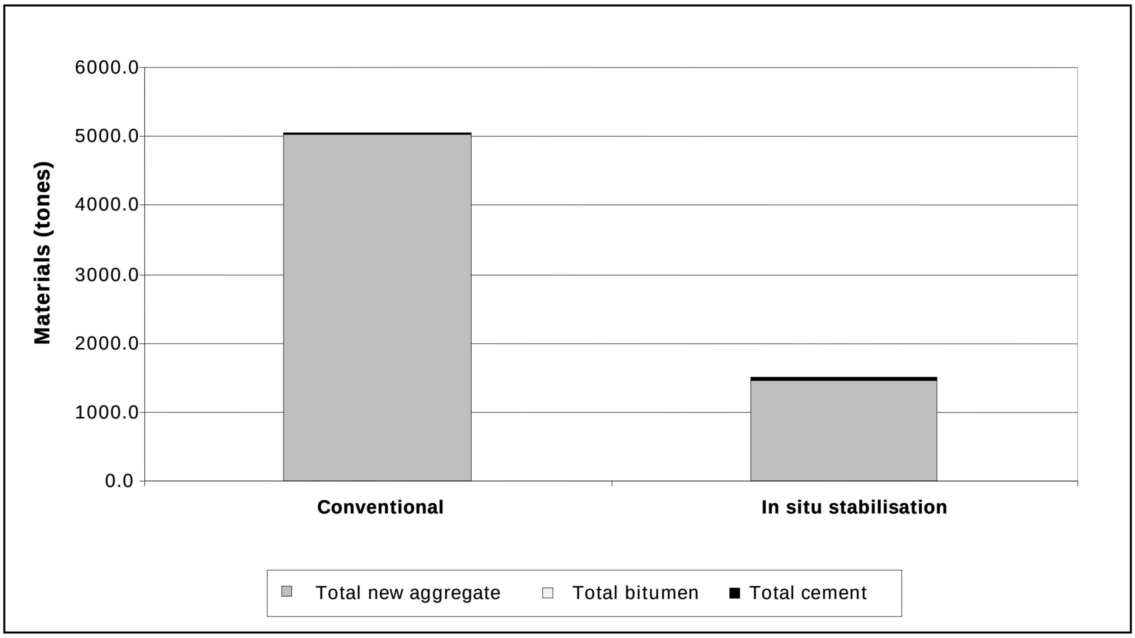


Figure 6.13 New materials used for traditional and stabilised pavements



7. Conclusion

A methodology has been developed to quantify the benefits of waste minimisation in road construction. The methodology uses the costs detailed in the EEM but allows users to input costs for other benefits, eg resource depletion.

The methodology makes estimates of the following:

- energy and emissions associated with
  - material manufacture
  - transport to site
  - construction
  - transport to waste
- quantities of raw and recycled materials used
- vehicle operating costs associated with traffic delays
- energy associated with traffic delay
- emissions associated with traffic delay
- traffic delay costs.

The methodology uses estimates of the energy used in all the operations. To convert this to emissions such as CO_2, the energy has been assumed to be consumed as diesel or electricity. In New Zealand, a significant proportion of electricity is generated in hydroelectric power stations and thus the emission levels for fixed plant such as that used for aggregate crushing is significantly lower than if the electricity generation was diesel powered. The methodology is flexible and allows the comparison of non-standard techniques, although users need to have knowledge of construction methods and equipment requirements.

Three examples are given and it is demonstrated that the major area where waste could be minimised is associated with using construction methods that minimise traffic delays. The travel delay costs (waste of time and fuel) tend to be an order of magnitude larger than the costs associated with other aspects of construction. The examples illustrate the environmental gains that can be made in terms of CO_2 emissions and resource depletion through using recycling techniques.

The methodology as described does not take life cycle costs directly into account. These are routinely calculated by roading engineers in comparing treatments by following the methods in the EEM. The benefits developed in the methodology given in this report can be directly inputted into calculating present worth value where the lives of the treatments are different.

It is considered that the methodology is a useful tool to enable RCAs to decide on the merits of using a waste minimising technique, and to compare the benefits with the costs associated with implementing the policy.

8. References

Alcorn, A (2003) *Embodied energy and CO_2 coefficients for NZ building materials.* Wellington: Centre for Building Performance Research, Victoria University.

Auckland City Council (2005) No threat to Auckland city's glass collections*. Media release 26 April 2005.*

Bailey, R, V Dravitzki and J Patrick (2001) Recycling of materials for more sustainable construction. *Transfund New Zealand research report 219.* Wellington: Transfund New Zealand.

Canadian Construction Authority (2005) *Road rehabilitation energy reduction guide for Canadian road builders.* Ottawa, Canada: Canadian Construction Authority.

Centre for Sustainability (2006) *The promotion of the benefits of recycled and secondary aggregates (RSA) use in the reduction of CO_2 emissions*. Banbury, Oxford, England: Waste and Resource Action Programme, Centre for Sustainability.

Department for the Environment, Food and Rural Affairs (2009) Aggregate levy and sustainability fund in England. Accessed 4 January 2010. *http://www.defra.gov.uk/environment/quality/land/aggregates/index.htm*

Department for Sustainability and Environment (2005) Our environment our future. Accessed 10 March 2010. *http://www.dse.vic.gov.au/CA256F310024B628/0/57E3ADC456387BFCCA256FE800239E30/$File/Enviro-Sustainability-Framework-Final.pdf*

Dravitzki, V, P Cenek, I Kvatch and N Locke (2004) Review of heavy vehicles limits study: assessment of environmental impacts. *Opus International Consultants Central Laboratories Report 5-27690.*

Ferry A (1998) Unsealed roads are sustainable*. IPENZ Transactions No1/Gen*: pp 54–64.

Gupta, JD (1998) Cost effective analysis of recycled products for use in highway construction. *Federal Highways Association report OH-98/018*. Washington, DC: Federal Highways Association.

Halstead, W (1981) Energy involved in construction materials and procedures*. National Cooperative Highway Research Program Synthesis of Highway Practice 85.* Washington, DC: Transportation Research Board USA.

Hawthorne, R (1975) Energy requirements for road pavements*. New Zealand Road Research Unit Newsletter No. 55*: pp 16–18.

Herrington, P, I Kvatch and K O'Halloran (2006) Assessing the environmental effects of new and recycled materials in road construction. *Land Transport New Zealand research report 306.* Wellington: Land Transport New Zealand. 70pp.

Hyman, W and B Johnson (2000) Assessing public benefits of reusing waste materials in highway projects. Transportation Research Record 1702: 97–107.

Kett I, A Browne and G Quickfall (2005) Quantifying the intangible benefits of stabilisation. *New Zealand Institute of Highway Technology Conference*, Christchurch 6–8 November 2005.

Meil, J (2006) A life cycle perspective on concrete and asphalt roadways: embodied primary energy and global warming potential. Accessed 4 January 2010. *http://www.mrmca.com/paving/athena.pdf* Athena institute Canada

Ministry for the Environment (MfE) (2003) *The New Zealand waste strategy.* Wellington, New Zealand: Ministry for the Environment.

Ministry for the Environment (2007) Regional waste recovery 2: Total waste stream and quantities of plastic and glass. Accessed 17 June 2010. *http://www.mfe.govt.nz/publications/waste/devt-regional-waste-recovery-sector/html/page4.html*

New South Wales Government (1998) Waste minimisation and management a 1995 No 102. Accessed 10 March 2010. *http://www.legislation.nsw.gov.au/sessionalview/sessional/act/1995-102.pdf*

NZTA (2010) Economic evaluation manual 2007 – volume 1. Accessed 4 January 2010. *http://www.nzta.govt.nz/resources/economic-evaluation-manual/volume-1/index.html*

onSITE (1997) Victorian case study 2: Calder interchange construction. Accessed 4 January 2010. *http://onsite.rmit.edu.au/CASE/case002V.htm*

Patrick, J, S Reilly and G Cook (2006) Trials of recycled asphalt and rubber materials for New Zealand roads. *Land Transport New Zealand research report 309*.

Peploe, R (2006) Application of asphalt millings on New Zealand roads. *Land Transport New Zealand research report 298.* Wellington: Land Transport New Zealand.

Peploe, R and A Dawson (2006) Environmental impact of industrial by-products in road construction – a literature review. *Land Transport New Zealand research report 308*. Wellington: Land Transport New Zealand. 38pp.

Reid, J and J Chandler (2001) *Recycling in transport infrastructure*. Berkshire, England: Transport Research Laboratory.

Slaughter, G (2004) Environmental comparison of cutback bitumen and bitumen emulsions for sealing roads. *Towards Sustainable Transport Conference.* Christchurch, New Zealand.

Smith W, and G Vorobieff (2007) Recognition of sustainability by using stabilisation in road rehabilitation. In *Proceedings of the Australasian (Iron and Steel) Slag Association Sustainability and Slag Conference*, Sydney, May 2007.

Transit New Zealand (2005) *TNZ M/10 specification for asphaltic concrete.* Wellington: Transit New Zealand.

Transit New Zealand (2006) *TNZ M/4 specification for basecourse aggregate.* Wellington: Transit New Zealand.

Vuong, BT and, G Arnold (2006) Predicting in-service performance of alternative materials for New Zealand conditions. *Land Transport New Zealand research report 304.* Wellington: New Zealand.

Wright, J (2006) *U.S. Department of Transportation Federal Highway Administration memorandum on the use of recycled materials date: February 7, 2002*. Washington, DC: Federal Highways Administration.

Wilmot, T and G Vorobieff (1997) Is road recycling a good community policy? *Ninth National Local Government Engineering Conference*. Melbourne, Australia.

Zapata, P and JA Gambatese (2005) *Energy consumption of asphalt and reinforced concrete pavement materials and construction.* Journal of Infrastructure Systems 11(1) March 2005: 9–20.

Appendix A Energy values calculated by the WRAP project

Table A1 Data use for calculating energy use associated with hydraulic bound material pavements (taken from Centre for Sustainability (2006))

Base data variables	Value	Unit
Conversion factors		
CO_2 emissions per MJ of electric power	119.00	g/MJ
CO_2 emissions per MJ of diesel in engines, excluding precombustion	69.00	g/MJ
CO_2 emissions per MJ of diesel in engines, including precombustion	73.00	g/MJ
Calorific power of diesel	35.10	MJ/L
Embodied energy/CO_2 emissions of raw materials, cradle to factory gate		
Energy use (diesel) for vehicles in the production of crushed aggregates	16.99	MJ/tonne crushed aggregates
Electric power consumption in the production of crushed aggregates	21.19	MJ/tonne crushed aggregates
Energy use for vehicle operation in sand and natural gravel extraction	16.00	MJ/tonne gravel
Electric power consumption for the extraction of sand and natural gravel	11.00	MJ/tonne gravel
Embodied energy, cement	4770.00	MJ/tonne
CO_2 emissions, cement	801.00	kg CO_2/tonne
Embodied energy, conditioned PFA[a]	11.62	MJ/tonne
CO_2 emissions, conditioned PFA	0.89	kg CO_2/tonne
Embodied energy, dry PFA	11.62	MJ/tonne
CO_2 emissions, dry PFA	0.89	kg CO_2/tonne
Embodied energy, HRB[b]	1876.51	MJ/tonne
CO_2 emissions, HRB	315.11	kg CO_2/tonne
Embodied energy, GBS[c]	0.00	MJ/tonne
CO_2 emissions, GBS	100.00	kg CO_2/tonne
Embodied energy, GGBS[d]	0.00	MJ/tonne
CO_2 emissions, GGBS	100.00	kg CO_2/tonne
Embodied energy, lime	2836.80	MJ/tonne
CO_2 emissions, lime	800.00	kg CO_2/tonne
Transport by road		
Energy use, distribution truck, driving in non-city area (14-tonne load), max load/empty return trip	11.93	MJ/vkm[e]
Energy use, long distance transport, (32-tonne load), max load/empty return trip	13.34	MJ/vkm

Table A1 (cont.) Data use for calculating energy use associated with hydraulic bound material pavements (taken from Centre for Sustainability (2006))

Base data variables	Value	Unit
Other transport modes		
Coast ship energy use	0.13	MJ/ tonne-km
Train (electrical) energy use	0.09	MJ/tonne-km
Train (diesel) energy use	0.26	MJ/tonne-km
Mix in plant		
Cold mixing plant[f]	5.62	
Mix in place (does not require laying of material)		
Approximate with cold recycler Wirtgen W2200	12.29	MJ/tonne HBM
Cold recycling with cement		
Cold in situ recycling (whole cycle: milling, taking up, mixing with binder, laying, but needing full compacting) (Wirtgen 4200)	5.84	MJ/tonne HBM[g]
HBM mixtures laying and compacting		
Compaction of HBM (taken as being similar to compaction of ground) per 150mm thick layer, energy use (diesel)	0.69	MJ/m^2 of compacted surface
Laying by paver, energy use (diesel)	2.03	MJ/tonne

Notes to table A1:

a PFA = pulverised fuel ash

b HRB = hydraulic road binder

c GBS = granulated blast furnace slag

d GGBS = ground granulated blast furnace slag

e vkm = vehicle-kilometres

f Taken as being similar to asphalt plant: Wirtgen KMA200, 200 tonne/hour capacity

g HBM = hydraulic bound material

Table A2 Data for calculation energy use associated with unbound pavements (taken from Centre for Sustainability (2006))

Base data variables	Value	Unit
Conversion factors		
CO_2 emissions per MJ of electric power	119.00	g/MJ
CO_2 emissions per MJ of diesel in engines, excluding precombustion	69.00	g/MJ
CO_2 emissions per MJ of diesel in engines, including precombustion	73.00	g/MJ
Embodied energy of raw materials, cradle to factory gate		
Energy use (diesel) for vehicles in the production of crushed aggregates	16.99	MJ/tonne crushed aggregates
Electric power consumption in the production of crushed aggregates	21.19	MJ/tonne crushed aggregates
Energy use for vehicle operation in sand and natural gravel extraction	16.00	MJ/tonne gravel
Electric power consumption for the extraction of sand and natural gravel	11.00	MJ/tonne gravel
Transport by road		
Energy use, long distance transport, (32-tonne load), max load/empty return trip	13.34	MJ/vkm
Other transport modes		
Coast ship, energy use	0.13	MJ/tonne-km
Train (electrical) energy use	0.09	MJ/tonne-km
Train (diesel) energy use	0.26	MJ/tonne-km
Unbound mixtures laying and compacting		
Compaction of material (taken as being similar to compaction of ground) per thick layer, energy use, oil	0.69	MJ/m^2 of compacted surface
Laying by paver, energy use (diesel)	2.23	MJ/tonne

Table A3 Data for calculation energy used associated with bitumen bound pavement (taken from Centre for Sustainability (2006))

Base data variables	**Value**	**Unit**
Conversion factors		
CO_2 emissions per MJ of electric power	119.00	g/MJ
CO_2 emissions per MJ of diesel in engines, excluding precombustion	69.00	g/MJ
CO_2 emissions per MJ of diesel in engines, including precombustion	73.00	g/MJ
CO_2 emissions per MJ of liquid petroleum gas	59.40	g/MJ
Calorific power of diesel	35.10	MJ/l
Embodied energy of raw materials, cradle to factory gate		
Embodied energy, bitumen (electricity)	173.00	MJ/tonne
Embodied energy, emulsion	58.70	MJ/tonne
Embodied energy, cement	4770.00	MJ/tonne
Energy use (diesel) for vehicles in the production of crushed aggregates	16.99	MJ/tonne crushed aggregates
Electric power consumption in the production of crushed aggregates	21.19	MJ/tonne crushed aggregates
Energy use for vehicle operation in sand and natural gravel extraction	16.00	MJ/tonne gravel
Electric power consumption for the extraction of sand and natural gravel	11.00	MJ/tonne gravel
Transport by road		
Energy use, distribution truck, driving in non-city area (14-tonne load), max load/empty return trip	11.93	MJ/vkm
Energy use, long distance transport, (32-tonne load), max load/empty return trip	13.34	MJ/vkm
Other transport modes		
Coast ship, energy use	0.13	MJ/tonne-km
Train (electrical), energy use	0.09	MJ/tonne-km
Train (diesel), energy use	0.26	MJ/tonne-km
Various machinery		
Wheel loader, energy use for loading, L/t loaded asphalt	0.40	L/tonne hot asphalt
Hot mixing		
Hot mixed asphalt: electric power consumption at asphalt plant per tonne of asphalt	32.00	MJ/tonne asphalt
Hot mixed asphalt: energy use, fuel oil for heating at plant per tonne of asphalt	340.00	MJ/tonne asphalt

Table A3 (cont.) **Data for calculation energy used associated with bitumen bound pavement (taken from Centre for Sustainability (2006))**

Base data variables	Value	Unit
Cold mixing, 100% virgin aggregates		
Cold mixed asphalt, 100% virgin: electric power consumption for emulsion plant per tonne of asphalt	1.27	MJ/tonne asphalt
Cold mixed asphalt, 100% virgin: energy use (fuel oil) for heating at emulsion plant per tonne of asphalt	5.81	MJ/tonne asphalt
Cold mixed asphalt, 100% virgin: diesel consumption for electric power generation at mobile cold asphalt plant per tonne of asphalt	21.10	MJ/tonne asphalt
Cold mixing, 100% RAP		
Cold mixed asphalt, 100% RAP: electric power consumption for emulsion plant per tonne asphalt	0.59	MJ/tonne asphalt
Cold mixed asphalt, 100% RAP: energy use (fuel oil) for heating at emulsion plant per tonne asphalt	2.68	MJ/tonne asphalt
Cold mixed asphalt, 100% RAP: diesel consumption for electric power generation at mobile cold asphalt plant per tonne of asphalt	21.10	MJ/tonne asphalt
Recycling		
Cold milling, whole lane, up to 350mm depth (Wirtgen W2200)	12.29	MJ/tonne milled road
Cold in situ recycling (whole cycle: milling, taking up, mixing with binder, laying, full compacting) (Wirtgen 4200)	14.74	MJ/tonne milled road
Hot in situ recycling (Wirtgen Remixer RX4500) (whole cycle: milling, taking up, mixing with binder, laying, full compacting)	169.18	MJ/tonne milled road
Asphalt laying and rolling		
Asphalt laying (diesel) energy use for engine per area unit paved surface, one asphalt layer	0.59	MJ/m^2
Asphalt laying (liquid petroleum gas) energy use for heating per area unit paved surface, one asphalt layer	0.11	MJ/m^2
Asphalt rolling, energy use per area unit rolled surface, one asphalt layer	0.88	MJ/m^2

Appendix B Sample spreadsheet

Tables B1 to B4 are an example of the spreadsheet matrix used for calculating the benefits of using a particular waste minimisation technique (divided into several sections to suit the format of the report; the cells relating to intangible benefits (table B3) and traffic delays (table B4) appear immediately below the main spreadsheet (see figure B1 for how the whole spreadsheet is laid out). The cells highlighted in pale grey are for user inputs. The spreadsheet shown in this appendix gives values for a typical pavement constructed using a conventional method.

The spreadsheet makes the following assumptions when calculating traffic delays:

- In order to calculate the VOCs, the delay time is calculated by combining the time a vehicle is stopped and the time a vehicle is delayed by a temporary speed limit.
- The vehicle interaction delay is assumed to be zero.
- The speed changes and low speed travel were not considered.

Figure B1 Diagram of how tables B1–B4 appear in the full spreadsheet (not to scale)

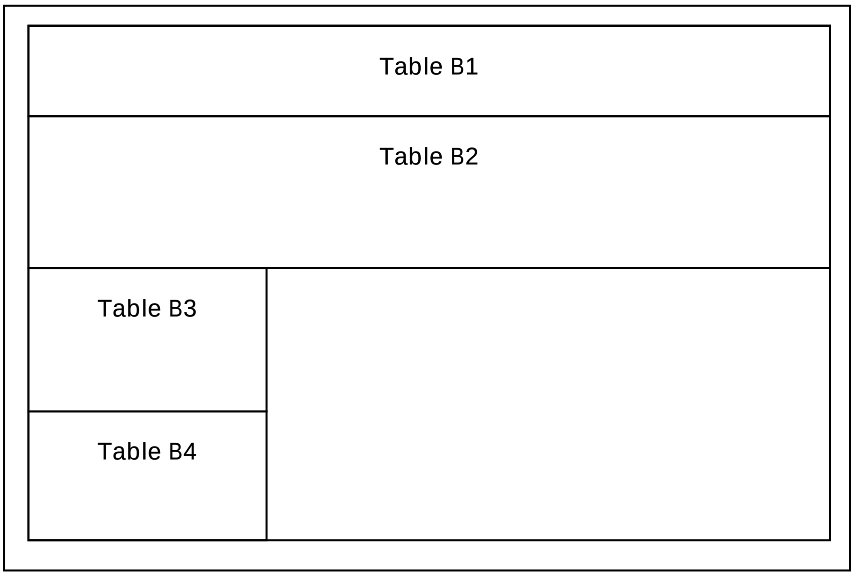


Table B1 Sample spreadsheet used for calculating the benefits of a construction technique (conventional in this example): materials and plant manufacture, and transport.

Name: Conventional														**Waste**	**Total**
	Surfacing				Basecourse				Waste						
	Binder	Chip	Asphalt	Alt*	Crushed granular	Plant stabilised	In situ stabilised	Alt*	Crushed granular	Natural aggregate	Plant stabilised	In situ stabilised	Alt*		
Materials and plant manufacture															
Thickness (mm)			50		0	0		0	0	0	0		0		
Volume (m^3)	0	0	0.05	0	0	0		0	0	0	0		0		
Density (tonne/m^3)	1.03	2.65	2.25	2.22	2.22	2.22		2.22	2.22	2.22	2.22		2.22		
Weight (tonne)	0	0	0.1125		0	0		0	0	0	0		0		0.1125
Additive**			B			C									
Additive % by weight			7			1									0.007875
Energy (kJ/tonne)	6.00E=06	5.00E=04	489,500	0	50,000	69,200		0	50,000	20,000	69,200		55,620		0
Energy required	0	0	55,069	0	0	0		0	0	0	0		0		
Total energy required for manufacture (kJ/m^2)															55,069
% energy in form of electricity	0	50	10		50	50			50	60					
Total energy in form of diesel	0	0	51,379.14	0	0	0	0	0	0	0	0	0	0		51,379.1
Transport to site															
Transport distance (km)	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0		0.0
Energy/t/km	900	900	900	900	900	900	900	900	900	900			900		
Energy for transport kJ	0	0	0	0	0	0		0	0	0			0		
Total energy for transportation to site (kJ/m^2															0

* Alt = alternative

** B = bitumen, C = cement/lime

Table B2 Sample spreadsheet used for calculating the benefits of a construction technique (conventional in this example): construction and transport to waste

Name: Conventional															
	Surfacing				Basecourse				Sub-base						
	Binder	Chip	Asphalt	Alt*	Crushed granular	Plant stabilised	In situ stabilised	Alt*	Crushed granular	Natural aggregate	Plant stabilised	In situ stabilised	Alt*	Waste	Total
Construction															
Additive**							C	C				C	C		
Additive % by weight							1	1				1	1		0
In situ stabilised depth (mm)							0	0				0	0		0
Density (tonne/m^3)							2.22	2.22				2.22			
Weight (tonne)							0					0			
Energy for construction (kJ/tonne or kJ/m^2	165,000	3000	20,000	65,800	65,800	65,800	76,250	65,800				76,250	65,800		0
Total energy required for construction (kJ/m^2)															
Transport to waste															
Excavation depth (mm)														0	
Volume (m^3)														0	
Density (tonne/m^3)														2.2	
Weight (tonne)														0	0
Excavation energy														19,000	
Transport distance (km)														30.0	30.0
Energy excavation – dump														0	
Total energy excavation – dump (kJ/m^2)															0
Grand total (kJ/m^2)															**57,319**

* * Alt = alternative

** B = bitumen, C = cement/lime

Table B3 Sample spreadsheet for calculating the intangible benefits of a construction technique (conventional in this example)

Item	Number	Cost
Number of days needed for the construction	0	
Affected length by construction length (km)	1	
Free speed (km/h)	100	
Gradient in percent	0	
Number of households affected	100	
Rural strategic*	3	
% of CO$_2$ (tonne) from VOC and the cost	0.0015	$40

*In the original spreadsheet, this cell has a number of options that can be selected from a drop-down menu.

Table B4 Sample spreadsheet used for calculating the traffic volume and delays

Factor	Morning peak	Daytime off-peak	Afternoon peak	Total
Traffic volume (AADT)	0	0	0	0
Speed during construction (km/h)	30	30	30	
Speed before construction (km/h)	100	100	100	
Delay per vehicle (min)	1.4	1.4	1.4	
Stopping time (min)	0	0	0	