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Packaging Stewardship Forum

Recycled Crushed Glass as Base Aggregate in Shared Pathways

Summary Report

February 2011

INFRASTRUCTURE | MINING & INDUSTRY | DEFENCE | PROPERTY & BUILDINGS | ENVIRONMENT

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Executive Summary

The reuse of glass, while still largely limited to container glass, has gained momentum over the past decade, and is now being widely accepted across many industries, including engineering, architecture, and industrial processes. Recent research has been undertaken by industry and university bodies into the use of recycled crushed glass (RCG) in civil construction applications. This report summarises the information available to date regarding incorporation of RCG in the construction of the base course layer for footpaths and shared pathways.

Construction of two demonstration projects incorporating between 15 and 30% RCG have recently been undertaken by two Victorian Councils: Manningham City Council and Brimbank City Council. Swinburne University has overseen the development and implementation of these sites, undertaking both field and laboratory testing on raw material samples and sections of constructed pathways. The results of these demonstration sites have shown that with appropriate batch control during the crushing phase, the physical characteristics of RCG comply with current industry material standards for crushed rock base. Furthermore, with adequate construction control, pavements including moderate proportions of RCG within the base course layer can meet accepted compaction and strength requirements.

Development of a draft specification was funded by the Packaging Stewardship Forum of the Australian Food and Grocery Council (PSF) in partnership with the Municipal Association Victoria (MAV), which allowed for the use of up to 30% RCG in Class 3 base course material. The specification also sets out the material sources, physical properties and minimum compaction standards.

Three primary sustainability benefits have been identified for the use of RCG in shared pathway construction. One is that by replacing virgin materials means that these materials are not being used therefore not depleted, nor are the concomitant environmental impacts of quarrying, processing or transporting the virgin materials realised. The waste glass material (approximately 170,000 m^3/year) is being diverted from landfill. And finally, on a ‘cradle-to-cradle’ basis the primary energy consumed and emissions generated in the manufacture, distribution, use, recovery etc of glass are reduced.

Given that the inclusion of RCG in base aggregate is in an early phase of its lifecycle, market rates remain transient. Our industry research has shown that projected supplier costs are not expected to exceed standard aggregate cost, and pending throughput volumes and batch sizing, there exists some cost reduction potential. Similarly, the paving costs involved are comparable to those of standard aggregate. However, ongoing maintenance and lifecycle costs are yet to be determined pending the outcomes of studies currently underway.

The main cost/benefit differential is the averted landfill costs typically associated with disposal of glass waste. At current volume forecasts (130,000 tonnes/year of crushed glass) and indicative landfill rates ($90/tonne), these costs are estimated as being $11,700,000/year.

Stakeholder perceptions of councils and contractors having had exposure to the use of RCG in shared pathway construction is positive. These councils have indicated an intention to incorporate the use of recycled demolition materials including RCG following assessments of the medium term performance of trial sections, and release of the MAV standard for the use of recycled demolition materials. However, many councils without direct experience of the product are currently unaware of its performance and potential.

1 Introduction

1.1 Background

The Packaging Stewardship Forum (PSF), of the Australian Food and Grocery Council (AFCG), is delivering industry recycling, litter reduction and education programs on behalf of its members – Australia's largest beverage companies and their packaging suppliers.

The PSF is driving a glass recovery and recycling initiative, which is looking at higher glass recycling yields and uses for non-recyclable glass fines. As part of this initiative a partnership was established between MAV and PSF to demonstrate the use of recycled crushed glass as a viable medium for use as a sub base aggregate in shared pathways. The project involved Swinburne University undertaking laboratory testing of crushed glass, crushed rock and crushed brick in varying percentage mix designs and developing a recommended specification that was then used in the construction of demonstration sites in Brimbank and Manningham local government areas.

1.2 Scope

This report analyses the potential for using RCG as a base aggregate in the construction of shared pathways. In line with the work to date, this business case will specifically look at the implications of using a mixture of Class 2/3 crushed rock aggregate with unwashed recycled crushed glass fines as a base course for shared footpaths.[1]

A shared path is defined as a pavement which is used by pedestrians and bicycles, and may carry infrequent light traffic loads (mowers, tractors, maintenance trucks, earthmoving equipment/fire fighting). Base course is defined as the layer directly beneath the bituminous or concrete surfacing.

In addition, this business case provides an overview of the history of this initiative, as well as engineering, sustainability, economic and stakeholder assessments – pertaining to the costs, benefits and risks of this initiative.

1.3 Key Stakeholders

The key stakeholders identified related to the incorporation of recycled crushed glass (RCG) in shared pavement base aggregate include, but are not limited to:

- Collectors of glass waste;
- Large scale producers of glass waste;
- Engineering material suppliers;
- Pavement construction contractors;
- State and national road authorities;
- Local government authorities, including councils and over-arching council coordination bodies;
- Sustainability bodies;
- Users of shared pavements; and
- Research institutions.

[1] AustRoads (2008), *Guide to Pavement Technology Part 4A: Granular Base and Subbase Materials*, pp 55

2 Glass Today

The history of glass production can be traced back to 3500 BCE in Mesopotamia. Historically the primary applications of glass have been windows and packaging. Recently, as part of the rapid technological innovation and development of the late 20th and early 21st century, the optical and physical properties of glass have been recognised and are now utilised in a wide range of fields. Typical applications of glass today include:

- **Flat Glass**: vehicle windscreens, housing, industrial screening, building facades;
- **Container Glass:** drinks, household products, chemical storage;
- **Optics and Optoelectronics:** light bulbs, lenses, telescopes, solar panels;
- **Thermal Insulation:** glass wool;
- **Reinforcement Fibre:** glass-reinforced plastic, glass fibre reinforced concrete; and
- **Art:** sculptures.

Currently, waste glass is sent to recycling facilities is treated in four separate ways:

- Recycling into new glass products (particle size limits apply);
- Reprocessing into alternate products such as fibreglass, filtration medium,other boutique products; and aggregate
- Reuse, including direct reuse of containers; and,
- Disposal to landfill/stockpile;

The processing of glass into alternate products has gained momentum over the past decade, and is now being widely accepted across many industries. Typical applications include:

- **Engineering:** unbound aggregate, drainage, sandbags, landfill cover, bedding sand, roof tiles, fibreglass, beach sand;
- **Architecture:** Synthetic marble, glasphalt, landscaping;
- **Industrial processes:** Sandblasting, ice control; filtration medium and
- **Boutique products:** Glass beads, ornaments, benchtops, tiles, etc..

While ultimately the end use for reused glass will be a market-based decision, the potential for reuse of recycled crushed glass is currently underutilised.

3 Project History

August 2008:

- GHD develops a Business Case looking at *"The Use of Crush Glass as Both an Aggregate Substitute in Road Base and in Asphalt in Australia"*. Commissioned by PSF, this Business Case provides that crushed glass may be successfully used as an aggregate in asphalt and road base.

September 2008:

- Hyder Consulting releases a report titled *"Australian Beverage Packaging Consumption, Recovery and Recycling Quantification Study"*. This report quantifies annual volumes of waste recycled glass available for use.

July 2009:

- Agreement signed between the Municipal Association of Victoria and Swinburne University to conduct laboratory testing of crushed glass cullet and crushed brick for use as a road base aggregate.

December 2009:

- Swinburne University published final laboratory testing report *"Laboratory Testing of Reclaimed Demolition Materials for Footpaths and Shared Paths".* Outcomes suggest that 30% of crushed glass fines may be added to Class 3 base for footpaths, and this may increase to 50% pending the outcomes of field trials.

April 2010

- Agreement signed between MAV and PSF for the development of recommended specifications for the use of recycled crushed glass and other materials for use as base aggregate in shared pathways construction and to establish two demonstration sites within two Victorian councils

May 2010:

- Swinburne University and ARRB recommended a local Government specifications titled *"Reclaimed Demolition Materials for Granular Base in Footpath and Shared Footpath";* and
- Brimbank Council constructs 188.75 m^2 footpath between Pecks Road and Charles Court in Sydenham, with 25% crushed glass cullet and 75% recycled concrete as base aggregate. This project used approximately 10 tonnes of recycled crushed glass.

July 2010:

- Manningham Council constructs 287.50 m^2 of shared path alongside Andersons Creek Rd in Doncaster East, with 212.5 m^2 containing 30% crushed glass cullet and 70% crushed rock, and 75 m^2 containing 15% crushed glass cullet and 85% crushed rock. A 125 m shared path containing 100% crushed rock was also constructed as a control measure. This project used approximately 12 tonnes of recycled crushed glass.

August 2010:

- Swinburne University commenced field testing at survey points installed along Andersons Creek Road, Doncaster East in Manningham City Council.

Plan Moving Forward:

- MAV to develop toolkit for Councils (October 2010 to February 2011); and
- Launch project (March 2011).

4 Engineering Assessment

4.1 Local Demonstration Projects and Applications

Two demonstration sites have been constructed by local Victorian councils, incorporating various proportions of crushed glass in the base aggregate mix for concrete and asphalt shared pathways. Both sites were constructed in early to mid 2010 using up to 30% recycled crushed glass (RCG), with all materials supplied by Alex Fraser Recycling, Laverton North. A summary of each project, based upon information gathered from discussion with local council representatives is provided below. Further discussion on council perceptions of the materials is provided in Section 7.

4.1.1 Manningham City Council

The Manningham Council site comprised the construction of a 200 m long, 2.5 m wide asphalt shared pathway, along Anderson Creek Road, Doncaster East in June 2010. The pathway was divided into three sections: a 100 m long control section using standard Class 2 crushed rock aggregate; a 50 m long section incorporating 15% RCG in the aggregate mix; and the final 50 m with 30% RCG. The RCG component comprised a 5 mm minus glass aggregate. (i.e. a maximum particle size of 5 mm.)

The RCG aggregate mixes were mixed at Alex Fraser Recycling facility in Laverton North, and delivered to site at optimum moisture content (OMC). The material was then laid immediately by an approved Manningham contractor. Density testing was undertaken for each section of base course, confirming compliance with the design compaction standards of 92% maximum dry density (MDD).

The sample containing 15% crushed glass was found to have greater compactability than that containing 30% crushed glass. The latter appearing damp and requiring more work to expel the excess moisture. It is noted that no moisture content tests were performed on site.

On-going visual assessment of the pathway will be carried out by Swinburne University over the next four years on a 6-monthly basis.

4.1.2 Brimbank City Council

The Brimbank Council site comprised the construction of approximately 90 m of 2.5 m wide concrete shared pathway between Pecks Road and Charles Court, Sydenham in May 2010. The entire trial section adopted a base course mix of 25% RCG and 75% crushed concrete.

The RCG aggregate mixes were mixed at Alex Fraser Recycling facility in Laverton North, and delivered to site at optimum moisture content (OMC). The material was stockpiled at one end of the works area, and transported by plant along the pathway. Additional moisture was added to the material on site, which necessitated additional work to expel the excess moisture. The combination of double handling and over-wetting resulted in minor segregation of the material components.

The layer thickness of the base course for this pavement was less than the standard nuclear testing gauge (125 mm), requiring some modification of the field test results to obtain representative field compaction ratios. A result of 89% modified MDD; slightly below the minimum required result of 90% modified MDD was obtained.

4.2 Existing Local and International Applications

A desktop assessment of existing applications of crushed glass in similar civil engineering applications was undertaken by ARRB Group as part of its development of the Specification for Recycled Crushed Glass as an engineering material. The results of this desktop assessment, along with additional resources sourced by GHD have been summarised and included as Appendix B to this report. The examples referenced are generally related to road construction, although not exclusively limited to base course applications. However, the adoption of recycled crushed glass in road construction, which is by nature subject to higher design loads, helps to validate its adoption for shared pathways.

4.3 Engineering Performance

Swinburne University, working in conjunction with MAV, PSF and Manningham City Council, undertook research into the engineering characteristics and applied performance of recycled crushed glass as a percentage component of base aggregate for shared pathways. This research has involved field[2] and laboratory testing[3] of both raw aggregate and pathways constructed using various proportions of crushed glass.

Materials were supplied by Alex Fraser Recycling, Laverton North, with the demonstration sites constructed on the shared pathways by Manningham and Brimbank City Councils (see Section 4.1 and Section 4.2).

A range of geotechnical laboratory testing was performed on material samples of crushed rock and recycled crushed concrete with varying proportions of RCG – ranging from 10 to 50%. The results of laboratory testing indicate that incorporation of RCG into basaltic rock or crushed concrete has low to minimal impact on the physical and mechanical properties of the original material. A mixture of Class 3 crushed rock and concrete with up to 30% RCG was recommended as suitable for use as a Class 3 base course material for pathways.

Demonstration project results have confirmed the suitability of incorporating RCG into base course aggregate materials. Results also indicated that the addition of RCG can improve the workability of standard crushed rock base material, with higher levels of compaction achieved for the 15% RCG mix than that of the standard quarry material – 96% and 93% modified MDD, respectively. However, a corresponding decrease in strength (as measured by California Bearing Ratio (CBR) testing) was observed with higher percentages of RCG (30% RCG).

On the basis of the limited number of demonstration sites completed in Australia to date, the optimum percentage inclusion of RCG in base aggregate for shared pathways appears to be 15%. Completion of further demonstration sites should help to refine the recommended upper bound value.

As with all road construction materials, variations in material grading can affect the strength and workability of the material, and consequently the quality of the end product. As the addition of crushed glass is an emerging concept to the broader construction industry, it will be necessary to get individual suppliers to develop mix designs that meet the new specifications. As part of this process it may be advantageous to work with suppliers to ensure the practicality of the new specification – and to amend any aspect that may warrant it. Also, when the material is being used in the field, a similar approach should be adopted with compaction testing and any placement techniques.

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[2] Vuong, B., Arulrajah, A. (2010) "Field Trials of Recycled Crushed Class in Footpaths and Shared Paths", Swinburne University of Technology.

[3] Arulrajah, A., Vuong, B., Wilson, J., Ali, M.M.Y., (2009) "Laboratory Testing of Reclaimed Demolition Materials for Footpaths and Shared Paths."

4.4 Product Specification

Currently there are no formal guidelines for using recycled crushed glass and reclaimed demolition materials or RCG as base materials in footpaths and shared paths; councils generally base their specifications on VicRoads specifications for trafficked road pavements. This results in overdesign of footpaths and shared pathways, when considering the minimal loading experienced by these structures.

To this end, MAV, SV and PSF have funded a research and development project, undertaken by Swinburne University, aimed at investigating the viability of including recycled demolition materials and RCG in the construction of footpaths and shared pathways. Swinburne University have since developed draft specifications for the use of recycled demolition materials and RCG in footpaths and shared pathways. A full copy of the draft specification is provided as Appendix A.

Working in conjunction with ARRB Group, Swinburne University and PSF MAV has compiled a draft specification for the use of recycled demolition materials in footpaths and shared paths, including RCG (reference). A full copy of the draft specification is provided.

The draft specification allows for the inclusion of up to 30% RCG in Class 3 base course material for footpaths and shared pathways, with physical properties conforming to the following:

- Particle size distribution as shown in Table 1 (Appendix A);
- Plasticity, Hardness and Particle Shape conforming to Table 2 (Appendix A);
- Compacted densities of 90% and 92% modified MDD for footpaths and shared pathways, respectively;
- Minimum soaked field CBR of 20% (at 90% modified MDD) for footpaths, and 28% (at 92% modified MDD) for shared pathways;
- The material shall consist of recycled glass food and beverage containers, drinking glasses, window (or flat) glass and plain ceramic. Glass from hazardous waste containers, reinforced and laminated glass, light bulbs, fluorescent tubes and cathode ray tubes shall not be included; and
- The material shall be free of debris such as paper and cardboard, plastic, fabrics and toxins.

The material should be delivered to site well mixed and at no less than 85% OMC. On the basis of current experience the material is best laid straight from the truck, with stockpiling of material to be avoided where possible.

A material specification for the use of RCG in a number of applications has also been prepared by the ARRB Group, on behalf of the PSF[4].

While there is concern regarding the incorporation of RCG into aggregate mixes for concrete, due to alkali silica reactions with glass fines, no evidence of adverse impacts when used as a percentage component of base course material was found during this study.

4.5 Safety

Trials and testing for the use of crushed glass as a pipe embedment material, conducted by the Department of Environment and Climate Change (NSW) (DECC) 2007, Sydney Water Corporation (SWC) and Benedict Sand and Gravel, found:

[4] Andrews, R., Vuong, B., (2010). Specifications for Recycled Crushed Glass as an Engineering Material. Prepared by ARRB Group for The Packaging Stewardship Forum of the Australian Food and Grocery Council.

- Recycled crushed glass contains less than 1% crystalline silica. The dust generated by glass cullet is not considered hazardous and does not contribute to silicosis or cancer;
- Particles less than 19 mm represent no greater hazard of causing skin cuts than conventional crushed construction aggregates;
- Glass particles smaller than 6 mm are completely benign; and
- Because of its abrasive qualities, crushed glass can be a greater skin irritant than conventional aggregates and soils[5].

Simple measures, such as damping down and use of PPE, aid in controlling the hazards listed, and in minimising the risk of exposure. Inspection of a range of Material Safety Data Sheets for crushed glass and standard aggregate show little if any difference between the two materials.

Feedback from the field trials conducted by Manningham and Brimbank City Councils indicated the contractors experienced no major issues working with the mixed RCG base materials. Neither council had difficulty sourcing contractors to undertake the works. In both cases the material was delivered to the site in a wet condition (at OMC), and the standard appropriate PPE (glasses, dust masks, gloves) were worn.

4.6 Suppliers

Based upon the desktop study undertaken by ARRB[6], suppliers of RCG exist in a number of Australian states. The current suppliers include:

- **Glass Granulates Pty Ltd (NSW) Benedict:** Quarried and recycled materials;
- **Recycled Glass Solutions (NSW):** Non-standard aggregate materials;
- **Alex Fraser Recycling (VIC):** Recycled construction and demolition products;
- **Colmax Glass (NSW/National):** Non-standard aggregate materials;
- **Hazell Bros (TAS):** Recycled construction and demolition products; and
- **Fulton Hogan (WA):** Recycled construction and demolition products.

One of the barriers to wide-spread implementation of recycled crushed glass in a broader civil engineering context may be the distance from the nearest supplier. Internationally this problem has been overcome by the adoption of mobile glass crushers, in addition to stationary fixed facilities. PSF have implemented support in regional areas of Australia with the installation of local glass reprocessing infrastructure to provide a local solution where the transport of the glass to recycling facilities is cost prohibitive. Locally processed glass provides a local solution in regional areas where the recycled crushed glass can be used as a sand replacement medium in civil construction; such as in asphalt, concrete and pipe embedment.

[5] Department of Environment & Climate Change NSW (2007), *Trial of Recycled Glass as Pipe Embedment* ***Material*****, http://www.environment.nsw.gov.au/warr/crushedrecycledglass.htm, pg 8**

[6] Andrews, R., Vuong, B., (2010). Specifications for Recycled Crushed Glass as an Engineering Material. Prepared by ARRB Group for The Packaging Stewardship Forum of the Australian Food and Grocery Council.

5 Sustainability Assessment

5.1 Waste Hierarchy

Most glass is recyclable and can be recycled over and over again without any reduction in quality provided contaminants are dealt with adequately.

Increased levels of glass recovery has meant that large quantities of glass remain and are being stockpiled or disposed of after recovery. This happens for several reasons such as a disparity in the colour of glass manufactured locally versus that recovered because recovered glass can contain (large volumes of) imported glass. This represents both an economic and environmental impact[7].

For this reason the creation of alternative markets for cullet has been the subject of much work in many countries.

The subject of this assessment is the use of RCG as a base aggregate in concrete pathways. This represents the use of waste (glass) material as recycled crushed glass. In terms of the waste hierarchy this is therefore better than disposal to landfill, where it is estimated that 130,000 of beverage container glass ends up annually.

This represents significant sustainability benefits. Recycled crushed glass is diverted from landfill and replaces virgin materials, meaning that these materials are not being mined or depleted, nor are the concomitant environmental impacts of quarrying, processing or transporting the virgin materials realised. Further, on a 'cradle-to-cradle' basis the primary energy consumed and emissions generated in the manufacture, distribution, use, recovery etc of glass are reduced. This is discussed in the following section.

Importantly this use of recycled crushed glass supports the dematerialisation of our economy, in that it reduces dependence on new resources and reduces the environmental impact of the use of resources.

[7] Sustainable waste management and recycling: glass waste: proceedings of the international conference organised by the Concrete and Masonry Research Group and held at Kingston University - London on 14-15 September 2004, M Limbachiya, J. J. Roberts Ed.'s; Thomas Telford, 2004 - 362 pages

5.2 GHG Emissions and Primary Energy Demand

The Glass Packaging Institute (GPI)[8] commissioned PE Americas to conduct a complete Life Cycle Assessment of North American container glass[9].

The cradle-to-cradle LCA inventory of container glass addresses all inputs and outputs for the production and end-of-life management of 1 kg of container glass including:

- Extraction and processing of raw materials and cullet;
- Transportation of raw materials and cullet;
- The production and combustion of fuels and energy for the melting and formation of glass (including all non-melting activities at the facility);
- The impacts of post-consumer cullet treatment; and
- Transportation of the finished container to the end user.

This Life Cycle Assessment compares primary energy consumption and greenhouse emissions for different percentages of recycled cullet (up to 50%) by calculating the net of:

- Recycling into Container Glass;
- Recycling into Glass Wool;
- Recycling into Aggregate;
- Additional Transport;
- Landfill;
- Washing;
- Treatment of Post-Consumer Cullet;
- Non-Melting;
- Melting; and
- Batch (Including Cradle-to-Gate Transport).

The results show that both primary energy demand (MJ/kg glass) and emissions (kg CO2/kg glass) are significantly reduced as the percentage of recycled glass rises.

5.3 Environmental Impacts

Contaminants from road construction materials primarily enter the environment through the process of leaching.

[8] GPI is the trade association representing the North American glass container industry.

[9] 'Cradle-to-Cradle: The Complete Life Cycle Assessment of North American Container Glass,' Sept 2010, PE Americas for The Glass Packaging Institute

Herrington[10] et al (2006) in work for Land Transport New Zealand state that:

"In terms of potential environmental impact, reclaimed glass in roading materials should not be expected to release any harmful chemicals into adjacent land or water, provided that the cullet used undergoes quality assurance for its source and contamination level. The risk of contamination would be greater from glass used to contain hazardous materials, or from light bulbs, cathode ray tubes, fluorescent tubes and vehicle windscreens."

This risk of contaminants in recycled crushed glass is treated through State based environment protection regulations for waste (in Australia). A national specification for recycled crushed glass has recently been developed by ARRB Group (September 2010) which was commissioned by the PSF.

5.4 Compliance with Environment Regulations

5.4.1 Recent Examples

Sydney Water has demonstrated the use of crushed glass as pipe embedment material (2007) with the Department of Environment & Climate Change (NSW) to confirm compliance with:

- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (2000), Volume 1: The Guidelines ('ANZECC 2000');
- National Environment Protection (Assessment of Site Contamination) Measure 1999, Table 5-A: Soil Investigation Levels; and
- Environmental Guidelines: Assessment, Classification and Management Of Liquid and Non-Liquid Wastes (DECC, 2004) (the 'Waste Assessment Guidelines').

Chemical testing of crushed glass carried out under this study[11] concluded that:

"For each of the four samples, all of the identified chemical and physical contaminants were either not detected or were present at background or trace levels; and

"The presence of any aluminium metal and/or metal compounds in the glass fines is not expected to present an unacceptable human health and/or environmental impact when used as a sand substitute."

Melbourne Water (through the Water Resources Alliance) has also undertaken a project that is using recycled crushed 'glass sand' as pipe embedment material. The material complied with Environment Protection (Industrial Waste Resource) Regulations 2009 - Part 5 Exempt Material Where Established Secondary Beneficial Reuse.

It refers to prior work by Roadside Care & Maintenance and state that:

"In August 2008 Roadside Care & Maintenance commissioned the sampling and analysis of 10 mm - fines and 4.75 mm sand. The findings revealed that the materials are well within the requirements of EPA Publication 448 Classification of Wastes (Table 2). The material is defined as Solid Inert (Industrial) Waste."

[10] Herrington, P. Kvatch, I. & O'Halloran, K. (2006) "Assessing the environmental effects of new and recycled materials in road construction, Proposed Guidelines", Land Transport New Zealand Research Report No. 306

[11] Department of Environment & Climate Change NSW (2007), Trial of Recycled Glass as Pipe Embedment Material, http://www.environment.nsw.gov.au/warr/crushedrecycledglass.htm

5.4.2 Existing Specifications

NSW

The 'Specification for Supply of Recycled Material for Pavements, Earthworks and Drainage,' 2010[12] NSW Department of Environment, Climate Change and Water in association with the Institute of Public Works Engineering Australia (NSW) (IPWEA NSW) Roads & Transport Directorate.

The use of other recycled materials such as crushed glass fines as well as blends of recycled and virgin materials is provided under the Guide.

WA

The Curtin University and ARRB Group 2010 draft specification[13] targeted at industry and local government for the use of recycled construction and demolition (C&D) materials in road construction.

National

ARRB Group Glass Sand Specification 2010 for the use of recycled crushed glass (RCG) in four civil construction applications: partial mix in asphalt paving; sand replacement in concrete; bedding sand; and, aggregate mix in paving. The specification was commissioned by PSF and peer reviewed by GHD Geotechnics, and also included a MSDS.

5.4.3 Compliance Issues

In Victoria, exemptions for secondary beneficial reuse carry similar (quality assurance) conditions to those set out in the NSW exemption under the Protection of the Environment Operations Act. The treatment of waste glass under local regulations and the requirement for exemption for secondary beneficial reuse therefore depends on the source of the glass, and should be confirmed with the local EPA.

[12] http://www.environment.nsw.gov.au/resources/warr/104SupplyofRecycledMaterial.pdf

[13] http://www.insidewaste.com.au/storyview.asp?storyid=1139632

6 Economic Assessment

6.1 General

The economic assessment compares cost inherent in the supply and use of typical Class 2/3 base aggregate and a mixture consisting of Class 2/3 base aggregate with added crushed glass cullet.

6.2 Key Variables and Considerations

The following variables are relevant to this assessment:

Table 1 Key Variables for Economic Assessment[14]

Variable	Figure	Source
Recycled Glass Volumes (total recovered glass) (Australia, Total)	490,000 tonnes/year	NEPM[15]
Recycled Glass Waste Volumes (portion of recovered glass sent to landfill/stockpile) (Australia, Total)	130,000 tonnes/year	NEPM[16]
Landfill Costs (Industry quotes in Victoria)	$90/tonne	Industry rates (Indicative quote) Varies in each state
Class 2/Class 3 base aggregate (100% rock and recycled concrete)	$20/tonne (pickup cost*)	Industry rates (Indicative quote)
Class 2/ Class 3 base aggregate (w/ glass) (30% crushed glass, 70% rock and recycled concrete)	$20/tonne (pickup cost*)	Industry rates (Indicative quote)
Concrete Paving Labour Costs (Same for both, with and without crushed glass)	$70/m^2	Industry rates (Indicative quote)

Notes: * Assuming contractor collects the material from the supplier depot, i.e. excluding transport costs.

Some further considerations are as follows:

- Class 3 base aggregate is typically about 5% cheaper than Class 2 base aggregate;
- Industry costs for base aggregate with recycled crushed class cullet are not yet definitively set, and will depend on ongoing demand. As an indication, aggregate with recycled crushed glass will not cost any more than standard aggregate, and may be marginally cheaper;
- Transportation costs are the same for Class 2 and Class 3 base aggregate, with or without recycled crushed glass; and
- Supplier Material Safety Data Sheets (MSDS) show no additional safety requirement for aggregate containing recycled crushed glass than other naturally occurring aggregates.

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[14] Figures will vary and are to be used for indicative purposes only

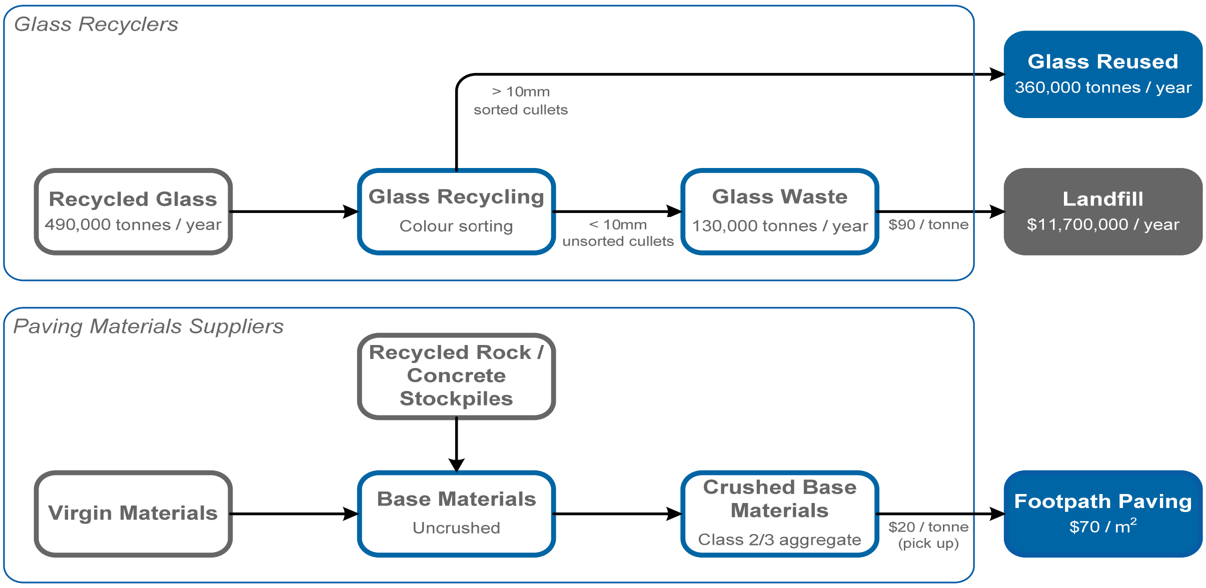
[15] Hyder Consulting Pty Ltd, *Australian Beverage Packaging Consumption, Recovery and Recycling Quantification Study*, Packaging Stewardship Forum of the Australian Food and Grocery Council, 2008, pp.10-11.

[16] ibid.

6.3 Standard Base Aggregate

Standard Class 2 and Class 3 base aggregate costs approximately $20/tonne (excluding transportation), and concrete paving costs with this aggregate costs approximately $60/m^2.

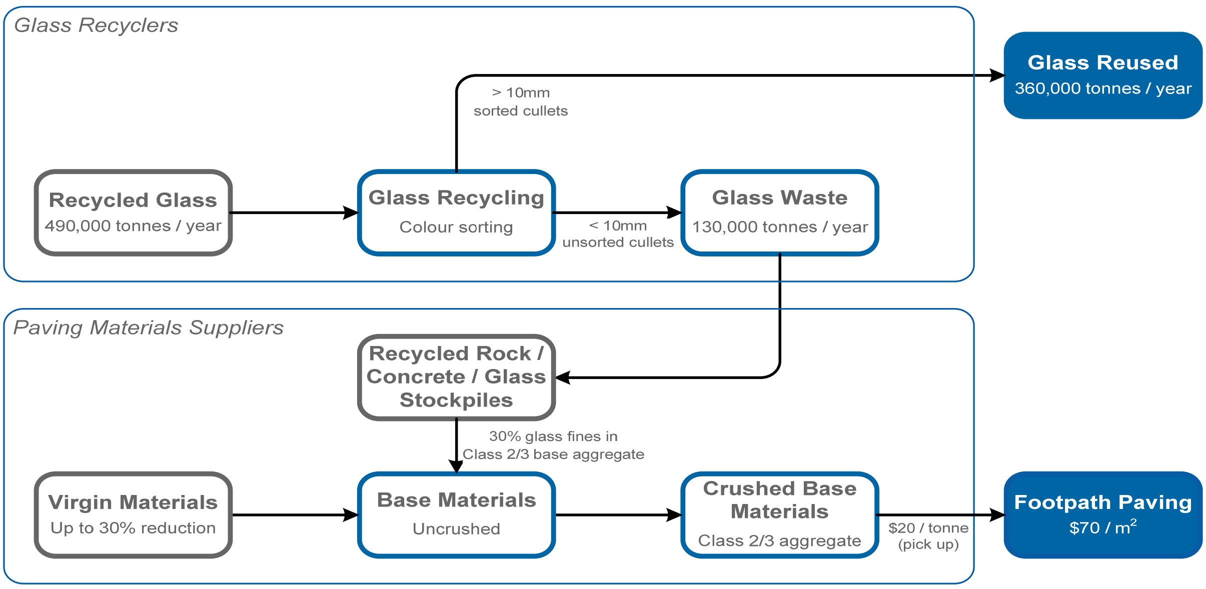
An additional cost of $11.7 million/year is then generated from the need to direct glass waste into landfill at an approximate rate of $90/tonne.



6.4 Crushed Glass Cullet in Base Aggregate

The processes involved in crushing glass are not dissimilar to those involved in crushing rock, and as such, while the cost of Class 2 and 3 base aggregate with RCG has been quoted as $20/tonne (excluding transportation), this is likely to decrease with larger material throughput and batch sizing.

However, one important difference with using RCG in Class 2 and 3 base aggregate is the elimination of the $11.7 million/year cost associated with directing glass waste into landfill.



6.5 Cost/Benefit

Using recycled crushed glass as a base aggregate additive does not increase any CAPEX costs, and likewise, should not impact the laying OPEX costs.

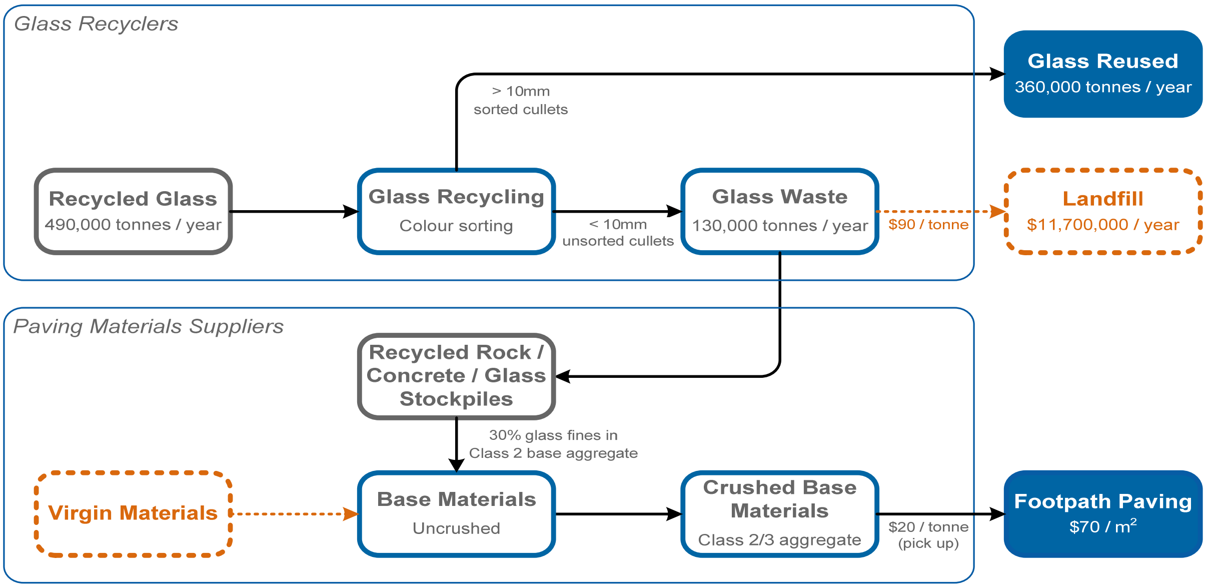
Field studies are currently being carried out to determine longevity and lifecycle OPEX costs.

The key differential in using recycled crushed glass as a base aggregate additive is the foregone cost (fiscal, environmental and social) of waste glass disposal into landfill (approximately **$11.7 million/year)**.

6.6 Unquantified Impacts

The use of recycled crushed glass in base aggregate conveys benefits additional to those quantified above.

These are depicted in the diagram below.



- Glass waste is not placed in landfill:
  - Glass Recyclers save on landfill costs, potentially driving costs down; and
  - Reduce landfill use by approximately 170,000 m^3/year[17].
- Reduction in use of virgin materials:
  - Possible reduction in Paving Material Supplier costs, potentially driving costs down; and
  - Conservation of natural resources.

[17] Based on industry sought waste glass density figures

7 Stakeholder Perceptions

7.1 Manningham City Council

Manningham City Council is actively pursuing the use of recycled materials throughout its civil works program, and is revising its standards to incorporate recent technological advancements, including the use of recycled materials throughout many disciplines.

Manningham Council has a positive view of the incorporation of RCG in the base course for pathways, following on from its experiences during the construction of the demonstration site in June 2010. Of the two trial mixes (15 and 30%), it has indicated a preference for the material containing 15% RCG; the compaction of this material requiring less effort.

The material was delivered to site at near optimum moisture content, and appropriate PPE was worn by contractor personnel. Material safety data sheets were also obtained from Alex Fraser Recycling prior to commencement of the works. Through the adoption of these standard safety precautions, the council see no particular safety hazard posed by the use of RCG.

It is its intention to monitor the performance of the trial pathway section, along with the ongoing testing by Swinburne University. Subject to the performance of the demonstration sites, and issuing of a specification by ARRB Group and MAV, Manningham Council will be including RCG mixes in its engineering pathway specifications.

7.2 Brimbank City Council

Brimbank Council also reported positive experiences with the incorporation of RCG in base aggregate. It reported the material appeared more than adequate and, based upon visual inspection, appeared more solid than standard crushed rock material. Furthermore, it was reported that the presence of glass is not readily apparent to the naked eye. While some material segregation occurred during construction, largely due to over-wetting of the material following delivery to site, the quality of pavement produced was still satisfactory. In addition, Council has indicated confidence that, with no additional wetting on site the workability of the material would improve.

Based upon its experiences Brimbank Council indicated it would be happy to include up to 25% RCG in its base aggregate for future pathway construction. Council is now awaiting issue of the RCG material specification by ARRB Group and MAV.

7.3 Contractors

It was outside the scope of this report to seek the opinion of road construction contractors on the use of base aggregate containing a percentage component of RCG. However, through discussion with council representatives we understand that the contractors involved in the construction of the demonstration sites were happy to work with this material. Furthermore, when putting out to tender the construction of demonstration sites using recycled materials (including RCG), there was no difficulty obtaining a sufficient number of tender responses.

7.4 Swinburne University of Technology

Swinburne University have indicated it has confidence in the use of recycled materials such as RCG in base course layers for pavement construction. It believes that the current dependence of council standards for footpath and shared pathway construction on VicRoads flexible road pavement standards leads to overdesign of the former, with no real net benefit in design life. For this application, discernible improvements in pavement quality are more likely to be gained from awareness by councils and contractors of construction quality control techniques.

Swinburne believes the primary barrier to overcome prior to broad-scale implementation of recycled demolition materials in road design is tighter material batch quality control.

We understand from discussions with Swinburne University that, following the demonstration site for heavy duty pavements conducted at the Alex Fraser Recycling depot in Laverton North, VicRoads are currently considering provision for the addition of up to 20% RCG in road base materials within its specifications. Furthermore, that ARRB and AustRoads are currently working on a campaign to unify the various state pavement engineering standards with respect to the inclusion of recycled materials.

8 Conclusions

In summary:

- The incorporation of RCG in base aggregate for shared pathways may result in an annual estimated reduction of 170,000 m^3 of landfill space;
- Successful sites incorporating between 15 and 30% RCG in asphalt and concrete shared pathway construction have recently been undertaken by two Victorian Councils: Manningham City Council and Brimbank City Council;
- Laboratory and field testing of materials and constructed pavements has largely demonstrated the applicability of RCG material mixes with current industry standards;
- Development of a draft specification by the ARRB Group has been funded by PSF and MAV, allowing for the use of up to 30% RCG in Class 3 base course material. The specification also sets out the material sources, physical properties and compaction standards for use of this material;
- Base course mixes incorporating RCG should be delivered to site at no less than 85% optimum moisture content, to ensure adequate moisture condition and improve dust suppression. On this basis, standard PPE, including gloves, dust masks and safety boots have been deemed sufficient material handling controls;
- The incorporation of RCG in base aggregate for shared pathways is a positive step towards an overall reduction in virgin material use and the quantity of recyclable material being sent to landfill;
- The primary energy consumed and emissions generated in the manufacture, distribution, use and recovery of glass are reduced through its use in road construction;
- There currently appear to be no added material, labour or paving costs associated with the incorporation of RCG in base aggregate for shared pathways;
- The incorporation of RCG in base aggregate for shared pathways may result in an annual estimated saving of up to $11.7 million in landfill costs;
- Stakeholder perceptions are generally positive, when based upon actual experience with the product; and
- Successful implementation of RCG in shared pathway construction is believed to require ongoing education campaigns targeted at council engineering groups, tighter controls on material batch quality, and further field trials to determine ideal material proportions.

Appendix A

MAV Draft Material Specification for Footpaths and Shared Paths

DRAFT SPECIFICATION: RECLAIMED DEMOLITION MATERIALS FOR GRANULAR BASE IN FOOTPATHS AND SHARED PATHS

1 DESCRIPTION

This specification covers the requirements of 20 mm nominal size, crushed reclaimed demolition materials and plant mixed wet-mix crushed reclaimed demolition materials for granular base in footpaths and shared paths.

2 DEFINITIONS

For the purpose of this specification, the following definitions apply.

2.1 Crushed Reclaimed Demolition Materials (CRDM)

Crushed Reclaimed Demolition Material is composed of recycled crushed rock or recycled crushed concrete with or without crushed brick, fine glass cullet, sands and/or filler, produced in a controlled manner to the requirements of this specification.

2.2 Plant Mixed Wet-Mix Crushed Reclaimed Demolition Materials (PMWM-CRDM)

Plant mixed wet-mix reclaimed demolition materials is a mixture of CRDM, any granular additives and water, produced at a controlled mixing plant to close tolerances of grading and moisture content based on the optimum moisture content of the material relative to modified compaction.

2.3 Crushed Concrete

Crushed concrete is composed of rock fragments coated with cement with or without sands and/or filler, produced in a controlled manner to close tolerances of grading and minimum foreign material content.

2.4 Crushed brick

Crushed brick is composed of crushed fired clay brick or concrete blocks. Unfired clay brick or mud brick are not included.

2.5 Fine glass cullet

Fine glass cullet is composed of crushed food and drink glass containers, drinking glasses and window (or flat) glass. Glass from hazardous waste containers, reinforced and laminated glass, light bulbs, fluorescent tubes and cathode ray tubes shall not be included.

2.6 Footpath

Footpath is a pavement which is used mainly for pedestrian and driveway traffic.

2.7 Shared path

Shared path is a pavement which is used for bicycles and may carry infrequent light traffic loads (mowers - tractors - maintenance trucks -earthmoving equipment/fire fighting).

2.8 Granular base pavement

Granular base pavement is the layer directly beneath the bituminous or concrete surfacing and in the case of block paving, the layer directly below the bedding sand layer.

3 COMPONENTS

The components making up the product shall be a combination of:

(a) crushed reclaimed concrete derived from crushing and screening;

(b) crushed brick derived from crushing and screening;

(c) sands and or fillers derived from natural sources or other crushing operations;

(d) glass cullet shall be crushed to approximately the gradation shown in Table 1 with the material coarser than 4.75 mm containing not more than 1% window (or flat) glass.

Table 1 – Approximate Gradation for Glass Cullet

Particle Size (mm)	Percent Finer
9.5	100
4.75	70 - 100
2.36	35 - 90
1.18	15 - 45
0.30	4 - 15
0.075	0 - 5

4 MANUFACTURED PRODUCT

The product shall be manufactured by crushing and screening construction and demolition waste to the requirements of this specification.

(a) The Product shall comply with the relevant requirements of Table 2.

Table 2 – Physical Properties

Physical properties	Test method	Test value	
		Foot Path	Shared Path
Plasticity Constants	Liquid Limit (AS 1289 3.1.1)	Max 35%	Max 35%
	Plasticity Index (AS 1289 3.3.1)	Max 10%	Max 10%
	Linear Shrinkage (AS 1289 3.4.1)	Max 8%	Max 8%
Bearing Strength	California Bearing Ratio (AS 1289 6.1.1)	Min 40% (1)	Min 40% (1)
Aggregate Hardness	Los Angeles Abrasion (AS 1141.23)	Max 60%	Max 60%
Particle shape	Flakiness Index (AS 1141.15)	Max 35%	Max 35%

Notes:

(a) Value applicable to material passing 19.0 mm sieve: initially at optimum moisture content and 90% of maximum dry density as determined by test using Modified compactive effort, but then soaked for 4 days prior to the CBR test.

(b) Crusher fines from different material sources (crushed brick, fine glass cullet) in that fraction of the product retained on a 4.75 mm sieve shall not exceed the percentages by mass specified in

(c) Table 3. In no circumstances shall the product contain any asbestos or asbestos fibre.

Table 3 – Permissible Composition of Product

Material Type	Percentages by mass	
	Foot Path	Shared Path
Concrete	Up to 100%	Up to 100%
Brick	Up to 50%	Up to 50%
Metals, ferrous and non- ferrous	Less than 1%	Less than 1%
Glass cullet	Up to 30%	Up to 30%
Low density materials such as plastic, rubber, plaster, clay lumps and other friable material	3	3
Wood and other vegetable or decomposable matter	0.5	0.5

Notes:

(a) For PMWM-CRDM, the aggregates and water shall be mixed at a mixing plant by continuous or batch mixing.

5 WATER

Where it is specified that water shall be added to the crushed CRDM prior to delivery, such water shall be clear and substantially free from detrimental impurities such as oils, salts, acids, alkalis and vegetable substances.

6 GRADING OF UNCOMPACTED CRDM AND PMWMCC BASE BEFORE COMPACTION

After completion of production, but before compaction, crushed CRDM and PMWM-CRDM base shall comply with the relevant grading requirements of Table 4.

(a) The Contractor shall aim to produce the crushed CRDM and PMWM-CRDM in such a way that the grading coincides with the relevant target grading specified in Table 4. The permitted ranges of grading in these tables provide for random fluctuations in the production process.

(b) The crushed CRDM shall not be graded from near the coarse limit on one sieve to near the fine limit on the following sieve or vice versa.

Table 4 – Grading Requirements

Particle Size (mm)	Target grading	Percent Finer
26.5	100	100
19.0	100	90 - 100
4.75	55	40 – 65
2.36	20	10 - 30
0.075	9	5 - 15

7 STOCKPILING PRIOR TO DELIVERY

Crushed CRDM may be stockpiled prior to delivery provided the following requirements are fulfilled:

(a) the product, after recovery from the stockpile, complies with this specification;

(b) the stockpile site is clean, adequately paved, and well drained;

(c) if a stockpile is constructed in more than one layer, each layer is fully contained within the area occupied by the upper surface of the preceding layer;

(d) no cementitious filler is used.

8 HANDLING OF CRUSHED RECLAIMED DEMOLITION MATERIALS

(a) Handling of crushed CRDM, including the loading of trucks and stockpiling, shall be effected in such a manner as to minimise segregation.

(b) Purchase of CRDM shall be accompanied by a Materials Safety Data Sheet supplied by the manufacturer.

9 QUALITY ASSURANCE

The manufacturer of CRDM shall provide quality assurance to the Principal suggesting:

(a) compliance with the Waste Management of Australia (WMAA) National Construction and Demolition Division "Code of Best Practice for Waste Processing in the Construction and Demolition Industries";

(b) quality systems accreditation to ISO 9001 series Quality Management or an equivalent.

Product compliance to this specification shall be demonstrated by the supplier providing supporting documentation including NATA (National Association of Testing Authorities) laboratory test certificates of product quality control.

10 FIELD COMPACTION

After completion of compaction of a layer, the compacted dry density shall be determined and shall be:

(a) not less than 90 % modified compaction (AS 1289.6.2) for footpath;

(b) not less than 92 % modified compaction for shared path.

11 TRIAL SECTIONS

Where field trials are proposed for different source materials, in addition to laboratory characterisation, field CBR determinations using the Clegg Impact hammer are suggested to confirm post compaction bearing strength in view of the particle breakdown which may occur under the maximum aggregate hardness (LA) specified.

Appendix B

Existing Local and International Applications

Table B1 Existing Application of Recycled Crushed Glass to Civil Infrastructure

Location	Usage of RCG
The Washington State Department of Transportation	▸ Up to 15% for unbound aggregate; and ▸ Up to 100% for wall backfill, pipe bedding, drainage blankets.
The Oregon Department of Transportation	▸ Up to 100% for drainage blankets, utility bedding and backfill and subsurface drains.
The California Department of Transportation	▸ Up to 100% for base and sub-base for the support of flexible and rigid pavements (dependent upon desired material class).
The State of Connecticut	▸ Up to 25% for roadway embankments.
The New York State Department of Transpiration	▸ Up to 30% for roadway sub-base material; and ▸ Up to 30% for embankments.
The New Hampshire Department of Transportation	▸ Up to 5% for roadway base course material.
American Association of State Highway and Transportation Officials	▸ Up to 20% for roadway base course material, with higher proportions allowed at the discretion of the design engineer.
Massachusetts DOT	▸ Up to 10% for general pavement material (M2 Specification).
UK	▸ DMRB 7.1.2 HD 35/04 'Conservation and Use of Secondary and Recycled Materials' allows for the incorporation of recycled crushed glass in pipe bedding; embankment and fill; capping layers; unbound mixtures for sub-base; hydraulically bound mixtures for sub-base and base; and bitumen bound layers. Specifically with respect to unbound sub-base material for all pavements, recycled crushed glass is accepted as up to 15% of the aggregate mix. ▸ A number of demonstration sites have been completed using recycled crushed glass in conjunction with incinerator bottom ash and recycled asphalt plannings.
Institute of Public Works Engineering Division (NSW)	▸ Up to 10% for road base materials (Class R1 and R2); ▸ Up to 10% for select fill (Class S); ▸ Up to 50% for bedding material (Class B); and ▸ Up to 100% for drainage mediums.
City of Canning (WA)	▸ Mandates a minimum of 5% in asphalt, with the opportunity for higher inclusions based upon further testing.
Clarence City Council (Tasmania)	▸ Demonstration project undertaken utilising 100 % RCG for pipe bedding; 5 % RCG in asphalt; and, 40% RCG in sign pole footings, concrete footpaths, kerbing and guttering.
Transit New Zealand	▸ Up to 5% in various pavement layers.

GHD

180 Lonsdale Street
Melbourne, Victoria 3000
T: (03) 8687 8000   F: (03) 8687 8111   E: melmail@ghd.com.au

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		Name	Signature	Name	Signature	Date
0	J Ellis G Shinkarsky V Ahuja	R Warwick	*R Warwick	R Warwick	*R Warwick	08/10/2010
1	J Ellis G Shinkarsky V Ahuja	R Warwick	*R Warwick	R Warwick	*R Warwick	28/02/2011
2	J Ellis G Shinkarsky V Ahuja	R Warwick		R Warwick		23/03/11

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