Project 3B3: Kwinana Industrial Inorganic By-Product Reuse

Review of International and Australian Frameworks and Standards for the Reuse of Inorganic Industrial By-products

September 2008

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This project is carried out under the auspice and with the financial support of the Centre for Sustainable Resource Processing, which is established and supported under the Australian Government's Cooperative Research Centres Program. The Centre for Sustainable Resource Processing is a joint venture between Alcoa, ANSTO, BHP Billiton, CSIRO, Curtin University of Technology, Newmont, Rio Tinto, The University of Queensland, Xstrata, Anglo Platinum, TAFE, Murdoch University. OneSteel, Orica, Rocla, Department of the Environment and Heritage, Hatch, Kwinana Industries Council, Minerals Council of Australia, Gladstone Area Industrial Network, GHD and URS.

Acknowledgements

This report is an output of the research project of the Centre for Sustainable Resource Processing (CSRP) on Kwinana Industrial Inorganic By-Product Reuse project 3B3). The research was conducted by Curtin University of Technology (a core participant of CSRP) through its Centre of Excellence in Cleaner Production (CECP). GHD provided in-kind support for the Project Leadership.

Special acknowledgement goes to Mr Dick van Beers (Curtin) for his contribution to project 3B3 to date. The author also wishes to acknowledge the contributions made to the research by the industry representatives Mr. David Cooling and Mr. Cameron Schuster for their feedback and guidance.

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EXECUTIVE SUMMARY

Various mineral processing operations produce large volumes inorganic residues that are currently stockpiled at designated locations within the Kwinana Industrial Area (KIA). A significant number of these have potential value as useful by-products for various commercial, particularly infrastructure, applications. Many of the inorganic residues generated within the KIA could be utilised as alternative or supplemental sources for the growing demand for construction materials providing these meet specific environmental criteria and technical specifications.

A recent market assessment undertaken as part of the 3B3 Project has identified a number of imminent and planned infrastructure, residential and commercial development projects within a reasonable distance from KIA (approximately 20 km) to assure economic viability for the potential reuse of inorganic materials generated within the KIA. One of, if not the biggest, potential issues related to the reuse of inorganic by-product/waste materials as useful substitutes for virgin materials however is the lack of a regulatory frameworks and suitable standards to enable the routine utilisation of these by-products in commercial infrastructure and development projects.

In light of these known regulatory issues a literature search was undertaken to establish the extent of inorganic by-product use in other parts of Australia and overseas, and what regulatory frameworks, exist, if any to support, or enable, this. Various information sources were found on utilisation rates for inorganic by-products used in a vast range of applications in other countries. These revealed reuse rates of up to 100% in some countries for inorganic by-products similar to those in the KIA. The investigation found that applications of the covered inorganic by-products, or so called secondary materials in some countries or recycled materials in others, were predominantly limited to road/highway construction (predominantly as fill), aggregates for different purposes and cement production.

The Australian experience was found to be limited to a small number of inorganic by-products being used in individual projects. Generally accepted materials are iron and steel slags, as well as fly ash. The use of these products can be attributed to the existence of industry associations for these materials whose primary objective is to conduct research and technology transfer on behalf of their members and to assist in developing market opportunities in the use of these materials for all stakeholders.

It was found that those countries with high re-use rates, such as the USA, a number of European countries and New Zealand, have well established regulatory frameworks and standards for inorganic by-products and their use in a range of applications. Some countries, such as Sweden in fact require that contractor's document why they are not using recycled materials in their projects. There has also been significant research related to the reuse of inorganic by-products in infrastructure projects, showing that, with appropriate regulatory frameworks and standards they can be reused effectively without any adverse environmental impact.

There have been a number of projects within Australia that have re-used industrial by-products, but there are, as yet, no regulatory frameworks or Standards that enable their routine, widespread use. Some individual standards exist (such as in NSW) for the re-use of some materials in roads or cement manufacture. The relatively widespread utilisation of fly ash and iron and steel slag in Australia can be linked to the existence of specific industry associations related to these materials. The Ash Development Association in Australia (ADAA) has developed a range of technical notes, reference data sheets and case studies for fly ash in various applications. The technical notes feature fly ash use in concrete for marine construction, fly ash for embankment construction and soil amendment, as well as ultra fly ash for pavement construction. The published reference data sheets provide technical information on material properties as well as assessment criteria for specific uses.

It is concluded that a number of other countries have already developed regulatory frameworks and Standards that have led to the successful routine, widespread re-use of inorganic by-products. Extensive research related to the reuse of inorganic by-products in infrastructure projects, has shown that, with appropriate regulatory frameworks and standards, they can be reused effectively without any adverse environmental impact. Based on the extensive work already done in a number of other countries, and using what is already done, it would be possible, and relatively easy, to develop, in a relatively short time, an appropriate regulatory framework and standards for the re-use of inorganic by-products in Western Australia (and Australia more widely). This would enable the widespread use of inorganic by-products in a range of infrastructure projects and applications. Separate work has shown that this would have significant benefits for the Western Australian infrastructure industry, which has a shortage of reasonably priced, suitable materials. It would also have enhanced sustainability benefits.

This paper recommends that the CSRP and KIC proactively, and quickly, commence work with the Western Australian Government to develop the relevant regulatory framework and standards to enable the reuse of inorganic by-products in infrastructure projects. Using the range of existing regulatory frameworks and standards that already exist in other countries these could be developed relatively quickly for Western Australia, or Australia as a whole.

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1. Introduction

Various mineral processing operations produce large volumes inorganic residues that are currently stockpiled at designated locations within the KIA. A significant number of these have potential value as useful by-products for various commercial applications. Many of the inorganic residues could be utilised as alternative or supplemental sources for the growing demand for construction materials providing these meet specific environmental criteria and technical specifications.

A recent market assessment undertaken as part of the 3B3 Project has identified a number of imminent and planned infrastructure, residential and commercial development projects within a reasonable distance from KIA (approximately 20 km) to assure economic viability for the potential reuse of inorganic materials generated within the KIA. The assessment was also prompted by the increasing difficulties in obtaining large volumes of basic raw materials in the recent years and the escalated demand expected in the short to midterm future, prompted by the announcements of numerous large-scale commercial and residential development in the region.

One of the potential issues related to the reuse of inorganic by-product/waste materials as useful substitutes for virgin materials is the lack of a regulatory frameworks and suitable standards to enable the utilisation of these by-products in commercial infrastructure and development projects

This report seeks to present a review and summary of existing international and Australian (where they exist) regulatory frameworks and standards for the reuse of inorganic industrial by-products in infrastructure projects.

2. BACKGROUND

Harris (2007) has recently undertaken an investigation into the regulatory issues and barriers to regional synergies in the Kwinana Industrial Area (KIA). In the report five case studies are presented that highlight the key issues of the current regulatory framework that hinder further regional synergies (or the reuse of industrial by-products in commercial infrastructure projects). The study found that although current regulations do not function as direct 'barriers' per se, the current regulatory framework does not encourage or support regional synergy developments. The main findings of the scoping study were that:

- "For inorganic by-products, in particular, there are no standard requirements of reuse for many applications, e.g. as soil conditioning, or for use as a road base;
- The process of authorisation can be time consuming and laborious (particularly because of the above point) and there is often no 'end point' or sign-off for companies;
- As a result companies have continuous concerns of potential opposition to the reuse, with no foreseeable support from government, in particular, because there are no defined
- standards which the activities can be proven against;
- There is a corresponding lack of leadership and support from government when dealing with related community issues and concerns;
- The combined effect of the above points mean that a company's investment in by-product reuse has a lack of security, especially where community concerns can blow out of proportion and effectively end the reuse; and
- Furthermore, by-products continue to build up in storage facilities, and this practice is likely to increase in the future with new companies in the start-up phase and further operations being planned in Kwinana (but also in other parts of Western Australia)."

The paper recommends that, in the short term, the most immediate policy support requirement to foster further resource synergies is the development of standards and guidelines for reuse. These could be customised depending on the particular by-product material and reuse conditions. This would foster the safe reuse of materials and assist companies in showing that they have met the required regulatory standards, which are deemed scientifically safe.

3. Overview of Existing Regulatory Framework in Western Australia

The state and territory environment agencies characterise and regulate industrial residues in different ways (for an overview see: (EPHC 2005)). For most uses, current legislation does not cover specific controls on the use of by-products, notably for the application to land as fertilizers or soil conditioners. In Western Australia, the Department of Environment and Conservation (DEC) is responsible for administering the legislation concerning environmental regulation. The principal piece of legislation with regard to by-product reuse is the Environmental Protection Act 1986.

The DEC regulates the application of biosolids at licensed premises (>1,000 t/a) in accordance with the Draft Guidelines for the Direct Land Application of Biosolids and Biosolid Products (2002). These provide a framework and a system for determining appropriate application rates to avoid building up excess concentrations of metals in soils. The Environmental Protection Act 1986 can deal with instances such as when waste is inappropriately applied to land via a discharge such that it caused pollution, under Section 65 (EPHC 2005). Alternatively, if the site were to become a contaminated site, it could be managed via the Contaminated Sites Act 2003. The Fertiliser Regulations 1978, administered by the WA Department of Agriculture and Food, prohibits the use of prescribed fertilisers, which are defined in terms of metal content.

Legislation for by-product reuse at the Commonwealth level primarily relates to the international transfer and sale of by-products or wastes through legislation such as the Trade Practices Act 1979. The Hazardous Waste (Regulation of Exports and Imports) Act 1989, was developed to enable Australia to comply with obligations under the Basel Convention, and is administered by the Department of Environment and Water Resources (EPHC, 2005). Fertilisers or soil conditioning products are not covered under the Basel convention but are regulated by the Organisation for Economic Co-operation and Development (OECD) control system. Industrial residues can potentially be considered as industrial chemicals and could therefore be subject to the National Industrial Chemical Notification and Assessment Scheme (NICNAS).

In Western Australia, there is currently no set procedure for gaining approval for the reuse of an industrial by-product. One method of gaining approval is through submitting a ‘Notice of Intent’ to the Department of Industry and Resources, which is followed by a formal ‘Public Environmental Review,’ prior to hopefully gaining approval from the Environmental Protection Authority. Alternatively, for projects that have less potential effects on the environment, applications can be submitted to the DEC/EPA for consideration on a case-by-case basis. The EPA reviews documentation sent with the application, such as studies performed by the proponent to examine factors like contaminant levels, potential for any contaminants to leach etc. The EPA itself has no levels to compare the application against and typically compares levels against documentation on contaminated site levels, water quality or bio-solid guidelines.

4. Overview of International and Australian practices in inorganic by-products reuse

4.1. International Experience

Various information sources were found on utilisation rates for inorganic by-products used in a vast range of applications, while in a number of countries no consistent data was available. The information discovered is presented in Table 1, showing the typical rate of reuse for a choice of inorganic by-products relevant or similar to ones generated in Kwinana.

The investigation found that applications of the covered inorganic by-products, or so called secondary materials in some countries or recycled materials in others, are limited to road/highway construction (predominantly as fill), aggregates for different purposes and cement production. The investigation was also restricted to a number of countries due to limited available data.

Table 1: Type and Rate of Reuse of Inorganic By-products Internationally.

Inorganic By-Product	Country	Rate of Reuse	Typical applications	References
Iron making Slag/Blast Furnace Slag	NZ	n/a*	Sub-base aggregate, sealing chip, stabilising additive	(LTNZ 2006)
	Finland	22-36%	Road constructions	(Mroueh et al. 2002)
	USA	90%	Aggregate in concrete	(FHWA 2000b)
	Sweden	45%		(FHWA 2000b)
	Germany	100%		(FHWA 2000b)
	The Netherlands	100%	Cement production	(FHWA 2000b)
	Denmark	70%	Aggregate in unbound layers	(FHWA 2000b)
	France	22%	Aggregates; hydraulic binders	(FHWA 2000b)
	Germany	92%		(FHWA 2000b)
Steel making slag	Denmark	100%	Demonstration/research (low quantity)	(FHWA 2000b)
	Sweden	100%		(FHWA 2000b)
	Finland	10%	Asphalt aggregate	(Mroueh et al. 2002)
	The Netherlands	100%	Hydraulic works and base course; some as sand	(FHWA 2000b)
	France	15%	Bituminous mixes; surface dressings	(FHWA 2000b)
	USA	n/a*	Aggregate; granular base	(FHWA 2000b)

INORGANIC BY-PRODUCT	COUNTRY	RATE OF REUSE	TYPICAL APPLICATIONS	REFERENCES
Fly Ash	NZ	n/a*	Filler, stabilising additive	(LTNZ 2006)
	Finland	40%	Road and field construction, earthfill, asphalt filler	(Mroueh et al. 2002)
	USA	27-39%	Cement production; structural fill	(FHWA 2000b) (ACAA 2004a)
	Germany	86%		(FHWA 2000b)
	Denmark	100%		(FHWA 2000b)
	The Netherlands	100%	Cement, concrete and asphalt filler; as aggregate	(FHWA 2000b)
	France	25%	Hydraulic binders; concrete filler; embankments	(FHWA 2000b)
Bottom Ash	Finland	70%	Road and field construction	(Mroueh et al. 2002)
	USA	31-47%	Asphalt aggregate; granular base	(FHWA 2000b) (ACAA 2004a)
	Germany	96%		(FHWA 2000b)
	Denmark	100%		(FHWA 2000b)
	The Netherlands	100%	Lightweight aggregate; concrete blocks	(FHWA 2000b)
Sand (foundry)	USA	32-45%	Construction fill and concrete	(Anon. 2007) (Guney et al. 2006)
	Finland	n/a*	Insulation structures	(Mroueh et al. 2002)
	France	n/a*	aggregates	(FHWA 2000b)
Chemical Gypsums (FGD** & PG+)	USA (FGD)	75%		(ACAA 2004a)
	Germany (FGD)	100%		(FHWA 2000b)
	EU (FGD)	67-71%		(ECOBA 2004) (ECOBA 2005)
Construction and Demolition Debris (C&D)	The Netherlands	100%	Concrete and masonry granulates used in base course and; in concrete	(FHWA 2000b)
	France	15%	Aggregates; embankments and fill	(FHWA 2000b) (Vázquez et al. 2004)
	Belgium	87%	Aggregates	(Vázquez et al. 2004)
	UK	60%	Aggregates; embankments and fill	(QPA 2007)
	Spain	10%	Base and sub-base; soil base; fill	(Vázquez et al. 2004)

INORGANIC BY-PRODUCT	COUNTRY	RATE OF REUSE	TYPICAL APPLICATIONS	REFERENCES
Boiler Slag	USA	81-91%	Blasting grit; snow and ice control; road base; structural fill; aggregate in asphalt paving; decorative stone and gravel	(FHWA 2000b) (ACAA 2004b)
	EU	100%		(ECOBA 2004) (ECOBA 2005)
Recycled Concrete Aggregate/Crushed concrete	NZ	n/a*	Pavement base or sub-base aggregate	(LTNZ 2006)
	Finland (cc)	17%	Road and field construction	(Mroueh et al. 2002)
	Denmark	81%		(FHWA 2000b)
Recycled asphalt pavement	NZ	n/a*	Recycled asphalt, sub-base aggregate	(LTNZ 2006)
	Finland	n/a*	Recycling to pavement	(Mroueh et al. 2002)
	USA	80%	Aggregate in hot and cold mix asphalt; asphalt cement binder	(FHWA 2000b)
	Sweden	95%		(FHWA 2000b)
	Germany	55%		(FHWA 2000b)
	Denmark	100%	New asphalt	(FHWA 2000b)
	The Netherlands	100%	Hot mix asphalt	(FHWA 2000b)
	France	n/a*	Wearing courses and base	(FHWA 2000b)
Cement Kiln Dust	USA	64%		(FHWA 2000b)

*n/a= not available, **FGD = Flue gas desulphurisation, +PG = phosphogypsum

A 2003 report by Chesner et al. (2003) identified 43 types of secondary/recycled materials used in road construction in the US. Table 2 from this paper shows some of these.

Table 2 By-products and their Application in Roads (from Chesner 2003)

MATERIALS	APPLICATIONS: Asphalt Concrete	Portland Cement Concrete	Stabilized Base	Flowable Fill	Granular Base	Embankment Fill
Baghouse Fines	✓					
Blast Furnace Slag	✓	✓			✓	
Coal Bottom Ash/Slag	✓		✓		✓	
Coal Fly Ash	✓	✓	✓	✓		✓
Flue Gas Scrubber Material						
Foundry Sands	✓			✓		
Kiln Dusts	✓		✓	✓		
Mineral Processing Wastes	✓				✓	✓
Municipal Combustor Ash	✓				✓	
Nonferrous Slags	✓				✓	✓
Quarry Byproducts				✓		
Reclaimed Asphalt Pavement	✓				✓	✓
Reclaimed Concrete Pavement		✓			✓	✓
Roofing Shingle Scrap	✓					
Scrap Tires	✓					✓
Sewage Sludge Ash	✓					
Steel Slag	✓				✓	
Sulfate Wastes			✓			
Waste Glass	✓				✓	

4.2. Australian Experience

Australian Experience is limited to a small number of inorganic by-products. Generally accepted materials are iron and steel slags, as well as fly ash. The use of these products could be attributed to the existence of industry associations for these materials whose primary objective is to conduct research and technology transfer on behalf of their members and to assist in developing market opportunities in the use of these materials for all stakeholders.

Iron and Steel Slag - accepted and used as a cement replacement, with a combined utilisation rate for 2003 of 69% (Gregory et al. 2005). Listed below are some of the projects where slag has been used as an alternative material:

- Blue Scope Steel as a cement replacement (can also be used as a sand substitution);
- Sydney Harbour Tunnel segments to replace 65% of the ordinary cement to provide exceptional performance in the marine environment;

- The third runway at Sydney airport;
- North West Shelf project offshore platform and land based installations. Cement replacement of 25 to 90% (grout application) were used;
- Sea wall of the Sydney Opera House forecourt ;
- As a road paving for sections of Sydney's F4 Freeway (because of anti-skid attributes); and
- In the construction of the concrete walls, floors and beams in many of Sydney 2000 Olympic venues (incl. Equestrian Centre & Velodrome).

Fly ash - For the year 2006/07, approximately 13.5 Mt (million tonnes) of coal combustion products (CCP's) were produced within Australasia (Australia and New Zealand). Of the CCP's produced, some 6.165 Mt (or 46%) can be said to have been effectively utilised. Thirteen percent, or 1.74 Mt, of the CCP's was used in high value added applications such as cementitious applications or concrete manufacture, while 0.744 Mt (6%) was used in non-cementitious applications. In all, 3.684 Mt (27%) was used in projects offering some beneficial use (i.e. mine site remediation, local haul roads etc.). From 1990 to 2006, utilisation rates have increased from 8.4% to 46% (ADAA 2007).

Recycled Asphalt Paving (RAP) - 95% of the RAP generated during maintenance works in NSW for 2005–06 was reused or recycled (NSW RTA 2006).

Flue Gas Desulphurisation Gypsum - In 1998 the Clean Gypsum project was jointly entered into by Pasminco Hobart Smelter (PHS) and Australian Cement Holdings (ACH) to investigate the production and use of market quality chemical gypsum. ACH at Railton produces around 1.2 million tonnes of cement annually and uses approximately 50,000 tonnes of mineral gypsum to achieve this. With all the relevant issues addressed and resolved to the satisfaction of both ACH and PHS a three year supply contract was entered into. Since February 1999 gypsum from PHS has been transported to the ACH Railton plant and mixed on a 1:3 ratio with traditional mineral gypsum sources (DEWR 2003).

Construction and Demolition debris - There is some scattered data for the utilisation of recycled construction and demolition debris (C&D) in Australia. (Cardno BSD 2006) reports 1,616,613 tonnes of building waste was produces in the Perth Metropolitan region for 2003-04 that makes up 56% of the total waste stream. (Cardno BSD 2008) reports that a total of 333,870 (or 20.6 %) tonnes were recovered for that same period. The report states also marginal increase of the recovered material for the following reporting periods in line with the increased volume of disposed C&D. Similar data is available for South Australia (Nolan-ITU 2001) where an estimated 700,000 tones are being processed annually by recycling operators. The Productivity Commissioner (Productivity Commission 2006) states a 57% recycling rate for C&D in Australia for 2002/03, where the rates vary significantly between states. The highest (71%) is in NSW and the lowest (21%) in WA.

5. OVERVIEW OF REGULATORY FRAMEWORKS, GUIDELINES AND STANDARDS

The following Chapter summarises most of the publically available information on International and Australian regulatory frameworks, guidelines and standards related to the reuse of inorganic by-products. The information is limited to documents in English; hence the range of countries review is restricted. The level of detail for different countries varies significantly and the investigators have tried to capture the complexity of the issues associated with assessing the engineering and environmental security of industrial by-products and recycled materials in road construction, and construction in general, as well as other applications.

5.1. International

5.1.1. European Union

The EU has a long history of promoting the use of alternative (or recycled as they are called in some countries) materials. Extensive collaborative research initiatives have been started to promote the reuse of alternative materials as a contribution to sustainable development. Some of the main initiatives related to the scope of this report are outlined below:

- EU Alternative Materials Framework (ALT-MAT Project) (TRKC 2003; CORDIS (n.d.)-b)

  The ALT-MAT program is a very large, comprehensive research program involving Great Britain, Denmark, Sweden, France, Finland, Austria, and Switzerland. This research is addressing issues that will remove and reduce uncertainties associated with using recycled materials. The ultimate objective is to define methods by which the suitability of alternative materials for use in road construction can be evaluated under appropriate climatic conditions. Methods being investigated cover mechanical properties, functional requirements, leaching characteristics, and long-term stability. Also included are inspections of existing roads, preparation of specifications for conducting full-scale trials on embankments, and comparison of the pollution potential with that from sources such as road traffic. The program will also develop recommendations for mitigation measures that can be used to enable the use of alternative materials. Better correlation of laboratory test results to performance in the field is an important goal of the program.

  The outcome of the ALT-MAT project is a toolkit of test methods for assessing the mechanical performance, hydrodynamic properties and potential leaching of contaminants under a range of scenarios. Several national-application tables giving the mechanical test methods and limiting values for alternative materials in different road layers have been prepared, and form a useful guide to the requirements for the use of alternative materials at the present time. A number of environmental tests (primarily leaching tests) are proposed to enable assessments of the potential, or actual, impact on the environment caused by alternative materials, and a model for assessing the environmental impact on groundwater quality is presented. The results can be used both in a site-specific context and in a more general way to develop a rationale for the setting of criteria for material quality and road design, which will ensure adequate protection of the environment.

Inspection and monitoring of existing roads has shown that alternative materials give support to the road pavement layers that is as good as the natural reference materials, and sometimes better. The sites investigated ranged from northern Sweden to south-western France, and hence covered a wide range of climatic conditions. The performance in the field was often better than would have been predicted from laboratory test results. Leaching tests and groundwater sampling indicated that the alternative materials did not appear to be having any negative effect on groundwater quality.

- EU “thematic network “ - use of recycled materials as aggregates in the construction industry” (CORDIS (n.d.)-a)

Along the lines of the EC Directive 91/156/EEC, waste management plans, which are generally developed in a partnership between government, industry and consumers, are currently in the process of implementation at EU and Member State levels. In view of the huge quantities of construction and demolition waste involved (C&D waste for the EU was estimated at 221 to 334 million tons in 1995, which is about twice the amount of municipal solid waste generated), most of these management plans contain measures to stimulate the recycling and recovery of construction and demolition waste as valuable secondary resources. Indeed, when properly sorted, graded and cleaned, the C&D rubble can, as an alternative to dumping, be recycled as secondary aggregates, which can be re-used in the construction sector.

This Thematic Network contributes specifically to a European wide initiative in this respect. Therefore, its main objectives can be summarised as follows:

- to contribute to the introduction of standards and codes of practice related to the recycling of C&D waste on a European level;
- to realise a co-ordination between the non-EC funded R&D efforts regarding the recycling of C&D waste and the use of recycled materials coming from other industrial sectors as aggregates in the construction industry;
- to establish a proven service record for the use of recycled aggregates based on network co-ordinated research actions and reports that compile the results of related R&D projects; and
- to disseminate information with regard to the service record of recycled materials using different tools such as the publication of newsletters, annual reports and strategic notes.

- As one outcome of the above initiatives in 2004 the EU has introduced the new European Standards for aggregates. A significant aspect is that these standards are for ”aggregates from natural, recycled and manufactured materials”, focusing on fitness for purpose and not discriminating between different resources (AggRegain n.d.-a; CEN n.d.). The European Standards facilitate the use of larger amounts of recycled and secondary aggregates across a broad range of applications, including higher value uses, which are contributing to boost the market share of these sustainable materials.

One of the most important standards is BS EN 12920:2006, Characterisation of waste. In recent years the characterisation of leaching behaviour by testing materials under pH controlled conditions has increased significantly. This has been prompted by the fact that pH is one of the most crucial parameters governing the release of constituents from the solid phase into solution. For a wide range of granular materials, this type of characterisation of leaching has allowed identification of key controlling factors. It has facilitated geochemical modelling and, as a result of these actions, it can lead to better choices in waste management by identifying minimal release conditions that can be guaranteed for long periods of time. This type of characterisation has been extended into the field of construction products and stabilised waste to identify in a similar manner controlling factors in cement-based products and cement-stabilized wastes. It allows modelling of geochemical phases and use of the information gained for choices on the long term behaviour of such products both during the phase that they are intact (e.g. service life) as well as during stages in their life cycle that they deteriorate ("end of life"). For the latter situation in particular, the pH dependence test offers the potential to identify the changes in leaching behaviour to be expected; as such situations often involve a change in exposure pH. In addition, it provides the possibility to quantify the magnitude and direction of such changes (van der Sloot 2002).

The pH leachability test outlined above is a key element of the latest European standard. BS EN 12920:2006: Characterization of waste. Methodology for the determination of the leaching behaviour of waste under specified conditions.

The step-wise standard approach covers the following methodology:

- question to be answered;
- description of the scenario;
- description of the waste;
- determination of the influence of parameters on release;
- modelling of the leaching behaviour;
- model validation; and
- conclusions and study report.

- In 2007 the EU has reviewed the definitions of waste and by-products with a view to facilitating waste management classification in the European countries (as per the definition in the communication from the Commission to the Council and the European parliament on the Interpretative Communication on waste and by-products) (EU 2007). It distinguishes between two separate terms for what we commonly call in Australia by-product residue and is generally classified and regarded as waste:
  - *Production Residue* – a material that is not deliberately produced in a production process but may or may not be a waste. The characteristics of the material in terms of its readiness for further use in the economy can mean that it should not be considered to be a waste; and
  - *By-Product* – a production residue that is not a waste.

5.1.1.1. Sweden (FHWA 2000a)

Swedish Road Standard 94 contains specifications for constructing roads and permits the use of recycled materials. It states that residual products may be used if they are accepted by the client and are acceptable from an environmental point of view, do not cause problems during reuse, landfill or destruction, and can be shown to posses at least as good a bearing capacity, stability and durability properties as the materials they replace.

The Swedish codes require that the contractors' document why they are not using recycled materials.

5.1.1.2. Denmark (FHWA 2000a)

The Danish government supports research investigations and demonstrations, tax policies on waste disposal, issuing recommendations, guidance, and requirements for recycling, and also provides assistance in the start-up of private sector companies to process recyclable materials. It also supports research for the use of recycled materials in road construction. The Danish Road Institute is responsible for developing specifications, standards, and guidelines for using recycled materials in road construction. The process involves all interested parties, such as material suppliers, environmental authorities, the Danish Road Directorate, the owner agency, and the contractors.

5.1.1.3. Germany (FHWA 2000a)

In Germany the Closed Substance Cycle and Waste Management Act (1996) administers the producers' responsibility for the entire life cycle of the products they manufacture. As far as possible all residues generated during this life cycle must be fed back into the closed substance cycle. Only waste that cannot be recovered and recycled may be disposed of using methods protective of human health and the environment. Since 1999, companies larger than a certain size must submit waste life-cycle plans. The objective of these requirements is to help increase recycling within and among companies.

Germany uses a different terminology when it comes to materials that can be reused or recycled. A number of materials from construction demolition are classified within the EU as "waste" Germany considers these "secondary materials." For example the EU classifies scrap tires as waste for energy recovery, while Germany refers to them as raw materials to be used in production

A number of standards govern the general requirement for materials (e.g., cement, sand, and bitumen) used in Germany's roads. There are requirements for special applications and these explicitly permit the use of recycled materials and industrial by-products. Recycled materials must, however, fulfil the same requirements as natural materials. Special conditions for using recycled materials include proving that they are environmentally acceptable.

5.1.1.4. The Netherlands (FHWA 2000a)

For instance, in the Netherlands, the Dutch have a formal policy for sustainable development in highways and other construction that supports the use of recycled materials. There is public opposition to the land filling of waste materials and to the excavation of natural materials. The government has a policy that minimises the use of natural materials and promotes the use of recycled materials within a market system supported by government policies. The government cooperates with industry by sharing risk and profit and providing unambiguous technical and environmental standards. The Netherlands is well advanced as far as developing and integrating policies, economic tools, regulations, and other factors needed for increased recycling and the use of recyclables for sustainable road construction.

From an environmental perspective, sustainable development involves three main policies: the Waste Materials Policy, the Soil Protection Policy, and the Surface Mineral Policy. Objectives of the Surface Mineral Policy are to encourage the conservation of raw materials, stimulate the use of secondary materials as much as possible, support the use of renewable raw materials, and ensure that adequate supplies of raw materials are available for construction.

The Dutch Building Materials Decree (Eikelboom et al. 2001) is based on the soil protection act and the surface water protection act. The decree gives quality criteria for the application and re-use of stony materials and earth used as building materials. No difference is made between primary materials, secondary materials and waste materials. The decree is applicable in case these materials are used in constructions where they are in contact with rain, surface water and ground water (e.g. in embankments, road building, outside walls of buildings, foundations and rooves). For the implementation of the decree in the construction industry a large number of standards, methods for testing and certification schemes were developed.

The decree also includes material specific enforcement protocols for an assessment of the quality of the batch examined on the basis of the requirements in the Building Materials Decree.

The Dutch sustainability model emphasises that products should be manufactured for future recycling. Construction should consider future maintenance and demolition requirements. Furthermore, demolition should be done using methods that enhance recovery and utilisation of the materials (e.g., dismantling a building rather than using a wrecking ball).

There are a number of reasons for the high level of recycling in the Netherlands:

- space requirements in a small country with a high population density;
- the need for long-term care of landfills and the desire to minimise this burden;
- avoidance of Waste to Energy where feasible
- use of financial incentives (e.g., high landfill costs, subsidies, etc.) to promote recycling; and
- a ban on land filling of recyclable waste (e.g., C&D).

5.1.1.5. France (FHWA 2000a)

France has a long history of using waste materials, especially during the period of heavy infrastructure building. During this period (1955-1975), blast furnace slag, coal fly ash, coal mining wastes, and other industrial wastes were recycled into construction. At present there is a landfill ban in place as of 2002 that will restrict land filling to only those wastes that cannot be recycled. Other parts of the French policy involve the need to increase the quantities and quality of secondary materials and to improve the quality of household waste.

In France there are two main ways to implement increased use of recyclables in road construction:

- The Directorate for the national road network and the local authorities responsible for their roads can use the technical references for a construction project to permit the use of recycled materials; and
- The contractor can develop bids in response to contract proposal requests that include the use of recycled materials in place of traditional materials, even if the contract request does not include this provision.

Similar to other countries there are no specific standards, specifications, guidance documents, and technical references for the use of recycled materials developed, forcing contractors to use standards for natural aggregates. Therefore the Ministry of Public Works facilitates research to encourage increased use of recycled materials in the industry. The research is conducted by public technical research organisations such as Service d'Etudes Techniques des Route et Autoroutes (SETRA) and Laboratoire Central des Ponts et Chaussées (Central Bridge and Road Laboratory - LCPC). Research generated by these organizations is used to develop regulations, specifications, and codes of practices for using recycled materials. A major objective for supporting this research is to help assure road authorities, consulting engineers, and others that the candidate recycled materials will meet performance requirements.

5.1.1.6. Spain (Vázquez et al. 2004))

After reviewing the consumption of natural aggregates in 1999 the Ministry of the Environment published a National Construction and Demolition Waste Plan (PNRCD) in 2001. The term for application of the Plan is five years and its goals for waste management call for a 10% reduction of construction and demolition waste and attainment of a level of 25% recycling by 2006.

In order to attain these goals, one of the means required by the Plan is the "technical regulation of quality standards for re-usable or recyclable materials obtained from construction and demolition waste". For that purpose, Technical Guidelines for Use have been drawn up for road construction and for application as aggregate in concrete.

The draft regulation establishes certain limitations on the use of recycled aggregate for structural concrete, such as restricting the use of recycled aggregate to mass concrete and reinforced concrete only; and recommending the use of aggregate obtained from the recycling of conventional concrete.

5.1.1.7. Finland (Mroueh et al. 2002) (Mroueh et al. 2000)

In Finland, fly ash and blast-furnace slag has been used in earth construction for over 30 years. However, until the 1980s, much less attention was paid to the assessment of environmental compliance. For most of the materials used there is little information about their long-term performance. Therefore, the use of the materials was hindered by uncertainty about their environmental impacts and technical performance. There was also some confusion about the procedures that should be used for the assessment of technical and environmental applicability of the products. In 1995, a national technology programme—Ecogeo programme—was started with the financial support of Tekes (National Technology Agency). Development of earthworks materials from industrial secondary materials and improvement of the preconditions of use of these materials was one of the main objectives of this programme. Technical and environmental properties of the materials were studied in laboratories and under extreme conditions in numerous test structures and practical applications. As a consequence, several new materials have come into use.

The environmental legislation does not refer to the term by-product. Usually, the industrial by-products and recycled materials are regarded as waste. According to the new Environmental Protection Act, which came into force in 2000, an environmental permit is required for the utilisation of waste. Only short-term utilisation in pilot structures is free from permit.

The permit is granted by the local environmental authority if the amount of waste being used is less than 5000 tonnes. For larger amounts, the permitting authority is the regional environmental centre. In order to apply for an environmental permit, the applicant has to obtain sufficient information about the properties of the waste that is to be deposited, to investigate its environmental and technical compliance, and to draw up plans to prevent possible environmental and occupational hazards.

The Ministry of Environment has started the preparation of a decree of the Council of State, which covers the use of selected environmentally compliant waste materials in earth construction. The aim is to give general regulations, the conditions in which the use of the materials is permitted, and thus, release their use from the permit obligation.

5.1.1.8. Northern Ireland (CPDNI 2006)

The Sustainable Construction Group was set up in 2004 to provide guidance to project sponsors and project managers in relation to sustainable construction. The work of the group is guided by the Policy Framework for Construction procurement and has developed a number of documents that set targets and objectives, as well as a set of guidance notes discussing issues and measures required to implement sustainability in construction.

One of these guidance notes aims at promoting the reuse and recycling of bulk inert materials in construction to reduce consumption of natural resources, energy, transport cost and waste going to landfill. The note features several distinct groups of bulk materials and among these are manufactured aggregates obtained from secondary materials from industrial processes, such as fly ash, blast-furnace slag and glass, as well as recycled aggregate resulting from the processing of inorganic material previously used in construction.

5.1.1.9. UK

The Netherlands is recognised as a leader of reusing recycled material for road construction. However the UK, thanks to the Government's drive to bring more recycled aggregates into the industry, has managed to satisfy it's aggregate needs for 2001 by using 17% recycled aggregates, while the Dutch have managed to achieve only 14.6 (QPA n.d.). Material suitable for use as recycled aggregates fall into two broad groups: demolition and construction materials and industrial by-products (such as glass, foundry sand, fly/bottom ash, etc).

The use of recycled and secondary aggregates is set to 60 million tonnes by 2011 with 40 million tonnes reused in 2001 (WRAP 2004b). A series of projects have been financed by the UK government to look into the sustainable use of resources for the production of aggregates as well as improving their specifications and standards for their use (WRAP 2004a).

The UK Government launched its new strategy for sustainable development, Securing The Future, in conjunction with a Strategic Framework in 2005. The UK Minerals Policy aims to ensure that there is an adequate and steady supply of minerals in the long-term and outlines a number of policies that encourage the use of recycled and secondary aggregates. Furthermore the Waste Management Licensing Regulations (amended in 2006) identify the "*beneficial reuse of waste without further processing*" as one excluded from requiring a licence or exempt from licensing (AggRegain n.d.-b).

5.1.2. USA

In the USA there are several initiatives to increase the use of industrial by-products.

5.1.2.1. USEPA Beneficial Use of Secondary Materials Reusing and (Recycling Industrial Materials) Action Plan (USEPA 2005).

The USEPA Action Plan, developed in 2005 focuses on three materials, considered strong candidates for beneficial use:

(1) Coal Combustion Products, including fly ash, bottom ash, flue gas desulphurisation gypsum, wet and dry scrubber materials, boiler slag and fluidised bed combustion slag;

(2) Foundry Sand from ferrous and non-ferrous metal castings; and

(3) Construction and Demolition Debris, including material generated from construction, demolition, renovation of buildings and infrastructure, and from land clearing.

The objective of the action plan is to increase the amounts of these materials that are beneficially used in an environmentally sound manner, which is in line with the Agency's goals for extending the useful life of landfills, conserving virgin resource and reducing energy use and associated GHG emissions (USEPA 2006a).

5.1.2.2. USA Industrial Waste Reuse Programs (USEPA 2002)

In 2003 the EPA estimated that 7.6 billion tons of non-hazardous industrial waste were generated and disposed of annually in the U.S (USEPA 2006b). Accordingly, the EPA is promoting recycling and emphasising the importance of waste reduction and more efficient and sustainable use of resources (USEPA 2006a). This approach stresses government policies that more effectively promote, and reduce unnecessary regulatory constraints on, more efficient use of the "many materials now considered wastes that will instead be used to produce new materials and products".

The underlying concept of all the state reuse programs is to ensure the protection of human health and the environment by identifying and minimising the potential risks of reusing industrial wastes. This goal is accomplished through one or more of the following approaches: requiring risk assessments for each proposed reuse project; developing general concentration thresholds (both for leachate from the industrial waste and for contaminants in the waste itself) applicable to specific reuses; and implementing other requirements designed to prevent an unacceptable level of risk, such as restrictions on the siting of reuse projects and sampling and testing, notification, and reporting requirements.

The rules and guidance for industrial waste reuse vary significantly across the US states. Some states have a single set of requirements for all industrial by-products or wastes, while others have developed specific regulatory requirements for individual types of industrial wastes (e.g., foundry sand, waste tires, fly ash).

States use a variety of approaches for approving reuse of non-hazardous industrial waste. A key distinguishing factor across state programs is the extent to which they provide streamlined authorisation processes, which can greatly reduce the effort required for a by-product generator and an end user to initiate and sustain a reuse project. Streamlined processes allow for other than case-by-case review of proposed reuses, thereby simplifying and standardising the review process, which can lead to a shorter and more predictable timeline for project approval. They also can lead to improved and more transparent decision-making by providing clear criteria for determining appropriate reuses.

These procedures range from general permitting to exempting wastes meeting strict criteria from industrial waste regulations. *Waste Exemption* is most streamlined procedure to grant an exemption from non-hazardous industrial waste management requirements when the material meets specified, stringent thresholds. Some states exempt waste from notification requirements if it is certified to meet state reuse standards and is being used in a listed, state-approved activity. *Prior Notice* is the process that allows projects to proceed with only prior notification for a range of applications. The process varies between states with certain large projects also requiring a degree of departmental review and approval, while some states require notification of any reuses on their approved lists. States also issue G*eneral Permits* that allow multiple qualified applicants to engage in particular reuses. General permits can cover a particular reuse where any producer of waste material meeting the specified thresholds can apply to join the permit or a general permit is issued to allow users to receive by-products from generators without additional approval from the State. Also in some states most approvals are on a case-by-case basis, but permits can be issued for a specific reuse of waste material from multiple sources at multiple locations.

5.1.2.3. User Guidelines for Waste and By-product Materials in Pavement Construction (FHWA 1998)

This user guideline manual was developed as the result of research conducted for the Federal Highway Administration (FHWA) on the use of waste and by-product materials in pavement construction. This document presents the available information on 19 waste and by-product materials and guidelines for their use (where appropriate) in 6 pavement construction applications. General information on evaluating the suitability of a waste or by-product material for use in pavement construction, including engineering evaluation, environmental issues, and cost issues, is also provided. The 6 pavement construction applications featured are: (1) Asphalt Concrete; (2) Portland Cement Concrete; (3) Granular Base; (4) Embankment or Fill; (5) Stabilised Base; and (6) Flowable Fill. This document includes guidelines for 19 waste and by-product materials. Listed in alphabetical order, they include:

(1) Baghouse Fines	(11) Quarry By-Products
(2) Blast Furnace Slag	(12) Reclaimed Asphalt Pavement
(3) Coal Bottom Ash/Boiler Slag	(13) Reclaimed Concrete Material
(4) Coal Fly Ash	(14) Roofing Shingle Scrap
(5) Flue Gas Desulphurisation (FGD) Scrubber Material	(15) Scrap Tires
(6) Foundry Sand	(16) Sewage Sludge Ash
(7) Kiln Dusts	(17) Steel Slag
(8) Mineral Processing Wastes	(18) Sulphate Wastes
(9) Municipal Solid Waste (MSW) Incinerator Ash	(19) Waste Glass
(10) Nonferrous Slags	

For the 19 materials and 6 major application categories, a total of 55 material-application combinations are included in these guidelines.

The framework presented within the guidelines is intended for use by a waste or by-product material generators who are interested in finding markets for their material, the transportation or environmental official who must evaluate the proposal and assess the suitability of the material and the application, or perhaps a legislative body that may be considering mandated use of a material in a specific pavement construction application.

Generally the user guidelines consist of six major steps in a non-conventional material evaluation process that should be considered:

1. Identification of all relevant engineering, environmental, occupational health and safety, recyclability, and economic issues associated with the proposed material and application;
2. Establishing laboratory testing and assessment procedures and criteria that the material and the product should meet prior to its acceptance;
3. Testing and assessment of results of the material and application for approval or disapproval using the established procedures and criteria defined in Step 2;
4. In case of nonconforming material considering the possibility of modifying the material or the product prior to rejecting it;
5. Identification of issues that could impose significant constraints of the proposed implementation; and
6. Determining whether a field demonstration is necessary to supplement the evaluation and assessment tests and criteria and implementing the demonstration, if required.

5.1.2.4. Framework for evaluating use of recycled materials in the highway environment (FHWA 2001)

Following the development of the User Guidelines for Waste and By-product Materials in Pavement Construction the US Department of Transportation, Federal Highway Administration has developed this framework as a guidance and assistance for States in developing a comprehensive and consistent review and evaluation process for recycled materials use. The purpose of this evaluation framework is to articulate logical process whereby a decision maker can evaluate a recycled material utilisation application and determine whether the proposed application is technically and environmentally feasible. The framework presented is intended as a road map. It follows the process from conception through job-specific production with decision points to modify the recycled materials, if problems are encountered, or to deny the proposed application if problems cannot be rectified. The road map is intended to be a consensus-based document so that all parties in the decision-making process are aware of the evaluation procedure and the criteria that will be used to approve or reject the application.

The evaluation framework consists of a number of stages and is schematically presented in Figure 1. There are seven major application categories in the highway environment in which recycled materials have their greatest potential applicability. These include:

1. asphalt concrete pavements;
2. Portland cement concrete pavements;

3. granular base;
4. embankment or fill;
5. stabilised base;
6. flowable fill, and
7. landscaping applications.

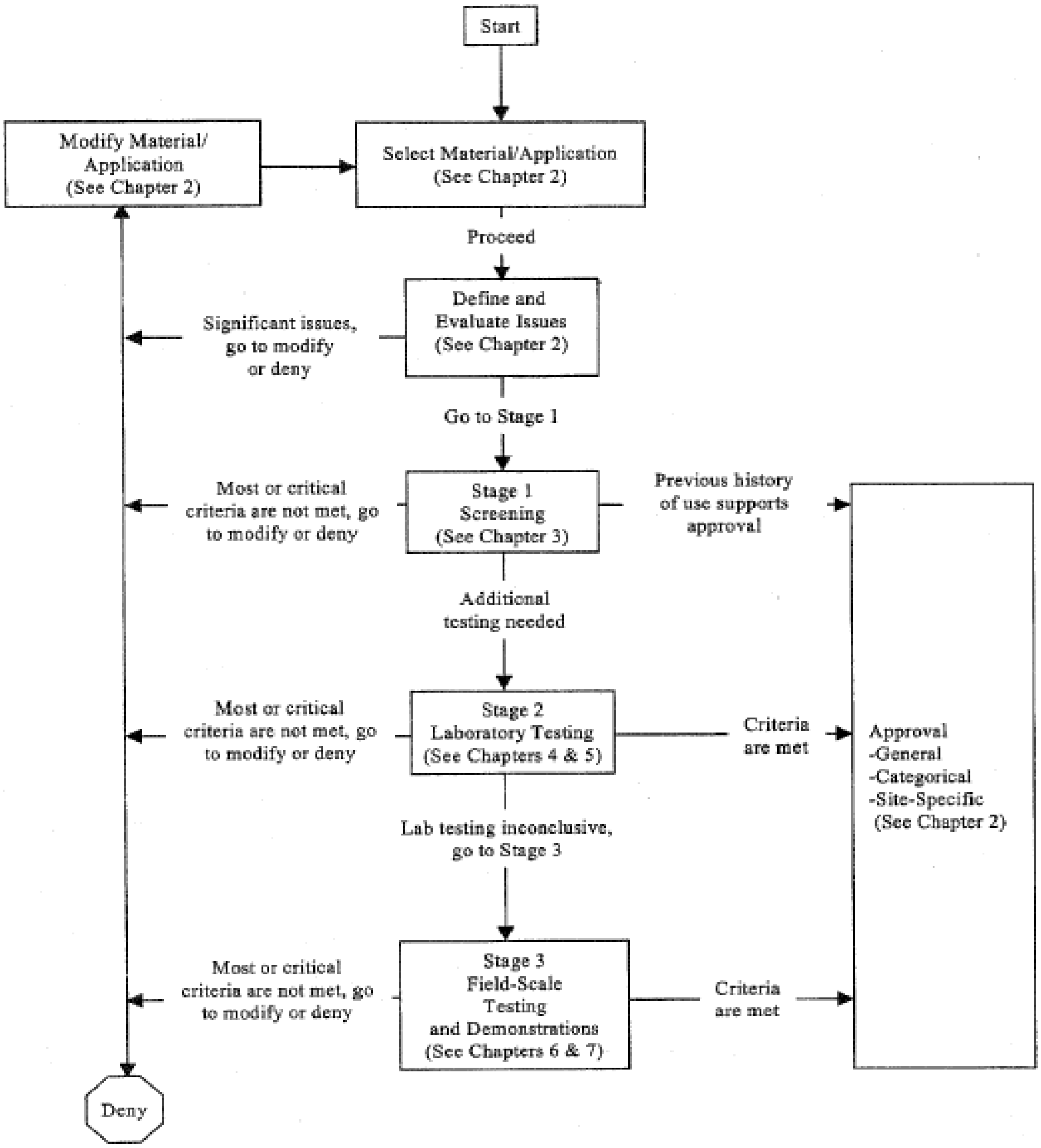

Figure 1: Evaluation flow process (FHWA 2001)

5.1.3. Brazil (Oliveira et al. 2004)

Institutions linked to civil construction in Brazil have been developing studies since 1996 for the reduction, utilisation or recycling of materials suitable for aggregates. Many of the studies about building construction residues were presented in the Seminaries promoted by the Technical Environmental Committee 206 of IBRACON - Brazilian Institute of Concrete, and helped in the elaboration of the Base Texts made by the Work Group of the Civil Construction Industry Syndicate on São Paulo State and forwarded to ABNT – Brazilian Association for Technical Standards.

Resolution 307/02 from the National Environment Council – CONAMA, establishes policies, criteria and procedures for the management of civil construction residues in Brazil. Commissions CE 0213005 and CE 0213006 from ABNT were responsible for establishing the necessary norms to implement activities and technologies resulting from civil construction residues management as defined by CONAMA 307/02 Resolution. The following norms have been developed, though not yet implemented:

- Solid residues from civil construction and voluminous residues. Select and Transfer Areas. Directives for project, implementation and operation;
- Solid residues from civil construction and inert residues. Select and Transfer Areas. Directives for project, implementation and operation;
- Solid residues from civil construction. Recycling Areas. Directives for project, implementation and operation;
- Recycled aggregate from civil construction solid residues. Pavement layers execution. Procedures;
- Recycled aggregate from civil construction solid residues. Employment in pavement and preparing of non-structural concrete. Requirements.

5.1.4. New Zeeland

The current status of environmental criteria for industrial by-products in New Zealand is generally reactive rather than proactive. However, Transit New Zealand has recently promoted the use of industrial by-products and recycled materials by including specifications for the use of smelter slag, crushed concrete and waste glass in the current (M/4) specification for premium base course aggregates (TNZ 2006). The Transit M/4 specification also includes brief descriptions of environmental mitigation procedures for each material. This approach is consistent with Transit's so-called 'triple bottom line reporting', where all major projects are evaluated in terms of three key factors: economic viability, environmental viability, and social viability.

In 2006 international consultants were contracted to develop a set of guidelines to evaluate and screen new and recycled materials used in road construction with respect to any potential for adverse effects on the environment. They recommended that a three-stage material evaluation process be adopted, summarised as follows:

• **Stage 1: initial assessment:** All existing information on the proposed material is gathered and assessed to determine if the material is deemed to be hazardous with respect to ecotoxicity. If the information is insufficient for drawing a conclusion regarding the material's properties and environmental security, the evaluation process moves to Stage 2.

• **Stage 2: material screening tests:** Samples of the proposed material are subjected to a testing programme to determine if leachable contaminants are present that could have an unacceptable environmental impact if the contaminants are released. The leachates are analysed to establish their chemical composition and to identify any aquatic ecotoxicity properties. The evaluation process extends to Stage 3 if the acceptance criteria are not achieved.

- **Stage 3: comprehensive environmental impact assessment:** If the first two stages of the evaluation indicate that materials contain contaminants that have the potential to adversely affect the environment, then a more comprehensive study is required. This considers factors such as: construction parameters;
  - material location and configuration;
  - contaminant release mechanisms;
  - leaching potential with respect to pH;
  - leaching potential with respect to water/solid ratio;
  - effect of sorption;
  - cumulative release of contaminants; and
  - site-specific acceptance criteria for the receiving environment.

A recent report published by Land Transport New Zealand (LTNZ 2006) proposes a material assessment strategy based on a three-tier classification for waste and industrial by-products namely:

- inert;
- notifiable; and
- assessable materials.

Producers of waste or industrial by-products who wish to supply materials for road construction activities would provide evidence to the presiding Territorial Authority (TA) regarding the classification of their products. The various classifications are described in the following paragraphs.

Inert materials pose no threat to the environment and would be accepted for use in road construction applications without limitations and without the need for prior approval. Inert material status could be achieved on the basis of precedent, local or international literature, or by showing compliance with appropriate acceptance criteria without necessarily carrying out specific testing.

Notifiable materials can be considered to be environmentally acceptable in certain applications, locations, quantities or construction processes. Notifiable materials would receive blanket approval by the presiding TA once the producer or user provides evidence of the material's environmental security to the satisfaction of the TA. Such evidence would need to be specific to the proposed application and could include specific conditions or restrictions on use.

Users of notifiable materials would need to notify the TA of any intended use of the particular material, along with a description of the location and application. Permission to use the material would not be withheld unless the application is outside any of the restrictions established for that material.

Assessable materials may be seen as being a significant risk to the environment. The producer or user would need to provide evidence of a rigorous, site specific environmental assessment for each individual application to the satisfaction of the presiding TA prior to using the particular material.

The suggested environmental assessment system would require the material processor or supplier to be proactive in the assessment process and that a high level of co-operation should exist between the supplier and the TA. Ultimately, the TA would have the final say in the acceptability of the proposed material and its status for use. The day-to-day working of the system would be contained in the authority's engineering standards documentation.

A schematic diagram of the proposed assessment process is presented in Figure 2. The key juncture in the process is the testing and compliance check stage. The level of compliance required would be determined by the presiding TA.

Under the proposed system, producers of waste and industrial by-product materials would be able to apply to the TA to raise the classification of any particular material on the basis of additional testing and a favourable track record. Similarly, materials could have their status demoted if worse than expected performance or variability in the quality or composition of the material is discovered. This means that notifiable materials could achieve 'assessable material' status and assessable materials could achieve 'inert material' status at the discretion of the TA.

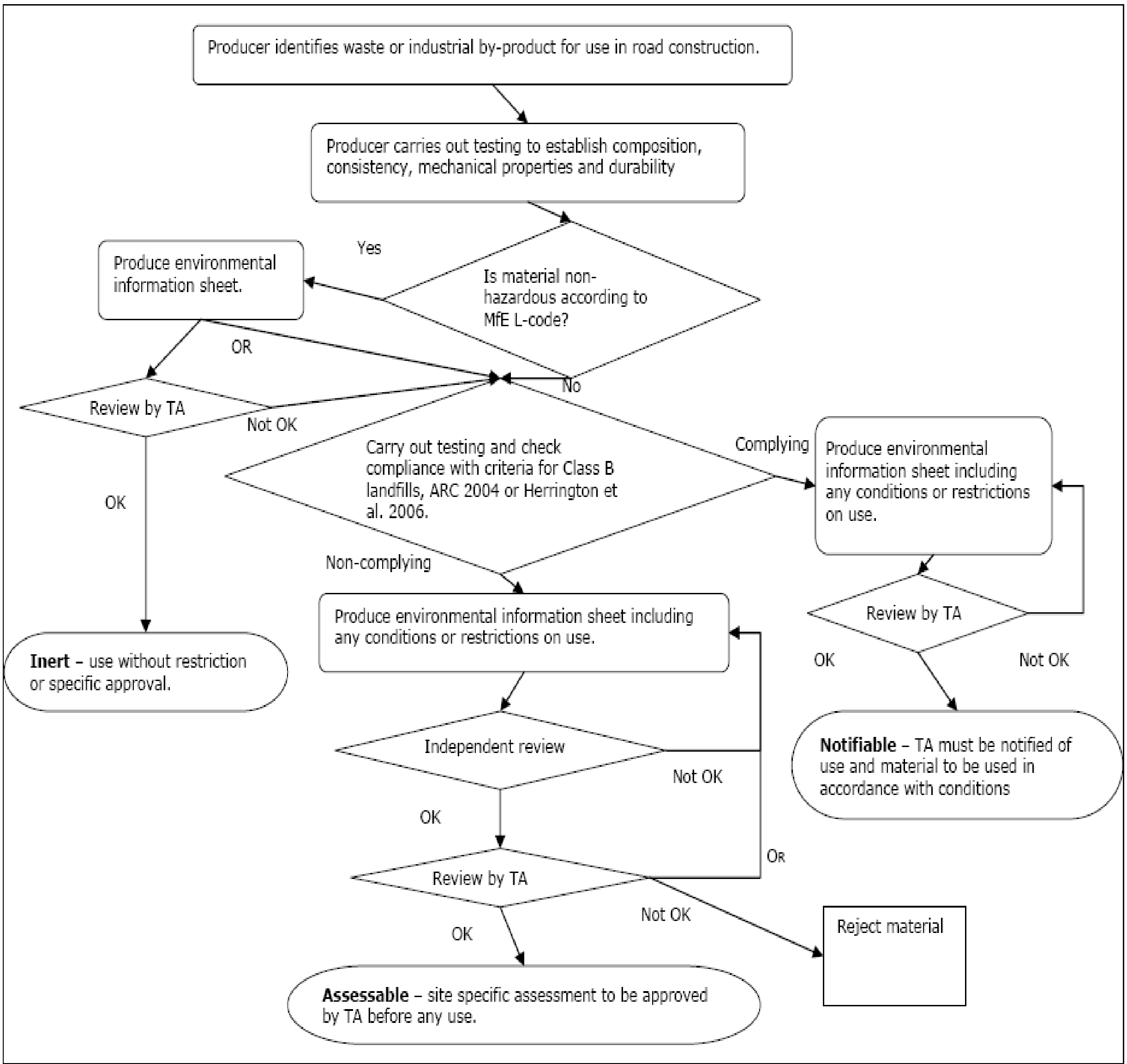

Figure 2: Schematic outline of proposed material assessment process (LTNZ 2006)

In addition in 2006 the Crown Entity responsible for state highways, Transit New Zealand, developed Best Practice Guidelines for the Use of Alternative Materials and Processes in Road Construction (TNZ 2006) featuring alternative materials such as asphalt millings, recycled concrete, meltor slag, steel slag, scrap tyres and glass cullet.

5.2. Australian

Although many by-products such as fly ash, iron and steel slag and recycled road materials have been reused in some applications, methods for evaluation of the engineering and environmental suitability of these materials have not been formally developed. Some state agencies (e.g. NSW Road Transport Authority) have adopted specifications for facilitating the potential for using the recycled materials, but the absence of definitive methods of evaluation and specific criteria for determining the suitability of using these have limited the reuse of many other inorganic residues currently being stockpiled around Australia.

5.2.1. Recycled materials in construction and road works

5.2.1.1. Commonwealth

The Commonwealth Government has provided a guide to the use of recycled Concrete and masonry material, incorporating materials specification at a national level (DEWHA n.d.).

5.2.1.2. NSW

In 2003 Resource NSW published a technical specification (Resource NSW 2003) for the supply of recycled materials, primarily crushed concrete, brick and reclaimed asphalt blends for the following uses:

- Road base for urban roads with light to medium traffic;
- Select fill for use on subgrades to enhance strength or for raising site levels, particularly in roadways and beneath buildings;
- Bedding material for paving blocks to be used in pedestrian areas, carparks, shopping malls, etc; and
- Drainage medium for drainage lines and drainage structures.

This Specification supports the NSW Waste Avoidance and Resource Recovery Strategy 2003, which has targets for waste avoidance and resource recovery. The Strategy is a framework for action designed to guide all sectors to better deal with products and materials in accordance with the principles of ecologically sustainable development. The Strategy is broadly supported by industry, community groups, environment groups and State and Local governments, all of whom have expressed a commitment to working together to achieve the Strategy's goals.

One of the key outcome areas in the Strategy is the 'increased recovery and use of secondary resources'. The Strategy has a target for the increased recovery and utilisation of materials from the construction and demolition sector from 65% in 2000 to 76% by 2014. Increasing the demand for and use of recycled concrete, brick, tile and asphalt materials will make an important contribution towards achieving this target.

In NSW considerable amounts of Reclaimed Asphalt Pavement (RAP) wastes are produced during maintenance works on asphalt road surfaces. An estimated 233,107 tonnes of RAP were generated during maintenance works by, or on behalf of, the Road Transport Authority (RTA) during 2005–06 (NSW RTA 2006). Approximately 224,548 tonnes of this material was reused/recycled. Maintenance contractors are contractually bound to take ownership of RAP wastes and must develop waste management plans that minimise waste where permitted. RAP has multiple potential reuses including within new asphalt mixes, in blended road products as natural aggregate replacements and as fill and road shoulders.

The RTA has developed construction and maintenance specifications that promote waste minimisation and the purchase of materials with recycled content, as follows:

- G34 specification for maintenance works – requires contractors to propose materials and products with recycled content where cost and performance are competitive and environmentally preferable to the non-recycled alternative.
- G35 and G36 for construction works – requires contractors to propose recycled-content materials where cost and performance are competitive and at least the environmental equivalent of the non-recycled alternative. The cost competitiveness of a product or material must be assessed on a project lifecycle basis, considering issues such as impacts on construction practices and future maintenance and disposal requirements. The RTA has a range of specifications (www.rta.nsw.gov.au/doingbusinesswithus/specifications/) with specific allowances for the use of recycled materials, or greater material recyclability at end-of-life, that include:
  - use of RAP within asphalt;
  - use of recycled materials within base and sub-base of pavements;
  - use of scrap rubber within certain modified binder classes;
  - use of slag;
  - crushed concrete, crushed bricks and crushed reclaimed asphalt pavement within road shoulders;
  - stockpiling and reuse of soil from site and the use of cellulose fibre mulch, which must be produced from *pinus radiata* plantation timber or from recycled paper;
  - use of slag/lime blends for stabilisation of earthworks;
  - use of recycled materials as aggregates and binders at depths of around 170 to 300 mm within pavements;
  - mechanical incorporation of existing pavement with binding agents (by-products of the steel and electricity industries);
  - use of recycled materials in the manufacture of geotextiles; and
  - use of recycled glass reflective beads for road linemarking.

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The RTA is involved in a number of research and development projects. For 2005–06 these project have featured three main recycled materials:

- Scrap rubber asphalt - development a Code of Practice and specification for the manufacture and handling of asphalt containing finely ground scrap rubber and to promulgate its commercial application. Once finalised, the Code of Practice and specification are expected to provide an industry-wide standard that would enable uptake of this valuable and technically proven technology;
- Manufactured sands – the project's objective is to revise specification acceptance criteria and associated test procedures for natural and manufactured sands for asphalt and concrete mixes; and
- Recycled crushed glass within concrete - to assess the performance of recycled crushed glass fines as partial cement and sand replacements within concretes used for road pavement construction and related civil works.

5.2.1.3. Victoria

Since 1993, VicRoads, the State Road Authority of Victoria, has allowed the use of recycled crushed concrete as a stabilised subbase material through the inclusion of specific clauses in its standard roadworks specifications (VicRoads 1997). In March 2005, VicRoads released its Environment Strategy 2005-2015 and gave a commitment to manage and plan its activities in a manner that is consistent with the principles of ecologically sustainable development. In line with this commitment VicRoads has developed a number of specifications (VicRoads 2006) for Tyre/Rubber material, Glass, Concrete and Quarry By-products.

5.2.1.4. South Australia

Zero Waste SA waste strategy establishes waste reduction goals and targets for C&D materials and set out steps to achieve these goals and targets. State and Local Government tenders now specify that 30-50% of materials and products with recycled content must be used in construction (Cardno BSD 2006).

5.2.1.5. Western Australia

Main Roads WA 501 (Pavements) specifications recognise the use of recycled concrete aggregate. City of Canning has recently amended their road-base tender documents to include recycled materials. Another example is the City of Cockburn which allows the use of Rock Base, Recycled Concrete or Recycled Asphalt material for Base/Sub-base for pavement & drainage of Non Trafficable lay-down Industrial areas. The material needs to conform to the general specification of road base material (City of Cockburn n.d.)

5.2.2. Slags and Fly Ash

As mentioned previously the relatively widespread utilisation of fly ash and iron and steel slag in Australia can be linked to the existence of specific industry associations related to these materials.

The Ash Development Association in Australia (ADAA) has developed a range of technical notes, reference data sheets and case studies for fly ash in various applications (ADAA 2007). The technical notes feature fly ash use in concrete for marine construction, fly ash for embankment construction and soil amendment, as well as ultra fly ash for pavement construction. The published reference data sheets provide technical information on material properties as well as assessment criteria for specific uses.

The physical, chemical and environmental characteristics of slags produced in Australia have been well researched over the years and have confirmed slag from the iron and steel industry to be inert when classified against NSW EPA waste classifications (Gregory et al. 2005).

The Australasian Slag Association (ASA) has been successfully promoting the utilisation of iron and steel slags since 1990. The ASA have published a number of guides to the use of iron blast furnace slag in cement and concrete, steel furnace slag in asphalt and thin bituminous surfaces and the use of iron and steel slag in roads. Also a number of studies have been carried out assisting the further utilisation of slags, for example studies for the ecotoxicity and chemical characterisation of experimentally generated leachate from slags as well as a study for the slag by-product waste classification.

5.2.3. Foundry Sand (and other foundry by-products)

In 1999 the Queensland EPA published a draft guideline for the beneficial reuse of ferrous foundry by-products (QLD EPA 1999). This guideline provides some options that a foundry have its waste reused as by-products. It provides procedures which the EPA considers are appropriate for an operator to adopt as a significant component of meeting the general environmental duty under the EP Act. The four primary categories of potential by-products featured are: (1) sand; (2) slag and used refractory materials; (3) baghouse dust/scrubber waste; and (4) shotblast wastes.

In the guideline the product sustainability must be determined by a quality assured sampling and analysis program as outlined in Figure 3

Waste assessment to determine current waste stream quantities and qualities
∇
Determine the current cost of disposal
∇
Identify wastes that have potential to become by-products
∇
Segregation of by-products from each other and waste streams
∇
Representative sampling of by-products
∇
Analysis of samples for contaminant levels
∇
Determine consistency of by-product contamination over time
∇
Select potential re-use options for each by-product
∇
Approach potential re-user with proposal
∇
Determine specifications for potential re-use option
∇
Match by-product with these specifications
∇
Assess potential human health and environmental impacts from the by-products
∇
Determine reliability and means of supply over time
∇
Perform a cost benefit analysis to demonstrate a return
∇
Enter into agreement with re-user
∇
Continue segregation and on-going quality assurance

Figure 3: Flowchart of steps to achieve acceptable reuse option (QLD EPA 1999)

6. THE WAY FORWARD

Based on the extensive work already done in a number of other countries, and using what is already done, it would be possible, to develop, in a relatively short time, an appropriate regulatory framework and standards for the re-use of inorganic by-products in Western Australia (and Australia more widely). This would enable the widespread use of inorganic by-products in a range of infrastructure projects and applications. Separate work has shown that this would have significant benefits for the Western Australian infrastructure industry, which has a shortage of reasonably priced, suitable materials. It would also have enhanced sustainability benefits.

This paper recommends that the CSRP and KIC proactively, and quickly, commence work with the Western Australian Government to develop the relevant regulatory framework and standards to enable the reuse of inorganic by-products in infrastructure projects. Using the range of existing regulatory frameworks and standards that already exist in other countries these could be developed relatively quickly for Western Australia, or Australia as a whole. This includes a standard, similar to the European one, for testing materials.

Concurrently with this, CSRP and the KIC should undertake research to develop the required beneficiation methods and equipment to prepare the materials to the required standard and specifications. A number of trials, or demonstration projects should be undertaken, in conjunction with the relevant Government agencies, using the materials in a range of infrastructure applications. Research should also be undertaken to assess the life-cycle sustainability benefits (or otherwise) of reusing inorganic by-products compared to using virgin conventional materials. This could produce a number of case studies that could inform Government and the community about the sustainability benefits of using these materials.

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