

**MARKET DEVELOPMENT STUDY FOR
RECYCLED AGGREGATE PRODUCTS**

Report to

WASTE REDUCTION ADVISORY COMMITTEE

Thurber Engineering Ltd.
Calgary, AB

H.S. Crawford, P.Eng.
Review Principal

<p>PERMIT TO PRACTICE THURBER ENGINEERING LTD.</p> <p>Signature _____</p> <p>Date _____</p> <p>PERMIT NUMBER: P 5186 The Association of Professional Engineers, Geologists and Geophysicists of Alberta</p>
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S. Cullum-Kenyon, M.Sc.
Project Engineering Geologist

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1 INTRODUCTION

1.1 General

Thurber Engineering Ltd. was retained by Alberta Environment to provide technical input to their Construction, Renovation and Demolition (CRD) Waste Reduction Advisory Committee (WRAC) with respect to the use of recycled aggregates within the province of Alberta. The scope of the assignment was discussed in a meeting between Mr. Henry Crawford, P.Eng. of Thurber and the committee chairman, Mr. Clyde Fulton, P.Eng. of CH2M Gore & Storrie, on September 26, 2000 and outlined in a fax received from Mr. Fulton on September 28, 2000.

This assignment has been undertaken under the terms of Alberta Environment Agreement No. 01-0164. The contact person at Alberta Environment has been Ms. Judy Morris.

1.2 Scope of Work

The scope of this study has been as follows:

- Identify potential uses of recycled aggregates
- Identify technical issues that impact on the use of recycled aggregates
- Research the state of practise in other jurisdictions with respect to use of recycled aggregates (e.g. other provinces, the United States, Europe)
- Meet with representatives from the major users or potential users of recycled aggregates in the province (e.g. Alberta Infrastructure, City of Edmonton, City of Calgary) and report on their state of practise with respect to use of recycled aggregates
- Identify measures that could be taken to increase the use of recycled aggregates in Alberta
- Present the results of the study to the WRAC committee and prepare a report documenting the findings.

1.3 Methodology

Much of the information for this study was obtained by literature review, with significant sources of data being information posted on the internet by various national, regional and local government, environment, highways and research groups. Two 3-ring binders of relevant documents obtained from the internet are being submitted under separate cover as well as a single CD containing electronic versions of the references obtained from the internet. These include technical articles as well as example specifications used by different government agencies.

Information on local practice specific to Alberta was obtained through interviews with both end-users and producers. Specific individuals contacted included:

Mr. John Mundy and Mr. George Calvez,	City of Edmonton
Mr. Hubert Crevels and Mr. Mel Portigal,	City of Calgary
Mr. Ted Harrison,	Alberta Infrastructure
Mr. Bruce Blue,	Alberta Infrastructure
Mr. Don Scheurman	Fish Creek Contractors

2 NATURAL VERSUS RECYCLED AGGREGATES

2.1 Definitions

For the purposes of this study, aggregates are defined as particles of rock or recycled materials, used bound or un-bound, as part of an engineered structure. Natural aggregates are produced from natural sources, such as fluvial or terrestrial gravel deposits. Recycled aggregates are produced from re-processing of mineral waste material, with the largest source being construction, renovation and demolition (CRD) waste.

2.2 Natural Aggregates

Natural or virgin aggregates include crushed rock and dredged or terrestrial sand and gravel. Terrestrial sand and gravel sources include fluvial (river)

and glacial deposits, and weathered or eroded rock in arid or tropical regions.

The primary sources of natural aggregates in Alberta are fluvial or glacial deposits of gravel. These deposits occur on both crown and private land and are developed as “gravel pits”. The distribution of gravel pits across the province is quite variable resulting in virgin aggregates being more plentiful in some areas than others. Not surprisingly, the market value of the aggregate will vary regionally depending upon the number and relative proximity of the gravel pits within the area. (It should be noted that a large component of the cost of aggregate is the transportation cost of hauling the aggregate from its source to the point of usage).

Natural aggregates from gravel pits can be used in an unprocessed form, generally referred to as “pitrun”, or they can be processed, which typically entails passing the natural aggregate through a crusher. Gravel producers typically will use a crushing plant to produce a range of gradations suitable for various applications.

Other aggregate processing includes the use of washing plants, where excess fines (minus 80 micron material) are “washed” from the natural aggregate.

Aggregates can also be produced by crushing massive rock (bedrock) mined from quarries. Within Alberta, such quarries have been developed at selected locations within the Alberta Foothills.

2.3 Recycled Aggregates

Recycled aggregates are produced from the re-processing of mineral waste materials, with the largest source being construction, renovation and demolition (CRD) waste. A significant proportion of CRD waste is Portland cement concrete which produces Recycled Concrete Aggregate or RCA. Recycling of asphalt concrete road surface millings, produces Recycled Asphalt Pavement (RAP).

Other materials that are recycled and used as aggregate include municipal waste e.g., crushed glass, and industrial or mining by-products, such as blast-furnace slag, pulverized fuel ash (fly ash) or colliery spoil. These recycled materials are not the subject of this study, but provide an important additional source of aggregates for a number of uses.

2.4 Composition of CRD Waste

CRD waste used to produce recycled aggregates generally consists of varying proportions of concrete, brick and masonry. In North America, close to 75% of construction raw material is concrete, providing a potentially large source of good-quality raw material for recycling. In Europe, the literature suggests that mineral CRD waste consists of roughly equal proportions of masonry (brick) and concrete waste.

To produce good quality recycled aggregate, proper separation of unsuitable materials from the aggregate feedstock is important. RILEM, the international union of testing and research laboratories, has proposed a classification system for separated CRD waste for production of recycled aggregate, with limits on impurities (see Table 1). This classification and the associated specifications are being included in the European Standard specifications for aggregate (CEN Technical Committee TC154 'Aggregates'). Control of impurities is necessary to ensure that finished products, particularly concrete, have consistent quality and durability. It should be noted that heavy steel reinforcement in the concrete introduces additional problems and costs with respect to recycling the concrete.

Table 1 - Proposed composition of types of recycled aggregates (RILEM)

Type of Aggregate	Composition	Impurities	
		Foreign material ¹	Total organic material
I	Mainly derived from masonry (brick)	≤ 5%	≤ 1%
II	Mainly derived from concrete	≤ 1%	≤ 0.5%
III	Mixture with not less than 80% natural aggregate, not more than 10 % Type I, and up to 20 % Type II	≤ 1%	≤ 0.5%

¹ – Deleterious material such as glass, bitumen, soft materials

Most researchers recommend that separation of CRD waste occurs at the waste-originating site. For some demolition projects, such as a concrete bridge, this is not a significant issue as it is relatively easy to separate the concrete from the other building materials that may be present (e.g. metal railings, asphalt concrete road surfacing). However, for other demolition projects, such as buildings, separation of the various waste materials can add significantly to the demolition cost. In our literature search, it was found that some jurisdictions, mostly in Europe, had monetary incentives to ensure separation of recyclable wastes occurs during the demolition phase e.g. waste or landfill taxes which vary with types and composition of waste.

2.5 Recycled Concrete Aggregate (RCA)

Recycled aggregate produced from crushed concrete is generally regarded as a higher quality product than aggregate produced from mixed CRD waste. In some applications, RCA has been found to be superior in performance to natural aggregates.

RCA use in Portland cement concrete and other bound applications is subject to a number of technical issues, which in turn affect the range of acceptable uses and economics. The physical properties of Portland cement concrete produced using RCA are strongly influenced by the cement paste used in the original concrete. Other issues include:

- Unprocessed RCA generally has a higher fines content than processed natural aggregates. Fines produced from the cement paste in Portland cement concrete have an absorption of up to 8 times that of natural aggregate fines. This means that asphalt produced using RCA will require a greater proportion of bitumen than asphalt produced from crushed stone aggregate, increasing material costs and adversely affecting performance. Similarly, in Portland cement concrete, the additional absorption requires that more water be added, resulting in a higher water-cement ratio, and thus affecting the physical properties of the concrete. In particular, the compressive strength and modulus of elasticity of concrete produced from RCA with significant fines are lower than for concrete produced with natural aggregate. In the UK, RCA is generally screened to exclude material finer than 5 mm, with the fines used as a filler in other applications.
- In fill applications, the fines content of unprocessed RCA may restrict drainage, particularly in road sub-base applications. However, the fines

also serve to facilitate compaction and in some jurisdictions, the use of recycled materials is preferred for this reason.

- Dissolution and/or precipitation of mobile components of the cement paste e.g., calcium hydroxide and calcium carbonate, can potentially cause clogging of filter media, groundwater contamination, and inadequate aggregate soundness. However, for dense roadbase applications, dissolution and precipitation may actually serve to strengthen the roadbase.
- Reactivity of RCA may be of concern, particularly in relation to alkali silica reaction (ASR) and chloride content (where the new concrete is to contain embedded metal). Assessment for the potential for ASR in concrete produced with RCA is complicated by the alkali contribution of the RCA to the new concrete. Guidance on assessing ASR risk is available in UK BRE Digests 330 and 433.
- There is potential for contaminants in RCA depending on the previous use of the source concrete. Natural aggregates are also potentially subject to contamination, but generally it is easier to screen natural aggregates for contaminants than it is to screen recycled materials, particularly when the RCA is of mixed or unknown provenance.
- Drying shrinkage for concrete produced with RCA is 10 – 30% greater than for natural aggregates.
- Packing density for crushed materials is lower than for rounded natural aggregates, requiring more cement paste and hence increasing cost.

One of the main concerns related to RCA use is long-term durability. Additional research is currently being conducted in Europe and the US on recycled aggregate durability.

2.6 Recycled Asphalt Concrete Pavement (RAP)

Asphalt concrete can be reclaimed during road re-surfacing operations, either through a milling process, that typically removes the upper 25 to 50 mm, or through full removal of the entire asphalt layer. The recovered material can be incorporated into new asphalt mixes, either on its own (Hot In-Place Recycling) or as an additive in the production of new asphalt concrete.

In the US, 80% of the millings generated during asphalt pavement re-surfacing are re-used. Typically, asphalt re-surfacing materials in North America include up to 20% RAP.

In Europe there is a greater acceptance of the use of RAP. In the Netherlands, for instance, an innovative Swiss-designed double-drum hot mix plant is being used which is capable of recycling up to 70% RAP. Acceptance and use of RAP is highly variable within Europe and the United States, with a variety of factors influencing uptake.

3 USES OF AGGREGATES

3.1 General

Aggregates are used extensively in civil construction projects, including: the production of Portland cement concrete; the production of asphalt concrete; granular sub-base in road construction, and; as drainage or filter media (e.g. sub-drainage systems). Aggregates are also used for general or structural fill, railway ballast, and mortar or other jointing or surface rendering materials.

The following sections look at the major uses for aggregates and the physical properties required for each use. Table 2 lists the various test procedures applicable to each use. The suitability of using recycled aggregates is discussed at the end of each section.

3.2 Portland Cement Concrete

3.2.1 General

Aggregates used to produce Portland cement concrete are comprised of sand and gravel sizes, and are mixed with a binding cement paste and water to produce a rigid building material used extensively in civil construction projects. Varying the proportions of each component, and through the addition of various admixtures, the properties of the concrete (e.g. strength, rate of strength gain, freeze-thaw durability, workability, etc.) can be tailored to specific applications.

Aggregates used in the production of Portland cement concrete typically must be of good quality and must remain stable during the initial mixing, the curing period (as the cement hydrates) and over the design life of the structure.

In Alberta, two common issues that affect the durability of Portland cement concrete are:

- *Water soluble sulphates*. Water soluble sulphates are common in the soils across Alberta and, when present, will chemically attack conventional Portland cement concrete. Where these sulphates are known to exist, all buried concrete must be manufactured using “sulphate resistant” (Type 50) cement.
- *Alkali Aggregate Reactivity (AAR)*. AAR, sometimes referred to as “concrete cancer”, is a condition that occurs when the concrete aggregate is chemically unstable. Aggregates prone to AAR are known to exist in Alberta and hence extensive testing of potential aggregate sources must be completed before the aggregate can be used to produce structural concrete.

3.2.2 Suitability of Recycled Aggregates

Recycled aggregates are not commonly used for production of Portland cement concrete for several reasons. Firstly, Portland cement concrete is generally produced for the manufacture of structural elements that must meet strict strength and durability requirements. Consequently, stringent quality control procedures are required for all materials used in its manufacture. With respect to the aggregate, these include gradation and soundness criteria, and a range of other requirements, as noted in Table 2. Furthermore, the trend in civil engineering is towards more sophisticated concrete mix designs (and higher strength concrete) making the future specifications for aggregate even more demanding.

Recycled aggregates can be used in the production of some Portland cement concrete, however, their use requires strict control on the source(s) of the parent material. To produce recycled aggregate that potentially would meet the technical specifications and performance expectations for structural Portland cement concrete, would require extensive screening and testing of the recycled material, making it prohibitively expensive, at least for the foreseeable future in Alberta.

There are some applications where Portland cement concrete is used in non-structural applications where strength and durability is less of a factor. For example, concrete anchor blocks used in the pipeline industry are non-structural elements that could be produced using recycled aggregates. It should be noted, however, that concrete suppliers often produce such non-structural elements using conventional Portland cement

concrete that did not, for whatever reason, meet the technical specifications required for other applications. (i.e. if a concrete batch intended for use in structural concrete is rejected, it will be used to produce less critical concrete elements, such as anchor blocks).

3.3 Granular Base Course (G.B.C.) For Roads

3.3.1 General

Aggregates are used extensively in road building both in the unbound layers (granular base course) and the bound layers (Portland cement concrete or asphalt concrete). The key properties required of aggregates used for G.B.C. are: hardness, toughness, soundness and gradation. The range of tests used to evaluate GBC aggregates is summarised in Table 2.

The granular base course is typically placed directly on the native soil (sub-grade) and provides both strength and sub-drainage to the pavement structure. The granular base course may be comprised of one or more layers of gravel aggregate (typically two). For municipal roads, as well as major highways and secondary roads, the GBC is typically surfaced with asphalt concrete. For example, the pavement structure for a municipal collector road might consist of the following:

Asphalt Concrete	100 mm
Crushed Gravel (20 mm minus)	200 mm
Pitrun Gravel (75 mm minus)	300 mm

The thickness and composition (i.e. grain size distribution) of each layer will depend on several factors, including the quality of the subgrade, the quality of the aggregate, climatic conditions (e.g. freeze thaw cycles), the volume and type of traffic (i.e. axle loads) and the design life of the road.

3.3.2 Suitability of Recycled Aggregates

From a technical perspective, recycled aggregates can, and are, used as granular base course in road construction. The recycled material can consist of recycled Portland cement concrete, recycled asphalt concrete, or a blended mixture of the two.

In many applications, recycled aggregate will prove to be superior to natural aggregate for use as GBC. For example, if a new road (or parking lot) is to be built over an area of soft, wet subgrade, placing a base lift of

coarse, recycled concrete will serve to stabilize the base and provide an improved working surface for constructing the pavement structure.

It has also been demonstrated, particularly within the City of Edmonton, that using a blended mix of recycled Portland cement concrete with recycled asphalt concrete can produce a very stable base course for road pavements.

3.4 Asphalt Concrete

3.4.1 General

Asphalt concrete is used for paving of roads and is comprised of sand and gravel aggregate mixed with bitumen. The aggregate serves to provide both strength and skid resistance to the asphalt.

Aggregates used in asphalt pavement typically are crushed and must meet strict gradation and soundness requirements to optimize the strength, durability and workability of the asphalt. The range of tests applicable to asphalt concrete are identified on Table 2.

3.4.2 Suitability of Recycled Aggregates

Recycled Asphalt Pavement (RAP) is routinely used in the production of new asphalt concrete. Typically up to 20% of Recycled Asphalt Pavement (RAP) is used in conventional asphalt mixes although some jurisdictions will allow up to 50% or higher.

Hot-in-Place recycling of asphalt concrete is also gaining increased acceptance. As the name suggests, the process is done on site, and entails milling off the top surface of the asphalt, then heating and mixing the millings with additional bitumen and appropriate “rejuvenators” before re-placing it, all in a single operation. This technology is used mainly in urban settings where existing curbs and gutters make it more difficult to simply add another pavement overlay. Hot-in-Place Recycling is also often used for localized repair to existing asphalt pavements.

3.5 Embankment Fill

3.5.1 General

Aggregates are not commonly used to construct fill embankments because, in most cases, the cost of aggregate will be significantly higher than that of common fill. Nonetheless, there are cases, for example, where settlements cannot be tolerated, that the use of aggregates could be justified (compacted granular soil will settle significantly less than compacted cohesive soils).

More commonly, aggregates are used for selective “material replacement”. For example, if soft sub-grade conditions are encountered during road construction, it may be warranted to sub-excavate the soft material and replace it with imported granular fill. Similarly, if wet weather is encountered during construction, the road-building contractor may be prepared to pay a higher price for granular material because it is generally easier to compact in wet weather conditions than non-granular material.

3.5.2 Suitability of Recycled Aggregates

Recycled aggregates would be well suited for this purpose for the same reasons identified in Section 3.3.2.

3.6 Railway Ballast

3.6.1 General

Railway ballast consists of coarse aggregate, provides a free-draining foundation for the track. The aggregate used must be strong, angular material, with a high resistance to abrasion. Select crushed rock aggregate is generally used, though in the US crushed slag and crushed or uncrushed gravel are also used.

3.6.2 Suitability of Recycled Aggregates

Recycled aggregates are not commonly used for railway ballast because of concerns about strength, abrasion resistance and durability.

3.7 Drainage and Filter Media

3.7.1 General

A relatively small volume of aggregate production goes to provide drainage or filter media for various applications, including sub-drains for buildings, dams and other engineered structures, as well as filters for sewage and water treatment. Grading, strength and durability, particularly with respect to chemical attack, are the key properties in these applications.

3.7.2 Suitability of Recycled Aggregates

Recycled aggregates are not commonly used for filter or drainage media because of concerns about durability, particularly with respect to chemical attack from impurities in the groundwater or leachate being filtered.

Table 2 - Applicable tests to assess quality of aggregate

	Asphalt (RAP)	Portland Cement Concrete	Granular Base	Embankment Fill	Drainage Material
Characterization Tests					
Moisture Content	✓	✓	✓	✓	✓
Gradation	✓	✓	✓	✓	✓
Petrographic Examination	✓	✓			
Organic Impurities	✓	✓			
Soundness (Chemical)	✓	✓	✓	✓	
Freeze-thaw Soundness	✓	✓			
Particle Shape/Texture	✓	✓	✓		✓
Los Angeles Abrasion	✓	✓	✓		
Specific Gravity and Absorption	✓	✓			
Aggregate Expansion (Hydration)		✓	✓	✓	
Atterburg Limits (Plasticity)	✓	✓	✓	✓	
Potential Alkali-Silica Reactivity		✓			
Corrosion Testing (pH)		✓			
End Use Tests					
Mix Design	✓	✓			
Air Content/Slump		✓			
Marshall Analysis	✓				
Compressive Strength		✓			
Standard Proctor			✓	✓	✓
Permeability			✓	✓	✓
California Bearing Ratio			✓	✓	
Field Density Testing	✓		✓	✓	

4 USE OF RECYCLED AGGREGATES OUTSIDE ALBERTA

4.1 Europe

It is estimated that 'core' CRD waste amounts to around 180 m tonnes/yr in the European Union (EU), or about 1.3 kg/person/day. This compares to estimates of between 0.05 and 1.6 kg/person/day in North America. There is significant variation in CRD waste production across the EU, with Germany and the Netherlands producing 1.9 kg/person/day, while Sweden, Greece and Ireland produce less than 0.5 kg/person/day.

A number of programs and initiatives are underway in the EU to reduce and re-use CRD waste. These range from studies of CRD waste management practice and recommendations on policy, to development of EU-wide standards and specifications.

Although there is a general move towards sustainable development in the EU, there are significant regional differences in policy, implementation and standards. For example, tax structures (both incentives and disincentives) play a significant role in promoting recycling in the Highways environment in Denmark, Sweden and the Netherlands. The following sections summarise regional practice within selected EU countries. Further information is included in the EU ALT-MAT report and the US DOT/FHWA report on 'Recycled Materials in European Highway Environments' included in the appendix.

4.1.1 United Kingdom

The UK has a well-defined set of standards and specifications for aggregates and their use. BS 812 details testing of aggregates, while BS 882 provides specifications for natural aggregate used in concrete. General guidance on recycled aggregates is given in BS 6543, though this standard is rarely quoted in contract documents. The Institution of Civil Engineers has produced model contract documents for a wide variety of applications, which are used in most civil engineering contracts, while the Department of Environment, Transport and the Regions (DETR) 'Specification for Highway Works' details specifications for both bound and un-bound aggregates, including some guidance on recycled materials. The DETR specifications are used for all trunk road and motorway construction in the UK. With increased integration into the European Union, the UK will be expected to adopt European Standards for aggregates, including recycled aggregates, some of which are currently under development.

Quality Control and Quality Assurance (QC/QA) are an important aspect of UK civil engineering construction. All investigation and construction work for the Highways Agency requires BS 5750 QC/QA certification, with testing laboratories requiring NAMAS QC/QA accreditation. A joint initiative by the Quarry Products Association, the DETR and the Highways Agency in 1997 to review the 'Specification for Highway Works' to remove impediments to the use of recycled aggregates that could not be technically justified, identified that a formal quality control procedure was required for recycled aggregates. The result was a recommended procedure, published by the Building Research Establishment (BRE), which is expected to form a BSEN9002 registered QA scheme.

BRE has produced other guidance on the use of recycled aggregates, including Digest 433, which covers the use of crushed concrete and masonry and blends of recycled and natural aggregates (see Table 3 and 4 below), and Information Paper 5/94, which covers the use of recycled aggregates in concrete. BRE guidance often supplements or precedes specifications and procedures contained in the British Standards, and provides practical advice on design and specifications. BRE Digest 363 on 'Sulphate and acid resistance of concrete in the ground' has been generally adopted as a standard for assessing hazard due to sulphate attack.

BRE Digest 433 defines three classes of recycled aggregate, based on the RILEM proposed classes, which broadly define the composition of the material (see Table 3). Suggested maximum levels of impurity for various uses are given (see Table 4), together with more detailed guidance on specific end-uses, and discussion of acceptance of additional materials in other jurisdictions.

Table 3 – Recycled Aggregate (RCA) Classes (BRE Digest 433)

Class	Origin	Brick content (by wt.)	Description
RCA(I)	Brickwork	0 – 100 %	Lowest quality material: - low strength - high level of impurity 10% Fines (BS 812-111) \approx 70kN
RCA(II)	Concrete	0 – 10 %	Relatively high quality with low levels of impurity. Primarily crushed concrete, but may contain significant natural aggregate. 10% Fines (BS 812-111) $>$ 100kN
RCA(III)	Concrete and brickwork	0 – 50 %	Mixed material with similar levels of impurity to RCA (I) but wider range of uses e.g., 80/20 blend of natural aggregate/RCA(III) may be acceptable in all grades of concrete.

Table 4 – Maximum recommended levels of impurity (by wt.)

	Use in concrete as coarse aggregate	Use in road construction – unbound/cement-bound material ¹	Hardcore, fill or granular drainage material
Asphalt and Tar (as lumps, e.g., road planings, sealants)	Included in limit for other foreign material	10% in RCA(I) ² or 5% in RCA(II) ² or 10% in RCA(III) ²	10% ²
Wood (includes other materials less dense than water)	1% in RCA(I) or 0.5% in RCA(II) or 2.5% in RCA(III) ³	Sub-base Type1 & 2: 1%, or CBM (1-5): 2%, and Capping layer 2%	2%
Glass	Included in limit for other foreign material	Content above 5% to be documented	Content above 5% to be documented
Other Foreign Material (e.g., metals, plastics, clay lumps)	5% in RCA(I) or 1% in RCA(II) or 5% in RCA(III) ³	1% (by volume if ultra-lightweight)	1% (by volume if ultra-lightweight)
Sulphates	Concrete and CBM: 1% acid-soluble SO ₃ ⁴ . Unbound material: See Digest 363 if near concrete.		

¹ – Sub-base Type 1 or 2 or CBM 3,4 or 5: RCA(II) only; Capping layer 6F1 or 6F2 or CBM 1 or 2: normally RCA(I) or RCA(III).

² – No limit if physical and mechanical test criteria are satisfied.

³ – RCA(III) must not replace more than 20% of natural aggregate. Limits on wood and other foreign matter assume that there will be no contribution from the natural aggregate.

⁴ – Limit of 1% acid-soluble SO₃ applies to 1:4 mixtures of RCA(III):natural aggregate.

The Aggregates Advisory Service (AAS), a service of the DETR, has produced a number of reports, available online, providing information on recycling, case histories, sources of information and best-practices guidance. The service is designed to help the government “to achieve its objective of reducing the construction industry’s dependence on primary aggregates and increasing the contribution from secondary and recycled materials”. AAS Digest 101 provides a comprehensive review of requirements for secondary aggregates for use in road construction, including testing requirements and acceptability limits.

Other UK organisations that have produced guidance on use of recycled materials in construction include CIRIA, a construction industry research organization, and the Transportation Research Laboratory (TRL), a UK government research organisation looking primarily at road pavements.

Although measures such as landfill tax have helped to reduce the amount of CRD waste entering landfills in the UK, a number of barriers to increased uptake still exist. In particular, use of recycled aggregates in road construction has declined in the UK, primarily as a result of perceived financial risk under design, build, finance and operate (DBFO) schemes. In addition, there is still a lack of acceptance of recycled aggregates within the engineering community for higher value applications.

4.1.2 Germany

Waste prevention and recycling efforts in Germany have focused primarily on legislation, with the most significant contributor being the Closed Substance Cycle And Waste Management Act (1996), which establishes that producers have responsibility for the entire lifecycle of the products they manufacture. Despite strong encouragement, there have not been large increases in the use of recycled materials, particularly in road construction. Government does not play a strong role in research and marketing for recycled materials, and there are generally no provisions in road or other construction projects to favour the use of recycled materials. Other factors limiting the uptake of recycled materials in Germany include relatively cheap natural aggregates, and low landfill disposal costs. The lack of specifications and guidelines for the use of recycled materials is perceived as another barrier to further uptake, though existing specifications do often contain provisions for the use of recycled materials.

4.1.3 Netherlands

The Netherlands has an advanced set of policies, economic tools and regulations, which are highly integrated, in order to increase recycling of CRD waste, and along with Denmark, is highly regarded by the OECD for its use of recycled materials. The driving forces for this integrated policy system are:

- Recognition of future land requirements for residential, industrial and agricultural land-uses, and
- Environmental protection.

Stringent environmental protection requirements, high landfill taxes (between US\$35 and US\$352 per tonne), and phased bans on landfill disposal of CRD waste have driven increased recycling.

Development of policy, guidelines and specifications has included end-users and industry to ensure workable solutions. Co-operative research programs and the development of recycling technology, together with clear and un-ambiguous policy on engineering and environmental requirements have helped ensure the success of the Dutch recycling initiatives.

4.1.4 Denmark

The Danish government plays an active role in promoting recycling, through research and development, tax policies on waste disposal and development of guidelines and specifications for recycling. Government also takes an active role in promoting positive public attitudes towards recycling, an additional driving force for increased recycling.

Specifications are developed using a consensus approach, with participation by suppliers, environmental agencies, owners and contractors. Field tests and trials of recycled materials, including long-term evaluation of environmental performance is an important part of the Danish recycling initiatives.

Key in the Danish strategy is establishment of market forces favourable to the use of recycled materials, e.g., gradual implementation of landfill and disposal taxes. In addition, government-private partnerships have been used to help establish facilities for re-processing waste materials and to increase the value of recycled materials.

The use of RAP in Denmark is well established, with mixes routinely containing 50% RAP for base course and up to 30 % RAP in the wearing course. Batch plants which recycle only up to 15% RAP are not widely used any more.

4.2 North America

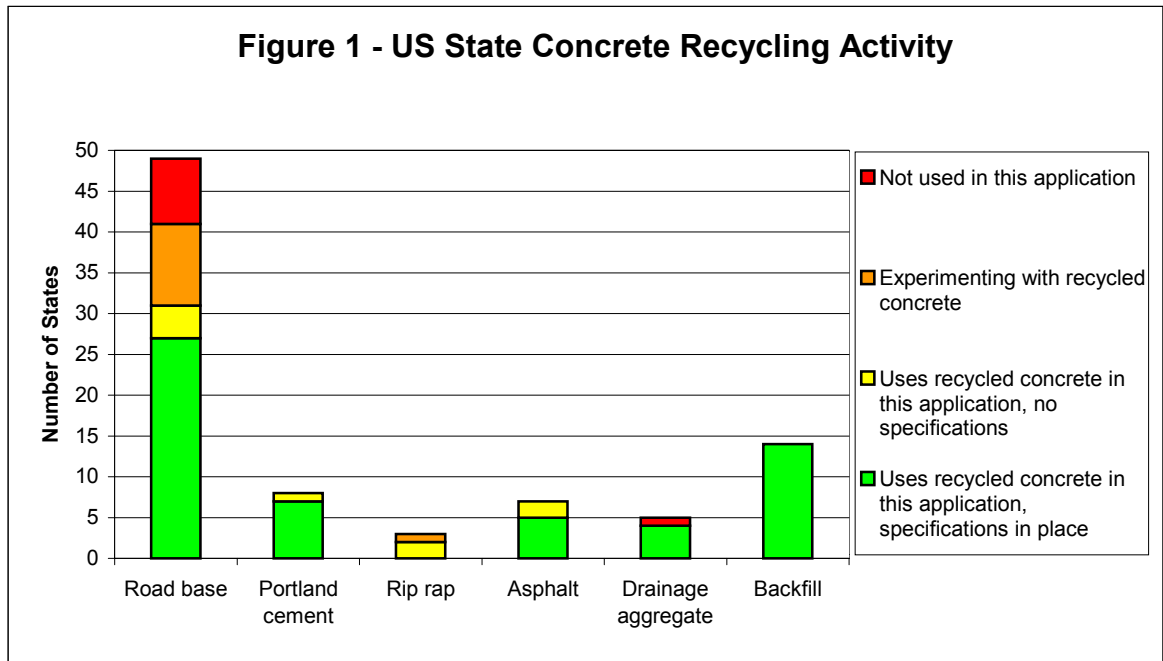
Neither Canada nor the United States have national standards for the utilization of CRD waste, though in the absence of national standards, a number of regional jurisdictions have set up their own requirements. In the US, the Federal Highways Administration (FHWA) and the US Geological Survey (USGS) have conducted research on the suitability and economics of re-using CRD waste. The FHWA has recently published a detailed report reviewing EU practice, as part of a Federal initiative to reduce barriers to recycling. A number of States and local governments in the US have passed legislation to promote recycling in road construction. Canadian experience is much the same, with some local governments, such as the Greater Vancouver Regional District (GVRD) actively reducing CRD disposal to landfill and encouraging re-use, while others have either not enacted CRD reduction and re-use policy, or have resisted increased use of CRD waste. The following sections describe regional practice in North America in more detail.

4.2.1 US

In the US, increasing urbanisation has generated demand for aggregates and increased quantities of construction debris, while at the same time pushing sources of natural aggregate further away from urban centres. The economics of CRD waste recycling are dependent on transport distances and costs at CRD sites, recyclers, landfills, natural aggregate producers and markets. Successful CRD recycling operations require favourable transportation and tipping fee structures, together with an abundant supply of consistent feed material. US recyclers rarely have much, if any control over product demand or pricing, which are primarily influenced by the amount of natural aggregate available in the local market. Factors such as the high capital investment requirements, inadequate public support and product quality problems or perceptions can make it difficult for CRD recycling operations to compete successfully.

US Federal policy currently favours waste reduction and recycling, and this is reflected locally in some States and local governments, notably Washington, Oregon, California and Colorado. A number of US States have very low acceptance of CRD waste recycling (see Figure 1). Most

recycled CRD waste is used in roadbase applications (68%), with relatively minor amounts used in asphalt, concrete and fill. Recycled concrete aggregate production has increased significantly, reaching about 4.8% of natural aggregate production in 1998. Approximately 85% of US RCA is used in road sub-base and general fill applications, due to availability, low transport costs and good physical properties.



Policy implementation for CRD waste recycling varies considerably between jurisdictions. Oregon, Washington and California have well-developed mechanisms to encourage diversion of CRD waste from landfills. In Portland, Oregon, for example, increased tipping fees for CRD waste of US\$75/tonne are the primary driving force for CRD recycling. Changes in city procurement policy to encourage use of recycled materials, together with efforts to link deconstruction projects to concurrent city infrastructure projects have also helped increase CRD diversion. Tucson, Arizona, has implemented a 'resource efficient procurement and utilisation policy' that favours products which reduce waste at source, are re-usable and are re-manufactured or contain recycled materials. Washington, Colorado and Oregon have provisions within State road construction specifications to allow use of recycled materials. The CalTrans and Green Book specifications used in California have standard special provisions to allow recycled materials in roadbase construction. LA, Modesto and Palo Alto all have purchasing policies that require use of recycled aggregate in road construction.

Currently in the US, 44 States allow use of RCA in roadbase, 15 States allow use in backfill applications, 8 States allow use in concrete and 7 States allow use in asphalt. Of the States that allow applications in roadbase, only 27 have formal specifications in place (see Figure 1). In general, RCA use in the US is restricted to applications where lower-quality products are used, where RCA meets or exceeds State specifications. RCA is not used in higher-quality applications often because of long-term performance considerations or because of perception by decision-makers.

A number of States have adopted specifications and policies for demolition or deconstruction which promote recycling, for example the North Carolina Triangle J Council of Governments 'Waste Spec', a model specification containing language promoting waste reduction, re-use and recycling. On the other hand, some jurisdictions have policies that either directly or indirectly dissuade use of recycled materials. For example, in New York, the Wicks' Law', which requires that at least 4 independent contractors work on projects valued over US\$50,000, is considered to have a major negative impact on waste reduction. Similarly, low bid policies are considered to negatively impact waste reduction through attracting lower-quality, wasteful bidders and eliminating contractor initiated schemes for waste reduction and recycling. In New York State, the high cost of labour in relation to materials is considered the single largest impediment to increased waste reduction and recycling.

4.2.2 British Columbia

In BC, disposal costs have increased rapidly, doubling since 1989. CRD waste represents between 20% and 40% of waste entering MSW landfills. Jurisdictions with high landfill development costs, restrictive land-use policies and high public awareness of recycling have tended to develop comprehensive waste reduction and recycling policies.

Provincial procurement and contracting policy has increasingly favoured deconstruction (separation of waste at site and recycling) over demolition. A recent example is the Oakalla prison demolition project, where bidders were required to submit prices for both demolition (including disposal costs) and deconstruction (including revenue from salvage of re-usable materials). The winning bid for this project had a price for demolition that was 35% higher than for deconstruction. The additional labour costs incurred for deconstruction were substantially offset by re-using approximately 97% of the wood salvaged from the site. All of the concrete debris was diverted from MSW landfill.

The Greater Vancouver Regional District (GVRD) in B.C., has published a number of guides and booklets providing information on how to institute a jobsite recycling program for CRD waste and the location and contact details of local firms involved in demolition/de-construction, hauling and recycling materials. In addition, the GVRD makes personnel available to advise on recycling programs. The GVRD imposes variable fees on CRD waste disposal at its landfill sites, and prohibits certain types of waste altogether, including cardboard and gypsum wallboard, increasing incentives to divert separated wastes to a recycling facility.

Studies within the Victoria Metropolitan Area suggest that recycled aggregates represent around 7% of current production, most of which are used in road construction. Increasing costs due to closure of local pit sources, increased haul distances and an increase in the proportion of material produced from crushed rock, are likely to increase the attractiveness of recycled aggregates. However, because of concerns over securing reliable supplies of raw material and ensuring the quality and consistency of the aggregate produced, it is anticipated that recycled aggregate production will remain a small fraction of total aggregate requirements. Evaluation of 20 mm crushed recycled material for the City of Victoria for base, sub-base and trench fill indicated that the material met specifications for durability, degradation and LA abrasion. However, gradation and variation in constituent materials were of concern.

5 USE OF RECYCLED AGGREGATES WITHIN ALBERTA

5.1 Alberta Infrastructure (Roads and Highways)

5.1.1 General

Based on discussions with Mr. Ted Harrison of Alberta Infrastructure (AI), it is understood that prior to their privatization initiative, AI used in the order of 20% recycled aggregates, principally in the form of Recycled Asphalt Pavement (RAP,) in their construction programs. Recycled concrete was less of a focus because there was never a consistent source for it. However, since their move to privatize, the use of recycled material has dropped to negligible amounts for three reasons:

1. In the past, they had a longer investigation period prior to construction so they would know in advance which projects were amenable to using recycled aggregate. The department was also in

a position to schedule a sequence of projects that could optimize the use of recycled materials between different projects. Since the privatization initiative, however, the investigative work is done by consultants on a project specific basis and on a very tight time line. This approach is not conducive to recycling the existing asphalt.

2. Since privatization, the department has placed more emphasis on end product specifications with significant penalties to the contractor if he fails to meet the target performance criteria (e.g. asphalt densities, or asphalt thicknesses). As a consequence, contractors are unwilling to use Recycled Asphalt Products (RAP) as it is more variable in composition and they are unwilling to accept the increased risk of not meeting the end product specification.
3. In recent years, the department has introduced more stringent specifications for their asphalt (enhanced stability mixes), requiring tighter specifications for the aggregate. These mixes are less amenable to using recycled products.

A fourth item that could adversely affect the use of RAP in the future is the increasing trend towards superpave technology that requires different gradations of aggregate (more coarse material) and is less amenable to RAP.

Mr. Harrison also commented that the way AI contracts are structured, the contractor owns any waste material generated from the project and hence is responsible either to use the generated materials from reconstruction, or appropriately dispose of them. Because there is no benefit to the contractor to recycle the material, he will typically sell any waste material to local farmers (that may use it to upgrade access roads or yard areas on the farm) or to the local gravel pit operator who will stockpile it and possibly sell it in the future. The material is seldom, if ever, taken to landfill.

5.1.2 Estimated Quantities

The province is currently in the middle of a strong highway construction program focussed on the North-South Trade Corridor. This has resulted in higher than usual consumption rates for both Asphaltic Concrete Products (ACP) and Granular Base Course (GBC). This increased consumption is expected to continue until about the year 2006.

Mr. Harrison estimates the current annual consumption to be in the following range:

Table 5 – Estimated current annual aggregate consumption

Material	Current Use (tonnes per year)	Long Term Average Use (tonnes per year)
Granular Base Course (GBC)	$\sim 5 \times 10^6$	$\sim 3 \times 10^6$
Asphaltic Concrete (ACP)	$\sim 4 \times 10^6$	$\sim 2 \text{ to } 3 \times 10^6$

It was noted that as the provincial road system matures, there will be less focus on new primary and secondary highway projects and a corresponding reduction in the use of GBC materials. However, there will always be a strong demand for ACP material required for the ongoing maintenance of the highways and secondary roads.

Alberta Infrastructure has also retained a consultant to develop a Pavement Management System that focuses on preservation of the highway system (e.g. micro surfacing, crack sealing instead of pavement overlays, repair of ruts only instead of complete re-construction, etc.). This should reduce the rate of ACP consumption.

5.1.3 Hot In-Place Recycling Of Asphalt

Alberta Infrastructure does not use Hot-In-Place recycling of asphalt very often because of concerns about the reduced service life of the finished product. Mr. Harrison commented that it is their experience that one can expect 50% of the design life from an HIR project (i.e. if conventional asphalt would have a service life of 20 years, the HIR would have a service life of 10 years). He also noted that the local contractors are not equipped to do HIR projects on a large scale. He expects, however, that the economics of HIR will improve as the price of oil increases.

AI is planning a full depth recycling program for portions of Highway 2 this year. This will entail digging up the full depth of ACP and GBC, mixing it with an emulsifier and re-placing it as a full depth composite product, before applying an ACP overlay. This will be an expensive operation but they hope to reduce the extensive reflective cracking that has been an ongoing problem with these particular stretches of highway.

5.2 City of Edmonton

5.2.1 General

The City of Edmonton is located in an area where natural aggregate sources are limited and hence the cost of virgin aggregate is significantly higher than in many other Alberta municipalities. As a consequence, over the past twenty years, the City has successfully developed a program that incorporates recycled concrete and asphalt into their ongoing road construction and maintenance programs. In fact, their program has been so successful, that its only limitation is a shortage of suitable recycled concrete and asphalt to meet their demands.

Mr. John Mundy of the City of Edmonton advised that initially the driving force behind the program was to reduce the volume of material going to their landfills, which at the time, were nearing capacity. Hence recycling of all waste materials was strongly encouraged. In the early years, the product they produced was not cost effective nor was it widely accepted by industry. However, as the technology and their materials handling procedures improved, the product became more and more accepted where now it is strongly endorsed by the construction industry.

The produced product is a composite material generally made up as follows:

Portland Cement Concrete	65%
Asphalt Concrete	25%
Granular/Soil-Cement	10%

Until recently, the City produced only one product with a maximum particle size of 63 mm. For the last two years, however, they have produced a second product with a maximum particle size of 25 mm, designed specifically for use as a base course beneath sidewalks (coarser gradation and higher permeability).

The recycled material is ideally suited for use as a pavement base course because it compacts well, it sheds water when compacted but left exposed, and provides good base strength to the pavement structure. At present, the recycled product is used almost exclusively for pavement base course although they also have used it as replacement material to stabilize small landslides (discussion with the City's Don Lewycky). Because there is a shortage of feedstock (i.e. concrete and asphalt rubble), they have not pursued alternate uses for the recycled product.

5.2.2 Production Facilities

The City of Edmonton maintains stockpiles and crushing facilities at two locations within the city. At either facility, they will accept at no cost any asphalt, concrete or granular construction debris delivered to their yard, provided it is clean and is less than 750 mm in its longest dimension. The incoming material is stockpiled selectively in a single pile such that the desired proportions of the various components are maintained. The stockpile is then worked with a Cat to ensure the feedstock is well mixed before being fed into the crusher.

Typically, the City of Edmonton will produce about 150,000 to 175,000 tonnes per year, though in peak years (1997, 1998) they produced as much as 400,000 tonnes. Exact figures are not known, but the tonnage of recycled material represents a significant portion of their total annual aggregate usage. In processing the reinforced concrete, they also produce about 100 tonnes of steel per year that is recycled.

In recent years, the Edmonton contractors have begun to produce their own recycled base course material. Conventional aggregate producers are setting up crushing operations. Similarly, smaller demolition contractors are stockpiling concrete or asphalt rubble, then selling it to the crushing contractors. This is becoming a problem for the City as it is reducing their source of feedstock.

5.2.3 Hot-In-Place Recycling

HIR is becoming increasingly popular in the City of Edmonton. In 2000 it is estimated that the City completed 332,000 m² of HIR which, based on a 50 mm milling depth, translates into 39,000 tonnes. Apparently this was an exceptional year and a more common amount would be in the range of 20,000 tonnes.

Asphalt planing (or milling) is also done by the City, with the millings stockpiled for future use in RAP. The City allows for addition of RAP into the City asphalt mixes as long as the mix meets the City's specifications.

5.3 City of Calgary

5.3.1 General

Mr. Hubert Crevels of the City of Calgary's Roads Department states that the City supports the use of re-cycled materials, provided they meet the same project specification that are applied to virgin materials. He also noted that their Standard Specifications For Road Construction has allowed for use of recycled construction materials for about 5 years. Article 300.06.00 of their current (Year 2000) specification titled "Alternate Construction Materials" states,

Unless otherwise specified, all alternate construction materials including, but not limited to, recycled plastic, recycled concrete, recycled asphalt, etc., proposed as an alternate to materials specified in these specifications, shall be subject to the same or similar specifications as applicable to the already specified material. The use of any alternate material shall be at the sole discretion of the Engineer.

The Engineer may, at his sole discretion, request additional tests to ensure that the alternate material is suitable for the application intended.

Note: Recycled concrete shall not be used as a surface course or as pipe zone backfill.

Recycled asphalt shall not be used as an alternate for gravel under hot mix asphalt.

Mr. Crevels also commented that he sees the City's use of recycled aggregates increasing as the existing gravel pits become depleted and virgin material has to be trucked from greater distances. He also commented that the City uses recycled plastics in their guard rails and fence posts.

5.3.2 Recycled Concrete

Mr. Crevels advised that the City first used crushed concrete as a base course material on the John Laurie and 14th Street interchange project in about 1993 (he was uncertain on the date) and it was considered to have been successful. Since then they have adopted the approach that RCA

can be used for road construction as long as it meets the same specifications used for virgin aggregates. He noted that it is their experience that suppliers often have to add fines to the RCA to meet the City specifications.

Mr. Crevel also noted that the City does not allow the use of recycled concrete as a surface course or as pipe backfill because of its sharp angularity and the risk of puncturing tires or external pipe coatings. He also said he would have a concern if RCA was proposed for use where the groundwater table was high and there was potential for sulphate attack on the aggregate.

5.3.3 Recycled Asphalt

The City of Calgary routinely uses RAP and/or asphalt planing chips for paving of back lanes noting that it is preferable to gravel as it serves to keep the dust down and allows less surface water infiltration. Apparently they maintain a stockpile of “planing chips” which they add asphalt oil to for repair work.

The City of Calgary does not allow RAP as a base course material for paved streets. Apparently they used it in one sub-division (Riverbend Phase 11) in about 1993 and the roads did not perform well, developing “wash boarding” or rolling. He also noted that their maintenance personnel do not like using RAP in the back lanes because it is more difficult to repair (i.e. cannot just send a grader to smooth out the lane).

The City’s Standard Specifications For Road Construction (2000 Edition) Section 307.02.07 titled “Recycled Asphalt Pavement”, states:

Recycled asphalt pavement (RAP) may be used in the first 110 mm of the asphalt pavement structure on major roads. Prior to its use, a proposed mix design shall be submitted to the Engineer for approval. In no instance shall the design incorporate in excess of 25% RAP.

It is anticipated, however, that the 2001 Specifications will likely be amended such that the maximum allowable amount will be reduced to 20%, but that would apply to the full depth of Mix A.

Mr. Crevels advised that The City of Calgary does not allow rubber to be used in their asphalt even though it may serve to improve its performance characteristics. Their rationale for this is that even though the rubber makes up a very small portion of the mix, the planings that will be

produced in the future become unusable as they cannot be re-heated for recycling. The City also does not allow used, whole asphalt shingles to be used in their asphalt as they are too weathered and not compatible with the mix. They will, however, allow the shingle tabs as they are less weathered and more compatible.

6 DISCUSSION AND CONCLUSIONS

6.1 General

A considerable amount of research has been conducted on recycled aggregates, both in terms of technical issues (performance and development of specifications), in terms of policy and economic issues. Much of this research has been conducted by various national agencies in Europe and the United States. A considerable amount of information was obtained for this review, but it is apparent that significant information is available that has not been reviewed.

This study has found that recycled aggregates are commonly used in road construction in Alberta, both in the granular base course (GBC) and the bound asphalt layer (RAP). However its use is largely dependent upon the availability (and cost) of natural aggregate sources. This is most evident by comparing the relatively high usage of recycled aggregates in Edmonton, where natural aggregates are scarce, to the relatively low usage in Calgary where, at least historically, natural aggregates have been plentiful.

The study also did not find a great acceptance of recycled materials within Alberta Infrastructure. This may be attributable to the fact that they are dealing largely with roads and highways that extend for great distances, often through rural areas with little development. As a consequence, there is not a plentiful supply of CRD waste to generate the needed recycled aggregates.

6.2 Economic and Technical Issues

This review has identified that technical specifications dealing specifically with recycled aggregates are available in some countries in Europe and in some states within the United States. There does not, however, appear to be any commonality between the different jurisdictions. What seems to be more common is jurisdictions that will accept recycled material provided it meets the technical specifications applied to non-recycled material. It was noted, however, that some jurisdictions have reviewed

their technical specifications to eliminate clauses that were not technically justifiable but which precluded broader use of recycled material.

Quality control and quality assurance is identified as a critical issue with respect to the processing and use of recycled materials, in several jurisdictions. Workable QC/QA policies have been developed by the UK BRE (Digest 433 and “Quality Control: The production of recycled aggregate”) and by the US Recycled Materials Resource Centre / FHWA. Further work should include development of a workable QC/QA guideline for use in Alberta, developed in conjunction with owners, contractors, suppliers and engineers.

6.3 Policy Issues

It is readily apparent that policy, either at the municipal level or at the provincial level, is a key factor with respect to encouraging the use of recycled materials. Jurisdictions where recycled building materials are being used to the greatest extent, mostly overseas, have implemented policies that encourage their use. These include:

1. Active government participation – varying levels of government involvement are seen in Europe and the US, including funding of research initiatives, development of standards and guidelines, legislation, and implementation of financial dis-incentives (taxes and fees) and incentives (grants and rebates). In Europe, the emphasis has tended to be on shifting the tax burden from labour to materials in a revenue-neutral way in order to make recycling more attractive. In addition, imposition of variable fees for landfilling waste, with higher rates for recyclable materials, has been particularly successful in diverting material and encouraging private-sector operation.
2. Development of clear specifications and consistent policy – experience in Europe suggests that development of specifications and policy in conjunction with industry, engineering, contractor and owner representatives is key to ensuring workable guidelines.
3. Co-ordination of policy – experience in Europe and the US suggests that where inter-agency policy is not co-ordinated, barriers to increased CRD diversion may exist in agencies that do not actively participate in CRD diversion. Terminology applied to CRD materials and environmental requirements are of particular concern.

4. Dissemination of information – research and publication of information, together with demonstration projects has proved to be a catalyst for private sector involvement in CRD recycling, particularly where there is significant perceived risk, either amongst engineers, contractors, or owners. In some cases, grants have been used to develop technology or plant that would otherwise be un-economic or too risky for private sector operators.

Within Alberta, the current trend towards privatization has served to discourage the use of recycled aggregates. This is partly because the projects are tendered on an individual basis and the contractor does not have the opportunity to incorporate waste material generated from one project and use it as recycled material on another one. A second factor is the trend towards “end-product” specifications with monetary penalties for not meeting the design requirements. Contractors are less willing to use recycled concrete or asphalt due to concerns about its variability and potential inferior performance compared with virgin materials.

6.4 Future Work

Although it cannot be quantified, it is apparent that there is a general concern within the industry about the use of recycled building materials and specifically, recycled aggregates. This was evident in our discussions with personnel from the City of Calgary as well as with Alberta Infrastructure. On the other hand, the City of Edmonton, largely through necessity, has developed a very successful road construction and maintenance program using recycled concrete and asphalt.

One of the top priorities to increase the use of recycled aggregate should be to educate the industry on the success stories related to its use. The most obvious example of this would be to research and publish case histories of various road-building projects within the City of Edmonton where recycled aggregates have been successfully used. Such publications should detail the design and construction procedures that were used but preferably should also provide data on its long-term performance.

It also would be prudent to educate the different levels of government on some of the tendering policies that are discouraging the use of recycled materials. This would not mean dissuading them from continuing with the privatization initiative that is ongoing. They could, however, introduce monetary incentives within their tender documents that would encourage the use of recycled materials. Similarly, they could also implement a

surcharge on landfill tipping fees for construction materials deemed to be recyclable.

Although we were not able to gather reliable estimates on the total quantities of aggregates being consumed within the province (contractors guard this information quite closely), it is readily apparent that the supply of natural aggregates is a finite resource that is being depleted at an increasing rate as the province grows. It is important that the various levels of government, and the general public, are informed of this. With this knowledge, there may be an increased public will to increase the usage of recycled CRD waste.