LVM
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# MINISTRY OF NATURAL RESOURCES ONTARIO

State of the Aggregate Resource
In Ontario Study (SAROS) – Paper 4
RFP OSS-077392

## Final Report

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# EXECUTIVE SUMMARY

With a substantial amount of the approximately 173 million tonnes of primary aggregates consumed annually for Ontario's infrastructure, enhanced recycling and reuse of excess materials and by-products in bulk applications has the potential to be a key contributing factor to aggregate resource sustainability.

Over the past 15 years, there has been an ever-increasing awareness of the need for sustainable development and preservation of non-renewable aggregate resources. This awareness, coupled with rising costs of energy, has contributed to a number of changes in the reuse and recycling 'landscape' that have significantly increased the amount of reuse and recycling being completed in the transportation sector.

The use of recycled material in road building grew substantially between 1991 and 2006 from approximately 6 million tonnes per annum to approximately 13 million tonnes. While this represents a significant percentage of the primary sources of typical recycled material, this still represents only 18 to 19 percent of the total aggregates used for transportation infrastructure construction. As the reuse and recycling of road construction materials has increased to such levels that the primary recyclable materials are virtually totally consumed, the focus of the industry has shifted towards processing and recycling in the most appropriate highest-best use. At the same time, effort has to be made in developing technology and processes in order to develop secondary and tertiary (and other wastes such as mine waste rock) materials that have suitable engineering properties that do not have any potentially harmful environmental impacts.

MHBC Planning as subconsultants to LVM-JEGEL, completed a review of provincial policies and initiatives along with official municipal plans from representative municipalities across Southern Ontario to identify the general policy framework for aggregate recycling and reuse in Ontario. Based on the review, recycled aggregate is not contemplated in most municipal official plans in terms of permitted uses or specific policies.

One of the main deficiencies identified for successful reporting on the level of aggregates reuse and recycling was a lack of a methodology or system to effectively track recycled materials use across

the Province. Consequently, this was considered to be an important focus of this Paper 4 Study. Based on the results of the survey of public agencies, and a review of similar international systems, the following is the recommended methodology to implement recycled aggregate tracking in Ontario:

1. Guidelines on how and what materials to be tracked should be developed in order to standardize the data being input into the system from across the province;
2. A computer software (online computer database) will have to be developed to provide a means for the public agencies to input their recycled aggregate use data;
3. In order for public agencies to be able to complete this additional work, they will require additional funding for staff and training on the systems;
4. In order to hold public agencies accountable for this additional work, the additional funding should be tied into proper completion of the data input activities;
5. In order to promote the social benefits of these activities, annual report cards should be completed outlining the successes and opportunities for improvement for recycled aggregate use across the province.

The reuse and recycling of road construction materials has increased to such levels that the annual production of primary recyclable materials has the potential to be nearly totally consumed. The transportation infrastructure construction and maintenance industry partners continue to promote processing and recycling in the most appropriate highest-best use. It is not only important to focus on improving the use of currently recycled aggregates, but also to develop secondary, and perhaps tertiary recycled aggregate streams to help further offset the tremendous need for construction aggregate.

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# INTRODUCTION

The Province of Ontario, through the Ontario Ministry of Natural Resources (MNR), Aggregate and Petroleum Resources Section of the Lands and Waters Branch, is mandated to protect and make available aggregate resources for the long term. The most recent major State of the Aggregate Resource Study was last carried out in 1992. In order to ensure the best planning and management of aggregate resources, current science, new data and information on the resource must be collected, and as part of its continuing mandate, the MNR has undertaken the process of completing a 2009 update of the State of the Aggregate Resource in Ontario Study (SAROS). In order to facilitate completion of this major update Study within the stated timelines, this process for the Updated Study was sub-divided into six complementary papers with each to be completed by a different consultant. Each of the six papers focused on a different component of the state of the aggregate resource:

1. Demand
2. Availability
3. Value of Aggregates
4. Reuse and Recycling
5. Supply
6. Rehabilitation

LVM-JEGEL, Division of John Emery Geotechnical Engineering Limited, Subsidiary of Dessau Ontario Inc., was selected by MNR to complete Paper 4 – Reuse and Recycling of the SAROS.

With a substantial amount of the approximately 173 million tonnes (TOARC, 2007) of primary aggregates consumed annually used in the construction, maintenance and rehabilitation of Ontario's infrastructure, enhanced recycling and reuse of excess materials and by-products in bulk applications such as construction aggregates has the potential to be a key contributing factor to aggregate resource sustainability. There are also significant and equally important parallel benefits attributable to reuse and recycling that can be realized, including recovery of energy and societal benefits such as waste reduction and the reduction of extraction in ecologically sensitive areas.

## 1.1 Project Scope

For this update study, the initial focus of Paper 4 was based on six interacting elements:

1. Estimate the on-site/in-situ use of aggregate resources in road construction by all public agencies;
2. Review and report on similar aggregate recycling systems and methodologies in other jurisdictions – Indicate the types of aggregates considered as recycled (e.g. processing fines);
3. Identify potential opportunities and barriers to utilization of recycled aggregates as they relate to communities, existing aggregate operations longevity, increased two-way haulage etc.;
4. Identify options and opportunities for recycling and reuse of aggregates in Ontario and linkages to initiatives such as the Leadership in Energy and Environmental Design (LEED) program. Investigate components/characteristics of recycled aggregates that would constitute positive environmental branding;
5. Determine what research is currently underway to utilize more recycled aggregates as substitutes for virgin material – Identify potential material for substitution;
6. Recommend a methodology to effectively track recycled aggregate use.

Throughout the Project, all of the selected consultants were to interact directly with MNR representatives who provided the required guidance and direction for each paper. An Aggregate Resource Advisory Committee (ARAC) was established at the invitation of the Minister, made up of leaders of key stakeholder organizations able to speak for their organizations and membership. The ARAC's role is to review the scope of the SAROS, monitor progress, review the consolidated report and provide recommendations back to government.

The SAROS governance structure also has provision for a Technical Expert Panel (TEP) made up of experts from various ministries, aggregate industry associations, academics and environmental stakeholders with specialized knowledge in areas of recycling, rehabilitation, economics, construction, geology, transportation, aggregate planning and management.

The Technical Expert Panel role and responsibilities are to:

- Provide advice to MNR in the development of the detailed requirements of the papers;
- Provide advice on the information and science development process;
- Review new science gathered and provide summary results; and
- Prepare the consolidated report for submission to Aggregate Resource Advisory Committee

## 1.2 Project Methodology

For this Report, and based on our discussions with MNR Representatives, the TEP and the ARAC, LVM-JEGEL developed the following methodology to meet the requirements of the Project Scope. In order to objectively and efficiently determine the state of recycling and reuse in Ontario, LVM-JEGEL selected a representative sample of potential interview candidates (16 in total), representing both large and small municipalities across Ontario. Individuals were selected who are familiar with the practical and technical aspects of recycling and reuse and who were able to provide, through their direct local experience, insight into the selection, use and performance of various reuse and recycling options. These interviews, in conjunction with a literature survey to confirm the current 'success stories' for municipal infrastructure and pavements, formed the core of the SAROS study for Paper 4 and provided significant inputs across the complete Project Scope.

The methodology that LVM-JEGEL followed is presented in more detail below.

1. A representative sample of public agencies, representing both large and small municipalities across Ontario was developed along with a list of standardized questions which were completed via telephone interview. Based on LVM-JEGEL's past experience with surveys (the 1992 Mineral Aggregates Conservation, Reuse and Recycling Report along with the 2007 Update of the Mineral Aggregates Conservation, Reuse and Recycling Report completed by LVM-JEGEL on the joint behalf of The Ontario Aggregate Resources Corporation (TOARC) and MNR which has been included as Appendix B), subscription to

letter or on-line surveys was quite low and follow-ups with public agencies were quite time consuming, and as such, given the tight project timelines, it was decided that the most effective form of survey would be direct, scheduled telephone interviews.

The public agencies were equally distributed throughout the Province and are estimated by LVM-JEGEL to represent nearly 90 percent of the Province's population (adapted using data from NRCan, 2006). The geographic distribution of the public agencies contacted is shown below in Figure 1. A copy of the Public agency Survey is provided in Appendix A.

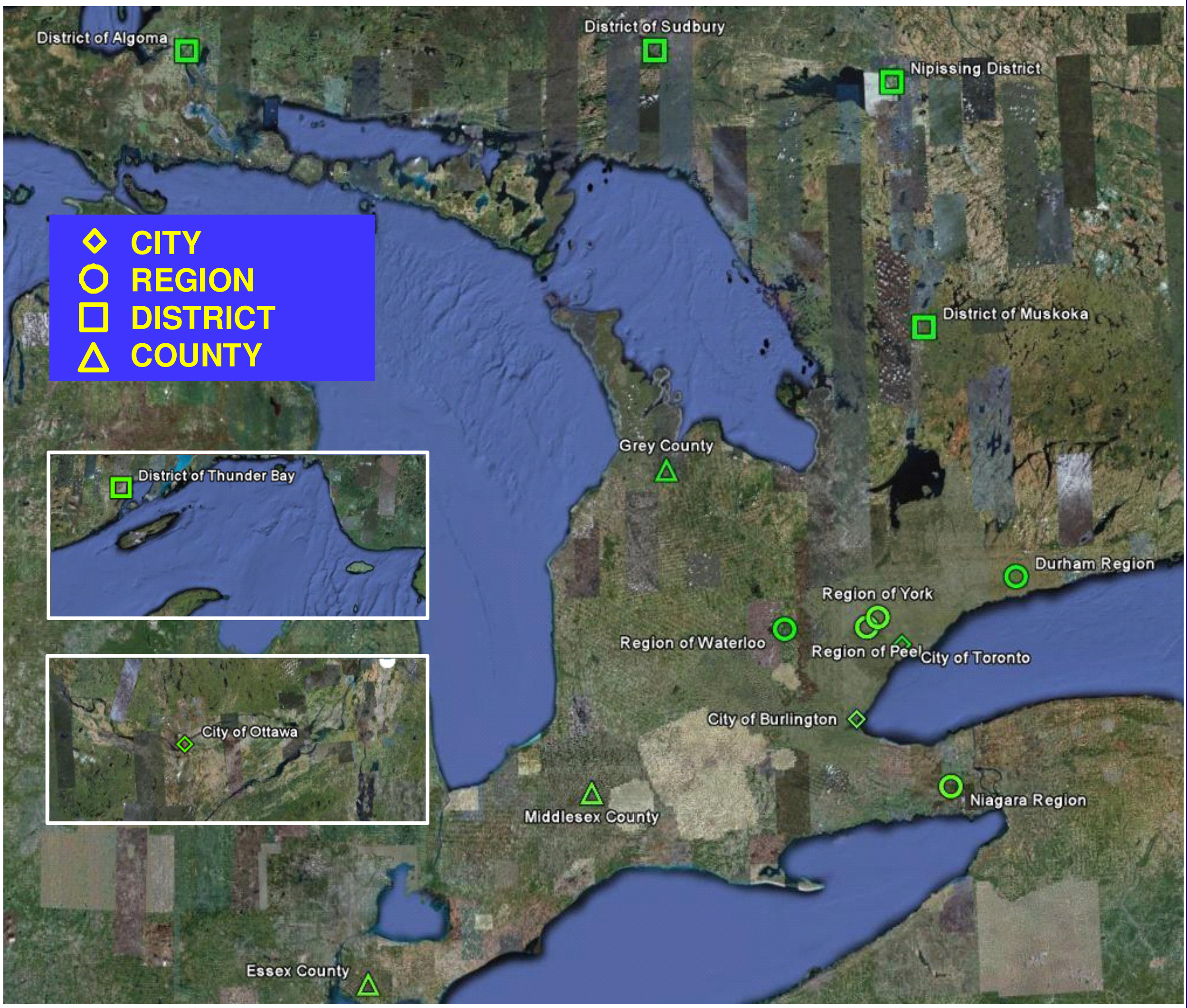


**Figure 1 – Distribution of Public Agencies Contacted for Study**

2. A review of the extensive LVM-JEGEL technical library was completed which includes in-house research and internal direct project involvement since 1991 (OECD, 1997; FHWA, 1998; NCHRP, 2000; NGSMI, 2005). This was followed by a scan of LVM-JEGEL's extensive network of contacts in municipal, provincial and federal transportation agencies, industry and international technical organizations to report on aggregate recycling systems and methodologies in other jurisdictions, and to determine what research is currently underway to utilize more recycled materials as substitutes for virgin material. This included provinces in which LVM-JEGEL and associated companies currently are active (Ontario, Quebec, Alberta, British Columbia) and colleagues on international technical committees of the World Road Association (PIARC) and the Organisation for Economic Cooperation and Development (OECD).

3. In order to identify potential opportunities and barriers to utilization of recycled aggregates, MHBC Planning completed a review of provincial and official plans on behalf of LVM-JEGEL to identify the policy framework for aggregate recycling and reuse across Ontario. This was supplemented by LVM-JEGEL direct experience in the opportunities and barriers to utilization of recycled aggregates in Ontario.

4. LVM-JEGEL completed research into different recycling and reuse of aggregates initiatives (such as the Leadership in Environmental Design (LEED) program), and investigated the feasibility of linkages to such initiatives.

5. Based on the results of LVM-JEGEL's previous two surveys (the 1992 Mineral Aggregates Conservation, Reuse and Recycling Report along with the 2007 Update (Appendix B)), there is a general lack of accurate records among both producers/suppliers and agencies with respect to recycled materials quantities. In this regard, the most important output of Paper 4 was to recommend a methodology to effectively track recycled aggregate use in Ontario. This was accomplished by synthesizing all of the information from the previous components of the study, along with research on other international initiatives, and taking into consideration the current systems in place in Ontario to identify a potential recycled aggregate tracking system.

# 2 AGGREGATE RESOURCE USE IN ROAD CONSTRUCTION

The use of aggregate resources in road construction across the Province is fairly well known based on estimates provided by TOARC, the MTO (Wilson and Rogers, 2006) and the Environmental Commissioner of Ontario (ECO Annual Report, 2006) and are covered in greater detail in the LVM-JEGEL 2007 Update Report on Mineral Aggregates Conservation Reuse and Recycling. For example, with over 160,000 kilometres (expressed in two lane equivalents) of roadways both municipally and provincially, an estimated 55 percent of all Ontario aggregates production is consumed in road construction and rehabilitation annually in Ontario (ECO Annual Report, 2003). Some typical quantities of construction aggregates required for road construction are shown below in Table 1.

**TABLE 1**
**TYPICAL QUANTITIES OF CONSTRUCTION AGGREGATES REQUIRED FOR VARIOUS TYPES OF ROAD CONSTRUCTION (tonnes)**

| | |
|---|---|
| 2-Lane Local Road (Southern Ontario)[1] | 6,500 |
| 4-Lane Major Arterial Road (Southern Ontario)[2] | 18,200 |
| 2-Lane Major Arterial Road (Northern Ontario)[3] | 13,300 |
| 4-Lane Freeway[4] | 44,300 |

1 – City of Toronto Local Road Standard Cross-Section
2 – City of Toronto Major Arterial Road Standard Cross-Section
3 – MTO Pavement Design and Rehabilitation Manual Typical Design
4 – Typical Provincial Freeway (Client)

Over the past 15 years, there has been an ever-increasing awareness in Ontario, across Canada and internationally, of the need for sustainable development and preservation of non-renewable aggregate resources. This awareness, coupled with rising costs of energy, has contributed to a number of changes in the reuse and recycling 'landscape' that have significantly increased the amount of reuse and recycling being completed in the transportation sector.

As an example, during the period between 2005 and 2008, the MTO reportedly used about 42 million tonnes of aggregates for primary and secondary highway and related transportation infrastructure construction, of which 8.3 million tonnes (19.8 percent) consisted of recycled materials (Kazmierowski, 2009). The various recycled or alternative materials used are shown below in Table 2.

The use of recycled material in road building grew substantially between 1991 and 2006 from approximately 6 million tonnes per annum to approximately 13 million tonnes. While this represents a significant percentage of the primary sources of typical recycled material (76 percent, excluding bottom ash), this still represents only 18 to 19 percent of the total aggregates used for transportation infrastructure construction, with only 2.1 percent additional available from primary recycled sources.

**TABLE 2**
**TYPES OF RECYCLED OR ALTERNATIVE MATERIALS**
**USED BY MTO BETWEEN 2000 AND 2004**
**(percentage)**

| | |
|---|---|
| Full Depth Reclamation (FDR) | 28% |
| Surplus Rock from Right-of-Way | 27% |
| Recycled Concrete in Granular Base | 18% |
| Cold In-Place Recycling (CIR) | 14% |
| Recycled Asphalt Pavement (RAP) in Granular Base and New Hot-Mix Asphalt (HMA) | 8% |
| FDR with Expanded Asphalt | 6% |
| Blast Furnace Slag in Lightweight Fill and Concrete | 1% |

# 3 SIMILAR AGGREGATE RECYCLING SYSTEMS IN OTHER JURISDICTIONS

At the time of the previous study, most recycling of road construction material was carried out at centralized plants, where potentially recyclable materials needed to be transported, processed and stockpiled prior to reuse. There is now a broad range of technically proven, cost effective, often in-place reuse and recycling options available on a national and international basis, which are covered by standard specifications (OPSS, AASHTO, for instance). Typical recycling systems include: central plant recycling (RHM); cold central plant recycling (CCPR); hot in-place recycling (HIR); cold in-place recycling (CIR); full-depth reclamation (FDR); full-depth reclamation with expanded asphalt; and rubblization. For more detailed information about these processes please refer to the LVM-JEGEL 2007 TOARC/MNR Updated Study Report.

Successful reuse and recycling of materials for use in transportation infrastructure construction involves the consideration of several important factors: the recycled materials must have suitable engineering properties; there must be sufficient quantities available to economically justify their use; and the recycled materials must not have any potentially harmful environmental impacts. The types of aggregate considered as recycled along with they potential application is presented in Table 3. The Table also classifies the potential recycled materials as primary (green), secondary (yellow) and tertiary (red) potential use.

# 4 OPPORTUNITIES AND BARRIERS

As the reuse and recycling of road construction materials has increased to such levels that the annual production of primary recyclable materials are virtually totally consumed, the focus of the industry has shifted towards processing and recycling in the most appropriate highest-best use. This concept is based on the premise that the best use of a material is in that which the material has the highest value. For instance, the best use for reclaimed asphalt pavement (RAP) is in applications where the full value of both the asphalt binder and the aggregates is realized. Recycling of RAP in asphalt mixtures can result in significant reductions in both the amounts of new asphalt binder and new aggregate required for pavement construction, and reduced energy consumption. However, while the use of RAP as granular base or subbase does reduce the amount of new granular material required, the value of the RAP asphalt cement as a binder and the energy invested to produce it is

**TABLE 3**
**RECYCLED MATERIALS POTENTIALLY SUITABLE AS AGGREGATES IN BULK APPLICATIONS (ADAPTED FROM FHWA, 2001)**

| Application | Recycled Material | |
|---|---|---|
| **Asphalt Concrete Pavement** | | |
| Mineral Filler | Asphalt Plant Dust<br>Cement Kiln Dust<br>Sewage Sludge Ash | Lime Kiln Dust<br>Coal Fly Ash |
| Hot-Mix Aggregate | Reclaimed Asphalt Pavement (RAP)<br>Coal Bottom Ash<br>Foundry Sand<br>Mineral Processing Wastes<br>Waste Glass<br>Steel Slag | Blast Furnace Slag<br>Coal Boiler Slag<br>Roofing Shingle Scrap<br>Scrap Tires<br>Municipal Solid Wastes Ash<br>Nonferrous Slag |
| Surface Treatment/Seal Coat Aggregate | Blast Furnace Slag<br>Coal Boiler Slag | Steel Slag |
| **Portland Cement Concrete Pavement** | | |
| Mineral Admixture/Cement Additive | Coal Fly Ash | Blast Furnace Slag |
| Portland Cement Concrete Aggregate | Reclaimed Concrete Material | |
| **Granular Base/Subbase** | | |
| Granular Base/Subbase Materials | Reclaimed Asphalt Pavement (RAP)<br>Blast Furnace Slag<br>Nonferrous Slag<br>Coal Boiler Slag<br>Waste Glass<br>Foundry Slag | Reclaimed Concrete Material<br>Steel Slag<br>Coal Bottom Ash<br>Municipal Solid Wastes<br>Waste Ceramics<br>Mineral Processing Wastes |
| **Stabilized Base/Subbase** | | |
| Stabilized Base or Subbase Aggregate | Coal Bottom Ash<br><br>Coal Boiler Slag<br>Reclaimed Asphalt Pavement (RAP) | |
| **Flowable Fill (Controlled Low-Strength Material (for Utility Cut Backfilling))** | | |
| Flowable Fill Aggregate | Coal Fly Ash<br>Foundry Sand | Quarry Fines |
| **Embankment and Fill** | | |
| Embankment or Fill Materials | C&D Debris<br>Reclaimed Asphalt Pavement (RAP)<br>Nonferrous Slag<br>Wood Chips<br>Mineral Processing Wastes | Coal Fly Ash<br>Reclaimed Concrete Material<br>Blast Furnace Slag<br>C&D Wood Waste<br>Scrap Tires |

**Green** indicates a byproduct that is currently technically and environmentally acceptable for use as aggregates in these bulk applications.
**Yellow** indicates a byproduct that has potential for reuse as aggregate in bulk applications, but there are some technical, environmental or economic factors that must be considered.
**Red** indicates a byproduct that has previously had some potential for reuse as aggregate in bulk applications, but significant technical or environmental issues preclude its current use.

lost. At the same time, effort has to be made in developing technology and processes in order to develop secondary and tertiary (and other wastes such as mine waste rock) materials that have suitable engineering properties that do not have any potentially harmful environmental impacts.

In addition to advances in in-place recycling technology (such as 'third generation' hot in-place recycling (HIR) equipment, cold in-place recycling (CIR) processes and full depth reclamation with foamed (expanded) asphalt stabilization (FDR)), a number of residuals and byproducts that were previously potential sources of construction aggregates are now being diverted for more appropriate uses to 'recover' the stored energy (steel slag now mainly being reused by the manufacturers in the steel production process; blast furnace slag mainly being used as a supplementary cementitious material (ground granulated blast furnace slag processed for slag cement manufacture) for use in portland cement concrete; foundry sands being reused in the foundries or as kiln feed in portland cement manufacture, etc.).

## 4.1 Official Plan Review

MHBC Planning, as sub-consultants to LVM-JEGEL, completed a review of provincial policies and initiatives along with Municipal Official Plans from representative lower and upper-tier municipalities across Southern Ontario to identify the general policy framework for aggregate recycling and reuse in Ontario. The following is a list of Official Plans that were reviewed (date of Official Plan in parentheses):

- Region of Waterloo Draft Official Plan (June 2009)
- York Region Draft Official Plan (June 2009)
- City of Kawartha Lakes Draft Official Plan (May 2009)
- Oxford County (April 2009)
- Wellington County (January 2009)
- Town of Caledon (December 2008)
- Region of Peel (November 2008)
- Town of Halton Hills (May 2008)
- Municipality of Clarington (January 2007)
- City of Hamilton Rural Official Plan (September 2006)
- City of Ottawa (May 2003)

### 4.1.1 Provincial Policies and Initiatives

The Provincial Policy Statement (PPS) defines the recycling of mineral aggregate resources and derived products such as asphalt and concrete, as a "mineral aggregate operation". Section 2.5.2.3 of the PPS states "…the conservation of mineral aggregate resources should be promoted by making provision for the recovery of these resources, wherever feasible."

The MNR encourages the reduction, reuse and recycling of aggregate materials but recognizes that recycled aggregate is expected to only temper a growing need for the resource (Aggregate Resource Conservation – website). The MNR is working with the MTO and MOE to develop a draft provincial conservation strategy for aggregate resources.

The Aggregate Resources of Ontario Provincial Standards (AROPS) recognize recycling as an allowable use within a licensed site. AROPS states that if a zoning by-law allows for accessory uses to a mineral aggregate operation, then recycling of aggregate should be considered as an accessory use and a minor amendment should be processed to allow the activity. If the zoning by-law does not discuss recycling, the licensee must request and obtain a letter of approval from the municipality prior to any approval of a site plan amendment.

Policies in the AROPS also restrict where the stockpiling of recycled aggregate can be placed. These materials cannot be within 30 metres of any water body or within 2 metres of the surface of the established water table. Approved recycling areas must be shown on the site plan.

The MTO encourages the use of recycled aggregate by allowing recycled asphalt in granular base, subbase and recycled hot mix asphalt, and crushed concrete in granular base and subbase applications. In the last four years, more than 8.3 million tonnes (Kazmierowski, 2009) of road building aggregates used by the MTO originated from recycled or recovered material.

### 4.1.2 Official Plan Review

MHBC's review of representative Official Plans revealed that few municipalities have policies directed specifically to the provision of recycled aggregate. Only three of the eleven official plans reviewed (Caledon, York and Halton Hills) have specific policies that encourage the use of recycled aggregate:

*"The Town of Caledon will support initiatives by the aggregate industry and the Province to conserve aggregate resources, through such measures as recycling, and matching aggregate quality requirements to specific job specifications"* (Town of Caledon, Section 5.11.2.9.7).

*"To encourage the use of alternative materials to sand and gravel and the reuse of construction materials where possible to ensure conservation of existing aggregate supply"* (York Region Draft OP, Section 6.5.11).

*"To promote the conservation of mineral aggregate resources through the recovery of these resources where feasible"* (Town of Halton Hills OP, Section A2.10.2 (h)).

The second issue or topic explored is whether recycled aggregate operations have different land use permissions than resource extraction operations. The survey found that, where contemplated, recycled aggregate operations are only permitted in resource extraction designations. In some cases, a recycled aggregate operation requires a site-specific zoning by-law regardless if permitted in a land use designation. This conflicts with the AROPS policy on recycling where such operations are permitted subject to a minor amendment to the site plan.

### 4.1.3 Summary

While many of the reviewed Official Plans have general policies that encourage the reuse, recycling and reduction of waste, very few explicitly refer to the provision of recycled aggregate. Based on the review, recycled aggregate is not contemplated in most municipal Official Plans in terms of permitted uses or specific policies.

While the MNR and MTO have policies that encourage the use and provision of recycled aggregate, this has not been explicitly encouraged in the municipal planning context.

## 4.2 Barriers to Recycled Aggregate Use

The major factors inhibiting reuse and recycling of various excess materials have not changed since the last study in 1992. The significant inhibiting factors are summarized in Table 4.

The MTO and MEA continue, with input from construction industry partners (,OSSGA, OHMPA, RMCAO, ORBA, ARRA), to show leadership in the development of standard specifications for construction materials that prescribe the use of recyclable materials (for instance, OPSS 1010, Material Specification for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material, that it regularly reviewed and revised and specifically permits the use of RAP, RCM, nickel slag, air-cooled blast furnace slag, and glass and ceramic materials in Granular A and Granular B Type 1). However, despite this continuing evolution in specifications, many agencies and consultants continue to prohibit or restrict the use of granular materials incorporating these 'approved' recycled materials, largely due to lack of experience or an unfavourable past experience.

**TABLE 4**
**FACTORS INHIBITING REUSE AND RECYCLING OF MAJOR ONTARIO WASTES AND BYPRODUCTS AS CONSTRUCTION AGGREGATES IN BULK APPLICATIONS**

| WASTES AND BYPRODUCTS | | FACTORS INHIBITING REUSE AND RECYCLING | | | |
|---|---|---|---|---|---|
| | | Technical | Environmental/ Social | Economic | Comments |
| Old Asphalt | Recycled in HMA (RHM) or as Road Base Aggregates | None | None | None | Mature uses, but agencies not fully utilizing available specifications |
| | In-Place Recycling (HIR, CIR, FDR, CIREAM) | None | None | None | Increasing use, but specifications review required |
| Old Concrete | Recycled in Road Base ( RCM or In-Place (Rubbilized)) | None | None | None | Mature uses, but agencies not fully utilizing available specifications |
| | Recycled in new PCC and HMA mixtures (RCA and CCA) | Higher absorption, lower strength, finishing and durability concerns | None | Some | Developing use, with greatest potential in areas where good quality natural aggregates are not readily available |
| Blast Furnace Slag (BFS) as Road Base Aggregate or in Hot-Mix Asphalt Aggregate | | None | Mainly aesthetic leachate concerns in road base | None | BFS producers have largely abandoned use of air-cooled BFS for road base in favour of granulation; supply limited, with most BFS being used for cementitious uses (slag cement production) |
| Roofing Shingle Waste in Hot-Mix Asphalt (post-industrial (MSM) and tear-offs (RSP)) | | None | Some concerns with tear-off roofing materials | Minor | Amount that can be incorporated in HMA is technically limited by waste shingle properties; some potential 'contamination' issues with tear-offs |
| Waste Glass and Waste Ceramics as Road Base Aggregate or in Hot-Mix Asphalt | | None | None | Minor | Waste glass generally not produced in sufficient quantities, or being diverted to other uses |
| Steel Slag in Hot-Mix Asphalt or Road Base Aggregate | | Consistency and volume instability concerns | None | None | Volume instability concerns were largely addressed by changes in steel-making/slag production; largely being reused within the steelmaking with only limited supply for HMA use |
| Nonferrous Slags (Copper and Nickel) as Road Base Aggregate (including use as Rail Ballast Material) | | None | Some leachate concerns (mainly aesthetic) | Some | Mature use, but most concentrated close to the point of production due to transportation costs |
| Bottom Ash as Road Base Aggregate and in Hot-Mix Asphalt | | None for coal bottom ash | None | Some | Supply of coal bottom ash limited, close to coal-fired thermal hydro generating stations. Use of Municipal Solid Waste (MSW) bottom ash in HMA is developing (currently only trial use). |
| Foundry Sand in Hot-Mix Asphalt | | None | Some leachate concerns for stockpiled foundry sand | None | Supply limited, with most spent foundry sand reused in the foundry |
| Mine Waste Rock as Construction Aggregate | | Comingling of 'good' material with unsuitable material | Leachate concerns for sulphide rock types (acid rock drainage) | Major | Production and stockpiles located far from point of use (high transportation costs). Co-mingled stockpiles not suitable for aggregate use. |

There has been a move toward high-performance materials, such as high-performance concrete and high-stability, rut resistant asphalt concrete mixtures in transportation applications since the early Nineties. These materials are intended to provide enhanced performance and increased service lives, and therefore require very high quality aggregates (high strength, durable 100 percent crushed natural aggregates). Recycled materials are often precluded from use in such applications, as the result of technical (physical properties) aspects, durability concerns, or cost. These aspects are jointly being addressed by construction and transportation industry partners (for example, the use of recycled materials, including RAP and roofing shingle material, in Superpave asphalt mixtures), but there remain ample opportunities and applications where recycled materials can be used without special considerations (conventional asphalt concrete mixes and as granular base/subbase aggregates). While this may not fully enable recycling and reuse opportunities meeting the highest-best use objective, there remain ample opportunities and applications where such materials can be reused and recycled without special considerations (conventional asphalt concrete mixes and as granular base/subbase aggregates).

## 4.3 Potential Opportunities for Recycled Aggregate Use

The obvious benefits of having increased recycled aggregate use continue to be a sustainable supply of quality construction aggregates with reduced landfill requirements along with cost savings. Ever rising, and recently very dramatic, energy cost increases have made use of recycled materials more attractive than ever. While perhaps most evident where recovered materials are able to be reused to produce new products (clear recovered glass recycled into new glass bottles at lower temperature and therefore lower cost, or as kiln feed in the production of cementitious materials), there are substantial energy and materials transportation savings realized by inplace recycling and/or using technically-suitable byproducts that are produced closest to the point of end use.

Increasing awareness of municipal agencies on the positive benefits of in-place recycling of asphalt pavements (cold in-place processes – CIR and FDR in particular) and rubblization of concrete pavements that represent nearly 100 percent recycling, is resulting in greater use of these technologies in Ontario, and across Canada. It is imperative, however, that the construction industry continues to improve the quality of these ‘burgeoning’ technologies and not become complacent – as was demonstrated when problems with steel slag aggregates first began to surface in the late

Eighties (and leading to the 1991 moratorium), regardless of the cost, agencies will only endorse the use of recycled products that have similar performance and life-cycle costs as conventional products.

# 5 IDENTIFY LINKAGES TO RECYCLING INITIATIVES

In order to identify various international recycling and reuse initiatives, LVM-JEGEL completed interviews with representatives of selected public agencies across the Province along with a scan of our extensive network of national and international industry and technical organizational contacts to determine the various initiatives which are ongoing and relevant to the use of recycled construction aggregates in Ontario. Based on our review, there are currently no new recycling and reuse initiatives ongoing in North America specifically for the use of recycled aggregates in construction. There is continuing research in Canada and internationally on expanding the current use of recycled aggregates in a variety of applications (University of Waterloo research on recycling of old roofing shingle material, and the ongoing initiatives through the Recycled Materials Resource Center at the University of New Hampshire for instance).

## 5.1 Leadership In Energy and Environmental Design (LEED)

While not specifically intended for the tracking and use of recycled aggregates, the Leadership in Energy and Environmental Design (LEED) is an internationally recognized green building certification program which provides credit in its rating system for the use of recycled aggregates. Originally formed in 1994, the LEED program has continued to be updated into what is now considered a comprehensive system of six interrelated standards covering all aspects of the development and construction process of a building. LEED certification is granted by the Green Building Certification Institute which is composed of a panel of third party reviewers which rate each of the proposed design and construction elements, and review the overall planning process to score a project based on the various LEED categories. Different LEED versions have varied scoring systems based on a set of required "prerequisites" and a variety of "credits" in the six major categories. The most prevalent to aggregates recycling is the Materials and Resources category which represents a possible 14 points out of the 100 total.

The majority of public agency respondents indicated that a LEED type certification or recognition initiative would provide incentive to complete more pavement recycling in their jurisdictions.

However, the LEED system, as it is currently structured, is primarily for buildings and would not adequately cover the benefits of the use of recycled materials to pavements and other civil infrastructure.

## 5.2 Waste & Resources Action Programme (WRAP)

The Waste & Resources Action Programme (WRAP) was originally launched by the Government of the United Kingdom in 2000 as an integrated strategy for dealing with the country's waste. The goal of the organization has evolved to help develop markets for material resources and remove barriers to their use. This includes funding support for recycling infrastructure development, assistance in specification, procurement and use of recycled materials, improving end-user awareness, and research on new recycled material uses. The overall program focus is on the entire waste stream, but the WRAP program also has a section dedicated to aggregates recycling called the WRAP Aggregates Programme or AggRegain.

AggRegain is the sustainable aggregates information service for WRAP. It provides information from the entire life-cycle of the recycled aggregate including: demolition; recycling; production; specification; tendering; and end use. The program is funded by the Department for Environment, Food and Rural Affairs (DEFRA) which is provided funding from the Aggregates Levy Sustainability Fund. The program goals are to improve the quality of supply through infrastructure (equipment) investment and advancement of technology, assist in overcoming technical and legislative barriers to recycled aggregates use along with providing continued funding to support research in order to remove barriers to the use of primary, and specifically secondary aggregates in construction.

As the WRAP program is the product of, and administered by, the government of the United Kingdom, it is likely not feasible to link to this program for recycled aggregates in Ontario. However, the framework and scope of the program definitely could provide the scope for a similar initiative in Ontario.

## 5.3 Waste Diversion Ontario (WDO)

In 2002, Waste Diversion Ontario (WDO) was created as a non-government corporation to be run by a Board of Directors comprised of industry, municipal and non-governmental representatives, in accordance with the Waste Diversion Act. The list of materials designated for diversion is created by the Minister of Environment (after public consultation) and then is enacted into law. The current waste diversion programs include: the Blue Box Program; Used Tire Program; Waste Electrical and Electronics Equipment Program; and Municipal Hazardous and Special Waste Program.

Once a diversion program is enacted into law, municipalities receive funding for tracking program statistics and submitting an annual report into the Municipal Datacall software. Any municipality which does not submit its annual report by the specified deadline loses the funding support for that calendar year.

While Waste Diversion Ontario does not consider potential recycled construction aggregates in any of its waste diversion programs, it does contain a legislative structure, along with an established software and tracking methodology which could make this initiative a potential candidate for coordination with the recycling and reuse of aggregates in Ontario.

# 6 CURENT RECYCLING RESEARCH

The survey of Agencies unanimously indicated that there is currently no new research on aggregates recycling which is being driven by Ontario municipalities. The majority of respondents indicated that policy decisions are usually made based on review of successes in National and International research programs.

## 6.1 Recycled Asphalt Shingles

Research on the recycling of asphalt shingles started in Ontario in about 1994 (Yonke et al, 1999) with advanced, performance related testing and field trials recently completed by Miller Paving Limited in conjunction with the University of Waterloo (Centre for Pavement and Transportation Technology, CPATT) (Tighe et al, 2008).

The processing of waste shingles typically involves shredding the shingle waste material to about 12.5 mm minus size followed by screening and blending with a carrier material (such as sand or RAP) to ensure product workability. The processed waste shingles are then typically used as an additive in hot-mix asphalt production to reduce the amount of virgin asphalt cement required but research has shown that the fibres contained in the processed waste shingles can also improve the performance and enhance the service life of these pavements.

With over 300,000 tonnes of asphalt roofing shingle waste generated annually across Canada, the use of recycled asphalt shingles has the potential to not only reduce the amount of material heading to landfill but also improve the performance and longevity of our pavements in Ontario.

## 6.2 Warm Asphalt Mix (WAM)

Warm asphalt mix generally refers to a group of technologies that have been developed to lower the production and placement temperature of hot-mix asphalt. The obvious benefits of reducing the production temperature include reducing fuel consumption and reducing the production of pollutants and greenhouse gases. Additional potential benefits include: better compaction; ability to haul mix for longer distances; and the ability to pave at lower temperatures.

As a consequence of the additives used, and production practices of some WAM technologies, there is a potential for increased RAP utilization in WAM mixes. While Ontario currently limits the amount of RAP in surface course asphalt to 20 percent, with 40 percent allowed in some binder course mixes (MTO, 2009), European research is underway which routinely allows 45 to 50 percent RAP in binder course mixes with German trials completed using 90 to 100 percent RAP.

## 6.3 Mine Waste Rock – Niagara Tunnel Project

Mining wastes, consisting of broken rock from open pit and underground mining and coarse mill rejects from screening and separation processes continue to be some of the largest sources of solid waste in Ontario. By some estimates, as much as 15 million tonnes of waste rock, excluding any waste rock having a potential for acid run-off generation, is produced each year (MNR, 2006). The continuing constraints on their use include chemical/environmental concerns (radioactivity, leachates), variability (comingling of different rock types in stockpiles) and economics (distance to market).

While not typically considered a mining operation, the expansion of the Adam Beck 2 Hydro-Electric Generating Station is expected to generate about 500,000 cubic metres of waste rock from the Queenston Shale formation along with varying quantities of other potential construction aggregates (Lockport Formation dolostone, for instance). Nearly all of this material is being used either on site as a construction aggregate, or in the case of the Queenston shale, for brick manufacturing.

### 6.4 Winter Sand Recycling

Sand is applied to the pavement surface in the winter to improve traction during winter maintenance. This material tends to be relatively high quality, durable aggregate. In urban areas, this winter sand is power swept and vacuumed and cleaned out of catchbasins each spring and usually sent for disposal at municipal landfills.

Recognizing that large quantities of winter sand are applied to roads each year, the City of Edmonton in partnership with the Edmonton Waste Management Centre of Excellence undertook a two year pilot project to determine the feasibility of winter sand recycling (NGSMI, 2005). Under this program, the City was able to recover, reprocess and recycle nearly 90,000 tonnes out of the approximately 140,000 tonnes per year of winter sand that is used on City roads.

### 6.5 Mixed Broken Glass (MBG) and Waste Ceramic Material (WCM)

Mixed broken glass is material that is collected by Ontario's blue box programs which cannot be recycled by the glass industry into new glass. Waste ceramic material is typically produced from old bathroom fixtures (toilets and sinks) and is typically material that cannot be reused to produce new ceramic material. This is another existing waste stream that has the potential to reduce virgin aggregate use in road construction.

In 2003, the City of Toronto completed a pilot study project using MBG blended with 50 mm minus crushed concrete for use as granular subbase for road construction. The performance monitoring of this roadway section is ongoing and, to date, there have been no performance related issues for this recycled roadway base. In 2004, another trial section was constructed incorporating WCM in crushed concrete granular base. There was no construction or performance issues associated with its use.

## 7 METHODOLOGY TO EFFECTIVELY TRACK RECYCLED AGGREGATE USE

One of the main deficiencies identified for successful reporting on the level of aggregates reuse and recycling was a lack of a methodology or system to effectively track recycled materials use across the Province. Consequently, this was considered to be an important focus of this Paper 4 Study.

A series of questions was developed to determine the potential for tracking and promoting recycled aggregates use by public agencies. The series of questions attempted to identify areas in a typical project life-cycle where the use of recycled aggregate could be promoted and tracked, starting from design, through to tendering, and construction, along with developing a culture of recycled aggregate use within the public agency through the development of agency-specific recycled aggregate use policies.

Most agencies consider the use of excess and recycled materials and recycling technologies during the design and tendering of projects. One of the questions considered the potential for giving preference to bids which contained the use of recycled aggregates such as a potential technical score bonus for including certain levels of recycled aggregate in their bids, a technical score bonus for exceeding defined recycling targets or a technical score deduction for not meeting certain recycling targets. For the most part, the agencies report that use of recycled material or recycling technologies is not given preference due to its potential social or technical factors, but is almost unanimously chosen based on economic (cost) factors.

The purpose of the survey of public agencies was also to determine the potential for tracking recycled aggregates use and the current inhibiting factors. Most agencies currently record some form of recycled aggregate quantities, be it volumes of RAP used as backfill or shouldering material or the volumes of in-place recycling completed (CIR, FDR, HIR), but these records are not generally summarized in any form and the information has to be extracted manually. The concept of developing recycling specific tender items was of interest to some public agencies as these quantities are updated on a regular basis during construction and totalled in order pay the constructers. This could potentially reduce the time required to tabulate recycled aggregate use information but could also represent a large cultural shift which could potentially confuse contractors resulting in higher bid prices.

The majority of public agencies indicated that they would be capable of collecting and tabulating the recycled aggregate use quantities, but would require additional funding to cover the extra staff time costs along with a software system (online computer database) to input the data. It was suggested that this software system should be operated and maintained by the Province.

Based on the results of the survey of public agencies, and a review of similar international systems, the following is the recommended methodology to implement recycled aggregate tracking in Ontario:

1. Guidelines on how and what materials to be tracked should be developed in order to standardize the data being input into the system from across the province. The guidelines will have to be developed in coordination with all public agencies. Suggest consultation with Waste Diversion Ontario (WDO) as they already have experience in this regard and may be able to provide initial suggestions, and coordination of this activity through MEA for instance;

2. A computer software (online computer database) will have to be developed to provide a means for the public agencies to input their recycled aggregate use data. As WDO is currently managing a similar initiative, should probably investigate the Datacall software and its potential compatibility;

3. In order for public agencies to be able to complete this additional work, they will require additional funding for staff and training on the systems. Research into adequate funding to complete this activity, and sources for funding will have to be completed;

4. In order to hold public agencies accountable for this additional work, the additional funding should be tied into proper completion of the data input activities. This may require the development of a legislative framework;

5. In order to promote the social benefits of these activities, annual report cards should be completed outlining the successes and opportunities for improvement for recycled aggregate use across the province.

# 8 CLOSING REMARKS

The Province of Ontario and its Municipalities have a good track record when it comes to recycling aggregates. This is demonstrated by the variety of recycled materials which have been approved for use in various OPSS specifications which began with MTO's Wasteless Highway initiative and the resulting 1994 Protocol of the Management of Excess Materials from Road Construction and Maintenance. At the same time, the Province has not consistently kept records of actual quantities of recycled aggregates reused and this has lead to the perception that the construction and transportation sectors are not partners in sustainable development despite obviously increasing use of recycled aggregate products and technologies.

For example, the reuse and recycling of existing roadway pavement granular bases, subbases, surplus rock from ROW and trench materials as either granular subbase or engineered fill material is a standard practice for most public agencies, but the very large quantities of new aggregates conserved by this activity are not generally calculated. In addition, the onsite demolition, processing and reuse of concrete materials such as the reuse of some 200,000 tonnes of concrete rubble recovered form the demolition of the former Toronto Pearson International Airport Terminal 1 or the over 100,000 tonnes of dolostone and 500,000 cubic metres of shale recovered on the Niagara Tunnel Project, often goes unreported.

The reuse and recycling of road construction materials has increased to such levels that the primary recyclable materials have the potential to be nearly totally consumed, except in major urban centres where the requirements for 100 percent crushed aggregate often precludes the use of some recycled aggregates. The transportation infrastructure construction and maintenance industry partners continue to promote processing and recycling in the most appropriate highest-best use. It is not only important to focus on improving the use of currently recycled aggregates, but also to develop secondary, and perhaps tertiary recycled aggregate streams to help further offset the tremendous need for construction aggregate.

The development of software to determine which construction aggregates are currently being recycled along with their quantities is a very important next step for the Province. This aggregate tracking system could also prove to be an invaluable tool to help direct future recycled aggregate research and use planning.

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# Appendix A Public Agency Survey Form

**LVM-JEGEL**
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# SURVEY OF AGENCIES
# STATE OF THE AGGREGATE RESOURCE STUDY IN ONTARIO
# RECYCLING AND THE AGENCY PERSPECTIVE
# PART ONE – TELEPONE INTERVIEW

Name: ______________________________ Title: ______________________________

Agency: ____________________________________________________________________

E-Mail: ______________________________ Phone: ______________________________

LVM-JEGEL, Division of John Emery Geotechnical Engineering Limited, it conducting a survey on behalf of the Ontario Ministry of Natural Resources as part of the State of the Aggregate Resources Study in Ontario. The ultimate goal of our portion of the study is to provide an indication of the current recycling activities by public authorities across Ontario and to provide a recommended methodology to effectively track recycled aggregate use, on an ongoing basis, in Ontario.

<u>Design</u>

1. Are recycling options considered during design? If so, are they given preference because of:
   a. Properties?
   b. Cost?
   c. Social considerations ‘green’?
2. Would you or have you considered the implementation of a zero waste policy for Civil construction projects, or have developed other recycling goals/targets? If so, for what materials?
3. How do you determine what recycling technologies and materials are appropriate for your agency/project?

<u>Tendering</u>

4. Do you have adequate information/specifications to support specifying recycled materials for your projects – OPSS, in house specifications and SPs?
5. Would you consider giving bidders who offer recycling preference in the bidding process?
   a. Points during bidding – 5% ‘bonus’ for contractors who include a certain level of recycling in their projects
   b. Bonuses for exceeding targets
   c. Penalties for not meeting targets
6. Are there specific items in your tenders which could be used to outline quantities of excess materials reuse?

Construction (and Maintenance)

7. Do you typically record quantities of recycled aggregate use? If so, can you provide examples of how?
8. Do you or could you keep records annually for recycled material use?
9. What resources do you think you would need or could be provided to facilitate the tracking of excess materials reuse in your jurisdiction?
10. What would be the incremental cost to record such data?
11. What incentives would be useful to encourage your agency and contractors completing your work to increase the use (and documentation of use) of recycled materials?

General Questions

12. Have you identified any barriers to recycled aggregate use in your jurisdiction?
13. Do you currently have any research underway on aggregate recycling and reuse?
14. Would LEED certification/recognition of your Civil construction projects be a motivation to track and recycle more materials?
15. Does your agency have a policy on the reuse and recycling of construction materials? If so, can we have a copy?

***THANK YOU!***

# Appendix B 2007 Update Report on Mineral Aggregates Conservation, Reuse and Recycling

# 1.0 INTRODUCTION

It has been some 15 years since John Emery Geotechnical Engineering Limited (JEGEL), Consulting Engineers, completed on behalf of the Ontario Ministry of Natural Resources (MNR), a Study Report entitled *Mineral Aggregates Conservation, Reuse and Recycling*, published in February 1992 (MNR 1992[*]). This 1992 Study was originally commissioned by MNR to augment the concurrent State-of-the-Resources Study in order to more fully assess the role of wastes and byproduct materials on Ontario aggregates conservation.

The 1992 Study concluded that there were seven wastes and byproducts commonly used in construction as aggregates in bulk and cementitious applications that make a significant contribution to materials and landfill space conservation in Ontario: old asphalt; old concrete; blast furnace slags; steel slag; nickel and copper slags; fly ash and bottom ash. Additional wastes and byproducts having a potential to be used as construction aggregates included kiln dusts, foundry sand, demolition wastes and mine waste rock. The data suggested that the use of wastes and byproducts in construction for bulk and cementitious applications at that time was about 6 million tonnes out of some 11 million tonnes annual production of potentially suitable wastes and byproducts, equating to about 3 percent of Ontario's total aggregate production. Based on the trends indicated at the time this Study was completed, the 1995 estimated use of wastes and byproducts was projected to range from 6 million to 9 million tonnes, or 3 to 5 percent of Ontario's total production of aggregates.

Since this 1992 study was published, there has been an ever-increasing awareness in Ontario, across Canada and internationally, of the need for sustainable development and preservation of non-renewable aggregate resources. This awareness, coupled with rising costs of energy, has contributed to a number of changes in the reuse and recycling 'landscape' that have had a direct impact on the transportation sector. These include changes in legislation (environmental regulations for instance, such as the 1997 *Guidelines for Use at Contaminated Sites in Ontario* (GUCSO) (MOEE, 1997) and subsequent 2004 Ontario Regulation 153 'Brownfields' requirements), ever-rising energy costs, etc. In addition to advances in technology (such as 'third generation' hot in-place recycling (HIR) equipment, cold in-place recycling (CIR) processes and full depth reclamation with foamed (expanded) asphalt stabilization (FDR)), a number of residuals and byproducts that were previously potential sources of construction aggregates are now being diverted to other uses to 'recover' the stored energy (steel slag now mainly being reused by the manufacturers in the steel production process; blast furnace slag mainly being used as a supplementary cementitious material (ground granulated blast furnace slag processed for slag cement manufacture) for use in portland cement concrete; foundry sands being reused in the foundries or as kiln feed in portland cement manufacture, etc.).

In his recently released 2005-2006 Annual Report, *Neglecting Our Obligations*, October 2006 (ECO, 2006), and the accompanying October 3, 2006 press release, the Environmental Commissioner of Ontario (The Honourable Gord Miller) singled out the transportation sector for its "…*massive demand for gravel and sand*" and the transportation and construction industries in general, and the aggregates industry specifically, for not adequately meeting the Province's waste diversion/reuse and recycling 'targets'. A perception that the construction and transportation sectors are not partners in sustainable management of aggregate resources persists despite obviously increasing reliance by municipal and provincial agencies and the private sector on reuse and recycling of pavement materials (aggregates, concrete and asphalt materials) to optimize and extend construction, maintenance and rehabilitation budgets; recent developments/improvements in roadway pavement rehabilitation technologies such as hot and cold in-place recycling (HIR and CIR) and full depth reclamation (FDR) of flexible (asphalt) pavements; rubblization of concrete pavements; etc., and implementation of 'long life' or 'perpetual pavement' concepts in the design, construction, maintenance and rehabilitation of roadway pavements. The necessity for the transportation sector partners to consider and adopt all practical reuse and recycling methods has been further driven by the need to preserve and extend resources, and the huge (and continuing) increases in energy

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[*] *see List of References at the end of this Report*

costs that impact on all aspects of transportation construction, materials production and transportation.

### 1.1 SCOPE AND METHODOLOGY

This updated Study has focused on the following elements from the 1992 Study, in order to assess and reflect the current status of reuse and recycling in Ontario and indicate opportunities for enhanced reuse and recycling, if any, that may still be considered. :

1. Synthesis of the current state-of-the-art technology for residuals and byproducts use as aggregates in Ontario, including research and development, based on world-wide experience;

2. Determination of the current and potential sources and quantities (stockpiled and/or rate of production) of residuals and byproducts in Ontario that were, or had the potential to be, recycled and reused as aggregates;

3. Evaluation of factors 'encouraging' residuals and byproducts recycling and re-use as aggregates in Ontario and development of strategies to further enhance such reuse and recycling, including a comparative summary of relevant North American legislation;

4. Evaluation of factors 'discouraging' residuals and byproducts reuse and recycling as aggregates in Ontario, including strategies to mitigate these constraints on such reuse and recycling, including a summary of typical actions by North American agencies in terms of policies incentives and specifications modifications; and

5. Determination of the current and potential contributions of residuals and byproducts recycling and reuse as aggregates to 'extending' Ontario's overall aggregate reserves, and specifically, the positive current and future impact(s) for the Greater Toronto Area aggregate consuming market and other significant areas identified.

This updated Study has also focused mainly on 'bulk' applications where residuals, byproducts and excess materials are used mainly as construction aggregates (as granular base and subbase, cement-stabilized base, and in portland cement concrete and asphalt concrete pavements), rather than on 'cementitious' applications where residuals, byproducts and excess materials are used as a principal component or in the production of cementitious materials (portland cement and supplementary cementitious materials such as slag cement, fly ash, kiln dust; rubber asphalt in asphalt pavements; etc.). The updated Study has identified and discussed the 'highest best use' principles throughout to reflect the positive technical and economic benefits of reusing and recycling of materials such as reclaimed asphalt pavement (RAP) that are replacements for both virgin aggregate and the asphalt cement binder in recycled hot-mix.

The 2007 state-of-the-art for the 'bulk' use of wastes and byproducts as construction aggregates, and associated information on factors that encourage (or discourage) such use, policy and/or legislative changes or incentives, was determined from:

1. review of the extensive in-house research and internal direct projects involvement files conducted by JEGEL since 1991, including FHWA, NCHRP and RILEM studies (FHWA, 1998; NCHRP, 2000; NGSMI, 2005; OECD, 1977; OECD,1997);

2. searches of online databases (Transportation Research Information Services TRIS Online for instance) on asphalt recycling, concrete recycling, ferrous and nonferrous foundry sands, fly ash and bottom ash, blast furnace and steel slags, etc.;

3. surveys of wastes and byproducts reuse and recycling, using the forms given in Appendix A, circulated to Ontario aggregate suppliers (Ontario Stone, Sand and Gravel Association (OSSGA) member firms), hot-mix asphalt producers (Ontario Hot Mix Producers Association (OHMPA) member firms), ready-mix concrete producers (Ready-Mixed Concrete Association of Ontario

(RMCAO)), road building contractors (Ontario Road Builders Association (ORBA) and demolition industry representatives, and a separate survey of agencies (Ontario Good Roads Association (OGRA) and Municipal Engineers Association (MEA) members) on reuse and recycling, specifications and legislation;

4. interviews and discussions with staff involved with wastes and byproducts utilization in government agencies (MTO and municipal agencies), contractor/ supplier associations (ARRA for instance) and industry (Dofasco for instance), owners (Greater Toronto Airports Authority for instance) and international contacts (through PIARC participation (John Emery);

5. detailed wastes and byproducts availability and utilization inventory development (old asphalt and old concrete, including in-place recycling processes; blast furnace slag, steel slag , nonferrous slags, etc.) by MNR and MTO regions/districts, and GTA, mainly through telephone and email contacts with contractors, suppliers and industry staff; and

6. follow-ups and synthesis of information and data on wastes and byproducts reuse and recycling as aggregates in bulk applications.

As was the case for the original 1992 Study, the wastes and byproducts inventory activity was particularly challenging for this Updated Study. In addition to being time-consuming, many producers/suppliers and agencies do not track the quantities of recycled material separately from virgin aggregate, especially for 'standard' recyclable materials such as old asphalt and old concrete that are now viewed as largely routine and covered by a variety of standard specifications (Ontario Provincial Standard Specifications (OPSS) for example). Additionally, it was found that the JEGEL direct involvement in recycled materials technology, and especially as authors and/or co-researchers on recent major reuse and recycling 'best practices' studies (FHWA 1998; NCHRP 2000, and NGSMI 2005 for instance), as well as specific byproduct utilization research (such as the 2003 City of Toronto Pilot Study on the use of recovered glass and ceramic materials for use as aggregate in road construction, rehabilitation and maintenance projects) was generally much more comprehensive than that indicated by the database searches and general technical literature.

## 1.2 USE OF AGGREGATES IN ONTARIO

As reported in the 1992 Study, in the five-year period between 1985 and 1989, the average annual total aggregates (stone, sand and gravel) production for use as construction aggregates and in industrial processes was about 178 million tonnes, with nearly 200 million tonnes reported for 1989. It was estimated at that time that about 25 percent of this total Provincial aggregates production was in the Greater Toronto Area (GTA), with GTA aggregate consumption significantly higher (about 40 percent of the total for the Province). Recent 2006 figures (NRCan, 2007) indicate that the total aggregate production (licensed production and permit production) for Ontario was about 171 million tonnes (5-year average for period from 2002 to 2006), and represents over 42 percent of the total Canadian annual aggregate production. This corresponds to 12 to 14 tonnes per annum per capita. The total value of this raw aggregate production exceeds about $1.4 billion, F.O.B. the point of production.

The major uses of stone, sand and gravel are in roads, concrete aggregates and asphalt aggregates, with 70 to 75 percent of the Ontario aggregates estimated to be used in these applications (about 115 million tonnes).

**TABLE 1**
**APPROXIMATE QUANTITIES OF CONSTRUCTION AGGREGATE REQUIRED FOR VARIOUS COMMON USES**
**(tonnes)**

| | |
|---|---|
| 1 km of Six-Lane Road | 51,800 |
| Average Brick House | 440 |
| Average School | 13,000 |
| Large Office Block | 16,000 |

**TABLE 2**
**ONTARIO AGGREGATES PRODUCTION**
**(million tonnes)**

| Source Type | 2002 | 2003 | 2004 | 2005 | 2006 | 5-Year Average |
|---|---|---|---|---|---|---|
| Licensed Pits and Quarries | 141 | 143 | 150 | 149 | 152 | 147 |
| Wayside Permits | 0 | 0 | 0 | 1 | 0 | 0 |
| Aggregate Permits | 7 | 7 | 7 | 8 | 11 | 8 |
| Forest Industry | 4 | 3 | 4 | 4 | 4 | 4 |
| Private Lands (Not Designated) | 12 | 12 | 12 | 12 | 12 | 12 |
| **Total** | **164** | **165** | **173** | **174** | **179** | **171** |

Source: Mineral Aggregates in Ontario, Statistical Update 2006 (Preliminary), The Ontario Aggregate Resources Corporation.

Comparing the above aggregate production figures with those previously reported in the 1992 Study, there has been no significant change (slight decrease) in the total amount of aggregate production (based on the 5 year average for the period from 2002 to 2006, inclusive). The geographic distribution of aggregate production across the province is shown in Table 3. Table 4 shows the total aggregate production distributed by Canadian Portland Cement Association (CPCA) geographic area. These tables clearly show that the vast majority of aggregates production (about 146 million tonnes) is in the densely populated areas of the Province (GTA, Niagara Peninsula, Central, Southwestern and Eastern areas).

**TABLE 3**
**2006 LICENCED AGGREGATE PRODUCTION BY MNR DISTRICT**
**(1000 tonnes)**

| District | Sand & Gravel | Crushed Stone | Clay/Shale | Other Stone | Total |
|---|---|---|---|---|---|
| Aurora (GTA) | 15,198 | 11,884 | 850 | 172 | 28,104 |
| Aylmer | 10,482 | 4,176 | 9 | 0 | 14,667 |
| Bancroft | 159 | 2,387 | 0 | 50 | 2,597 |
| Guelph/Cambridge | 23,988 | 13,646 | 234 | 2 | 37,871 |
| Kemptville | 5,341 | 13,519 | 158 | 1,106 | 20,124 |
| Midhurst | 14,267 | 7,380 | 8 | 258 | 21,913 |
| Pembrooke | 1,594 | 607 | 0 | 2 | 2,204 |
| Peterborough | 8,367 | 9,977 | 4 | 26 | 18,373 |
| Sault Ste. Marie | 1,154 | 32 | 0 | 3 | 1,189 |
| Sudbury | 3,137 | 555 | 0 | 1 | 3,693 |
| **Total** | **83,687** | **64,162** | **1,264** | **1,620** | **150,733** |

**TABLE 4**
**2006 ONTARIO AGGREGATE PRODUCTION BY CPCA GEOGRAPHIC AREA**
**(1000 tonnes)**

| Area | Licensed Production | Permit Production |
|---|---|---|
| Southwest | 19,230 | 5 |
| Niagara Pennisula | 15,720 | 0 |
| West Central | 39,500 | 0 |
| GTA | 28,104 | 0 |
| East Central | 16,942 | 299 |
| East | 26,352 | 56 |
| Northeast | 3,693 | 6,778 |
| Northwest | 1,189 | 3,354 |
| **Total** | **150,733** | **10,493** |

The Ontario Lake Carriers' Association has reported that approximately 6 million tonnes of aggregate is exported from Ontario to the US (mainly from Ontario quarries), and that about 1 million tonnes of aggregate (mainly sand and gravel) is imported to Ontario from the US. On this basis, the total tonnage of new aggregates used in Ontario annually is about 166 million tonnes.

## 2. AVAILABILITY OF SUITABLE WASTES AND BYPRODUCTS

### 2.1 GENERAL FRAMEWORK FOR REUSE AND RECYCLING

Since the 1992 Study was completed, there has been a significant international effort to develop standard methods for evaluating the suitability of various wastes and byproduct materials for use as construction aggregates. The most significant North American reference in this regard is the FHWA *User Guidelines for Wastes and Byproduct Materials in Pavement Construction* (FHWA, 1998) and *Framework for Evaluating Use of Recycled Materials in the Highway Environment* (October 2001), with the European state-of-the-technology described in *Recycled Materials in European Highway Environments: Uses, Technologies, and Policies* (FHWA, 2000).

The FHWA Framework Report describes a methodology for evaluating recycled materials (wastes, byproducts, excess materials) is six categories:

1. **Traditional Highway Materials** – recycled materials originating in the highway sector that have historically been used with good success in highway construction applications (recycling of asphalt or concrete pavement materials into new highway pavement construction);

2. **Traditional Recycled Materials in Traditional Applications** – recycled by-product materials originating in the industrial, municipal or mining sectors that have historically been used with good success in highway construction applications (for instance, coal fly ash or blast furnace slag as supplementary cementitious materials in portland cement concrete mixtures);

3. **Traditional Recycled Materials in New Applications** – recycled by-product materials originating in the industrial, municipal or mining sectors that have historically been used in one application proposed for use in a new application (for instance, use of reclaimed concrete aggregate in flexible (asphalt ) pavement construction);

4. **New Recycled Materials in Traditional Applications** – recycled materials that have not been previously used (little or no historical data) in applications where recycled materials have been used (such as nonferrous slags as a supplementary cementitious material in portland cement concrete);

5. **New Recycled Materials in New Applications** – recycled materials that have not been previously used (little or no historical data) in new applications (for instance, the use of bottom ash from municipal solid waste in asphalt concrete mixtures); and

6. **Recycled Materials in Appurtenances** – recycled materials (plastics for instance) used in the manufacture of signs, barriers, guard rails, etc.

The framework methodology provides detailed descriptions of the screening, laboratory testing and field evaluation portions of the process.

Table 5 provides a listing of potential uses of recycled materials in various applications.

### 2.2 WASTES AND BYPRODUCTS CONSIDERED

For this updated Study, the focus was on recyclable materials used as construction aggregates in bulk applications, and Table 5 has been adapted to highlight these uses.

The 1992 Study proposed initial screening criteria for the overall evaluation of wastes and byproducts for use in the construction industry that is still considered to be quite relevant and augments the FHWA framework, as follows:

1. the quantity of material available at the location must be large enough to justify the development of handling, processing, stockpiling and transportation systems. For bulk applications (such as aggregates and engineered fill), about 45,000 tonnes per year or equivalent stockpile for several years was considered to be appropriate;
2. transportation distances involved must be reasonable in terms of competition with conventional aggregate supplies; and
3. the processed material must not be potentially harmful either during construction or when in service (no leaching of toxic constituents, soluble compounds, etc.).

Using these initial screening criteria in conjunction with the potential uses for various recycled materials described in the FHWA framework for this Updated Study focus on wastes and byproducts used in bulk applications, the following Ontario wastes and byproducts are considered to have the greatest potential for use as construction aggregates in bulk applications:

- Old Asphalt (Reclaimed Asphalt Pavement (RAP))
- Old Concrete (Reclaimed Concrete Material (RCM))
- Blast Furnace Slag
- Roofing Shingle Waste
- Waste Glass
- Steel Slag
- Nonferrous (Copper and Nickel) Slags
- MSW Bottom Ash
- Mine Waste Rock (including Quarry Fines).

In order for these materials to be considered for use as replacements for conventional aggregates in bulk applications, technically sound, economically viable and environmentally responsible reuse and recycling options are required.

The joint Ontario Ministry of Transportation (MTO) and Ontario Ministry of the Environment (MOE, formerly MOEE) ‘wasteless highway’ initiative and resulting May 1994 *Protocol of the Management of Excess Materials from Road Construction and Maintenance* (MOEE, 1994) was reviewed in 1995, with a framework then developed for the evaluation and use of potentially excess materials to enable highway design and construction personnel to reuse and recycle materials generated on road construction and maintenance projects (JEGEL, 1995). The management of excess materials is covered by Ontario Provincial Standard Specification (OPSS) 180. As a result of this initiative, the reuse and recycling of existing roadway pavement granular base and subbase materials, either as granular subbase or fill material, is a standard, ongoing excess materials management activity, and hence, it is not possible to capture the very large quantity of new aggregates conserved by this activity.

During the period between 2000 and 2004 inclusive, the MTO reportedly used about 53.7 million tonnes of aggregates for road construction, of which 9.8 million tonnes (18.2%) consisted of recycled or alternative materials (Wilson and Rogers, 2006). MTO recycled or made available for reuse by others 100 percent of the material available. This consisted of:

- Full depth reclamation – 54%
- Surplus rock from ROW – 25%
- Recycled concrete and asphalt in granular base – 10%
- Cold in-place recycling – 4%
- FDR with expanded asphalt – 3%
- Hot in-place recycling – 2%
- Blast furnace slag – 2%.

It is also most noteworthy that this figure does not include reclaimed asphalt pavement (RAP) recovered by contractors from MTO projects and reused in recycled hot mix asphalt in conformance with Ontario Provincial Standard Specification requirements.

At the time that the 1992 Study was completed, most recycling of existing road construction materials was carried out at centralized plants, where the recovered materials were transported, processed and stockpiled for reuse. While the technologies for in-place recycling were generally known, there was only limited use of in-place recycling techniques for rehabilitation of existing pavements (both flexible pavements (asphalt concrete over granular base and subbase) and rigid pavements (exposed portland cement concrete and composite (asphalt concrete surfacing over portland cement concrete base). Since then, there has been a growing emphasis to recycle road construction materials as close as possible to their point of origin, with current, proven technologies now standard and covered by Ontario Provincial Standard Specifications and/or special provisions. Such in-place recycling techniques (hot and cold in-place recycling of hot-mix asphalt pavements, full depth reclamation and stabilization of asphalt pavements, and in-place recycling ("rubblization") of concrete pavements) are therefore also considered in their respective context as construction aggregates in bulk applications (old asphalt and old concrete).

### 2.3 INVENTORY OF ONTARIO WASTES AND BYPRODUCTS

The determination of the inventory (sources and quantities) of Ontario wastes and byproducts suitable for use as aggregates in bulk applications proved to be very time-consuming, with the initial responses to the surveys very limited, requiring several extensions to submission dates and re-distribution of the surveys by industry association representatives involved in the Project Advisory Panel. The survey results were subsequently supplemented by information obtained by JEGEL through direct telephone and email contact, as well as reviews of projects on file where JEGEL was specifically involved. Wherever possible, the veracity of this information was independently checked through comparison with other data sources (trade industry statistics for instance), and where discrepancies were identified, supplemented by recent published information/ statistics (EAPA, 2007; Kellerher, 2007, for instance).

Some producers/suppliers were extremely candid in their responses, providing detailed information on inventories and production quantities (cold in-place and full depth reclamation contractors for instance), while other responses, particularly where a proprietary process may be involved, were more difficult to substantiate. Every effort was made to quantify and corroborate the waste and byproducts inventory data, however, the figures provided are influenced by the level of detail in the information provided. The sources for the inventory information given in this report have been cited, with discussion, where appropriate, to assist in interpreting the data.

## 3. WASTES AND BYPRODUCTS

Each of the wastes and byproducts identified has been considered in terms of major Ontario sources; availability and uses; storage, processing and distribution; technical, environmental and economic factors; research and development; and impediments to increased use.

### 3.1 OLD ASPHALT

The current Canadian state-of-the technology for reuse and recycling of hot-mix asphalt pavements is described in detail in the National Guide for Sustainable Municipal Infrastructure (InfraGuide) 'best practice' guide that was prepared by JEGEL (NGSMI, 2005), and as such, is the principal reference used herein for the discussion of old asphalt reuse and recycling.

Reuse and recycling of old asphalt is not a 'new' concept, with both hot and cold recycling of asphalt materials recovered from roadways having been completed since at least the early 1900's (ARRA, 2001; PIARC, 2001). However, little advancement in asphalt recycling technology and equipment was made until the 1970's, when, spurred by the Energy Crisis, asphalt recycling efforts increased in response to social and environmental pressure to reduce the demand for products made using non-renewable fossil fuels/petroleum hydrocarbons.

The use of reclaimed asphalt pavement (RAP) to produce recycled hot-mix in a central asphalt plant (batch drum or combined batch-drum plants) is well-established and continues to grow across Canada, with recycled hot mix (RHM) included in most Canadian agency (provincial and many municipal) specifications for binder course mixes in particular, and some use in surface course mixes (Emery, 1991). Continuing advancements in recycling technologies, including hot in-place recycling (HIR), cold in-place recycling (CIR), cold in-place recycling with expanded asphalt modification (CIREAM), cold central plant recycling (CCPR), and full-depth reclamation (FDR), and their successful implementation and growing positive performance record, are providing pavement managers with a wider variety of technically acceptable, cost effective reuse and recycling options for roadway maintenance and rehabilitation work. However, notwithstanding these advancements and recent substantial increases in the price of new asphalt cement, there continues to be surplus RAP in major municipal areas (GTA, Ottawa, for example), where the amount of RAP generated from pavement construction and rehabilitation projects exceeds the amount currently being reused in recycled hot mix.

In recent years, CIR, CIREAM and FDR have become the preferred cold recycling processes for structural improvement/ strengthening and maintenance of municipal asphalt pavements, while evolving Canadian third generation forced hot-air preheater technology is resulting in enhanced quality for HIR asphalt rehabilitation (MTO, 2007). These pavement rehabilitation methods have been proven to provide cost effective, enhanced life-cycle performance. Asphalt recycling has become a key component of the Canadian paving industry, with Ontario largely viewed internationally as leaders in introducing and implementing techniques for asphalt recycling. Table 7 has been adapted from data recently compiled by the European Asphalt Pavement Association (EAPA, 2007) for 18 countries and Ontario (with Ontario's data supplied to EAPA by OHMPA). This table demonstrates that Ontario is somewhat ahead of most industrialized nations in terms of the total amount of RAP recycled in hot and cold asphalt mixtures (7$^{th}$ in terms of the amount of RAP available, and 5$^{th}$ in total amount used).

It is critical that the appropriate technology is adopted to ensure that the desired pavement quality is achieved. While RAP grindings, millings and/or pieces can be blended with conventional aggregate (sand and gravel or crushed rock) or RCM for use as granular subbase or shouldering material, such use is discouraged as it does not utilize the asphalt cement binder or recover the energy invested in its production. Reuse in paving mixtures is therefore preferred from both materials management and sustainable development viewpoints.

Current methods for reuse and recycling of old asphalt are described in the following sections. The ARRA *Basic Asphalt Recycling Manual* (ARRA, 2001) and the OHMPA *ABCs of Asphalt Pavement Recycling* (OHMPA, 2003) are recommended references for additional information.

### 3.1.1 Central Plant Recycling

According to recent (2006) survey data submitted by the Ontario Hot Mix Producers Association (OHMPA) to the European Asphalt Producers Association (EAPA), there are at least 160 hot-mix asphalt plants currently operating across in Ontario. This is comprised of about 125 stationary plants, and 35 portable plants. About 145 of these plants are currently equipped for to recycle old asphalt into new hot-mix production (recycled hot mix), the large majority of which are situated in the Greater Toronto Area and Greater Niagara Area, with the eastern and southwestern areas of the province also having a significant number of hot-mix plants. The hot-mix asphalt producers range in size from single plant operators serving a local market to large diversified construction materials and construction firms with multiple offices/plants such as Lafarge North America (27 hot-mix asphalt plants across Ontario), Miller Paving Limited (with 23 hot-mix asphalt plants), Dufferin Construction Company (with 10 hot-mix asphalt plants) and K.J Beamish Construction Co., Ltd. (having 8 hot-mix asphalt plants). The total 2006 production of hot-mix asphalt across Ontario was reported by OHMPA to be in the order of 13 million tonnes (Table 8), which also corresponds to the average total production for the past 6 year period (2001 to 2006, inclusive, ranging from 11 million tonnes in 2004, to 14 million tonnes in 2001 and 2002).

**TABLE 5**
**RECYCLED MATERIALS POTENTIALLY SUITABLE AS AGGREGATES IN BULK APPLICATIONS**
**(ADAPTED FROM FHWA, 2001)**

| Application | | Potential Suitability* of Recycled Material | | |
|---|---|---|---|---|
| | | **Green** | **Yellow** | **Red** |
| **Asphalt Concrete Pavement** | Mineral Filler | Asphalt Plant Dust<br>Coal Fly Ash | Lime Kiln Dust<br>Cement Kiln Dust<br>Sewage Sludge Ash | |
| | Hot-Mix Aggregate | Reclaimed Asphalt Pavement (RAP) | Coal Bottom Ash<br>Blast Furnace Slag<br>Coal Boiler Slag<br>Roofing Shingle Scrap<br>Scrap Tires<br>Municipal Solid Wastes Ash<br>Nonferrous Slag<br>Foundry Sand<br>Mineral Processing Wastes<br>Waste Glass<br>Steel Slag | |
| | Surface Treatment/Seal Coat Aggregate | Blast Furnace Slag<br>Coal Boiler Slag Steel Slag | | |
| **Portland Cement Concrete Pavement** | Mineral Admixture/Cement Additive | Coal Fly Ash<br>Blast Furnace Slag | | |
| | Portland Cement Concrete Aggregate | | Reclaimed Concrete Material | |
| **Granular Base/Subbase** | Granular Base/Subbase Materials | Reclaimed Asphalt Pavement (RAP)<br>Waste Glass<br>Reclaimed Concrete Material<br>Coal Bottom Ash<br>Waste Ceramics | Blast Furnace Slag<br>Steel Slag<br>Nonferrous Slag<br>Coal Boiler Slag | Municipal Solid Wastes<br>Mineral Processing Wastes<br>Foundry Slag |
| **Stabilized Base/Subbase** | Stabilized Base or Subbase Aggregate | Coal Bottom Ash<br>Reclaimed Asphalt Pavement (RAP) | Coal Boiler Slag | |
| **Flowable Fill (Controlled Low-Strength Material (for Utility Cut Backfilling))** | Flowable Fill Aggregate | Coal Fly Ash<br>Quarry Fines | Foundry Sand | |
| **Embankment and Fill** | Embankment or Fill Materials | Reclaimed Concrete Material | C&D Debris<br>Reclaimed Asphalt Pavement (RAP)<br>Nonferrous Slag<br>Wood Chips<br>Mineral Processing Wastes<br>Coal Fly Ash<br>Blast Furnace Slag<br>C&D Wood Waste<br>Scrap Tires | |

***Green** indicates a byproduct that is currently technically and environmentally acceptable for use as aggregates in these bulk applications.

**Yellow** indicates a byproduct that has potential for reuse as aggregate in bulk applications, but there are some technical, environmental, or economic factors that must be considered.

**Red** indicates a byproduct that has previously had some potential for reuse as aggregate in bulk applications, but significant technical or environmental issues preclude its current use.

**TABLE 6**
**MAJOR ONTARIO WASTES AND BYPRODUCTS AVAILABILITY AND USE AS CONSTRUCTION AGGREGATES IN BULK APPLICATIONS**
**COMPARISION BETWEEN 1990 AND 2006 DATA**

**(1000 tonnes)**

| WASTES AND BYPRODUCTS | | 1990 DATA[1] | | | 2006 DATA[2] | | |
|---|---|---|---|---|---|---|---|
| | | Annual Production | Annual Use | Currently Stockpiled | Annual Production | Annual Use | Currently Stockpiled |
| Old Asphalt | Recycled in Hot-Mix Asphalt or As Road Base Aggregates | Not Known | 1772 | 2281 | Not Known[3] | 1950[3] | 3000[3] |
| | In-Place Recycling[5] | Nil | Nil | Not Applicable | 1712 | 1712 | Not Applicable |
| Old Concrete | | Not Known | 1751 | 1254 | 6000[4] | 5000[4] | 1000[4] |
| Blast Furnace Slag | Air-Cooled[6] | 550 | 575 | Nil | 30 | 30 | Nil |
| | Pelletized[6] | 700 | 700 | Nil | 860[7,8] | 209[7,8] | 800[7,8] |
| | Granulated | 400 | 100 | 450 | Not Determined (used in cementitious applications only for the manufacture of slag cement) | | |
| Roofing Shingle Waste | | Nil | Nil | Nil | 47[9] | 124[9] | 77[9] |
| Waste Glass | | Nil | Nil | Nil | 120 (Ontario) | 30 | Not Known |
| | | | | | ~17.5 (Toronto) | Nil | Nil |
| Steel Slag | | 633 | 488 | >5000 | 600[7] | 90[7] | Not Known[7] |
| | | | | | ~30,000 t produced annually by Dofasco for use as HMA coarse aggregate and 60,000 t fine aggregate used as fill material in unconfined applications in the Greater Hamilton Area[7] | | |
| Nonferrous Slags (Copper and Nickel) | | 1550 | 1000 | 2900 | 1400[4] | 3000[4] | Not Known[4] |
| Bottom Ash | | 142 | 92 | 0 | 866[10] | 951 | 0 |
| | | (coal bottom ash; Ontario Hydro, now Ontario Power Generation) | | | ~33 (MSW bottom ash; Region of Peel)[11] | | |
| Foundry Sand | | 270 | 9 | Not Known | Poor information[4]; 1.6 million tonnes reportedly stockpiled (some use as kiln feed in portland cement manufacture) | | |
| Mine Waste Rock | | 2516 | Not Known | 95820 | ~15,000[4] | Not Known[4] | ~15,000 (managed on-site)[4] |

Notes:
1. from MNR, 1992;
2. from synthesis of 2007 survey data and JEGEL project files, except where noted;
3. from OHMPA (2006 information supplied by OHMPA for EAPA survey, 2007)
4. from data reported by Ontario Waste Management Association for 2006 (Kelleher, 2007);

5. "in-place" includes HIR, CIR and FDR in-place recycling processes, with 2006 quantities provided to JEGEL by the major Ontario specialist contractors.
6. production of air-cooled BFS for construction aggregates use suspended due to environmental (aesthetic concerns – leachate colour and odour);
7. data supplied by Dofasco for period from 2002 to 2006; data could not be obtained for Stelco (Hamilton) or Algoma Steel (Sault Ste. Marie).
8. processes modified in ~Year 2000 (Lafarge Litex® proprietary vitrification process for the manufacture of specialty lightweight slag aggregate for cement block manufacture and lightweight fill); no data available for Algoma Steel BFS use.
9. data reported by Ontario Waste Management Association for 2002; annual use includes ~60,000 tonnes/year of Manufactured Shingle Modifier (Lafarge 2004) and tear-off roofing waste.
10. data reported by Ontario Waste Management Association for Ontario Power Generation for 2004; includes fly ash, bottom ash and phosphogypsum.
11. Personal Communication; D. Melton, Region of Peel.

**TABLE 7**
**SUMMARY OF RAP AVAILABILITY/USE INTERNATIONALLY**
**(Adapted from EAPA, 2007)**

| Country | Estimated Amount of RAP Available (tonnes) | Amount Used in RHM (tonnes) | Amount Used in Cold Mix Asphalt (tonnes) | Total Amount of RAP Used (tonnes) | Percentage of New Hot-Mix Production That Contains RAP |
|---|---|---|---|---|---|
| Austria | 600,000 | 60,000 | 60,000 | 120,000 | 5.0 |
| Belgium | 1,300,000 | 650,000 | 0 | 650,000 | 36 |
| Czech Republic | 604,400 | 181,320 | 302,200 | 483,520 | 10 |
| Denmark | 240,000 | >19,200 | 0 | >19,200 | 53 |
| France | 6,500,000 | 825,500 | >130,000 | >955,500 | < 10 |
| Germany | 14,000,000 | 11,480,000 | 2,520,000 | 14,000,000 | 60.0 |
| Ireland | 48,000 | 18,240 | 0 | 18,240 | 2.1 |
| Italy | 14,000,000 | 2,520,000 | 280,000 | 2,800,000 | |
| Luxembourg | 200,000 | 180,000 | 20,000 | 200,000 | 60 |
| Netherlands | 3,400,000 | 2,720,000 | 680,000 | 3,400,000 | 65 |
| Norway | 590,000 | 38,940 | 155,760 | 194,700 | 8 |
| Poland | 1,000,000 | 40,000 | 550,000 | 590,000 | 0.2 |
| Slovenia | 22,000 | 11,000 | 2,200 | 13,200 | 15 |
| Spain | 690,000 | 207,000 | 103,500 | 310,500 | 5.0 |
| Sweden | 650,000 | 325,000 | 325,000 | 650,000 | 40 |
| Switzerland | 945,000 | 472,500 | 472,500 | 945,000 | |
| **Canada (Ontario)** | **3,000,000** | **1,500,000** | **450,000** | **1,950,000** | **40.0** |
| U.S.A. | 90,000,000 | 72,000,000 | | 72,000,000 * | - |
| Venezuela | 8,970,000 | 0 | 1,435,200 | 1,435,200 | 0 |

* This figure represents the total amount recycled in recycled hot mix and cold mix asphalt.

**TABLE 8**
**2006 DATA FOR ONTARIO ASPHALT PRODUCERS (EAPA, 2007)**

| | |
|---|---|
| No. of Hot-Mix Asphalt Plants | 160 (125 stationary, 35 portable) |
| No. of HMA Plants Currently Equipped for RHM Production | 145 |
| Total HMA Production | ~13 million tonnes |
| Total RAP Stockpiled | ~3 million tonnes* |
| Total Amount of RAP Used in RHM Production | ~1.5 million tonnes |
| Total Amount of RAP Used in Cold Mix Asphalt | 450,000 tonnes |
| Total Amount of RAP Used in Granular Base/Subbase, Shouldering, Etc. | ~1 million tonnes |

* Recent Ontario hot-mix asphalt industry estimates suggest that this figure may have risen to 3.5 to 4 million tonnes in 2007 due primarily to lack of end uses in the GTA and Ottawa areas.

The use of processed RAP in batch, drum, and combined drum-batch asphalt plants to produce RHM is the most common type of asphalt recycling, and is considered standard asphalt technology in Canada and internationally (TAC, 1994; MTO, 1995; OECD, 1997; FHWA, 2002, OHMPA, 2003, for instance). The two most common types of HMA plants capable of incorporating RHM are shown in Photographs 3.1 and 3.2.

On major road and highway rehabilitation projects, a substantial amount of RAP may be generated on-site by partial-depth milling of the existing surface or complete removal of asphalt concrete layers, then processed (crushed and screened) and re-incorporated directly into RHM for reuse on the project. However, in larger urban centres, RAP recovered from a number of small roadway and commercial paving projects may be collected and centrally stockpiled, usually at a hot-mix producer's plant, for reuse in RHM mixtures.

It is important that the RAP be properly processed to ensure that the engineering properties of the RAP are equivalent to virgin materials. Proper blending and crushing is required to produce a consistent gradation and asphalt cement content. This RAP management minimizes variations in the properties of the RAP from different sources, resulting in relatively homogeneous material in stockpiles. The RAP is processed (crushed and screened) using a portable plant or integrated processing operation that can handle both RAP and new hot-mix asphalt.

On major road and highway rehabilitation projects, a substantial amount of RAP may be generated on-site by partial-depth milling of the existing surface or complete removal of asphalt concrete layers, then processed (crushed and screened) and re-incorporated directly into RHM for reuse on the project. However, in larger urban centres, RAP recovered from a number of small roadway and commercial paving projects may be collected and centrally stockpiled, usually at a hot-mix producer's plant, for reuse in RHM mixtures.

**Photograph 3-1: Typical parallel flow HMA drum asphalt plant.**

The conveyor on the right transfers processed RAP to the top-centre where it is fed into the continuous drum mixer.

**Photograph 3-2: Typical counterflow drum – batch asphalt plant.**

The RAP cold feed bin and conveyor is shown in the right corner.

For batch mix plants, the amount of RAP incorporated is typically limited to less than 30 percent to ensure adequate drying and heat transfer in the pugmill from superheated aggregate, and to limit 'blue smoke' emissions. Depending on the amount of RAP to be incorporated in the RHM, it may be necessary for the new asphalt cement to have a higher (softer) penetration grade (lower viscosity) in order to offset the harder 'aged' asphalt cement in the RAP; this is generally not necessary with RAP addition rates less than about 25 percent. The need to soften the aged asphalt cement and to control potential emissions (blue smoke) limits the amount of RAP that can be incorporated in drum asphalt plants to between 40 and 60 percent (JEGEL, 1992; Earl and Emery, 1987).

The maximum amount of RAP permitted in HMA specifications varies somewhat from province to province. All provinces except Nova Scotia and Prince Edward Island permit RAP to be used in HMA, provided that testing is completed to ensure the quality (penetration/viscosity, or performance grading for Superpave mixtures or the asphalt cement) and uniformity of the RAP source and that the RHM meets all specification requirements for asphalt concrete. Ontario currently limits the amount of RAP in surface course HMA to 15 percent maximum, with 30 percent in conventional binder course mixes and up to 50 percent in certain situations subject to confirmatory testing. Newfoundland allows 10 percent RAP in levelling course only, whereas Québec accepts up to 15 percent RAP in RHM. Alberta and New Brunswick permit higher RAP addition levels (30 percent and 40 percent (± 5 percent), respectively). British Columbia, Saskatchewan and Manitoba do not limit the amount of RAP that can be added to HMA.
The steps involved in designing a recycled hot mix mixture are:

- Obtain representative samples of the RAP and determine RAP properties (gradation, asphalt cement content, penetration and viscosity of the recovered asphalt cement binder) in the laboratory;
- Complete Marshall mix design in accordance with AI MS-2 procedures; alternatively, for Superpave volumetric mix designs, the mix design should be completed in accordance with the most current (2003) AASHTO MP-2 and AASHTO PP-28 procedures (NCHRP 452, *Recommended Use of Reclaimed Asphalt Pavement in the Superpave Mix Design Method – Technician's Manual*, also provides specific technical guidance for mix designers);
- Conduct quality control and quality assurance (acceptance) testing during RHM production and placement to confirm that it meets specification requirements.

Central plant recycled hot-mix asphalt production is considered to be standard asphalt technology, with the only impediment to more widespread use being the current lack of hot-mix asphalt plants suitably equipped for introduction of the RAP and control of potential air emissions (mainly 'blue smoke', especially at higher RAP proportions) in some areas in Canada. Air emissions can however can be readily mitigated through the use of good environmental management practices during production, with the OHMPA Environmental Practices Guide providing 'best practices' for control of air emissions.

#### 3.1.2 Hot In-Place Recycling

In Hot In-Place Recycling (HIR), the old asphalt pavement surface is heated, softened and scarified to depths of 20 to 60 mm, the scarified material is then remixed, placed, and compacted as a part of a continuous in-place process. New aggregates, new asphalt cement, recycling/softening agents, and/or new HMA (commonly referred to as 'admix') can also be added to improve the engineering properties of the existing pavement and for increased structural capacity (for a total treatment thickness up to 75 mm). Pavement distresses which can be treated by HIR include: flushing/bleeding; raveling; rutting; shoving; poor surface friction (macrotexture and microtexture); and longitudinal and transverse cracking, and reflection cracking (Emery et al, 1989; MacKay and Emery, 1989; Kazmierowski et al, 1994; Dunn et al, 1997).

There are three types of HIR treatment (MacKay and Emery, 1989):

- Surface Recycling: To improve the profile of an asphalt surface course deformed by rutting or wearing, but in comparatively unaged condition with only minor cracking (no rejuvenation required). Surface Recycling consists of heating, scarifying, leveling, reprofiling and compaction of the mixture.

- Remixing: To improve the quality of old, cracked, aged surface course through the addition of a recycling agent/rejuvenator, aggregate or new hot-mix asphalt. Remixing involves heating, scarifying (with rejuvenator, mixing aggregates and/or new hot-mix asphalt added), mixing, leveling, reprofiling and compaction.

- Repaving: To improve the profile of an asphalt surface course severely deformed by rutting or wearing, improve frictional characteristics, and/or provide some strengthening. Repaving involves heating, scarification (with rejuvenator, aggregate and or new hot-mix added, if necessary), mixing, leveling and laying of new hot-mix asphalt, reprofiling and compaction, all in one pass.

It is recommended that a proper pavement evaluation be carried out to fully determine the cause(s) of the pavement distress and the most appropriate HIR process then selected to address the pavement conditions. Materials characterization and mix design by a qualified, experienced laboratory, in conjunction with quality control (QC) and with quality assurance (QA) verification testing during the rehabilitation work, are critical components of a successful HIR project. The most current HIR equipment is shown in Photograph 3-3 (Martec, 2002).

HIR technology has been steadily evolving, with continuing improvements in the overall quality and performance of HIR pavements. New third generation combined forced hot-air/radiant low-level heat preheaters have overcome previous issues with heater-scarification quality and depth, allowing increased treatment depth without degradation (aging) of the existing asphalt cement binder, including polymer-modified asphalt cements. This equipment has also reduced 'blue smoke' (emissions factor) to below that of conventional hot-mix asphalt plants (EPA/FHWA/Martec, 2003).

The JEGEL survey of producers/suppliers and agencies, as well as direct JEGEL communications with HIR specialist contractors, indicate that only a small quantity of Ontario asphalt pavements were rehabilitated using this process in 2006.

### 3.1.3 Cold In-Place Recycling

Cold in-place recycling (CIR) is an on-site process for the rehabilitation of asphalt-surfaces (on both flexible and composite pavements) to depths up to 150 mm. The old asphalt is milled to a specified depth, mixed with emulsified asphalt, or with foamed asphalt (cold in-place recycling with expanded asphalt modification (CIREAM)) and repaved to the required grade and profile. A surface treatment or hot-mix asphalt wearing surface is applied after the CIR mix has properly cured.

This process is being widely implemented by cities, rural agencies, provinces and states, and there are a number of qualified specialist Canadian contractors having state-of-the-art equipment and demonstrated direct municipal projects experience. Pavements exhibiting the following distresses can be considered for cold in-place recycling: longitudinal and transverse cracking; bleeding; corrugations; potential bonding problems; raveling; rutting; shoulder drop off; and shoving. The CIR mix is relatively stiff with high air voids and hence is effective in mitigating reflective cracking. Initially used mainly for rehabilitation of low volume roads, CIR is now considered to be a proven technology for higher AADT (higher ESAL) roadways.

The CIR process involves: milling or grinding of the existing asphalt surface to depth typically 75 to 125 mm; processing/mixing of the pulverized RAP (with addition of beneficiating aggregate, if any, foamed asphalt or water and emulsion (plus cement (one to three percent) or lime (one to two percent) addition to increase mix stability and reduce stripping potential, if necessary); compaction with water as an aid to densification, and densification as the water content comes into equilibrium with ambient conditions and surroundings. The CIR mixture continues to increase in strength and stiffness with time. Once fully cured (approximately two weeks for CIR and 3 days for CIREAM), the CIR mix must be overlaid with a wearing surface (conventional hot-mix asphalt or other surfacing depending on AADT).

**Photograph 3-3: Current HIR Remixing train rehabilitating a municipal roadway in a single pass, 2002**

Three combination forced hot-air/radiant low-level heat preheaters lead the HIR train (left side of photograph), followed by the preheater/milling unit; new HMA admix is loaded into a hopper at the front of the remixing unit where it is fed and mixed with the existing pavement material and distributed by the asphalt paver. Conventional HMA compaction equipment is used to simultaneously compact the HIR mix.

It is recommended that a pavement evaluation be carried out to assess overall suitability for CIR treatment, and the specific CIR process requirements. Materials characterization and mix design by a qualified, experienced laboratory, in conjunction with quality control (QC) and quality assurance (QA) verification testing during the rehabilitation work, are critical components of a successful CIR project.
CIR modifications developed for improved economics and/or special conditions include addition of supplementary beneficiating aggregate, special emulsions and cement or lime slurry addition.

CIR of the existing pavement overlaid with a surface course hot-mix asphalt layer designed to meet Superpave mix requirements has been used for enhanced durability and to minimize reflective and/or thermal cracking. CIR of the existing pavement, in conjunction with the placement of open graded cold mix wearing surface, is being developed for a ‘total cold’ system.

Ontario use of CIR has been increasing since this technology was commercially introduced in Ontario in the early to mid Nineties. The JEGEL survey of the major Ontario specialist contractors currently providing this process indicates that in 2006, approximately 1.25 million square metres of mainly municipal asphalt pavements were rehabilitated in-place using this process, which would be equivalent to approximately 265,000 tonnes of ‘new’ aggregate mixtures. It is important that the CIR mix design be completed by a qualified laboratory with CIR experience, using representative samples of the existing asphalt from each section (millings or cores (preferred)). A new approach to CIR mix design based on the SHRP Gyratory Compactor is currently under development (Emery, 2003).

Typical CIR equipment in use on Canadian (Ontario) municipal projects is shown in Photographs 3-4, 3-5 and 3-7.

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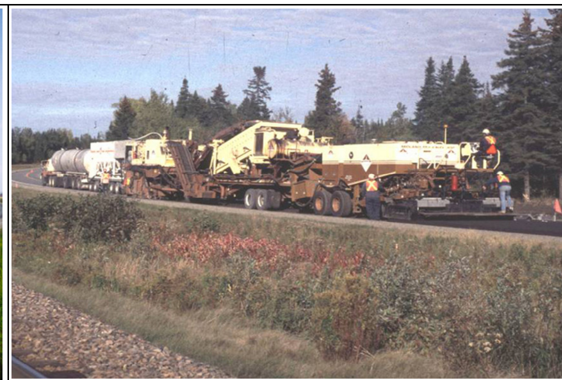
|  |  |
| **Photograph 3-4: Ontario CIR Project, 2000** This four piece recycling train consists of an emulsion tanker, milling machine, RAP crushing and screening unit and computerized pugmill/paver. | **Photograph 3-5: Ontario CIR Project with cement slurry addition, 1999** Added to this CIR recycling train is a cement slurry tanker which gives the pugmill/paver the ability to add cement slurry to the mix. |

### 3.1.4 Cold Central Plant Recycling

Cold central plant recycling (CCPR) produces the same end product as cold in-place recycling. The RAP obtained from the roadway, or from centrally-located homogeneous stockpiles, is processed (crushed and/or screened), then fed into a central mixing plant where the emulsified asphalt and any additives are added and blended. The CCPR mixture is then transported to the paving site and placed in the same manner, using conventional hot mix asphalt or RHM paving equipment. The cold central plant recycling option should be considered where large stockpiles of high quality RAP are readily available and where it may not be practical to recycle the existing pavement in place due to variability in the existing pavement or in-place recycling equipment may not be available. The same mix design procedures and QC/QA inspection and testing methods are required for CCPR as for CIR.

### 3.1.5 Full Depth Reclamation

There are a number of different types of full depth reclamation (FDR) techniques available to Canadian municipalities, including pulverization-mixing (‘pulvi-mixing’)/in-place reprocessing (without stabilization); FDR with bituminous stabilization (using asphalt emulsion (normal, high-float, polymer modified) or foamed asphalt); FDR with chemical stabilization (using cementitious systems such as Portland cement, fly ash, lime (hydrated or quicklime), cement kiln dust or lime kiln dust, or additives such as calcium chloride or magnesium chloride); and/or FDR with mechanical stabilization (by addition of corrective aggregate).

Full depth reclamation involves pulverization and in-place mixing of the full thickness of the asphalt pavement and a predetermined portion of the underlying materials (base, subbase and/or subgrade) to provide a homogeneous base material (ARRA, 2001). Full depth pulverization ensures mitigation of reflective cracking by eliminating pre-existing cracks. The pulvi-mixed base material may be structurally enhanced by stabilization.

The most common form of FDR includes bituminous stabilization with foamed asphalt. Until recently, this technology was not widely used in Canada (Dawley et al, 1993; TAC, 1994), but is rapidly growing (Brown et al, 2000; Donovan and Stefaniw, 2003; Emery and Uzarowski, 2003; Johnston et al, 2003; Lane and Kazmierowski, 2002). Two foamed asphalt stabilization processes in current use are shown in Photographs 3-6 and 3-7.

FDR with foamed asphalt stabilization consists of full depth pulverization of the existing roadway followed by addition and mixing of foamed asphalt with the pulverized material (typically at addition rates between 2 and 3.5 percent) to create a stabilized base. Depending on the properties of the material being stabilized, the FDR with foamed asphalt stabilization process

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| **Photograph 3-6: Ontario FDR Project, 2005** This two piece recycling train consists of a hot asphalt cement tanker (160°C or greater) and a computerized pulverizer/foamer/mixer machine capable of pulverizing/foaming to depths in excess of 200 mm. This machine, combined with a grader and conventional compaction equipment, is capable of full depth recycling. | **Photograph 3-7: Ontario CIREAM Project 2007** Similar to CIR with emulsion, this four piece CIREAM recycling train consists of a hot asphalt cement tanker, milling machine, RAP crushing and screening unit and computerized foamer/paver. This machine is capable of both partial and full depth recycling. |

may be enhanced by addition of lime or Portland cement (Emery, 2007). One to two percent lime may be added, if necessary, subject to the plasticity of the granular base/subbase or subgrade material to be stabilized, to increase mix stability or provide enhanced resistance to moisture damage/stripping (Figure 3-1). If the base material does not contain adequate fines for lime stabilization and/or increased stability is required, typically 1 to 3 percent Portland cement may be added to the FDR with foamed asphalt process. Treatment depths vary depending on the thickness of the existing pavement structure, but generally range between 100 and 300 mm (4 to 12 inches). Additional corrective granular or RAP material (mechanical stabilization) may be added if necessary to increase the pavement structural capacity.

The main advantages of foamed asphalt stabilization include: ease of application in a variety of municipal and highway settings; provision of a flexible layer with good rut resistance and fatigue properties; the ability to correct the pavement profile; and reflective cracking mitigation.

The design of a foamed asphalt mixture should be carried out by an experienced and qualified asphalt laboratory. The foamed asphalt cement expansion properties (expansion ratio and half-life with percent injection water) are determined in the laboratory, and a foamed asphalt mix design is developed for the optimum tensile strength ratio (TSR, resistance to moisture). There are several similar mix design methods available which are essentially based on the Wirtgen procedure (Wirtgen Cold Recycling Manual, 1998).

Proper quality control (QC) and quality assurance (acceptance) (QA) testing of both the foamed asphalt cement and the foamed asphalt mix during a foamed asphalt project are critical to its successful performance. During construction, the asphalt cement temperature, injection water percentage, expansion ratio and half-life are monitored for process control.

The JEGEL survey of the major specialist contractors offering FDR and PDR/CIREAM processes indicates that approximately 4.34 million square metres of municipal roadway and provincial highway pavements were rehabilitated in 2006 using these processes (3.3 million FDR and 1 million PDR/CIREAM), corresponding to conservation of about 1.52 million tonnes of new aggregate (as well as about 25,000 tonnes of new asphalt cement (approximately $12.5 million at a current cost of approximately $500/tonne).

### 3.2 OLD CONCRETE

The current Canadian state-of-the technology for reuse and recycling of old concrete is described in detail in the National Guide for Sustainable Municipal Infrastructure (InfraGuide) 'best practice' guide that was prepared by JEGEL (NGSMI, 2005), and as such, is the principal reference used herein for the discussion of old concrete reuse and recycling.

The reuse and recycling of old concrete (pavements, sidewalks, curb and gutter, as well as some concrete recovered during building construction and demolition (C&D)) is well-established. Old concrete is 100 percent recyclable in roadway construction applications such as pavement granular base and subbase, and may also be used as concrete aggregate in Portland cement concrete mixtures provide some precautions are taken (such as alkali-aggregate reactivity for instance), or processed in-place using rubblization techniques.

Prior to considering complete removal of old Portland cement concrete pavements for recycling, there are a variety of proven procedures for repair and rehabilitation of deteriorated concrete pavements that should first be considered to extend their life. Following completion of a proper pavement evaluation to confirm the current condition of the concrete pavement and the causes of distresses, the most appropriate concrete pavement rehabilitation technique (termed $CPR^3$ – restoration, resurfacing, reconstruction) can be selected. These $CPR^3$ techniques include full and partial depth repairs of cracked slabs; repair of deteriorated joints or cracking by retrofitting dowel bars or using cross-stitching techniques to restore load transfer efficiency; cracking and seating or slab stabilization (slab jacking or mud jacking) to restore continuous support to concrete pavement slab panels; and restoration of surface texture and frictional properties by diamond grinding, grooving or blast abrasion techniques (Skidabrader for instance). The rehabilitated concrete pavement can then be overlaid with asphalt concrete or either a bonded or unbonded Portland cement overlay, as necessary, to restore pavement profile or provide additional structural capacity.

The latest CPR techniques are described in various American Concrete Pavement Association (ACPA) publications and technical bulletins (www. pavement.com).

#### 3.2.1 Reclaimed Concrete Material (RCM) As Granular Base/Subbase

Portland cement concrete is normally produced using high quality coarse and fine aggregates that are well-suited for recycling. The use of reclaimed concrete material as construction aggregate and fill material is well-established and is largely considered to be a standard practice (TAC, 1994; OECD, 1997; FHWA, 1997; FHWA, 2004; Melton, 2004); for example, RCM has been an approved source of aggregate in Ontario Provincial Standard Specifications (OPSS) 1001 Aggregates – General, and OPSS 1010 Aggregates – Granular A, B, M and Select Subgrade Material, since the late 80s. Crushing and screening of RCM results in a well-graded, 100 percent crushed, angular material that has high strength when used in pavement base course applications (equivalent to 100 percent crushed natural aggregates) with good drainage properties.

Reclaimed concrete material (RCM) is generated through the demolition of concrete pavements, sidewalks, curb and gutter, runways and transportation structures, mostly in urban areas. Portland cement concrete from building foundations, walls and floor slabs recovered during the demolition of building structures can also be considered, but without careful source separation, these materials can potentially contain construction and demolition (C&D) wastes such as brick, wood, wallboard, glass, plastic, coatings (moisture and fire-proofing for instance), and other materials that are generally not suitable in construction aggregates. Consequently, it is recommended that a proper evaluation of all C&D wastes considered for use as construction aggregate be performed to ensure they meet appropriate standards before use.

After processing (crushing and screening, and removal of metal), the processed RCM can be reused as granular base and subbase material. The RCM may also include some old asphalt from composite (asphalt over concrete) pavements; for strength considerations, the amount of old asphalt that can be included in RCM subbase is typically limited to about 30 to 50 percent by mass. For example, based on

MTO research (Senior, 1992) indicating that the California Bearing Ratio (CBR) strength of the natural and recycled concrete aggregate decreases with increasing RAP content, OPSS 1010 limits the total amount of asphalt-coated particles in Granular A base and Granular B Type 1 subbase to 30 percent by mass. RCM has also been used as aggregate in lean-concrete, cement-stabilized base and in soil-cement mixtures (CAC, 2002).

A typical RCM processing operation consists of breaking large concrete pieces/slabs using crane and ball-drop, hydraulic or pneumatic breakers (hoe-ram equipment for instance), diesel hammers, etc.; removal of reinforcing steel; primary crushing and sizing (using jaw crushers most typically); and secondary crushing (cone, roll or impact crushers) and final screening. The crushing and screening circuit may also include a magnetic separator for additional metals removal/recovery (as scrap, potentially providing an additional source of revenue that may partially offset processing costs), and spray bars for dust control. Both portable and permanent crushing circuits are used, depending on the amount of RCM available.

The reuse and recycling of old concrete as granular base and subbase materials has been carried out by Transport Canada/Public Works Government Service Canada and the Greater Toronto Airports Authority at Toronto-Lester B. Pearson International Airport since the early Eighties. Most recently, for its Infield Terminal Apron construction project, the GTAA specified 100 percent use of RCM obtained during the demolition of the former Terminal 1 building and apron pavements (Wilson and Rogers, 2006). On this project approximately 180,000 tonnes of RCM was reused as granular subbase for the new Infield Terminal apron concrete pavement construction.

The JEGEL survey for this Study confirmed that in 2007, two contractors in the GTA produced over 1.6 million tonnes of RCM for use as granular base and subbase. A typical portable portland cement concrete crushing plant is shown in Photograph 3-8.

### 3.2.2 Recycled Concrete Aggregate and Crushed Concrete Aggregate

Recycled Concrete Aggregate (RCA) has been used as an aggregate in hot-mix asphalt (TAC, 1994) and in Portland cement concrete (FHWA, 1997; FHWA, 2004; FHWA, 2007; Kasai, 2004). The term *recycled concrete aggregate* (RCA) is generally used to refer to processed RCM used as aggregate in recycled concrete mixtures (‘new’ Portland cement concrete produced using recycled concrete aggregates). Recycled concrete aggregate has a higher absorption than conventional natural aggregates and generally yields concrete having lower strength (compressive strength, modulus of elasticity, tensile strength) at equivalent water/cement ratios and lower slump than conventional aggregates (JEGEL, 1992; FHWA, 2007). There is also a significant increase in the amount of drying shrinkage and the permeability of the hardened concrete. If recycled concrete aggregate is used, the workability/finishability of the fresh concrete also decreases. In addition, potentially deleterious substances, such as sulphates (from old plaster for instance), chlorides and alkali reactive aggregates, must be strictly controlled.

With careful attention at the mix design stage, quality concrete can be produced using recycled concrete aggregates. The higher absorption of recycled concrete aggregates may require adjustment to water and Portland cement content to achieve the appropriate water:cement ratio for concrete strength and durability (ECCO, 1999; CAC, 2002; Kasai, 2004). Due to their high absorption, prewetting of recycled concrete aggregates is recommended (FHWA, 1997; Kasai, 2004).

Reuse of recycled concrete aggregate in Portland cement concrete may be particularly appropriate in locations where there is a lack of natural aggregates satisfactory for use in quality concrete. However, in Ontario, the use of processed RCM has been mainly in granular subbase in urban areas where supply and transportation costs favour such use (MNR, 1992).

In contrast to RCM and RCA, *crushed concrete aggregate* (CCA) is the excess ‘fresh’ material from ready-mixed concrete manufacture, and consists of the fresh ready-mixed concrete material that was dispatched from the ready-mixed concrete plant but was returned from the job site and allowed to harden. In most cases, this represents ready-mixed concrete was not discharged from the transit mixer truck and was then returned to the plant for disposal. It could also potentially include the relatively small quantity of ready-mixed concrete that was rejected at the job site (did not meet specification requirements (usually as a result of ordering the wrong material), or which may have exceeded the allowable time limits between batching and discharging (typically 90 to 120 minutes depending on specific project specifications and Canadian Standards Association (CSA) requirements).

#### 3.2.3 Rubblization

Rubblization is an in-place rehabilitation technique that involves breaking the concrete pavement into pieces having a nominal maximum size of about 75 mm or less above and 200 mm or less below any reinforcement (AI, 2000). This process results in a structurally sound, rut resistant base layer which prevents reflective cracking (by obliterating the existing concrete pavement distresses and joints) that can then be overlaid with asphalt or Portland cement concrete. Proper drainage is critical to the success of a rubblization project. In areas of weak subgrade or high water table, the drainage system should be functioning as far in advance of the rubblizing as possible to allow the subgrade to be as stable as possible (Wolters, 2003).

The two most common types of rubblization equipment are resonant breakers and multiple head breakers. Resonant breakers (Photograph 3-10) produce low amplitude, high frequency blows by vibrating a large steel beam connected to a foot than can vary in width from 150 to 300 mm. The foot is moved along the concrete pavement surface in multiple passes to rubblize the full width of the pavement.

Multiple head breakers employ a number of large drop hammers (550 to 675 kg) in two rows with half of the hammers in a forward row and the remainder diagonally offset in the rear row. Each pair of hammers is attached to a hydraulic lift typically capable of cycling between 30 to 35 impacts per minute (MHB Badger, 2004, http://www.badgerbreaker.com/mhb.html) and generating between 2,000 and 12,000 foot pounds of energy depending on the drop height selected. Multiple head breakers can rubblize up to 3.95 m wide at 1.6 lane km per shift.

During the rubblization process, the concrete pavement is fractured into small pieces (generally 50 to 150 mm). The effectiveness of the rubblizing equipment in producing the desired particle sizes is also a function of the condition of the underlying base/subgrade, with smaller sizes more readily achieved over a firm stable base/subgrade (Wolters, 2003).

Prior to placement of the asphalt or concrete overlay, the rubblized concrete must be rolled with at least three passes of a high-frequency vibratory roller fitted with Z-pattern bars on the roller face (AI, 2000; Wolters, 2003). This further pulverizes the surface of the rubblized layer.

The thickness of the asphalt or concrete overlay over the rubblized base material must be properly designed to meet pavement structural requirements.

Rubblization is a cost effective, technically proven method for 100 percent recycling/reuse of an existing concrete pavement, with the process also covered by Ontario Provincial Standard Specification (OPSS) 361 (November 2002), *Construction Specification for Rubblizing Concrete Pavement and Concrete Base*. A typical rubblization process is shown in Photograph 3-9.

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| **Photograph 3-8: Crushing Old Concrete for Use as Granular Material**<br>The old portland cement concrete is stockpiled, and then loaded into the hopper for crushing and screening (portable unit shown above), and eventual uses as road bed aggregates. | **Photograph 3-9: Ontario Rubblization Project 2002**<br>In this process, the old asphalt concrete is removed, then the underlying portland cement concrete base is rubblized (also know as crack and seat) for use as granular base. This project also included a CIR overlay. |

### 3.3 BLAST FURNACE SLAG

While previously considered to one of the waste/by-product 'success stories', with hot-mix asphalt and granular base/subbase aggregate applications for air-cooled blast furnace slag well established and covered by standard specifications, the use of air-cooled blast furnace slag came under fire in the mid-Nineties as a result of mainly aesthetic concerns over leachate quality (colour and odour) generally associated with 'fresh' (un-aged) blast furnace slag used in applications where it was permitted to come into contact with water (surface or ground water). Consequently, these 'traditional' markets for air-cooled blast furnace slag aggregates evaporated, and the steel industry subsequently almost totally discontinued production of air-cooled blast furnace slag in the Hamilton area (Dofasco and Stelco). With the exception of relatively small amounts of air-cooled blast furnace slag produced during short periods of time when blast furnace slag pelletizing equipment is broken down (about 30,000 tonnes/year typically), all blast furnace slag is now pelletized for use as lightweight aggregate for primary use in concrete block manufacture, with some limited secondary use as lightweight fill.

There is currently about 850,000 tonnes of blast furnace slag produced per annum by the two major Hamilton-area steel producers (Dofasco and Stelco) (Dofacso, 2007), with virtually all of it fully utilized, in conjunction with Lafarge North America (Lafarge Slag), in the production of VITREX® ground pelletized slag cement, and LITEX® and True Lite® lightweight aggregates.

The annual usage (sales) of LITEX® lightweight aggregates has been relatively constant, increasing only slightly to about 210,000 tonnes in 2006 (200,000 tonnes in 2002, and 209,000 tonnes in 2004) for use in the manufacture of concrete masonry blocks, structural and non-structural concrete, soil stabilization and horticultural/landscaping applications. There has been relatively limited use of this pelletized blast furnace slag lightweight aggregate for fill applications.

Overall, pelletized blast furnace slag production has somewhat exceeded demand, and there is currently about 800,000 tonnes stockpiled in Hamilton.

Blast furnace slag is also generated at the Algoma Steel facility in Sault Ste. Marie; information could not be obtained on the amount of BFS produced at this location or its current use as construction aggregate. This material is currently processed by Superior Slag Products Inc. in Sault Ste. Marie. It is understood that a significant amount of this material is exported to Michigan, and that BFS production in Sault Ste. Marie is likely to increase with the recently announced expansion of the Algoma Steel operation (addition of a sixth blast furnace).

The VITREX® vitrified pelletized slag is ground for use in the manufacture of slag cement, a supplementary cementitious material used in conjunction with conventional portland cement (blended cements). A typical blast furnace slag pelletizer is shown in Photograph 3-10.

### 3.4 STEEL SLAG

Once considered to be one of the more successful waste/industrial by-product utilization examples, with 488,500 tonnes used in hot-mix asphalt in 1990 (MNR, 1992), concerns with volume instability (expansion) and consistency, with associated extensive early age random/map cracking and staining, led to an MTO moratorium on steel slag use as hot-mix aggregate in 1991. Annual production of steel slag has been relatively steady, with 310,000 tonnes produced at Dofasco in 2006 and a similar amount estimated for Stelco (Dofasco, 2007). The large majority of this steel slag (>200,000 tonnes at Dofasco) is returned to the steelmaking furnace where it has largely replaced coarse dolime (metallurgical grade dolomitic limestone) aggregate as a flux material in the steelmaking/ slag practice component of the process.

Despite steel industry efforts that led to substantial improvements in the quality of steel slag aggregates, field trials demonstrating that quality steel slag aggregates could be produced for use in hot-mix asphalt through strict control of flux and slag practices, performance-based testing to confirm low volume expansion characteristics and total quality management throughout (Farrand and Emery, 1995; Wang and Emery, 2004), steel slag aggregate has not been re-instated for use on provincial highway contracts and in most major municipalities (City of Toronto for instance). The City of Hamilton resumed limited use of steel slag aggregates after completing some favourable trials of the quality controlled product, but this usage has been quite localized and consistent at about 30,000 tonnes per annum. There have been no reported problems with the use of this material in the Hamilton area since these Dofasco quality improvements were implemented.

In addition to the above, approximately 60,000 tonnes per year of steel slag fine aggregate (passing 4.75 mm) is being used (sold) locally as engineered fill and gravel surfacing in unconfined applications. Additionally, a small amount is also sold for kiln feed in portland cement manufacturing (source of iron and silica). Air cooling of steel slag is shown in Photograph 3-11.

### 3.5 ROOFING SHINGLE MATERIAL

The composition of roofing shingles varies with the type of base material, with either an organic (cellulosic) or fiberglass base material used (ASTEC, 1998). Older shingles tend to have a somewhat different composition than newer shingles. In Ontario, new shingles are manufactured using a organic (cellulosic) felt impregnated/saturated/coated with a relatively hard (compared to the asphalt cement binder used in hot-mix asphalt) asphalt cement, then coated with high quality, durable trap rock aggregate granules.

Approximately 300,000 tonnes of asphalt roofing

**Photograph 3-10: Blast Furnace Slag**
Blast furnace slag pelletizer in action.

**Photograph 3-11: Steel Slag**
Dumping molten steel slag from a transporter at a cooling pit (1990s).

shingle wastes are generated annually across Canada (about 10 million tonnes in the United States) (Yonke et al, 1999; McGraw et al, 2007). Some of this waste material can be recycled in hot-mix asphalt to recover cellulosic fibre, mineral filler (limestone), aggregate (trap rock) and asphalt cement in the shingle material, with these components having the potential to replace and/or augment the asphalt cement and aggregates making up conventional hot-mix asphalt.

This use has developed in Ontario since about 1994 (Yonke et al, 1999), and over the past 20 years in the United States (McGraw et al, 2007). Provisional standard specifications were recently established by the Association of American State Highway and Transportation Officials (AASHTO) separately covering the use of manufacturers' (post-industrial) shingle scrap and tear-off (post-consumer) shingle scrap as an additive in hot-mix asphalt (AASHTO, 2006a and 2006b).

In comparison with the manufacturers' (post-industrial) shingle scrap, the tear-off (post-consumer) shingles can be quite variable and contaminated with nails, wood, insulation, roofing tars and waterproofing materials that must be removed. Consequently, since about the mid-Nineties, the recycling of asphalt shingle waste in Ontario has focused on post-industrial 'new' asphalt shingle manufacturing waste – Manufactured Shingle Modifier (MSM) – derived only from new asphalt shingle manufacturing waste (punch outs, tabs, etc.).

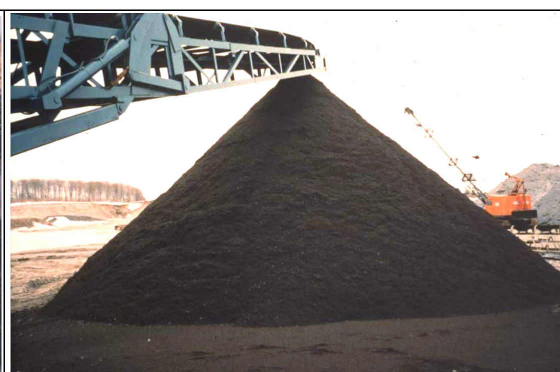
There are a number of reuse and recycling potential benefits from utilization of properly processed waste shingles in hot-mix asphalt mixtures (Yonke et al, 1999), including:

- Reduced cost for shingle waste disposal and conservation of landfill space;
- Reduced cost for production of hot-mix asphalt, resulting from a reduction in the use of new materials;
- Possible improved resistance to pavement cracking due to the reinforcement provided by fibres from shingles;
- Possible improved resistance to pavement deformation (rutting) due to a combination of the fibres and harder asphalt cement used in the shingles;
- Better durability and enhanced resistance to ravelling due to increased asphalt cement film thickness in MSM mixes; and
- An economic source of fibre for Stone Mastic Asphalt (SMA) mixes.

**Manufactured Shingle Modifier (MSM)**

Lafarge Canada Inc. produces MSM at several locations in Ontario, for incorporation in hot-mix asphalt mixes supplied to municipal and provincial, and commercial paving projects (Photographs 3-12 and 3-13). The processing typically involved shredding the shingle waste material to about 12.5 mm minus size using a rotary shredder or high-speed hammermill; screening to remove any oversize and produce a consistent gradation; followed by blending with a carrier material such as sand or reclaimed asphalt pavement to prevent the shredded material from agglomerating.

**Photograph 3-12: MSM**
Modified shingle modifier (MSM) processing plant.



**Photograph 3-13: MSM**
Modified shingle modifier being processed.

Current MSM usage in Ontario has been relatively consistent, at about 60,000 tonnes per year (Lafarge, 2006).

**Recycled Shingle Product (RSP)**

Commencing in about 2002, a concerted research effort was undertaken in Ontario on the processing and recycling of tear-off roofing shingle material in hot-mix asphalt mixtures (Tighe, 2007). This has included development of mix designs and laboratory evaluations as well as some recent limited field trials.

In 2007, trial mixes incorporated Recycled Shingle Product (RSP) were produced by Miller Paving Limited at its Markham Plant and placed on various roads in the Town of Markham (Photographs 3-14 and 3-15). Mix designs prepared in accordance with the Superpave mix design methodology were completed for both surface course and binder course mixes: SP 19 mm binder course hot-mix asphalt incorporating 18% RAP with 2% RSP and an SP 12.5 mm FC1 surface course hot-mix asphalt mix incorporating 3% RSP.

The RSP incorporated into the mix consisted of a 12.5 mm (½ inch) minus product that was blended into the hot aggregate before the batch plant's hot elevator and it was found to be evenly distributed. Premixing of the RSP with the hot aggregates and additional mixing time was undertaken to ensure uniform distribution of the high asphalt cement content of the RSP throughout the final mixed product.

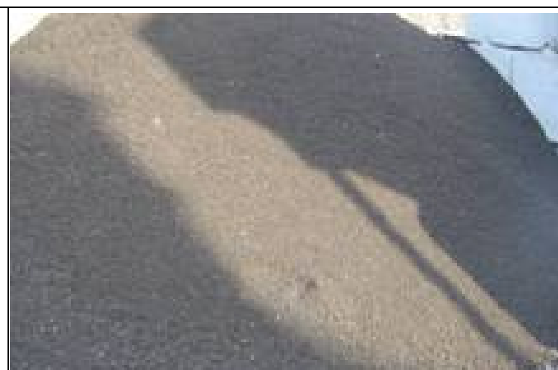
Approximately 740 t of SP 19 mm was placed November 2, 2007 on Green Lane in Newmarket, Ontario, incorporating 18% RAP with 2% RSP. Quality control (QC) and quality assurance (QA) testing during mix production and placement showed the resultant mix generally tested within the limits set for the virgin SP 19 mm HMA that was specified in the contract. Additional field trials and laboratory evaluations are currently proposed for 2008 and beyond to more fully prove the physical properties, performance attributes and favourable economics (including life-cycle costing) of the tear-off shingle scrap material in hot-mix asphalt mixtures.

### 3.6 WASTE GLASS AND CERAMIC MATERIAL

Municipal 'blue box' recycling programs and water-reduction incentive programs (rebates for switching to low-flow toilets) are generating substantial volumes of waste glass and ceramic material that have some potential for reuse and recycling as construction aggregates in bulk applications. These materials cannot currently be recycled to produce new glass or porcelain and therefore have largely been sent to landfills for disposal.

Mixed Broken Glass (MBG) is the glass collected in recycling programs that, because of its colour and other characteristics (coatings, contaminants for instance) can not be recycled by the glass industry in the production of new glass. This material has no current use as recycled glass and is being mainly dumped in landfill sites (Senior, Szoke and Rogers, 1994) with comparatively small amounts processed for

**Photograph 3-14:**
Tear-off waste shingle material prior to processing for RSP.



**Photograph 3-15:**
Processed 12.5 mm minus Recycled Shingle Product (RSP).

other uses such as glass beads for line markings. In a 2004 study completed by JEGEL for the City of Toronto, it was reported that approximately 17,500 tonnes of mixed broken glass (MBG) was collected in 2003 through the City's blue box recycling program, which was sent to a landfill in Michigan at a cost to the City of over $600,000.

Old bathroom fixtures (toilets and sinks), after removal of hardware and gaskets, also provide a source of waste ceramic material (WCM) that cannot be reused to produce new ceramic material/porcelain, but has some potential to be recycled.

The majority of MBG and WCM are collected and disposed of by private waste management contractors operating under contract to the municipalities. Stewardship Ontario reports that approximately 120,000 tonnes of mixed glass was collected, of which approximately 29,500 tonnes of clear glass was returned for recycling by the glass manufacturers ('bottle-to-bottle' recycling), and the remainder recycled in other applications (fiberglass for instance) or landfilled.

In 2003, the Liquor Control Board of Ontario reported that it sold more than 110,000 tonnes of glass containers. In February 2007, the Province of Ontario implemented a deposit-return program for wine and liquor containers in an effort to reduce the amount of materials sent to landfills. While no figures are yet available as to the success of the bottle-return program, it was anticipated that some 25,000 to 30,000 tonnes of waste glass would be diverted.

### 3.6.1 Waste Glass as Construction Aggregate

While there have been a number of road construction applications where waste glass has been investigated (commencing in the late Sixties), with early focus on 'glasphalt' (asphalt concrete incorporating processed crushed glass as aggregate) and higher value-added applications (including concrete), there is comparatively little 'standard' use of MBG and WCM in these higher value materials. Based on mix designs, testing and trial projects in the early Nineties, the former Municipality of Metropolitan Toronto (former MT 701 specification) allowed up to 20 percent waste glass to be used in hot-mix asphalt binder course. However, the overwhelming agency consensus and specifications emphasis appears to focus on the use of waste glass and ceramics/porcelain in granular base and subbase, and granular fill materials, at relatively modest addition rates (typically 15 percent maximum; OPSS 1010 and MTO Special Provisions for instance).

A City of Toronto pilot study project was completed in late 2003 using 15 percent (by mass) of MBG, blended with 50 mm minus crushed concrete (RCM) for use as granular subbase on a local residential roadway. No apparent problems were encountered that were attributed to the incorporation of waste glass. The trial section was subsequently overlaid with HL 8 binder course in late November 2003, and there have been no performance problems with this trial section. Additionally, environmental analyses completed on a sample of the blended material showed either trace or no detectable concentrations of inorganic and volatile organic compounds. Barium, fluoride and trichloroethylene were detected in trace concentrations.

The following potential applications of the waste glass as construction aggregate were identified:
*

- Granular base
- Granular subbase
- Roadway embankments
- Backfill for foundations
- Backfill for walls
- Backfill for pipe bedding
- Backfill for drains
- Drainage blanket
- Bedding material for rigid and flexible pipes
- Trench backfill
- Asphalt Aggregate
- Concrete Aggregate

In addition to these 'bulk' aggregate applications, some MBG can also be processed for use as kiln feed (source of silica), mineral wool manufacture, and fillers (paint and plastic products for instance).

The use of waste glass in asphalt mixes (glasphalt) has been limited. Moisture susceptibility/stripping resistance, ravelling, high tire wear and poor skid resistance are problems associated with the use of waste glass in asphalt mixes. Addition of hydrated lime as an antistripping agent is generally required to mitigate potential stripping problems (FHWA, 1998).

Waste glass is generally not recommended for use as concrete aggregate. Glass is potentially reactive with Portland cement concrete (alkali-silica reaction), and the possible presence of sugars in waste glass that can interfere with Portland cement hydration, may affect the final strength of the Portland cement concrete (Senior, Szoke and Rogers, 1994). Some limited work has indicated that small amounts of MBG can be used as fine aggregate in concrete mixes, but this is not a generally accepted practice (FHWA, 1998).

### 3.6.2 Physical Properties of Mixed Broken Glass (MBG) Aggregate

In general, the coarse crushed glass particles are angular and can contain some flat or elongated particles. In some cases, very sharp particles can be found, however, the smaller glass sizes are generally well-rounded. The amount of flat or elongated particles in crushed waste glass is a function of the crushing process and equipment used, with vertical impact crushers and jaw crushers generally producing more cubical material (as compared to cone or roll crushers). The size distribution of the waste glass also depends on the processing equipment (crushing and screening) used. In most of the construction applications, the crushed waste glass needs to be blended with conventional aggregates to meet the gradation requirements.

The crushed waste glass exhibits lower specific gravity values than natural aggregates, from about 1.95 to 2.4 and about 2.5 for fine waste glass.

Breakdown of the crushed glass can occur during handling especially in the larger size particles. The permeability coefficient for the crushed waste glass typically ranges from $10^{-1}$ to $10^{-2}$ cm/sec and is therefore similar to coarse sand. The permeability depends on the distribution of the glass particle sizes (gradation) and its shape.

The processed crushed glass can contain some organic debris, including paper, plastic labels, wood debris, food residue, plants, cork, etc., and inorganic materials such as plastic (caps, fibres), metal (caps, lids), ceramics, glass, bricks, concrete, stones, dust, etc.

### 3.6.3 Construction Procedures

The same methods and equipment used to store conventional aggregates are applicable for waste glass. However, when stockpiling and handling coarse waste glass, additional breakdown should be anticipated.

Most of the agencies allow up to 5 percent debris in waste glass. If necessary, magnetic separation can be used to remove metal debris (caps for instance) and air classification equipment for plastic or paper.

Glass dust, generated mainly during the crushing of the waste glass, is a potential health concern. Studies reveal that crushed waste glass contains less than 1 percent crystalline silica by mass and therefore it is not considered hazardous. However, the use of worker protection (ear protection, dust masks for instance) and dust control systems are recommended to avoid skin and eye irritation.

### 3.6.4 Waste Ceramic Material as Construction Aggregate

As there are no reuse options for old porcelain and ceramic tiles and fixtures, virtually all of these materials are disposed by landfilling. It is also not possible at this time to practically estimate the quantity of material that might be potentially available for recycling as construction aggregate. There also seems to be somewhat of a negative public perception on using old toilets and fixtures for public roadway construction despite the lack of any significant technical (physical or health/environmental) obstacles to such reuse.

The collection and storage of old fixtures does present somewhat of an operational obstacle, as the collected fixtures must be separated and transported to a location where all of the metal, plastic and rubber accessories can be removed (usually by hand). This operation takes up a lot of space due to the volume of the fixtures. Once the accessories have been removed, the stockpiled ceramic/porcelain fixtures can be smashed or crushed to reduce their volume. Care is required in crushing this raw material for blending with conventional construction base

|  |  |
|---|---|
| **Photograph 3-16: Waste Ceramic Material** Stockpiled waste ceramic material (15%) and crushed concrete Granular A (85%) RCM. | **Photograph 3-17: Waste Ceramic Material** Placement and compaction of waste ceramic material/RCM. |

and subbase aggregates. The 'glassy' material has a propensity to fracture concoidally, producing sharp shards and splinters. However, these sharp particles were observed to break down when the WCM is blended and stockpiled with the conventional granular materials.

The physical and chemical (mineralogical) properties of crushed porcelain and ceramic materials preclude their use as concrete and hot-mix aggregates. However, based on evaluation of WCM by MTO (Senior, Szoke and Rogers, 1994), OPSS 1010 was amended to permit incorporation of up to 15 percent WCM by mass in Granular B subbase material.
As a component of the 1993 City of Toronto MBG/WCM pilot study, a trial section of low-volume residential roadway was constructed in October 2004 using 15 percent WCM blended with Granular A (crushed concrete) base. While this trial was relatively small, involving less than 50 tonnes of crushed ceramic/porcelain, the blended material met all City of Toronto specification requirements (gradation and physical properties) and there were no problems observed during placement and compaction. The there were no problems observed during the production, placement and compaction of his material (Photographs 3-14 and 3-15). Additionally, environmental analysis of a representative sample of the materials did not indicate any bulk or leachate analysis concerns.

### 3.7 SPENT FOUNDRY SAND

The foundry industry in Ontario consists of ferrous (iron and steel) and nonferrous (mainly copper, aluminium and brass) foundries producing approximately 500,000 tonnes of product annually. Centred predominantly in southern and central Ontario (primarily Hamilton, Windsor and Cambridge areas), most of the spent foundry sand currently generated after recycling options within the foundry have been exhausted is being disposed of at municipal or private landfills or recycled for other purposes (MOEE, 1993).

Foundry sand consists of clean, pure, high quality silica sand having very uniform chemical/ mineralogical and physical characteristics. The foundry sand is bonded to form moulds for ferrous and nonferrous metal castings. There are two basic types of systems used for sand casting: green sand and no-bake sand. Green sand consists of a mixture of silica sand (~85%), bentonite clay (4 to 10%), with a carbonaceous additive (usually coal, 2 to 10%), and water to achieve bond strength. About 90 percent of the casting volume consists of green sand. No-bake systems use synthetic resins and are used for coremaking, which requires higher strengths to withstand the high heat from the molten metal, as well as mould-making. These resin sands generally consist of an organic binder (about 3% phenolic urethane for instance) that is activated by a catalyst.

As anticipated when the 1992 MNR and 1993 MOEE studies were completed, regeneration of spent foundry sand for reuse in the foundry has become more attractive, and in modern foundry practice, the foundry sand is typically recycled and reused through several production cycles (typically 20 percent new sand and 80 percent recycled sand, varying somewhat from foundry to foundry. In the United States, it is estimated that approximately 90 million tonnes of foundry sand is used in production annually, with about 5.5 to 9 million tonnes of spent foundry sand generated for disposal or recycling into other products and industries ((FIRST, 2007), representing about 10 percent of new foundry sand usage. Extrapolating this US data 10 to 20 percent proportioning to the Ontario foundry industry, approximately 475,000 tonnes/annum (average of three year period from 2002 to 2004) of new sand in foundry applications was imported from the US into Ontario, which would therefore suggest that only about 50,000 to 100,000 tonnes of spent foundry sand from ferrous foundries is currently being generated per annum. An additional 10,000 tonnes of spent foundry sand from nonferrous foundries is also generated, but this material cannot generally be readily reused or recycled because of contaminants (tramp metals) picked up in the casting process. This is substantially lower than the approximately 400,000 tonnes of spent foundry sand reportedly being generated in 1991 (MOEE, 1993), and estimated more recently by NRCan in 2006 (NRCan, 2006). It should also be noted that recent closures of major auto industry foundries (St. Catharines, Windsor) have also likely to have significantly reduced Ontario's foundry output and spent foundry sand generation.

Spent foundry sand from ferrous foundries can be recycled in a variety of bulk applications, including use as construction aggregate (hot-mix asphalt fine aggregate for instance) and engineered fill, as kiln feed in cement manufacture, with some additional, limited use in flowable fills, precast concrete products, bricks and pavers, grouts and mortars. The main limiting factor in its use as construction aggregate is its gradation, which is somewhat finer and more poorly graded ('gap-graded') compared to conventional asphalt and concrete fine aggregates.

A JEGEL survey of hot-mix asphalt producers conducted as part of the MOEE/Canadian Foundry Association Spent Foundry Sand Study (MOEE, 1993) indicated that only about 20,000 tonnes of spent foundry sand was being used as fine aggregate in hot-mix asphalt mixtures. The current survey conducted for this Updated Study did not identify any hot-mix asphalt producers (including those who had previously reported using spent foundry sands) currently using spent foundry sands in hot-mix asphalt mixes.

By nature of its chemical composition and mineralogy, silica sand is hydrophyllic, meaning that it has an affinity for water (attracts water to its surface). This property can result in 'stripping' of the asphalt cement coating surrounding the aggregate grains with resulting loss of fine aggregates from the pavement and rapid, progressive deterioration ('moisture-accelerated damage'). This feature, as well as the spent foundry sand gradation, limits the amount of spent foundry sand that can practically be incorporated in hot-mix asphalt mixtures to about 15 percent. While stripping resistance can be enhanced by the addition of anti-stripping additives such as hydrated lime or proprietary products, this obviously adds to the cost of producing hot-mix asphalts with spent foundry sand.

While the use of spent foundry sands from Ontario ferrous foundries was established in the late Eighties-early Nineties, with some spent foundry sand sources included in the MTO's Aggregate Sources Lists for hot-mix asphalt fine aggregate, the major impediments to use of spent foundry sands by the hot-mix asphalt industry from the hot-mix producer viewpoint are product consistency and adequate supply. The physical properties (including gradation) of spent foundry sands vary from foundry to foundry, and supply is generally not stable due to foundry plant shut-downs, etc. Additionally, many of the foundries only produce small quantities of spent foundry sands, and therefore multiple sources, with stockpiling and blending then required at a central location to achieve product consistency, are required to meet hot-mix asphalt production needs.

While there are few technical issues associated with use of spent foundry sands as construction aggregates in bulk applications (MOEE, 1993, FHWA, 2004a and 2004b), there are some Ontario environmental (leachate) concerns that, while readily addressed through proper site management/stockpiling practices, must also be considered. While generally considered to be an aesthetic parameter, the presence of phenols, in combination with chlorinated drinking water, form chlorophenols which can impart a foul taste to drinking water. The most recent Ontario Regulation 153 full-depth generic site condition standards in potable groundwater conditions limits the concentration of phenols in soil to 40 µg/g for all property use types, and 4200 µg/L in potable groundwater. The limits for

2-chlorophenol are much lower: 0.1 µg/g for soil and 0.3 µg/L for potable groundwater. Consequently, storage of spent foundry sands, even for a relatively short temporary period, must consider these environmental criteria. Precipitation percolating through stockpiles will mobilize leachable phenols which must then be removed before discharging into surface or ground water supplies. As phenols are highly mobile and dissipate rapidly, this environmental concern can be readily addressed through proper site design, requiring the design and construction of a temporary storage pad (impermeable base and sides) having suitable crossfall and capacity of collect any surface moisture or precipitation passing through the stockpiled spent foundry sand. The collected leachate can then be passed through an activated carbon filter to remove phenols and other minor contaminants.

## 3.8 OTHER WASTES

There are a number of waste and byproduct materials that, while produced in sufficient quantities to be considered for potential use as construction aggregates in bulk applications, do not meet all of the initial screening criteria described in Section 2.2. These include mine waste rock, MSW bottom ash, and nonferrous slags. In addition, there are other byproducts such as winter sand/road sweepings (sand applied to the roadway surface for traction during winter that is subsequently collected in spring by road sweepers) that can be recovered and reused as winter sand, reducing the amount of new winter sand required. Favourable trials of recycled winter sand have been completed in Edmonton, Alberta, for instance, where the City of Edmonton has developed its own winter sand recycling plant (NGSMI, 2005).

### 3.8.1 Mine Waste Rock

Mining wastes continue to be one of the largest sources of solid waste in Ontario, consisting of broken rock from open pit and underground mines (mine waste rock), coarse mill rejects from screening and separation processes, and mill tailings. Mine wastes tend to be located in remote areas well outside the practical distance for them to be economically transported to areas of high construction aggregate demand (GTA and southern-central Ontario). In addition, there are typically other significant constraints on their use, including fineness, chemical/environmental concerns (acid generation potential, radioactivity, leachates), and variability (due to commingling of different rock types in stockpiles). There have been some mine waste rock recycling ‘successes’, including the use of byproduct trap rock from roofing granule manufacture (primary product) from AECON’s Havelock and Marmora quarries processed for use as a premium surface course and fine aggregates in hot-mix asphalt (about 112,000 tonnes used in 2006). There has been some previous use of mine waste rock by MTO on highway projects in the Timmins area that were successful, but there were some concerns with potential acid rock drainage (leaching of sulphide minerals in the mine waste rock, forming sulphuric acid). There have also been some relatively small quantities of mine waste rock processing and localized use as construction aggregates close to production centres, but virtually all mine waste rock (and other mine byproduct materials) are being managed on site (stockpiled or utilized as aggregate/fill in cemented mine backfill materials).

While not a mining operation, the Ontario Power Generation Niagara Tunnel Project in Niagara Falls consists of a 14.4 m diameter tunnel, approximately 11.5 km in length, and to increase the capacity of the Adam Beck 2 Hydro-Electric Generating Station. Extending to a depth of approximately 140 m, the construction is expected to generate about 1.6 million $m^3$ of ‘waste’ rock, of which about 80 percent (1.3 million $m^3$) will consist of Queenston shale). Commencing in early 2006, the intake channel for the tunnel has been constructed almost entirely within Lockport Formation dolostone (Goat Island and Gasport Members) and extends to a depth of approximately 17 m. The dolostone from the intake channel construction was evaluated and determined to be suitable for use as construction aggregate. Approximately 750,000 tonnes of excess dolostone was stockpiled and processed (crushed and screened) for use on-site as granular base and subbase material, concrete coarse aggregate, and cofferdam in-fill material. Tunnel boring machine operations commenced in June 2006, with an anticipated completion date in early 2010. The Queenston shale ‘spoil’ recovered from the tunnel boring machine operation is also being stockpiled on Ontario Power Generation property for use in brick manufacturing.

### 3.8.2 MSW Bottom Ash

Since 1981, the Region of Peel has been carrying out research on the use of bottom ash recovered from the Algonquin Power Energy-from-Waste facility on Brampton. Approximately two-thirds of the municipal solid waste collected in Mississauga and Brampton (about 18,000 truck loads per year) is incinerated at this facility, generating about 40,000 tonnes of byproduct MSW bottom ash (as well as about 3000 tonnes of MSW fly ash). Of this, about 10,000 tonnes consists of oversized bottom ash that is landfilled, but there remains about 30,000 tonnes of MSW bottom ash after screening that could potentially be used as a partial replacement for natural fine aggregate in hot-mix asphalt. The Region also is investigating use of the finer materials as filler for brick manufacture and the bottom ash as aggregate in low-strength concrete.

Based on the results of trials completed since 1981, the Region of Peel has determined that up to about 10 percent screened MSW bottom ash can be incorporated in surface and binder course hot-mix asphalt mixtures used for Region of Peel paving projects (roads, parking lots, community recycling centres, works yards, and waste management facilities). There is approximately 50,000 to 100,000 tonnes of hot-mix asphalt paving carried out per annum on Region of Peel projects, and as such, there is only capacity, at present, to utilize about 5,000 to 10,000 tonnes of the 30,000 tonnes total generated in hot-mix asphalt. Additional trials are proposed in 2008, including a road rehabilitation contract that was tendered following the Region's standard tendering protocols.

### 3.8.3 General

Within the overall context of conservation of aggregate resources, those wastes and byproducts produced in low volumes such as waste glass, roofing shingles, spent foundry sands and MSW bottom ash have very limited impact of the total annual 170 million tonnes Ontario aggregate demand. The wastes and byproducts that continue to have the greatest impact as construction aggregates in bulk applications are clearly old asphalt and old concrete, with the development and implementation of in-place recycling technologies and processes substantially reducing the quantities of new construction aggregates required for major municipal road rehabilitation projects. These gains have been somewhat offset by reductions in construction aggregates use of byproducts such as steel slag and blast furnace slags that are now largely recycled within the source industrial processes or directed to higher value-added cementitious applications.

## 4. FACTORS INHIBITING AND SUPPORTING REUSE AND RECYCLING

### 4.1 INHIBITING FACTORS

The major factors inhibiting reuse and recycling activities have not changed significantly from those identified in the 1992 Study Report. Table 9 summarizes the significant inhibiting factors (technical, environmental/social, and economic) for the reuse and recycling of major Ontario wastes and byproducts as construction aggregates in bulk applications.

Since the 1992 Study was completed, the MTO and MEA have continued, with input from construction industry partners (ARRA, OSSGA, OHMPA, RMCAO, ORBA), to show leadership in the development of standard specifications for construction materials that prescribe the use of recyclable materials (for instance, OPSS 1010, *Material Specification for Aggregates – Base, Subbase, Select Subgrade, and Backfill Material*, that it regularly reviewed and revised and specifically permits the use of RAP, RCM, nickel slag, air-cooled blast furnace slag, and glass and ceramic materials in Granular A and Granular B Type 1). However, despite this continuing evolution in specifications, some agencies and consultants still do not consider or permit use of granular materials incorporating these 'approved' recycled materials, largely due to lack of familiarity or an unfavourable past experience.

There has been a move toward high-performance materials, such as high-performance concrete and high-stability, rut resistant asphalt concrete mixtures in transportation applications since the early Nineties. These materials are intended to provide enhanced performance and increased service lives, and therefore require very high

**TABLE 9**
**FACTORS INHIBITING REUSE AND RECYCLING OF MAJOR ONTARIO WASTES AND BYPRODUCTS AS CONSTRUCTION AGGREGATES IN BULK APPLICATIONS**

| WASTES AND BYPRODUCTS | | FACTORS INHIBITING REUSE AND RECYCLING | | | |
|---|---|---|---|---|---|
| | | Technical | Environmental/Social | Economic | Comments |
| Old Asphalt | Recycled in HMA (RHM) or As Road Base Aggregates | None | None | None | Mature uses, but agencies not fully utilizing available specifications |
| | In-Place Recycling (HIR, CIR, FDR, CIREAM) | None | None | None | Increasing use, but specifications review required |
| Old Concrete | Recycled in Road Base ( RCM or In-Place (Rubbilized)) | None | None | None | Mature uses, but agencies not fully utilizing available specifications |
| | Recycled in new PCC and HMA mixtures (RCA and CCA) | Higher absorption, lower strength, finishing and durability concerns | None | Some | Developing use, with greatest potential in areas where good quality natural aggregates are not readily available |
| Blast Furnace Slag as Road Base Aggregate or in Hot-Mix Asphalt Aggregate | | None | Mainly aesthetic leachate concerns in road base | None | BFS producers have largely abandoned use of air-cooled BFS for road base in favour of granulation; supply limited, with most BFS being used for cementitious uses (slag cement production) |
| Roofing Shingle Waste in Hot-Mix Asphalt (post-industrial (MSM) and tear-offs (RSP)) | | None | Some concerns with tear-off roofing materials | Minor | Amount that can be incorporated in HMA is technically limited by waste shingle properties; some potential 'contamination' issues with tear-offs |
| Waste Glass and Waste Ceramics as Road Base Aggregate or in Hot-Mix Asphalt | | None | None | Minor | Waste glass generally not produced in sufficient quantities, or being diverted to other uses |
| Steel Slag in Hot-Mix Asphalt or Road Base Aggregate | | Consistency and volume instability concerns | None | None | Volume instability concerns were largely addressed by changes in steel-making/slag production; largely being reused within the steelmaking with only limited supply for HMA use |
| Nonferrous Slags (Copper and Nickel) as Road Base Aggregate (including use as Rail Ballast Material) | | None | Some leachate concerns (mainly aesthetic) | Some | Mature use, but most concentrated close to the point of production due to transportation costs |
| Bottom Ash as Road Base Aggregate and in Hot-Mix Asphalt | | None for coal bottom ash | None | Some | Supply of coal bottom ash limited, close to coal-fired thermal hydro generating stations. Use of MSW bottom ash in HMA is developing (currently only trial use). |
| Foundry Sand in Hot-Mix Asphalt | | None | Some leachate concerns for stockpiled foundry sand | None | Supply limited, with most spent foundry sand reused in the foundry |
| Mine Waste Rock as Construction Aggregate | | Comingling of 'good' material with unsuitable material | Leachate concerns for sulphide rock types (acid rock drainage) | Major | Production and stockpiles located far from point of use (high transportation costs). Co-mingled stockpiles not suitable for aggregate use. |

quality aggregates (high strength, durable 100 percent crushed natural aggregates). Recycled materials are often precluded from use in such applications, as the result of technical (physical properties) aspects, durability concerns, or cost. These aspects are jointly being addressed by construction and transportation industry partners (for example, the use of recycled materials, including RAP and roofing shingle material, in Superpave asphalt mixtures), but there remain ample opportunities and applications where recycled materials can be used without special considerations (conventional asphalt concrete mixes and as granular base/subbase aggregates).

Where there have been some unfavourable experiences with specific wastes or byproducts (steel slag aggregate for hot-mix asphalt for example), some agencies are unwilling to review

and approve the use of these materials in these applications. Despite improvements in the quality of steel slag aggregates for use in hot-mix asphalt, and the favourable results of trials where improved quality steel slag aggregates were used, most agencies outside of the municipalities where steel slag is produced have not indicated any interest in revisiting/re-instating the use of quality steel slag aggregate in hot-mix asphalt.
The absence of a clear and concise environmental management policy for wastes and byproduct materials suitable for reuse and recycling in construction applications continues to be a significant impediment to enhanced reuse and recycling, and has actually discouraged beneficial use of some waste/ byproduct materials (blast furnace slag for instance), and excess materials generated during municipal public works construction projects. For example, the use of road deicing salts, particularly in urban areas, has resulted in 'contamination' of surficial soils and granular base/subbase materials within and near the road allowance, as represented by regular exceedances of O.Reg. 153 criteria for Sodium Absorption Ratio (SAR) and Electrical Conductivity (EC). While neither of these parameters generally represent a significant environmental issue in the urban context (high SAR can impede root development and is therefore mainly a concern in agricultural areas), such excess soils and aggregates are often being directed to landfill sites for disposal rather than being reused on site or as backfill materials in other construction projects. There have been many sites where, due to the presence of RAP, some granular materials have been 'classified' under O.Reg 153, as 'contaminated material' (as a result of exceedances of CCME F3 and F4 petroleum hydrocarbon limits in bulk analyses. While the 1988 MOE/MTO protocol for *Management of Surplus/Waste Materials Generated Through Road Maintenance and Construction* was quite effective, the introduction of the MOE Guidelines for Use at Contaminated Sites in Ontario (GUCSO), subsequently replaced in 2004 by O.Reg. 153, has resulted in a substantial quantity of excess materials containing RAP identified during environmental site assessments being removed and disposed of at landfills rather than being assessed through the time-consuming and costly O.Reg. 153 Site Specific Risk Assessment approach reqired for such RAP to be left in place or reused onsite. A more detailed guide, modelled after the recent FHWA User Guidelines (FHWA 1998) and Framework (FHWA, 2001) for instance, and giving more detailed environmental information for major Ontario wastes and byproduct materials, would be helpful to agencies and the construction industry and could foster increased use of some byproduct materials.

Although not quantified, it has been indicated that single-source waste management contracts have had a negative effect on recycling of some blue-box wastes such as glass. Source-separated waste collection made it somewhat easier to recover more of the blue-box waste glass without 'contamination' by other collected wastes such as paper, plastics, wood and metal.

### 4.2 SUPPORTING FACTORS

Notwithstanding the obvious benefits of having a sustainable supply of quality construction aggregates with reduced landfill requirements, the overwhelming supporting factors for conservation, reuse and recycling of technically-suitable wastes, byproducts and excess materials as construction aggregates in bulk applications are cost and availability. Ever rising, and recently very dramatic, energy cost increases have made use of recycled materials more attractive than ever. While perhaps most evident where recovered materials are able to be reused to produce new products (clear recovered glass recycled into new glass bottles at lower temperature and therefore lower cost, or as kiln feed in the production of cementitious materials), there are substantial energy and materials transportation savings realized by in-place recycling and/or using technically-suitable byproducts that are produced closest to the point of end use (RAP and RCM generated by construction projects in the GTA, fully utilized in the GTA, reducing the amount of 'virgin' aggregates (and new asphalt cement binder for recycled hot mix) produced outside of and transported into the GTA). The energy benefits should be maximized wherever possible, by the 'highest, best use' principle: RAP should be reused first in recycled hot mix, where both the aggregate component (95% by mass) and asphalt cement (5 percent) can be recycled, reduce both the amount of new aggregate and new asphalt cement needed.

Increasing awareness of municipal agencies on the positive benefits of in-place recycling of asphalt pavements (cold in-place processes –

CIR and FDR in particular) and rubblization of concrete pavements that represent nearly 100 percent recycling, is resulting in greater use of these technologies in Ontario, and across Canada. It is imperative, however, that the construction industry continues to improve the quality of these 'burgeoning' technologies and not become complacent – as was demonstrated when problems with steel slag aggregates first began to surface in the late Eighties (and leading to the 1991 moratorium), regardless of the cost, agencies will only endorse the use of recycled products that have similar performance and life-cycle costs as conventional products.

The lack of available landfill space, especially in the GTA with long haul distances to disposal sites in the US, and the ban by some landfills on accepting recyclable materials, also continues to encourage greater recycling. For example, the City of Toronto in 2003 indicated that the cost to dispose of blue-box waste glass was about $600,000 for the 17,000 tonnes generated).

## 5. CONCLUSIONS

Based on the figures presented in Table 6, the inventory of wastes and byproducts currently being recycled as construction aggregates in bulk applications totals about 13.1 million tonnes, and hence comprises between about 7.3 percent of the 179 million tonnes total aggregates (166 million tonnes of 'new' aggregates and 13.1 million tonnes of recycled aggregates) consumed annually in the Province of Ontario. This represents about 10 to 11 percent of total aggregates used for transportation infrastructure construction based on the estimate that 70 to 75 percent of the total production is used for construction aggregates,

This is somewhat higher than the 'optimistic' 3 to 5 percent utilization figure forecast in the 1992 Mineral Aggregates Conservation, Reuse and Recycling Study report. Given the nearly total loss of steel slag, blast furnace slag and spent foundry sand as bulk construction aggregates (corresponding to about 1 million tonnes of recycled aggregates prior to 1991), this demonstrates a substantial increase in reuse and recycling of 'conventional' byproduct aggregates (old asphalt and old concrete) that are technically accepted and widely viewed as equivalent to natural aggregates in applications such as granular base and subbase (RCM), and recycled hot mix (RAP, with the additional very significant benefit of the asphalt cement in the RAP that reduces the amount of new asphalt cement binder needed). This has largely been due to the use of in-place recycling methods/processes for rehabilitation of municipal flexible (asphalt concrete over granular base/subbase) and rigid (portland cement concrete and composite (asphalt concrete over concrete base) pavements).

## 6. RECOMMENDATIONS

This Updated Study of Mineral Aggregates Conservation, Reuse and Recycling has identified several areas where industry and agency initiatives could contribute enhanced use of wastes, byproducts and excess materials as construction aggregates in bulk applications.

There continues to be a clear need for continuing 'education' on the positive technical, environmental/social and economic benefits of reuse and recycling of suitable waste/byproduct materials as aggregates in construction applications. This includes continuing development, implementation and (primarily) dissemination of standard specifications (OPSS in particular) for standard wastes, byproducts and excess materials used as aggregates in construction. In particular, the rapidly growing implementation of relatively 'new' rehabilitation technologies such as in-place recycling, including cold in-place and hot in-place recycling, full and partial depth reclamation, and rubblization by municipal agencies has identified some general problems, mainly with respect to lack of compatibility between the QC, QA and acceptance requirements given in some OPS specifications and a specific (municipal) agency's practices. In this regard, municipal agencies should become more familiar with the rehabilitation acceptance approaches, and then develop supplemental special provisions to reflect their performance expectations and contracting practices. It may be helpful in this regard for municipal agencies to work more closely with the OPS Committee so that potential revisions to specifications are identified and considered during the regular OPS revisions process.

While this updated Study report has indicated that there has been a slight increase in the reuse and recycling of wastes, byproducts and excess materials in bulk applications since 1992, there is still some scope for additional reuse and recycling, that could be realized through rationalization and integration of environmental objectives with natural resources and engineering materials objectives.

It is anticipated that there will be some modest continuing increases in reuse and recycling that will be driven mainly by energy conservation in the face of rapidly rising energy costs, and dwindling landfill space. In this regard, it is imperative that the 'highest best use' principle continue to be applied for byproduct materials such as RAP to recover not only the bulk aggregate but also the 'old' asphalt cement binder.

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## GLOSSARY OF TERMS

**Absorption –** Fluid entering permeable pores of a solid material, given as percent increase in mass.

**Aggregate –** Granular material of mineral composition, such as sand, gravel, crushed stone, slags, and crushed concrete used in building and road construction.

**Asphalt –** Dark brown to black cementitious material in which the predominating constituents are bitumens that occur in nature or are obtained during crude petroleum refining.

**Asphalt cement (AC) –** Asphalt that is refined to meet specifications for paving, industrial and special purposes.

**Asphalt recycling agent –** Petroleum product additive, such as flux oil, used to restore aged asphalt cement to desired specification.

**Asphalt pavement –** Pavement consisting of surface and binder (or base) course asphalt concrete on supporting courses such as concrete base (composite pavement), asphalt treated base, cement treated base, granular base and/or granular subbase placed over the subgrade.

**Asphalt pavement surface recycling** – See hot in-place recycling or cold recycling.

**Base course –** Layer of material immediately beneath the asphalt concrete or Portland cement concrete surface of a pavement. (See asphalt pavement for instance.)

**Binder course –** The lower asphalt concrete course(s) of a flexible pavement.

**Catch basin clean-out material** – Earth and/or rock material removed from catch basins, including any accumulated debris such as leaves and litter that may have washed into the catch basin.

**Cement –** Portland cement (PC, CSA Standard A5) or blended cement (blended hydraulic cement, CSA Standard A362).

**Coarse aggregate –** Aggregate that is predominantly retained on the 4.75 mm (or 5.00 mm) sieve size.

**Cold recycling (cold asphalt pavement recycling) –** Full or partial depth reuse of old asphalt concrete pavement (can be used for surface treatment, and can include treated and untreated base) that is either processed in-place (by cold in-place recycling train or full-depth in-place asphalt pavement reprocessing method) or at a central plant, typically with the addition of emulsified asphalt (or other additive such as cutback asphalt, lime or cement) and occasionally new aggregate to achieve desired cold mix quality, followed by placement and compaction.

**Crushed stone** – Aggregate, from crushing of quarried rock, with all faces fractured (crushed).

**Ditch clean-out material** – Earth and/or rock material removed during ditch excavation and maintenance, including ditch vegetation, and any accumulated debris such as leaves and litter. See catch basin clean-out material.

**Earth** – All soils except those defined as rock, excluding stone masonry, concrete and other manufactured materials.

**Emulsified asphalt –** Anionic or cationic emulsion of asphalt cement and water that contains a small amount of an emulsifying agent, which sets by water separation/evaporation and/or chemically, leaving the asphalt cement to perform its cementing function.

**Excess material –** Rock, earth, aggregate, old asphalt concrete, old concrete, wood, etc., resulting from construction, that cannot be used at the site.

**Fill –** Material placed to level or raise the height of a site.

**Fine aggregate –** Aggregate that predominantly passes the 4.75 mm (or 5.00 mm) sieve size.

**Foamed asphalt** – A mixture of undried, cold RAP and/or virgin aggregate that is bound together by mixing it with an expanded asphalt cement binder formed by injecting a metered amount of cold water into a stream of hot asphalt cement in a mixing unit (causing it to foam, enabling it to coat the finer particles).

**Full depth reclamation (FDR) –** Full thickness of existing asphalt concrete or concrete pavement is processed and recycled, usually with mixing/blending with underlying granular base/subbase or subgrade. Full depth reclamation may also include stabilization using foamed asphalt, cement or lime.

**Granular –** Aggregate used in granular base, granular subbase or select subgrade.

**Gravel –** Granular material consisting of rounded, water-worn rock fragments 2 mm to 75 mm in size usually intermixed with sand.

**HL, hot mix, mixture, mix –** Hot-mixed, hot-laid asphalt concrete.

**Hot-mix asphalt (HMA) –** Designed aggregate and asphalt cement mix produced in a hot-mix plant (batch, drum or drum/batch) where the aggregates are dried, heated and then mixed with heated asphalt cement, then transported, placed and compacted while still at an elevated temperature (about 125 to 135$^{o}$C) to give a durable, deformation resistant, fatigue resistant pavement course.

**Hot in-place recycling (HIR) –** Hot reworking of the surface of an aged asphalt pavement (typically 50 – 75 mm) using preheaters and a heat reforming machine, typically with the addition of a rejuvenator, aggregate or new hot mix (HMA) to restore the condition of the scarified old asphalt pavement, and sometimes with an integral surface course overlay, all suitably placed and compacted in a single or multi-pass process.

**Milling (cold planing) –** Removing the surface of an asphalt concrete pavement, using a traveling machine equipped with a transverse rotating cutter drum (milling head with tips), typically 25 to 75 mm in depth. The resulting asphalt concrete millings (form of reclaimed asphalt pavement, RAP) are usually recycled.

**Pavement structure –** All courses (components) of a pavement above the subgrade to the traffic surface such as granular subbase, granular base, treated (asphalt or cement) base, asphalt concrete (HMA) and concrete (PCC).

**Portland cement –** Calcium silicate hydraulic cement produced by pulverizing Portland-cement clinker, and usually containing calcium sulphate and other compounds.

**Portland cement concrete (PCC) –** Composite material consisting essentially of a mixture of cement and water (binding paste) which are mixed with particles of fine and coarse aggregates.

**Portland cement concrete recycling –** Reuse of old concrete (PCC) such as foundation elements and pavements by processing into aggregates for use in place or, or mixed with, conventional aggregates in application such as trench bedding, granular base, treated base, asphalt concrete (HMA) and concrete (PCC).

**Quarry Fines** – quarry byproduct materials, including excess screenings, pond fines, etc., produced during quarrying or removed during aggregate processing (screening and washing), generally less than 75 µm size.

**Reclaimed asphalt pavement (RAP) –** Removed and/or processed pavement materials containing asphalt cement and aggregates.

**Reclaimed concrete material (RCM)** – Removed and/or processed old Portland cement concrete (PCC).

**Recycling –** When material is reclaimed from the waste stream and put to some use after varying degrees of processing.

**Recycled hot mix (RHM) –** Removal (surface milling or full depth) of old asphalt concrete (reclaimed asphalt pavement, RAP), processing, heating and mixing in a hot-mix plant (batch, drum or drum/batch) with new aggregates and new asphalt cement (softer grade or with recycling agent), relaying and compacting to meet specifications for conventional hot mix asphalt concrete (HMA).

**Reuse –** When material is reclaimed from the waste stream and put to some use with little or no processing.

**Reworking –** Processing existing unbound pavement materials in place, such as granular base, mechanically and/or by stabilization to improve performance.

**Road sweepings –** Material swept from roadways in the spring following winter sanding operations, containing recovered winter sand, road salt, and litter, sometimes contaminated with heavy metals, oil and grease. See Winter Sand.

**Rubblization** – In-place processing of old concrete pavement whereby the existing concrete pavement is broken into small pieces using specialty equipment.

**Sand –** Fine aggregate resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone.

**Stone –** Any natural rock deposit or formation if igneous, sedimentary and/or metamorphic origin, usually used as dimension stone or crushed stone in building or road construction.

**Street sand –** See Winter Sand and/or Road Sweepings.

**Subbase course –** Layer of material in a pavement immediately above the subgrade. (See asphalt pavement for instance.)

**Subgrade –** Soil prepared through cut, fill and/or fine dressing to support a pavement. (See asphalt pavement for instance.)

**Surface course –** Top hot-mix asphalt course (HMA) of a pavement, sometimes called asphalt wearing course. (See asphalt pavement for instance.)

**Trenching materials** – Earth, rock and existing pavement materials (granular base and subbase, concrete base and/or asphalt surfacing) removed during excavation for service trenches and utility cuts.

**Unshrinkable fill** – Low-strength (0.4 MPa 28-day maximum) mixture of concrete aggregates, water, Portland cement and admixtures, having a slump between 150 and 200 mm, that may be used as backfill for utility cuts.

**Winter sand** – Sand placed on roads and streets during winter for traction control and to maintain surface friction. Winter sand may be collected by vacuum sweepers during spring road maintenance work. Materials collected during summer sweeping operations are not considered recyclable. Sometimes known as street sand. See Road Sweepings.

## LIST OF ACRONYMS/ABBREVIATIONS

**AASHTO –** American Association of State Highway and Transportation Officials <www.transportation.org>

**ACI –** American Concrete Institute <www.concrete.org>

**ACPA –** American Concrete Pavement Association <www.pavement.com>

**AI –** Asphalt Institute <www.asphaltinstitute.org>

**APA –** Asphalt Pavement Alliance <www.asphaltalliance.com>

**ARRA –** Asphalt Reclamation and Recycling Association <www.arra.org>

**ASTM –** ASTM International <www.astm.org>

**CAC –** Cement Association of Canada <www.cement.ca>

**CAEAL –** Canadian Association of Environmental and Analytical Laboratories www.caeal.ca

**CPCA** – Canadian Portland Cement Association; changed to CAC (Cement Association of Canada www.cement.ca

**CSA –** Canadian Standards Association <www.csa.ca>

**C-SHRP –** Canadian Strategic Highway Research Program <www.tac-atc.ca/programs/cshrp.htm>

**CTAA –** Canadian Technical Asphalt Association <www.ctaa.ca>

**EPA –** Environmental Protection Agency <www.epa.gov>

**FCM –** Federation of Canadian Municipalities <www.fcm.ca>

**FHWA –** Federal Highway Administration <www.fhwa.dot.gov>

**MEA** – Municipal Engineers Association of Ontario <www.municipalengineers.on.ca>

**MNR –** Ontario Ministry of Natural Resources <www.mnr.gov.on.ca>

**MTO –** Ontario Ministry of Transportation <www.mto.gov.on.ca>

**NAPA –** National Asphalt Pavement Institute <www.hotmix.org>

**NGSMI –** National Guide to Sustainable Municipal Infrastructure <www.infraguide.ca>

**NRC –** National Research Council <www.nrc.ca>

**OECD –** Organisation for Economic Cooperation and Development <www.oecd.org>

**OHMPA –** Ontario Hot Mix Producers Association <www.ohmpa.org>

**ORBA** – Ontario Road Builders' Association <www.orba.org>

**OSSGA** – Ontario Stone, Sand & Gravel Association (formerly Aggregate Producers' Association of Ontario) <www.apao.com>

**PIARC –** Permanent International Association of Road Congresses (PIARC/AIPCR) <www.piarc.org>

**RMCAO** – Ready-Mixed Concrete Association of Ontario <www.rmcao.org>

**SHRP –** Strategic Highway Research Program <www.infoguide.ca>

**TAC –** Transportation Association of Canada <www.tac-atc.ca>

**TRB –** Transportation Research Board <www.trb.org>

## TECHNICAL TERMS

**AADT –** Average Annual Daily Traffic

**BFS** – Blast Furnace Slag

**CCA** – Crushed Concrete Aggregate

**CCPR –** Cold Central Plant Recycling

**CIR –** Cold In-Place Recycling

**CIREAM** – CIR with Expanded Asphalt Material

**CRCP –** Continuous Reinforced Concrete Pavement

**EC –** Electrical Conductivity

**ESAL –** Equivalent Single Axle Loads

**FDR –** Full Depth Reclamation

**FWD –** Falling Weight Deflectometer

**GBE –** Granular Base Equivalency

**HIR –** Hot In-place Recycling

**HMA –** Hot-mix Asphalt

**JPCP –** Jointed Plain Concrete Pavement

**LCC –** Life-cycle cost

**MBG** – Mixed Broken Glass

**MSM** – Manufactured Shingle Modifier

**PCC –** Portland Cement Concrete

**PDR** – Partial Depth Reclamation (see CIREAM)

**PG –** Performance Graded

**PGAB –** Performance Graded Asphalt Binder

**PGAC –** Performance Graded Asphalt Cement

**PMA –** Polymer Modified Asphalt

**QC –** Quality Control

**QA –** Quality Assurance

**RAP** - Reclaimed Asphalt Pavement

**RCA** – Recycled Concrete Aggregate

**RCM –** Recovered Concrete Material

**RHM –** Recycled Hot Mix

**ROW –** Right-of-Way

**RSP –** Recycled Shingle Product

**SAR –** Sodium Adsorption Ratio

**SMA –** Stone Mastic Asphalt

**WCM –** Waste Ceramic Material

APPENDIX A

PRODUCER/SUPPLIER AND AGENCY SURVEY FORMS

# JOHN EMERY GEOTECHNICAL ENGINEERING LIMITED

**CONSULTING ENGINEERS**

#1, 109 Woodbine Downs Boulevard, Toronto, Ontario M9W 6Y1

Telephone: (416) 213-1060 Facsimile: (416) 213-1070 E-Mail: jegel@jegel.com www.jegel.com


## SURVEY OF PRODUCERS/SUPPLIERS
## MINERAL AGGREGATE CONSERVATION
## REUSE AND RECYCLING

Name: ____________________ Title: ____________________

Company: ________________________________________

E-Mail: ____________________ Phone: ____________________

1) Does your company process any of the following residuals or byproduct materials as substitutes for natural aggregate or in bulk aggregate-related uses? Please circle if used, and where possible, indicate the approximate quantities (tonnes or square metres) processed in 2006 and currently stockpiled.

***Please indicate units (tonnes (t) or $m^2$ beside each).***

a) Old Asphalt/Reclaimed Asphalt Pavement (RAP):

i) As Granular Base, Subbase or Shoulder Granular ____________

ii) In Recycled Hot Mix ____________

iii) Cold In-Place Recycling ____________

*Please circle the typical processing depth(s): 75 mm; 100 mm; 125 mm; Other ____ mm*

iv) Hot In-Place Recycling ____________

*Please circle the typical processing depth(s): 50 mm; 75 mm; 100 mm; Other _____ mm*

v) Full Depth Reclamation with Foamed (Expanded) Asphalt Stabilization____________

*Please circle the typical processing depth(s): 150 mm; 200 mm; Other ___ mm*

vi) Partial Depth Reclamation with Foamed (Expanded) Asphalt Stabilization ____________

*Please circle the typical processing depth(s): 75 mm; 100 mm; 125 mm; Other ____ mm*

vii) Other ____________

b) Old Concrete/Recovered Concrete Material (RCM):

i) As Granular Base/Subbase ____________

ii) In Recycled Concrete Mixtures ____________

iii) Recycled In place (Rubblized) ____________

iv) Other ____________

c) Blast Furnace Slag: Air-Cooled/Pelletized/Granulated ______________________

d) Steel Slag: ______________________ e) Nickel Slag: ______________________

f) Copper Slag: ______________________ g) Mixed Glass: ______________________

h) Porcelain/Ceramic Materials: ____________ i) Waste Foundry Sand: ________________

j) Fly Ash: ______________________________ k) Bottom Ash: ______________________

l) Roofing Shingles (New Production Off-Cuts): ______________________

m) Roofing Shingles (Old Roofing Materials; Tear-Offs): ______________________

n) Scrap Tires (as Aggregate (Crumb Rubber Modifier)): ______________________

o) Crushed Brick: ________________ p) Mine Waste Rock: ______________________

q) Mixed C&D Wastes: ______________________
*Note: If C&D Wastes are source-separated, please include the estimated quantities for each specific material (old concrete, crushed brick, for instance) in their respective categories.*

r) Other (please specify material(s) and quantity(ies)): ______________________________________

2. Does your company process or stockpile use any of the following residuals or byproducts as replacements in manufacturing processes or substitutes for materials in cementitious applications? *Please circle if used; and where possible, indicate the approximate amount used in 2006.*

a) Blast Furnace Slag: Pelletized/Granulated (Slag Cement) ______________________

b) Micro Silica/Silica Fume: ______________________

c) Granulated Copper Slag: ________________ d) Granulated Nickel Slag: ____________________

e) Cement Kiln Dust: ____________________________ f) Lime Kiln Dust: ______________________

g) Surplus Sulphur: ______________________________ h) Crumb Rubber Modifier: ____________________

i) Fly Ash: ______________________________ j) Roofing Shingles: ______________________

k) Scrap Tires (in Asphalt Cement/Binder as Asphalt Rubber): ______________________

3) What are your principal sources of residual and byproduct materials (for instance, excess materials from road construction and maintenance; demolition; industry; other)?

_______________________________________________________________________________

4) Do you accept residual and byproduct materials from external sources, and if so, do you charge any tipping fees? Yes ____ No ____ Fee Charged: _________

5) What factors have encouraged your firm to adopt recycling and reuse of residuals and byproducts in your company? *Please circle.*

a) Lower cost; b) Superior performance; c) Lack of suitable aggregates;

d) Waste reduction; e) Other ____________________________________________________

6) Do you have any specific in-house protocols/practices that pertain to the reuse of residuals or byproducts for aggregate or aggregate-related uses? *If yes, please send copies*.

______________________________________________________________________

7) What impediments have you encountered that discourage you from processing residuals or byproducts for aggregate or aggregate-related uses? *Please circle.*

a) Higher cost; b) Poor performance; c) Supply problems;

d) Lack of technical literature or performance data;

e) Specifications precluding use of residuals or byproducts (*please give specific examples*):

______________________________________________________________________

______________________________________________________________________

f) Other: ______________________________________________________________

**PLEASE FEEL FREE TO ATTACH ADDITIONAL COMMENTS**

**IF YOU HAVE ANY QUESTIONS WHEN COMPLETING THIS SURVEY, PLEASE CONTACT JEGEL AT THE EMAIL ADDRESS BELOW.**

**PLEASE RETURN BY EMAIL TO rmirtorabi@jegel.com or FAX TO 416-213-1070 BY MAY 15, 2007**

***THANK YOU!***

**JOHN EMERY GEOTECHNICAL ENGINEERING LIMITED**
**CONSULTING ENGINEERS**
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**SURVEY OF AGENCIES**
**MINERAL AGGREGATE CONSERVATION**
**REUSE AND RECYCLING**

Name: ______________________ Title: ______________________

Agency: ____________________________________________

E-Mail: ______________________ Phone: ______________________

2) Does your agency use any of the following residuals or byproduct materials as substitutes for natural aggregate or in bulk aggregate-related uses? Please circle if used, and where possible, indicate the approximate amount used in 2006.

***Please indicate units (tonnes (t) or $m^2$ beside each).***

a) Old Asphalt/Reclaimed Asphalt Pavement (RAP):

i) As Granular Base, Subbase or Shoulder Granular ______________

ii) In Recycled Hot Mix ______________

iii) Cold In-Place Recycling ______________

*Please circle the typical processing depth(s): 75 mm; 100 mm; 125 mm; Other ____ mm*

iv) Hot In-Place Recycling ______________

*Please circle the typical processing depth(s): 50 mm; 75 mm; 100 mm; Other _____ mm*

v) Full Depth Reclamation with Foamed (Expanded) Asphalt Stabilization______________

*Please circle the typical processing depth(s): 150 mm; 200 mm; Other ___ mm*

vi) Partial Depth Reclamation with Foamed (Expanded) Asphalt Stabilization ______________

*Please circle the typical processing depth(s): 75 mm; 100 mm; 125 mm; Other ____ mm*

vii) Other ______________

b) Old Concrete/Recovered Concrete Material (RCM):

i) As Granular Base/Subbase ______________

ii) In Recycled Concrete Mixtures ______________

iii) Recycled In place (Rubblized) ______________

iv) Other ______________

**ISO 9001**
**Engineering / Research / Development / Education**
**Soil/ Rock / Aggregates / Slags / Asphalt / Cement / Concrete / Byproducts**
**JEGEL • PAVMATEC**

c) Blast Furnace Slag: Air-Cooled/Pelletized/Granulated ______________________

d) Steel Slag: ______________________ e) Nickel Slag: ______________________

h) Copper Slag: ______________________ g) Mixed Glass: ______________________

i) Porcelain/Ceramic Materials: ___________ i) Waste Foundry Sand: _______________

k) Fly Ash: ____________________________ k) Bottom Ash: ______________________

o) Roofing Shingles (New Production Off-Cuts): ______________________

p) Roofing Shingles (Old Roofing Materials; Tear-Offs): ______________________

q) Scrap Tires (as Aggregate (Crumb Rubber Modifier)): ______________________

o) Crushed Brick: _______________ p) Mine Waste Rock: ______________________

q) Mixed C&D Wastes: ______________________
*Note: If C&D Wastes are source-separated, please include the estimated quantities for each specific material (old concrete, crushed brick, for instance) in their respective categories.*

r) Other (please specify material(s) and quantity(ies)): _____________________________________

2. Does your agency permit the use any of the following residuals or byproducts as replacements in manufacturing processes or substitutes for materials in cementitious applications? Please circle if used; and where possible, indicate the approximate amount used in 2006..

d) Blast Furnace Slag: Pelletized/Granulated (Slag Cement) ______________________

e) Micro Silica/Silica Fume: ______________________

f) Granulated Copper Slag: _______________ d) Granulated Nickel Slag: ___________________

e) Cement Kiln Dust: ___________________________ f) Lime Kiln Dust: ______________________

i) Surplus Sulphur: _____________________________ h) Crumb Rubber Modifier: ___________________

i) Fly Ash: ______________________________ j) Roofing Shingles: ______________________

k) Scrap Tires (in Asphalt Cement/Binder as Asphalt Rubber): ______________________

4. Do you have or use any specific specifications that cover the reuse of residuals or byproducts for aggregate or aggregate-related uses? *If yes, please send copies.*

5. What factors encouraged the recycling and reuse of residuals and byproducts in your jurisdiction? *Please circle.*

a. Lower cost; b. Superior performance; c. Lack of suitable aggregates;

d. Waste reduction; e. Other ______________________________________________

6. Are there any specific items that discourage you from substituting residuals or byproducts for aggregate or aggregate-related uses? *Please circle.*

   a. Higher cost; b. Poor performance; c. Supply problems;

   d. Lack of technical literature or performance data; e. Other ____________________

   If you have experienced any performance problems, please briefly elaborate below.

   ______________________________________________________________________________

   ______________________________________________________________________________

   ______________________________________________________________________________

   ______________________________________________________________________________

**PLEASE FEEL FREE TO ATTACH ADDITIONAL COMMENTS**

**IF YOU HAVE ANY QUESTIONS WHEN COMPLETING THIS SURVEY, PLEASE CONTACT JEGEL AT THE EMAIL ADDRESS BELOW.**

**PLEASE RETURN BY EMAIL TO rmirtorabi@jegel.com or FAX TO 416-213-1070 BY MAY 15, 2007**

***THANK YOU!***

# Appendix C List of Abbreviations and Technical Terms

## LIST OF ABBREVIATIONS

**AASHTO –** American Association of State Highway and Transportation Officials <www.transportation.org>

**ARRA –** Asphalt Reclamation and Recycling Association <www.arra.org>

**CPATT –** Centre for Pavement and Transportation Technology <www.civil.waterloo/cpatt>

**CTAA –** Canadian Technical Asphalt Association <www.ctaa.ca>

**DEFRA –** Department for Environment Food and Rural Affairs <www.defra.gov.uk>

**ECO –** Environmental Commissioner of Ontario <www.eco.on.ca>

**FHWA –** Federal Highway Administration <www.fhwa.dot.gov>

**LEED –** Leadership in Energy and Environmental Design <www.usgbc.org>

**MEA** – Municipal Engineers Association of Ontario <www.municipalengineers.on.ca>

**MNR –** Ontario Ministry of Natural Resources <www.mnr.gov.on.ca>

**MTO –** Ontario Ministry of Transportation <www.mto.gov.on.ca>

**NGSMI –** National Guide to Sustainable Municipal Infrastructure <www.infraguide.ca>

**NRC –** National Research Council <www.nrc.ca>

**OECD –** Organisation for Economic Cooperation and Development <www.oecd.org>

**OHMPA –** Ontario Hot Mix Producers Association <www.ohmpa.org>

**ORBA** – Ontario Road Builders' Association <www.orba.org>

**OSSGA** – Ontario Stone, Sand & Gravel Association (formerly Aggregate Producers' Association of Ontario) <www.apao.com>

**PIARC –** Permanent International Association of Road Congresses (PIARC/AIPCR) <www.piarc.org>

**RMCAO** – Ready-Mixed Concrete Association of Ontario <www.rmcao.org>

**SHRP –** Strategic Highway Research Program <www.infoguide.ca>

**TAC –** Transportation Association of Canada <www.tac-atc.ca>

**TRB –** Transportation Research Board <www.trb.org>

**WDO –** Waste Diversion Ontario <www.wdo.ca>

**WRAP** – Waste and Resources Action Programme <www.wrap.org.uk>

## TECHNICAL TERMS

**BFS –** Blast Furnace Slag

**CCA –** Crushed Concrete Aggregate

**CCPR –** Cold Central Plant Recycling

**C&D –** Construction and Demolition

**CIR –** Cold In-Place Recycling

**CIREAM –** CIR with Expanded Asphalt Material

**FDR –** Full Depth Reclamation

**HIR –** Hot In-place Recycling

**HMA –** Hot-mix Asphalt

**JPCP –** Jointed Plain Concrete Pavement

**MBG –** Mixed Broken Glass

**WCM –** Waste Ceramic Material

**MSM –** Manufactured Shingle Modifier

**MSW –** Municipal Solid Waste

**OPSS –** Ontario Provincial Standards Specifications

**PCC –** Portland Cement Concrete

**RAP -** Reclaimed Asphalt Pavement

**RCA –** Recycled Concrete Aggregate

**RCM –** Recovered Concrete Material

**RHM –** Recycled Hot Mix

**ROW –** Right-of-Way

**RSP –** Recycled Shingle Product

**SAR –** Sodium Adsorption Ratio

**SMA –** Stone Mastic Asphalt

**WAM –** Warm Asphalt Mix

**WCM –** Waste Ceramic Material