Recycled Asphalt Pavement (RAP) Scoping Study

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1. Introduction

1.1 Overview of NZWC and RAP Pilot

The National Zero Waste Council, an initiative of Metro Vancouver, is leading Canada's transition to a circular economy by bringing together governments, businesses and NGOs to advance a waste prevention agenda that maximizes economic opportunities for the benefit of all Canadians. One of the projects established by its Construction, Renovation & Demolition Waste Working Group (CRD) in 2018 was to develop a recycled asphalt pavement (RAP) Pilot.

Used asphalt is a by-product in the field of asphalt road rehabilitation. When properly crushed, and screened, it becomes RAP. RAP consists of high-quality, well-graded aggregates coated by asphalt cement, which is an alternative to virgin aggregate. Focusing on solutions to asphalt waste, the City of Richmond, Lafarge Canada and the National Zero Waste Council initiated a pilot to test the performance of RAP on a road in Richmond and a commitment to document its performance throughout the life cycle.

A key goal of the pilot is to encourage expanded use of RAP as well as increase the percentage of RAP in asphalt pavement. This is expected if awareness and confidence in RAP, across the supply chain, can be increased. It also focuses on determining how procurement can be leveraged to reduce the amount of construction and demolition waste being generated from the built environment.

Four phases of project planning were defined to develop the pilot:

1. Stakeholder Engagement and Scoping Study
2. Development of Assessment Framework and Procurement Tool
3. Application of RAP Pilot on Richmond Road
4. Long-term Assessment and Validation

1.2 Purpose and Goals of the Scoping Study

The goal of the scoping study is to compile key considerations for best practices, challenges, and opportunities for RAP to inform the RAP pilot. This study can be used as a resource for future RAP applications across Canada.

2. Summary of Key Considerations and Best Practices Recognized Internationally

The objective of this section is to identify best practices for the specifications, design, production, testing, and placement of RAP mixes through research. This research utilized:

- Academic literature on RAP;
- North America databases related to transportation engineering;
- Provincial and local supplementary specifications such as Master Municipal Construction Documents

(MMCD), British Columbia (BC) Ministry of Transportation and Infrastructure (MoTI), Ministry of Transportation of Ontario (MTO); and

- The best practices from existing literature, experience from high RAP projects and trial sections, specifications, and the advice of experts in the industry.

Incorporating RAP in asphalt pavement has become a valuable strategy in maintaining balance in rising virgin material costs and improving the sustainability of transportation infrastructure. Strict guidelines on the nature of the recycled material (size distribution, bitumen content, filler content, bitumen viscosity or hardness, etc.) are enforced in the asphalt industry to guarantee high-quality and suitable materials. Homogeneity in terms of size, mineral type, and binder type is the most crucial quality criterion of RAP.

2.1 RAP Mix Design

MMCD recommendations

The amendments prepared by the Master Municipal Construction Documents (MMCD) Association in the Platinum Edition Updated November 18, 2016 state that:

- **Before:** Mix may contain up to a maximum 20% of RAP by mass without a special mix design. The Contract Administrator may approve a higher proportion of RAP.

- **Currently:** The MMCD recommends using up to 15% RAP by binder content in mix design. This is similar to the mix design for all virgin materials without changing the virgin binder grade. The virgin binder grade is usually fixed for specifications required of different performance grading (PG). This amendment increases the quality control in the RAP before the mix design, enhancing the quality of the final product.

Ministry of Transportation and Infrastructure

The BC Ministry of Transportation and Infrastructure (MoTI) recognized RAP as a high-value product that can be incorporated into new paving mixes. As part of the 2016 Standard Specifications for Highway Construction by MoTI, a new section 505 titled "Use of Reclaimed Asphalt Pavement in Asphalt Pavement Construction" was developed to address the incorporation of RAP into paving mixes. On July 20, 2017, the MoTI issued a Technical Circular T-05/17 with the following considerations:

- Use of RAP must be given careful consideration in rehabilitation and grading projects in a manner that will take full advantage of its residual properties and value.

- Where the use of RAP is not considered feasible, a written rationale shall be sent to the Senior Geotechnical Engineer, Pavements with a copy forward to the Director, Geotechnical Engineering by the Project Manager and/or Ministry Representative.

- Highway Design and Pavement Engineers need to familiarize themselves with:

    - T-Circular on Pavement Structure Design Guidelines; Section 502 (Asphalt Pavement Construction- EPS);

    - Section 505 (Use of Reclaimed Asphalt Pavement in Asphalt Pavement Construction);

- Section 511 (Cold Crushing) and Section 952 (Contractor Supply Asphalt); and
- Paving Materials for Highway Use to achieve optimized use of RAP in new pavement mix designs for Ministry Projects.

As per SS505, the MoTI highlights the crucial need to know the material sources of the RAP by defining it as a "classified RAP" when this is obtained from Ministry roadways and "unclassified RAP" for material from non-Ministry sources or "mixed with RAP" from other sources. When high-quality highway asphalt pavement is crushed and its properties are well-known (based on original mix testing and long-term performance), the contractor can specify a % of RAP to use (up to a maximum of 30%) in a new pavement mix design for either that particular project or a different paving project in the proximity.

2.2 RAP Guiding Principles

In countries with more than 30 years of experience utilizing RAP, such as the Netherlands, Belgium, Germany, Norway, Denmark, Japan, Brazil and the United States, two common guiding principles of asphalt recycling are:

- In all cases, mixes containing RAP must meet the same requirements as mixes containing only virgin materials, and
- The performance of mixes containing RAP is expected to be comparable or superior to that of virgin mixes.

Processing RAP has the following basic objectives:

- Create a uniform stockpile of materials;
- Sort or break up large agglomerations of RAP particles so they can be dried, heated and broken apart during mixing with virgin aggregates;
- Reduce the maximum aggregate particle size of the RAP to make the RAP suitable for use in surface mixes (or other small nominal maximum aggregate mixtures); and
- Reduce the generation of P200 (i.e., dust).
- There should be a sloped pad so that the water drains away from the loading end of the stockpile;
- This stockpile shall be shaped in a way that water will drain from the sides, and the angle of the sides should not be too steep to reduce the possibility of segregation; and
- To avoid the consolidation of the RAP, the height of the stockpile should be controlled.
- Adequate signage, such as the lot number, product description, approval for release, etc.

2.3 RAP Management

In the literature review, common best practices for management focused on:

- The elimination of contaminants;
- The control and analysis of the sources of the materials;
- The processing (crushing) of the RAP piles;
- The appropriate storage to reduce the moisture content;
- The properly process of sampling to characterize the crushed RAP; and,
- The exact identification of production lots to keep the accurate traceability of the final product.

2.3.1 Receiving

Incoming loads should be inspected to ensure that the material is suitable to be processed into RAP and free from any contaminants. Stockpiles should be kept free of contaminants from the beginning, ensuring that they are free of dirt, rubbish, vegetation, or other waste. Plant Quality Control personnel and the loader operator should inspect unprocessed and processed RAP stockpiles regularly to ensure no detrimental materials are present. If contaminants are found, they should be dug out immediately so that they are not covered up. Some contaminants should be screened out after the RAP has been processed. In all other cases, contaminated materials should be stockpiled separately.

2.3.2 Crushing

The correct approach to the storage and processing of recycled material in asphalt plants can help to control and reduce the heterogeneity of RAP. The heterogeneity of RAP makes it challenging to control the composition of the asphalt, gradation and air voids of the mix produced, especially in high percentages of RAP. It is recommended that the maximum aggregate size should be 1.5 inches in the processing of RAP. Crushing is a beneficial part of pavement rehabilitation affecting the size of the particles and eliminates too many oversized particles that would have to be screened and crushed or disposed of. Proper techniques for obtaining, stockpiling, and processing RAP are needed to produce quality mixtures. Stockpiles of well-managed RAP have a more uniform gradation than virgin aggregates. Each stockpile lot shall not exceed 1,000 tonnes and must contain up to 5% of P200.

2.3.3 Moisture

Due to environmental conditions and the nature of the local materials, moisture damage potential is of special concern for mixtures in the Lower Mainland of British Columbia. The moisture control in the RAP stockpile is crucial to assure the quality of the final product. To minimize moisture in RAP, the stockpile should be stored in an open-sided shelter to facilitate material dryness.

2.3.4 Inventory

A lack of adequate management of RAP stockpiles is commonly cited by cities, contractors, and consultants as a reason for hesitancy to add RAP to asphalt mixtures. Good inventory management practices are always a part of the quality control program for all asphalt mix production operations. In inventory management, the following factors may be considered:

- Components of RAP, such as special classes of aggregate, steel slag, or asphalt rubber, that require handling separately from other materials;
- If the client allows RAP from other sources to be incorporated into asphalt mixes produced for its projects;
- Client requirements regarding captive stocks or ability to replenish stockpiles continuously;
- The area at the plant site available for the RAP processing and stockpiling;
- Calculating the RAP percentage to be used in the asphalt mixing; and
- The percentage of RAP that comes from a single project.

2.3.5 Sources

RAP materials gathered from different sources must be processed to attain a uniform composition for new asphalt mixtures. If the stockpiled RAP is from a single project, the material may be consistent enough to feed directly into the plant. It is important to make the decision to combine or separate RAP from different sources with care to ensure streamlined processing. During the processing operation, blending is crucial for creating consistent RAP from multiple sources. A digging machine should use multiple layers of the stockpiled material to feed the processing unit so that the material leaving is a composite of layers and sources of RAP.

2.3.6 Samples

It is considered best practice to sample at least one set of tests in every 1,000 tons of RAP. Good practice for sampling aggregate applies to the sampling of RAP. The aggregate should typically be tested more often than virgin aggregate, but if it is intended to make up any significant portion of an asphalt mixture, it should be tested frequently. To obtain good statistics for consistency analyses, a minimum of 10 tests should be performed on a RAP stockpile. Proper sampling procedures normally used for virgin aggregates may also be used to sample RAP aggregate and are provided in Section X1.2 of AASHTO T 2, Sampling of Aggregates or ASTM D75-03.

2.4 Results of the Best Practices

2.4.1 U.S. Context

In recent surveys of the asphalt paving industry by the National Asphalt Pavement Association (NAPA), the average RAP content in asphalt mixtures has steadily increased, averaging around 20% in the U.S. The design and production of recycled mixes have been successful for many years. A recent study comparing the performance of

recycled versus virgin mixes based on Long-Term Pavement Performance (LTPP) data from 16 U.S. states and two Canadian provinces shows that overlays containing at least 30% RAP performed equal to overlays using 100% virgin mixtures. At the National Center for Asphalt Technology (NCAT) Test Track, test sections containing 50% RAP, using standard Superpave mix design procedures for each layer, outperformed companion test sections of 100% virgin materials.

NCAT examined the Specific Pavement Studies 5 (SPS5) information in the database of the Long-Term Pavement Performance program (LTPP). SPS5 consisted of 50 mm and 125 mm overlays constructed from virgin and 30% RAP mixtures. The NCAT study found that the 30% RAP overlays performed as well as the virgin overlays in terms of the international roughness index, rutting, block cracking, and ravelling.

NCAT has evaluated Hot Mix Asphalt (HMA) with a higher RAP content on the pavement test track in several studies. Four surface mixtures containing 50% RAP with various asphalt binders (PG 52-28, PG 67-22, PG 76-22, and PG 76-22 with Sasobit) were constructed over a perpetual asphalt pavement foundation to assess surface performance. The RAP and virgin structural sections were designed and constructed to have equivalent binder contents, and all other properties were held within normal production tolerances. The structural sections containing 50% RAP withstood 10 million ESALs of trafficking, and their performance was equivalent to that of the control with regard to both cracking and rutting.

The analysis used approximately 10 years of in-service pavement containing 20% to 72% RAP across the United States to evaluate the performance of the sections versus that of the virgin control sections. Although there were differences in performance, the RAP sections were less crack-resistant, of lower ride quality, and more rut resistant than the control sections. These differences were in many cases not statistically significant. None of the distress factors were severe enough to be detrimental to the expected life cycle of the RAP sections, which were typically 5% less than the virgin sections. In many of the case studies presented, high RAP sections have performed to a level equivalent to that of a virgin section, and have outperformed virgin sections.

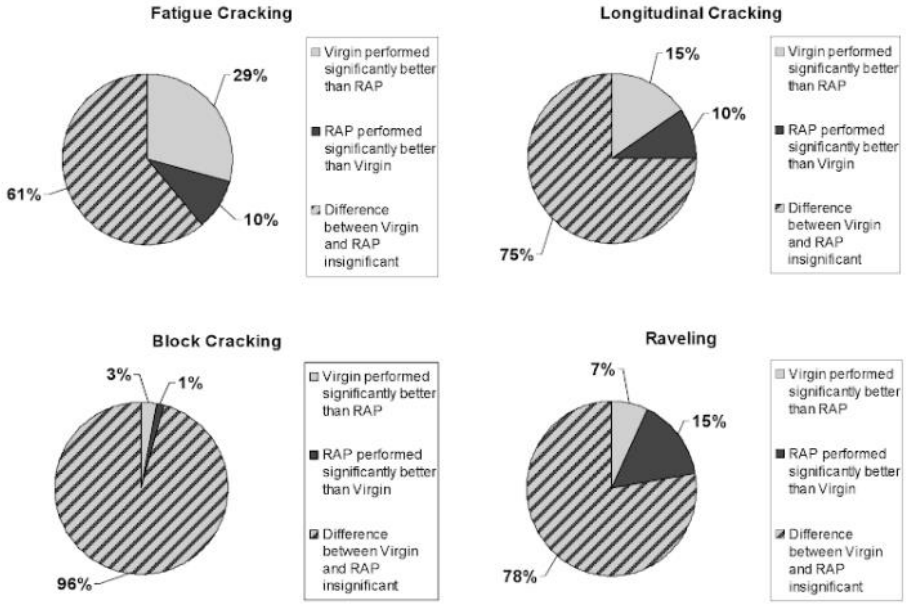

Figure 01 - Long-Term Pavement Performance result

2.4.2 Japan Context

Pavements and roadways in Japan exemplify a focus on quality and attention to detail. Contractors and road owners in Japan follow a simple mix design and materials testing process that emphasizes performance. Based on the observations and experiences in Japan, the asphalt mixtures with higher RAP content (> 25%) maintain equivalent or better quality and performance. RAP utilization in asphalt pavements should be pursued through a collaborative effort between the asphalt mixture producers, contractors, and suppliers, as well as the federal, regional, and local governments.

I. In Japan, on average, 47% RAP is used in asphalt pavements.

II. Of those 55 million tons, about 41.9 million tons contain recycled HMA (produced in 1,150 asphalt plants).

III. Approximately 15% of asphalt mixtures in Japan use polymer-modified asphalt binder.

IV. Asphalt mixtures in Japan now contain an average of 47% RAP on average, up from 33% on average in 2000. In Japan, like the U.S., 99% of RAP is recycled into asphalt pavement mixes. However, some RAP is reused as base course.

V. Keeping the stockpiles and bins covered and using as little water as possible in crushing activities helped Japanese mix producers reduce moisture in raw materials. Generally, Japanese plants dry and heat RAP in a separate drum, a method known as parallel heating.

VI. Japanese mixes with high RAP content often contain rejuvenators (softening agents). A rejuvenator can restore some physical characteristics in a RAP binder. A small pugmill is used to mix rejuvenators directly with heated RAP. Using this procedure, a rejuvenator can be quickly absorbed into aged RAP binders.

Japan attributes its success in using high levels of RAP in HMA to three factors:

I. A focus on quality (reducing variability), including processing RAP (i.e., fractionating) and covering stockpiles.

II. Heating the RAP to drive out moisture and soften the RAP binder.

III. Using a softening agent (and other mixing best practices) to achieve desired mix characteristics.

A strong emphasis on materials preservation, avoiding waste generation, and recycling is a product of political and cultural factors. Japanese law requires the responsible re-use of waste pavement materials. Consequently, recycling is driven primarily by economic and environmental concerns. RAP is effectively utilized in high percentages by Japanese contractors who are willing to invest heavily in sophisticated asphalt mixing plants and RAP processing plants. The Japanese requirements for mixes containing RAP are, however, not complex. Their specifications appear to encourage the use of high RAP content. Road contractors and owners in Japan follow a simple mix design and materials testing process that emphasizes performance.

The Japanese asphalt recycling specification includes the following aspects:

I. RAP is generated from a variety of sources. No restrictions are made as to the origin of the RAP.

II. RAP quality is judged by three criteria:

- Asphalt content must be at least 3.8%.
- RAP binder recovered from the compacted pieces must have a penetration greater than 20 or an IDT coefficient less than 1.70 MPa/mm.
- The P200 fines in RAP cannot exceed 5%.

III. The fractionation of RAP is a contractor's decision, not a requirement. Contractors commonly fractionate RAP.

IV. A blend chart is used to determine ratios of virgin or recycled binders or dosage rates for recycling agents. Mix designers can use virgin asphalts or recycled agents to achieve the desired penetration value for the composite binder or indirect tensile coefficient.

V. The Marshall Method and criteria are used in combination with a simple supplemental performance test, the indirect tensile coefficient, which limits mixes with very high stiffness (and low crack resistance).

2.5 Recycling Certification Institute

Local governments are requiring that all construction and demolition (C&D) waste generated in their jurisdiction be recycled at a minimum standard rate. A certification process was created by the Recycling Certification Institute (RCI) in response to the growing demand for reliable recovery and recycling reporting by C&D recycling facilities. The RCI uses independent third-party evaluators to verify the accuracy and reliability of the recovery/recycling rates reported. The Institute offers protocols, guidelines, and tools to professionally review and certify recoveries/recycling of participating C&D recyclers to increase certainty and build trust in the recycling marketplace for project owners, architects, the environmental community, municipalities, and the general public. Although the Certification process varies based on the size and type of facility, it remains consistent in measuring and analyzing a facility's material input and output to determine the facility's overall re-use, recycling, and recovery performance.

The Certification standard aims to achieve the following objectives:

- Establish a systematic process to account for the inputs and outputs of materials at a facility over a given period.
- Assist companies in communicating their reuse, recycling, and recovery of construction and demolition materials through a transparent, objective process.
- Ensure the procedure and declarations are applied consistently and verified by users of certified facilities.

Certification standards have the following goals:

- A procedure for accounting for the material inputs and outputs of a facility over a specified period;
- An objective, transparent, and reasonably priced process for eligible entities seeking to communicate their reporting of C&D materials reuse/recycling rates conforms to an established standard; and,

- Users of certified facilities have an assurance that the procedures and declarations are consistently applied and verified.

3. Market Considerations

3.1 Requirements and Expectations

Cities, as clients, expect high-quality materials that meet specifications and are guaranteed to perform. Cities are most concerned with the source of recycled material. They are willing to increase the recycled content given that the source is from their own projects which they are most comfortable with reusing since they have historical data to justify the quality of the material. Cities would like to know:

- How old is the recycled material?
- Where is it from?
- What is the composition of the material?

The above questions are reasonable to understand the material's origin and performance history. However, with respect to operations, it is very difficult for suppliers to provide answers and keep a record of various sources on a day-to-day basis. It is unrealistic for suppliers to keep stockpiles of material from different sites separately – generally, all material is placed in a centralized area before processing. Separating the materials based on sources and keeping a record of materials will not only take up more space at the facilities but also require more labour.

Using only materials from their own projects, with known quality, is the reason why the MoTI has been successful in utilizing the hot-in-place replace method for highway applications, which uses up to 90% RAP. The MoTI has confidence the existing roads and highways are of good quality asphalt pavement; therefore, are willing to recycle and reuse the millings.

Cities confirm that they accept mix designs that conform to the MMCD specifications – however, how the specifications are deciphered is based on the cities' interpretations. Their biggest resource in terms of guaranteed performance and quality to the final product is the geotechnical engineer/consultant who is hired by the municipality. As long as the geotechnical engineer is satisfied with the quality control measures and lab test results, proper sign-off can be obtained which gives cities the confidence to proceed with using recycled materials.

3.2 Technical Recommendation and Standards

3.2.1 Cities

Cities are using the MMCD specifications as a basis for municipal projects, which encourage 15% RAP. The MMCD is not a standard that must be followed. Some cities have created and implemented their own supplementary specifications. This is to ensure that the specifications are applicable to local conditions and meet requirements set out by a municipality's engineers and designers. For example, one municipality may be susceptible to high water table levels, where another may be prone to ground vibrations, and the MMCD is modified to address these issues.

The MoTI on the other hand follows its own standard specifications. They have spent 10 years and many resources to develop precise specifications for provincial projects. The magnitude of provincial projects is far greater than that of municipalities, driving the need for in-house engineers and labs to verify mix designs, as well as an internal database that tracks and monitors projects. It has been mentioned in various discussions with industry stakeholders that the MoTI's specifications may be a good resource for the MMCD to reference and build off. Not only are the MoTI's specifications more detailed, but they also list the types of tests that must be carried out and results that must be met.

3.2.2 Technology Considerations

One test that some cities are exploring is the Hamburg wheel test, which is performance-based test. A local testing agency has the equipment and is monitoring results from in-house tests. At the time of this study, the test results were set to be shared with the industry in the near future. From cities' perspectives, the Hamburg wheel test can be used to test different mix designs within a short amount of time, saving cities and suppliers the time and costs associated with years of monitoring and gathering sufficient data. It is noted that the Hamburg wheel test is indeed a good method to test performance; however, in the consultants' point of view, it is not a realistic representation of actual site conditions. A limitation is that there are no specifications for the Hamburg test in Canada, although there are specifications in the United States. Each municipality has its own testing procedures; however, the criteria are not standardized.

3.3 Consultants

As mentioned in a previous section, geotechnical engineers hired by municipalities approve mix designs submitted by the suppliers/contractors. As long as the mix designs are compliant with the cities' specifications, the geotechnical engineers approve and sign off. With that being said, decisions are based on risks and liability. Consultants have expressed that they are more comfortable with either little or no recycled material used, as they have more confidence in designing with virgin materials which historically have a greater guarantee of performance. Their perception is that recycled material will not behave in the same way as virgin material in terms of performance

There is a gap between consultants and suppliers: consultants are not often informed of the suppliers' processes and thus are not confident in the life cycle guarantees as well as the quality control measures performed by the suppliers. Should any failure arise on a project, the consultant's reputation would be compromised and costs would increase. There are no trends, data, records to document these failures and mix designs which can be useful lessons learned for all industry stakeholders. There is also no standardized procedure or tests for examining these failures. The blame would naturally fall on the quality of the recycled product before any investigation.

Lastly, even though recycled materials theoretically have the same properties as virgin materials – plus the added environmental benefits – consultants have admitted that they expect recycled materials to be cheaper than virgin materials. They confirm that the most influential factor in nearly every project is cost.

There is one application, however, that consultants are comfortable with and that is increasing more RAP in local and laneway roads, rather than arterials and collectors. These low-traffic and less sensitive applications can be explored and implemented immediately.

4. Supplier Considerations

4.1 Quality Control

Each supplier has its own quality control measures which includes carrying out in-house materials testing. They also hire a third-party testing agency and send samples to an external lab outside of BC to test and validate their own quality control results. Some have labs certified by the Canadian Council of Independent Laboratories (CCIL), while one is certified by ISO 17011. Suppliers have documentation and paperwork justifying the quality of their material; this information is readily available should clients require proof of quality. The tests are based on North American standards and best practices such as the ASTM, which are common quality control standards followed by the suppliers.

The higher the recycled material content, the more tests are required. For bigger, global suppliers, the costs of additional tests would still be considered minor when compared to overall project costs. These suppliers also have the financial support to perform annual materials testing and auditing which is available to the public. However, for smaller, local companies, increasing tests could impact the final cost of the product significantly.

Suppliers who are employed by the MoTI are meeting the MoTI's quality control specifications which require an increased frequency of tests as well as a broader range of tests. Suppliers confirmed that they are ready to meet specifications and pay for more tests should municipalities choose to modify the MMCD to reflect a similar level of strictness as that of the MoTI.

Common tests that the suppliers are currently performing include:

- Sieve analysis;
- California bearing ratio (CBR);
- Marshall tests;
- Proctor tests;
- Moisture content.
- Superpave;
- pH;
- Fracture count;
- Density tests (air voids); and

4.2 Operational Processes

It has been observed that the following common processes are executed at every plant:

- Conducting visual inspections of the truckloads at the entrance of the plant;
- Installing open-sided shelters to keep materials dry;
- Setting up an in-house lab and quality control procedures. Suppliers also involve a third-party testing agency to conduct sampling; and

- Fractionating (sorting) the recycled material so that the gradation is as similar to virgin as possible. They are always exploring new ideas, for example, using roofing shingles and glass in asphalt.

From storing to stockpiling, to crushing, to mixing, each recycling facility has its own procedures and processes. Storage of recycled material is a common issue in facilities as there is more material sent to the suppliers for recycling than there are clients who specify the use of recycled material on projects. Suppliers are encouraging material drop-off and product pick-up at the same time to reduce greenhouse gas emissions (GHGe), gas consumption, and costs for trucking services.

Education on plant processes and procedures is critical for plant operators to handle recycled material properly without compromising the quality and performance of the final products. Some suppliers are investing in their staff through annual in-house training and courses on the latest mix designs, best practices for plant operations, and updates on technological advancement.

4.3 Technology in Facilities/Plants

Technology found on site is similar across suppliers. Some have purchased the equipment and others have rented. It is not easy to handle recycled material – it is tougher on the equipment and hence requires suppliers to invest in good quality equipment. However, all suppliers have confirmed that they are investing or ready to invest in new technology to improve, future-proof, and enhance plant operations.

4.4 Challenges

Virgin vs. Recycled

Suppliers confirm that recycled material is priced cheaper than virgin materials (suppliers however did not provide the prices of the materials). Oftentimes the price is fairly close to virgin material due to logistic/geographic limitations. With a proper mix design, the performance of recycled material is comparable to virgin material. The type and amount of binder plays a key role in asphalt mix designs. The performance of the binder is very important.

Competing with virgin material in the Lower Mainland of British Columbia is a recognized barrier amongst all suppliers:

- There is a surplus of virgin material as it is readily available in quarries around the Lower Mainland for a competitive price. However, it is noted that the supply of virgin material will eventually be depleted and should be conserved as virgin materials are necessary to make up for gradation loss in recycled products.

- There are cases where engineers specify the use of non-recycled products only, and suppliers lose the opportunity to bid on these jobs using RAP. As for jobs that allow the use of recycled products, bids are competitive between recycled and virgin, and clients may default to the virgin option. Again, this poses a challenge for suppliers that have an abundance of recycled material to implement the material in the market. Consequently, this hinders the building of trust in the material from the clients and engineers. The perception that recycled materials produce an “inferior” product compared to virgin materials needs to change.

- Risks arise when a project that uses recycled materials fails. Oftentimes one of the client's first assumptions is that the failure is due to the performance of the recycled material, and such claims are made prior to investigating the failure in detail. This creates a setback for the suppliers with regards to overcoming the stereotype and correcting the clients' mindset. In some cases, when cities run investigations, the outcome often proves that the cause of failure is not due to the recycled material content, but rather other reasons such as improper handling, etc.

It has been observed that recycled material performs well as a sub-base for roads, in other words, non-structural applications (parking lots, curbs, etc.). Suppliers are currently exploring the option to use such material for surface applications (which are mostly procured using virgin material).

4.5 Best Practices

The suppliers' biggest clients are the MoTI and municipalities. Best practices, quality criteria, and technical specifications are therefore driven by these clients.

5. Environmental Considerations

5.1 Greenhouse Gas Emissions

Calculating the greenhouse gas emissions (GHGe) involved in recycling processes versus quarry operations is beyond the scope of this study. A consultant or subject matter expert should be engaged in a supplementary study to calculate GHGe reductions. No data has been provided to this study from the industry stakeholders with regards to GHGe reductions. It is not part of the criteria in projects to meet GHGe reductions; thus, suppliers don't typically process paperwork on the matter. At the time of this study no cities are known to have included reductions as a contribution to their sustainability goals.

5.2 Waste to Landfill

Minimal material is landfilled from suppliers. To avoid the high costs of dumping in landfills, suppliers enforce strict policies for material drop-off from clients. If the truckload is filled with materials such as garbage, bricks, wood, plastics, the load is rejected and the client must haul the load away.

In terms of reducing waste, again this is not a priority of the suppliers, consultants, or clients. These parties are aware that more recycled material used is better the environment as it encourages a circular economy and promotes zero waste. However, it is not a priority when it comes to project applications. Poor practices such as illegal dumping on First Nations land and mass hauling of good quality material to the landfill should be documented and published to raise awareness and such operations should be ceased.

5.3 In-situ Applications Considerations

There is limited data on existing RAP applications. To prove that RAP performs well, there need to be applications where a monitoring schedule is in place by a third-party testing agency. This will allow for long-term field data to be collected throughout the application's life cycle.

Trial and error applications should be considered on roads that are well-travelled but not highly publicized. Such applications should be monitored on an annual basis for 5 to 10 years to prove whether recycled material applications perform or not. Although time-consuming, these results would be more realistic as compared to the Hamburg wheel test. With joint efforts between cities, this initiative can commence immediately in various parts of the Lower Mainland of British Columbia.

6. Challenges and Opportunities

6.1 MMCD

The MMCD presents barriers to encouraging circular economy and zero waste targets in the construction, renovation and demolition (CRD) industry. The wording in the MMCD can be ambiguous which allows cities, consultants, and suppliers to have different interpretations of RAP specifications. Some parties' understanding is that the RAP percentage is based on binder content, where others have inferred that RAP content is by mass. This needs to be clarified by the MMCD Association. The MMCD also does not have detailed quality control and quality assurance measures in place that cities would like to see enforced and followed by suppliers/contractors. In addition, because the MMCD is not a standard that all cities must follow, many cities have implemented supplementary conditions often to limit and lower the RAP/RCA content. This counters the initiative to increase the use of recycled materials.

6.2 Cities

Another challenge is the common mindset within municipalities:

- **Recycled versus virgin:** Recycled materials are not necessarily cheaper than virgin material due to how accessible virgin material is in BC. Several cities believe that recycled material is not readily available and thus involves double handling (i.e. extra trucking to and from the recycling facilities, additional steps in processing, etc.). Recycled materials cost just as much as virgin materials. *"Why take a risk and use processed material when the costs are equivalent?"*

- **Testing:** Cities would have to carry out extra effort to conduct more tests to ensure the recycled material is up to the standards of virgin materials. This ultimately increases costs to obtain quality assurance guarantees in the products.

- **Cost:** Increasing the use of recycled material only provides cost savings for suppliers/contractors and in turn does not provide savings back to clients. At the end of the day, cost plays a big role in which option is chosen.

- **Lack of knowledge and experience working with RAP:** There is a false perception that increasing RAP in a mix design will lower the life expectancy of the roads/products.

- **Environment:** Priority is in lowering costs and guaranteeing performance and longevity of the roads. Environmental benefits are not always a concern or consideration when creating specifications and requirements.

6.3 Ongoing Research and Pilot Applications

In addition, cities lack resources to review mix designs or explore ways to improve the specifications that govern mix designs. Research and pilot projects are ideal to assist the cities in this regard.

7. Conclusion

This scoping study is the first step in addressing the initiative set by the National Zero Waste Council (NZWC), City of Richmond and Lafarge Canada to create and implement a Reclaimed Asphalt Pavement (RAP) pilot. These findings will inform the planning of the RAP pilot and can be accessed as a resource for the planning of future RAP projects.

APPENDIX A: Sources for the literature review

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