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ANNUAL SUMMARY REPORT

Project Title: P57: Implementing the Use of Reclaimed Asphalt Pavement (RAP) in TMR - Registered Dense - Graded Asphalt Mixes (Year 1 - 2016/17)

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SUMMARY

This study is an extension of Austroads Project No. TT1817 – *Maximising the re-use of reclaimed asphalt pavement* which has the aim of facilitating increased usage of Reclaimed Asphalt Pavement (RAP) through greater confidence in the design and performance of asphalt mixes containing higher proportions of RAP.

This report presents the findings of the first year of a research project to implement the use of higher percentages of RAP in TMR-registered dense-graded asphalt mixes. The outcomes are prepared in the form of the following two reports presented in Appendix A and Appendix B of this document:

1. Management of reclaimed asphalt pavement (RAP) material – current national and international practice (Appendix A).
2. Implementation of high RAP content asphalt mixes (Appendix B).

The first report (Appendix A) presents the outcomes of a literature review of international best practice in the management of RAP used in the manufacture of asphalt mixes containing RAP.

The use of RAP in the manufacture of asphalt is well established in Australia, particularly in the major centres which have the greatest availability of RAP. Management practices adopted by asphalt manufacturers in Australia are a reflection of the proportions of RAP permitted by the various road agencies and relevant inspection and test requirements. These RAP management practices compare well with international best practice for the proportions of RAP currently used.

Re-use of RAP in the manufacture of hot mix asphalt (HMA) provides significant economic and environmental benefits. Although poorly documented, there is evidence that not all the RAP available from road pavements is being fully and effectively used. RAP management is considered to be one of the inhibiting factors in increasing the usage of RAP.

The primary elements of a RAP management plan are traceability of the source and/or properties of processed RAP, prevention of contamination by deleterious materials, processing, stockpiling and inspection and testing.

The second report presents the outcomes of a literature review of international practices in incorporation of RAP into new asphalt mixes using different types of asphalt plants.

This literature review found that there is a great deal of diversity in the proportion of RAP that can be incorporated into asphalt mixes depending on the type of asphalt manufacturing plant available.

The primary plant-related factors that govern the maximum amount of RAP that can be incorporated into asphalt mix are:

- type of mixing plant
- RAP processing method and whether RAP is fractionated
- method of introducing RAP into the mixing plant
- RAP heating mechanism (heat transfer mechanism)

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- plant venting system.

This project also includes a laboratory study to evaluate the variability in the properties of RAP supplied to TMR. The laboratory investigation commenced in August 2016 and will continue for 12 months. The results of the laboratory testing obtained to date are presented in Appendix C. Test results include RAP aggregate grading, RAP binder content and RAP binder viscosity. Once the laboratory testing program is completed, the results will be used to investigate the impact on the end-product when RAP sources of different variability are used.

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1 PROJECT OVERVIEW

The use of reclaimed asphalt pavement (RAP) in asphalt has become standard practice in Australia and around the world. RAP is by far the most re-used construction waste material. There are many benefits associated with incorporating RAP in asphalt including:

- Reduction in asphalt cost: asphalt containing 15% RAP is approximately 10% cheaper than asphalt without RAP. At 40% RAP content, the cost reduction may increase to about 30% compared to virgin asphalt.
- Reduction in consumption of natural resources (aggregate and binder).
- Reduction in material going to land fill.
- Performance can be at least equivalent to asphalt that does not contain RAP (if the mix is properly designed).

Queensland Department of Transport and Main Roads (TMR) has recently released a new harmonised specification for dense-graded asphalt (MRTS 30) (TMR 2017a). The specification now allows the use of more RAP in asphalt mixes, up to 20% for surfacing layers and up to 40% for basecourses. These limits are reflective of the international state of practice. The previous version of the specification did not allow the use of RAP in surfacing layers and only 15% RAP in basecourses.

While MRTS30 now allows RAP contents of up to 40% in basecourses, for contractors to use in excess of 15% RAP, they must have a 'history of proven performance' (of up to five years). The 'history of proven performance' requirement is a significant barrier to the implementation of higher RAP contents in asphalt mixes. The use of higher RAP contents could significantly reduce the cost of asphalt and reduce the amount of high-quality material being sent to 'waste' or being used in lower-order applications. As the 'history of proven performance' requirement is perceived as a significant impediment to the use of high RAP content mixes by asphalt contractors, there is a need for technically sound acceptance criteria to replace this requirement.

Austroads published the findings of a recent research project (TT1817 Maximising the Use of Reclaimed Asphalt Pavement in Asphalt Mix Design) which investigated the mix design requirements to ensure asphalt mixes with high RAP contents will provide adequate performance (Austroads 2013, 2015, 2016). The performance implications of including higher percentages of RAP in asphalt mixes were also evaluated. In addition, mix design procedures to mitigate negative impacts associated with the inclusion of higher percentages of RAP were developed and validated.

1.1 Objectives

The aim of the current NACoE research project (P57) is to transfer the learnings and implement the findings from the Austroads RAP project into TMR's asphalt and RAP specifications – MRTS30 and MRTS102 (TMR 2017b). The incorporation of learnings from the Austroads project could enable a relaxation in the 'history of proven performance' requirement that currently exists in TMR specifications for asphalt mixes containing RAP contents above 15%.

1.2 Scope

The following three main tasks were undertaken during the first year of the project:

1. Project scoping and literature review of international best practice in RAP management.
2. Review of plant RAP processing capabilities and the requirements to incorporate high percentages of RAP.

3. Evaluation of the variation of the RAP properties supplied to TMR projects.

Two reports addressing Tasks 1 and 2 were issued during the first year of the project:

- Management of reclaimed asphalt pavement (RAP) material – current national and international practice (Appendix A). This report presents the outcomes of a literature review of international best practice in the management of RAP used in the manufacture of asphalt mixes containing RAP.
- Implementation of high RAP content asphalt mixes (Appendix B). This report focuses on the plant requirements that are necessary for the manufacture of asphalt mixes containing in excess of 15% RAP. A literature review was conducted to investigate the capability of various asphalt plants to allow the use of high percentages (> 15%) of RAP into asphalt mixes. The results of this investigation are presented in this report.

Task 3 involves testing of RAP samples for binder content, RAP aggregate grading and RAP binder viscosity supplied by three RAP processing facilities. One of the RAP facilities produces two fractions of RAP (14 mm and 10 mm) while the other two facilities provide only one RAP size (14 mm). Overall, 12 months' supply of four different RAP materials (48 RAP samples) was included in the testing program.

The collection of RAP samples commenced in August 2016 and will continue for 12 months until August 2017. The laboratory test results obtained to date are summarised in Appendix C. Upon completion of the laboratory testing, statistical analysis will be carried out to evaluate the variation of the RAP properties over time. The outcomes of the statistical analysis will provide a good risk assessment tool for both asphalt manufacturers and TMR.

In addition, a draft Technical Note is being prepared to provide guidance to prequalified asphalt contractors on how they can demonstrate compliance with the binder blend viscosity requirements of MRTS30 for high RAP content mixes (i.e. mixes containing > 15% RAP). The publication of this Technical Note has been postponed to the second year of the project after the RAP variability evaluation study is complete.

1.3 References

Austroads 2013, *Maximising the re-use of reclaimed asphalt pavement: binder blend characterisation*, AP-T245-13, Austroads, Sydney, NSW.

Austroads 2015, *Maximising the re-use of reclaimed asphalt pavement: outcomes of year two: RAP mix design*, AP-T286-15, Austroads, Sydney, NSW.

Austroads 2016, *Maximising the use of reclaimed asphalt pavement in asphalt mix design: field valid*ation, AP-R517-16, Austroads, Sydney, NSW.

Department of Transport and Main Roads 2017a, Asphalt Pavements, Technical specification MRTS30, TMR, Brisbane, Qld.

Department of Transport and Main Roads 2017b, Reclaimed asphalt pavement material, Technical specification MRTS102, TMR, Brisbane, Qld.

APPENDIX A MANAGEMENT OF RECLAIMED ASPHALT PAVEMENT (RAP) MATERIAL – CURRENT NATIONAL AND INTERNATIONAL PRACTICES

A 1 INTRODUCTION

This report presents the outcomes of a literature review of international best practice in the management of RAP used in the manufacture of asphalt mixes containing RAP.

Maximisation of the re-use of RAP has significant economic and environmental benefits. Current Australasian practice generally allows limited usage of RAP in asphalt mixes.

In 2012, Austroads commenced a three-year study which had the overall goal of reducing uncertainty surrounding the performance of asphalt mixes designed and manufactured with RAP through improved guidance on the design and specification of asphalt mixes containing increased proportions of RAP.

The project (TT1817 – *Maximising the use of reclaimed asphalt pavement in asphalt mix design*) included a study of the characteristics of binder blends in RAP mixes, the performance of laboratory mixes containing different percentages of RAP, and the validation of the design procedure for plant-produced mixes. The outcomes of this project were published in three Austroads reports (Austroads 2013, Austroads 2015 and Austroads 2016).

As a follow up to that project, a project has commenced under the NACoE research program, the aim of which is to implement the findings of Austroads Project TT1817 into TMR specifications (MRTS30) for dense-graded asphalt (TMR 2017a).

The use of high proportions of RAP (> 15%) in the design and manufacture of asphalt mixes requires particular attention to ensure reliable and consistent properties of RAP. Without this control, the performance of mixes containing high proportions of RAP is also likely to vary.

This report provides a summary of the literature, with specific reference to Australasian and international best practice in the management of RAP.

Issues to be addressed in this study include:

- The importance of an implemented RAP management plan: best practices for implementation.
- Strategies or approaches for the sourcing, processing, transporting and storage of RAP, including:
  - traceability of the RAP source
  - ensuring that the RAP does not contain road base material, concrete, coal tar, plastics, brick, timber, scrap rubber, etc.; the RAP must also be free from dust, clay, dirt and other deleterious matter
  - processing and storage of the RAP
  - the determination of the maximum aggregate size and the management of oversize material
  - handling and transport from the processing site to the asphalt plant
  - handling and storage at the asphalt plant
  - inspection and test plan.
- Auditing of an implemented RAP management plan.

A 2 RAP MANAGEMENT PRACTICE

A 2.1 General

All state and territory road agencies in Australia and New Zealand allow the use of RAP in the manufacture of HMA although with some differences in terms of the proportion of RAP permitted in various mix types and layer applications as well as variations in requirements for RAP management.

The greatest users of RAP, which commenced as early as the 1970s, have been NSW and Victoria. This is a reflection of the availability of significant volumes of RAP in the urban regions of Sydney and Melbourne. Similarly, Brisbane City Council has also been a long-term user of RAP through its own asphalt manufacturing facility.

Most road agency specifications include requirements for RAP management and most asphalt manufactures have developed RAP management plans that meet, or exceed, the requirements of the relevant specifying authorities.

An outline of RAP usage guidelines and management requirements in various jurisdictions and other referenced documents is now presented.

A 2.2 New South Wales

Roads and Maritime Services New South Wales (RMS) QA specification 3153 – *Reclaimed Asphalt Pavement Material* (RMS 2011) details the process control and conformity of RAP material.

RAP must be blended, crushed and screened to a nominal maximum size (i.e. 100% passing the 26.5 mm sieve). The material shall be free-flowing with a consistent particle size distribution (PSD) and have minimal fracture of aggregates. At the processing site, separate stockpiles for processed and unprocessed RAP must be established and each stockpile must not exceed 1 000 tonnes.

Requirements during transport of the RAP are also stated. This includes ensuring that no segregation or contamination of the processed RAP occurs, and delays that impact on production of the mix should not occur during transportation. At the asphalt plant, stockpiles must not exceed 500 tonnes and, much like the other state road agencies, RAP must be traceable. A stockpile must be stored to prevent contamination and must remain free-flowing. If it is not free-flowing or contains lumps, it cannot be used and may need to be reprocessed.

RMS QA Specification R116 – *Heavy Duty Dense Graded Asphalt* (RMS 2013a) sets out prerequisites to allow the use of up to 10% of RAP in all mixes, including wearing courses and asphalts containing PMB, and progression (other than PMB mixes) to RAP approval levels of up to 20% in wearing courses and up to 40% in other layers subject to additional requirements for testing and demonstration of field performance. RAP is not permitted in stone mastic asphalt (SMA) and open-graded asphalt (OGA).

Similar prerequisites, with slightly higher limits, apply in RMS QA Specification R117 – *Light Duty Dense Graded Asphalt* (RMS 2013b).

Basic testing requirements on each lot include PSD and binder content, together with daily testing of moisture content. Progression to higher percentages of RAP requires a production and placement trial along with checking of recovered binder viscosity and specific performance tests (i.e. resilient modulus, wheel tracking, beam fatigue and moisture sensitivity) to be repeated on an annual basis or when there is a change in the nominated mix.

Suppliers are required to implement a RAP management plan that verifies compliance with the RAP specification.

A 2.3 Northern Territory

Part 9 of the NT Department of Infrastructure *2015/2016 Standard Specification for Roadworks* (NT DoI 2015) specifies the following requirements for RAP:

> Crush and screen RAP from milling or excavation of existing asphalt as necessary to achieve a well graded, free flowing and consistent product. Ensure a maximum size no greater than the maximum size of the asphalt being produced. RAP material must not contain tar binder and be free of contaminants such as unbound granular base material, concrete, clay, soil, organic matter or any other deleterious material. Place processed RAP material in separate stockpiles prior to use. Where RAP material has been stockpiled for some time and is no longer in a free-flowing condition, reprocess to ensure that it is free flowing at the time of use.

RAP is not permitted in wearing courses but up to 15% RAP may be used in basecourses.

A 2.4 Queensland

Queensland Department of Transport and Main Roads (TMR) requirements for the use of RAP in asphalt are set out in TMR specification MRTS102, *Reclaimed Asphalt Pavement Material* (TMR 2017b).

RAP process control requirements, including processing, stockpiling, transport, stockpiling at the asphalt plant and traceability are similar to RMS specification 3153 (RMS 2011).

Further requirements, similar to RMS 3153, include a statement that the contractor's procedures, as detailed in their RAP management plan, must ensure the distribution of RAP aggregate in each stockpile is visually homogeneous and meets the requirements to control moisture content in stockpiles.

A minimum frequency testing for binder content and aggregate grading is required for each 500 tonnes of RAP with an additional requirement of one recovered binder viscosity test being completed per 1 000 tonnes of RAP when the percentage of RAP binder exceeds 15% of the total binder in the mix.

Allowable proportions of RAP for use in the manufacture of dense-graded asphalt containing bitumen or Multigrade bitumen binders are set out in TMR technical specification MRTS30 *Asphalt Pavements* (TMR 2017a). The basic proportion of RAP allowed in all mixes except SMA, OGA or mixes manufactured with PMB binder, is 15%.

Provision is made for progressive levels of approval in the proportion of RAP of up to 20% in surfacing courses and up to 40% in courses other than the surface, subject to the application of additional performance testing and demonstration of performance that follows similar guidelines to that of RMS R116 and R117 used in New South Wales (RMA 2013a and 2013b).

A 2.5 South Australia

The Department of Planning, Transport and Infrastructure South Australia (DPTI) Specification Part R27 (DPTI 2015) requires RAP to be obtained from milling or excavation of existing asphalt pavements or asphalt plant waste.

For the use of RAP within asphalt mixes, the Contractor's Quality Plan must include a Reclaimed Asphalt Pavement Management Plan and Industry Code of Practice meeting the following minimum requirements:

(a) RAP must be crushed and screened as necessary to ensure a maximum size no greater than the maximum size of asphalt being produced and to achieve a reasonably well graded, free flowing, and consistent product.

(b) The processed RAP of each size must be placed in separate stockpiles not exceeding 1 000 tonnes and represent a lot. Each lot must be tested for binder content, grading, viscosity and moisture content at a minimum of one per lot. Test results must be traceable to the asphalt mix containing the RAP.

(c) RAP that has been stockpiled for some time and has bound together in some way must be reprocessed, to ensure that it is in a free-flowing state at the time of use.

Up to 10% RAP may be used in medium and heavy duty dense-graded wearing course mixes and up to 20% RAP in light duty dense-graded wearing course mixes. Provision is made for higher proportions of RAP, up to 50%, in basecourse mixes subject to the determination of RAP binder content and viscosity and the use of a softer grade of binder or rejuvenating agent to achieve a binder equivalent to Class 320 in all mixes where the total proportion of RAP exceeds 10%.

Indirect tensile strength (ITS) testing is also required on a daily production basis where the proportion of RAP exceeds 10%.

The addition of RAP is not permitted in SMA or OGA and is limited to 20% in any mix incorporating a PMB binder.

A 2.6 Tasmania

For all new contracts advertised after 1 August 2016, the Department of State Growth, Tasmania, has adopted specifications based on VicRoads standard specifications. VicRoads specification requirements are described in Commentary A 2.7. Previously, the Department of Infrastructure, Energy and Resources (DIER) had provided the RAP management requirements in G7 asphalt production general specification (DIER 2.12).

A 2.7 Victoria

VicRoads specification Section 407 – *Hot mix asphalt* (VicRoads 2017) includes basic requirements for RAP consisting of milled or excavated asphalt pavement free of foreign material such as unbound granular base, broken concrete or other contaminants, and crushed and screened to a maximum size not exceeding the size of asphalt produced.

RAP complying with basic requirements may be used in proportions of up to 10% or 20% in wearing course mixes, depending on the traffic level and mix type, and up to 20% or 30% in basecourse mixes. The use of RAP is not permitted in very heavy duty wearing course mixes, OGA, SMA or any mix containing a PMB.

A further 10% RAP may be added to permitted mix types subject to additional performance testing and a RAP stockpile management plan that addresses particular requirements for ensuring uniform grading and binder content of the processed RAP. Assessment of RAP stockpiles for use in high RAP mixes includes testing of multiple samples for grading and binder content and a statistical assessment of variability. Once the processed RAP stockpile has been assessed for compliance, with the registered asphalt mix design RAP grading and bitumen content, no more processed RAP may be added to that stockpile.

During asphalt production, the testing frequency for grading and bitumen content of the RAP stockpile is one test per 1 000 tonnes used.

A 2.8 Western Australia

Similar to other state road agencies, Main Roads Western Australia (MRWA) specification 511 – *Materials for Bituminous Treatments* (MRWA 2016a) states that RAP shall be obtained from surplus plant mix or the material reclaimed from an asphalt wearing or intermediate course by cold planning. It must be free from specified contaminants.

RAP must be traceable by keeping it in lots. A management plan must also be prepared detailing the stockpiling, processing storage and testing of RAP. A minimum of three samples are to be taken for every 1 000 tonnes in each lot of processed RAP and tested for PSD, bitumen content and moisture content.

Processing and storage of the RAP also includes a requirement to maintain separate stockpiles of RAP prior to processing for use in the asphalt mix. RAP is required to be crushed and screened to produce a nominal 7 mm or 10 mm sized material incorporating fines, as well as a nominal 14 mm size having less than 2% of the material passing the 6.7 mm sieve.

RAP must be stored in a storage facility that has a concrete sloping floor (to drain out excess moisture after screening). The RAP stockpile must be covered on top and on at least three sides to prevent it from becoming wet. As with other state road agencies, RAP must be free-flowing and consistent in appearance. Where the stored RAP is not free-flowing it must be crushed and/or re-screened.

Up to 10% of RAP by mass of the total aggregate may be used in the production of 14 mm or 20 mm asphalt intermediate and basecourse asphalt (MRWA 2016b). RAP is not allowed in the manufacture of dense-graded wearing course asphalt, SMA or OGA.

A 2.9 New Zealand

The New Zealand Transport Agency (NZTA) Specification for *Dense Graded and Stone Mastic Asphalts*, M10 (NZTA 2014a) includes the following requirements for RAP materials.

> RAP shall be crushed and screened as necessary to ensure a maximum size no greater than the maximum size of asphalt being produced and to achieve a reasonably well graded, free flowing and consistent product.
>
> RAP shall be stored in separate stockpiles. Stockpiles shall be homogeneous and sampled for mix design validation prior to use.

The quality plan shall indicate the procedures for monitoring the consistency of grading and binder properties of incoming RAP materials.

Further requirements in the Notes to the Specification NZTA M10 (NZTA 2014b) include the following:

> Up to 15% RAP is permitted in all dense-graded asphalt mixes. A further 15% up to a total proportion of 30% RAP is permitted in dense-graded mixes subject to selection of a suitable binder grade or rejuvenator to correct binder viscosity. The use of more than 30% is subject to additional performance testing and demonstration of suitable RAP management practices and manufacturing capability.

A 2.10 Austroads Guide to Pavement Technology – Part 4B: Asphalt

The current Austroads *Guide to pavement technology* (AGPT) Part 4B (Austroads 2014) provides the following guidelines for RAP materials:

> Incoming RAP materials generally require crushing and/or screening to remove oversize materials and break up agglomerations in order to ensure a consistent grading and provide a free-flowing product. Separation into different-sized fractions further assists control of combined grading of the asphalt mix. The process of reclamation and crushing tends to produce an increase in fines in RAP compared to the original asphalt mixture. Separation into separate sized fractions assists in recombining materials to a particular grading target, particularly if the content of RAP exceeds around 20% of the mixture. Screening into separate sizes is essential if the RAP is to be used in mixes with special grading requirements, such as stone mastic asphalt, OGA or fine gap graded asphalt.
>
> Materials should be inspected or tested for contamination and suitability for recycling. Materials containing tar are not suitable due to the risk of fuming. Aggregates that are rounded or polished may only be suitable for basecourse applications.
>
> Stockpiles of RAP should be carefully controlled to:
>
> - identify and keep separate, different quality or sizes of RAP materials
> - avoid consolidation of large stockpiles
> - avoid moisture retention.
>
> RAP materials can retain a great deal of moisture and undercover storage can reduce subsequent heating and drying costs.

A 3 OTHER COUNTRIES

A 3.1 North America

North America, including the USA and Canada, has long been recognised as a leader in asphalt recycling. Not surprisingly, any literature search reveals a large number of documents originating in North America, mostly from the USA. Among the more significant documents are those representing the outcomes of various cooperative programs, including publications of the Asphalt Institute (AI), Federal Highway Administration (FHWA), National Asphalt Pavement Association (NAPA), National Centre for Asphalt Technology (NCAT), National Cooperative Highway Research Program (NCHRP) and the Transportation Research Board (TRB).

Like Australia, there is significant variation between individual States in both the proportion of RAP used in the manufacture of asphalt and RAP management practice. Similarly, the proportion of RAP usage is steadily increasing. NAPA Information Series IS 138 – *Asphalt pavement industry survey on recycled materials and warm-mix asphalt usage: 2014* (NAPA 2014) notes that the average percentage of RAP used in asphalt mixes has increased from 15.6% in 2009 to 20.4% in 2014, with an overall rate of over 99% of all RAP being recycled.

In a further comparison with Australia, national programs are directed at encouraging the use of greater proportions of RAP. One of the foremost researchers in this field is the Director of NCAT, Randy West. In a 2009 presentation (West 2010), he noted stockpile management as being the leading factor in barriers to increasing RAP usage.

General guidelines for stockpile management are addressed in a range of publications including *The asphalt handbook* (Asphalt Institute 2007), NAPA Information Series 123 *Recycling hot-mix asphalt pavements* (NAPA 2007), *RAP in asphalt mixtures: state of practice* (FHWA 2011) *NCHRP report 752 – improved mix design, evaluation, and materials management practices for hot mix asphalt with high reclaimed asphalt pavement content* (TRB 2013) and NCAT report *Reclaimed asphalt pavement management: best practices* (West 2010).

Other reports of more specific application include *RAP stockpile management in Texas* (FHWA 2010), *Fractionation of recycled asphalt pavement materials: Improvement of volumetric mix design criteria for high-RAP content surface mixtures* (Shannon 2012) and *Reclaimed asphalt pavement ('RAP'): stockpile emissions and leachate* (NAPA 2012).

The NAPA Quality Improvement Series QIP 129 – *Best practices for RAP and RAS management* (NAPA 2015a) – provides a comprehensive summary of best practice that incorporates most of the elements described in the documents referred to above. An outline of key factors, with particular reference to QIP 129, is now presented.

Reclaiming

According to NAPA (2015a):

> RAP may be obtained from several sources. The most common method is through pavement milling operations, also known as cold planning. Two other common sources of RAP are full-depth pavement demolition and waste asphalt plant mix.

The selection of the correct milling depth is critical. In some cases, it may be desirable to mill the surface layer in a separate pass to the underlying layers. This could be appropriate where it is desired to recover higher-quality, polish-resistant aggregates for the wearing course or where the wearing course contains particular binder or aggregate materials, e.g. slag, that need to be processed separately to other RAP materials.

Other important factors to be considered in the planning of milling operations are the need to avoid contamination from base materials or other debris and inspection of milled surfaces for signs of 'scabbing' where thin weakly-bonded layers are left in place.

Large chunks of asphalt obtained from pavement reconstruction can be more difficult to process. It is important that the quality of this type of material is closely monitored to avoid contamination and deleterious materials. When pavement rubble is contaminated with underlying layers and soil, it is better for this material to be crushed and used as a shoulder or base material than used in an asphalt mix.

Plant waste, including job surplus, will contain binder that is less aged than other sources of RAP as well as fewer fines from milling or reprocessing. Waste materials must be thoroughly mixed and processed to make them uniform and suitable for recycling. Plant waste materials are often combined with other sources of RAP in multiple-source stockpiles.

Inventory

QIP 129 describes RAP management as beginning with a basic inventory analysis of available RAP and mix production including four simple steps:

1. an inventory of RAP on hand and RAP generated per year
2. a summary of mixes produced per year by mix type and customers
3. the determination of the maximum amount of RAP that can be used
4. a comparison of the quantity of RAP available to the amount of RAP needed.

A particular piece of advice relating to inventory is the suggestion that, where the supply of RAP is limited, it is logical to use a relatively consistent amount of RAP in all mixes rather than a lot in some mixes, thereby leaving a shortage or RAP for remaining mixes. Running higher RAP contents could be more competitive on certain jobs, but there may be additional costs associated with higher RAP contents, such as additional materials testing, higher RAP processing costs, plant modifications, and higher plant maintenance costs. Using a consistent percentage of RAP is likely to be easier on the plant, mix design and QC staff, and paving crews.

One of the first decisions in inventory management of RAP should be whether or not to put all incoming RAP materials into a single pile or to create separate stockpiles for RAP obtained from different sources. The decision will likely depend on the following factors:

- components in the RAP that warrant handling the material separately from other sources
- whether the state or local agency allows RAP from other sources in asphalt mixes produced for its agency specifications
- whether or not the state or local agency requires captive stockpiles or allows continuous replenishment of stockpiles
- the space available at the plant site for RAP processing and stockpiling
- the target RAP percentages in the asphalt mixes to be produced
- how much RAP comes from a single project.

Most road agencies in the USA allow the use of RAP from multiple sources, including RAP that has been combined and processed into a single uniform stockpile. However, there are some agencies that only allow RAP from their own projects to be used in their mixes.

QIP 129 provides an indication of the diversity in road agency requirements. This is further emphasised by the survey of RAP management practices in the Midwestern States included in the fractionation of RAP (Shannon 2012).

A requirement imposed on RAP stockpiles by some agencies is that no additional material can be added to a RAP stockpile once it is created and tested. This is referred to as a 'captive' RAP stockpile. This conservative captive stockpile approach is based on the premise that the properties of the stockpile must be precisely known if it is to be used as a component in an asphalt paving mix.

However, some contractors have been able to develop RAP-processing practices using continuously replenished stockpiles that have very consistent gradations, aggregate properties, and asphalt contents over a long period of time. Determining if the RAP processing provides a consistent material over time requires regular testing and analysis of the RAP to document the RAP stockpile variability. Guidelines for sampling and testing are referred to shortly.

Recommendations for the operation of continuously-replenished stockpiles are described in QIP 129.

Processing

The basic goals of processing RAP are to:

1. create a uniform stockpile of material
2. separate or break apart large agglomerations of RAP particles to a size that can be efficiently dried, heated, and broken apart during mixing with the virgin aggregates
3. reduce the maximum aggregate particle size in the RAP so that the RAP can be used in surface mixes (or other small nominal maximum aggregate size mixes)
4. minimise the generation of additional dust (size minus 75 µm).

A common limitation to increasing RAP contents in asphalt mixes is the dust content in the RAP. Because milled RAP already contains appreciable amounts of fines due to the milling of the material from the roadway, it is best to minimize further crushing of milled RAP whenever possible.

QIP 129 refers to the increasing popularity of fractionating of RAP by screening into, typically, two or three sizes. Shannon (2012) provides additional emphasis on the value of fractionation in enabling the use of higher proportions of RAP.

The critical factor in fractionating RAP is to avoid the creation of excess fines. The choice of crusher type, crusher settings and crushing techniques, such as pre-screening to separate smaller fractions are some of the elements to be considered in avoiding excessive breakdown of aggregate particles.

Stockpiling

The following points are considered important during stockpiling:

- Prevention of contamination and minimisation of moisture: stockpiles should be built on appropriate surfaces (e.g. paved, sloped surfaces) to provide drainage and prevent contamination. Conical stockpiles can shed rain more effectively than flat or irregularly-shaped stockpiles. Preferably, RAP should be stored undercover to minimise fluctuations in the moisture content (e.g. covering with tarps, storing under roofed structures).

- Prevention/limitation of segregation: the base of the stockpiles should be constructed to minimise segregation, as well as provide a secure work platform. To avoid compaction of stockpiles, heavy machinery should not be driven on the stockpile and the stockpiles should be routinely skimmed to break up lumps. Unprocessed or milled RAP stockpiles should be arc-shaped and uniformly layered. For processed RAP material, the stockpiles should be conical or small, low sloped piles.
- Provision of separate stockpiles: separate stockpiles based on the category of RAP, size of processed material, quality and binder content may need to be considered. For higher percentages of RAP, stockpiles may need to be fractionated in order to control the variability in binder content, aggregate size and grading.

The risk of fugitive dust or leachate from RAP stockpiles is considered minimal. NAPA Special Report (NAPA 2012) states that fugitive dust is unlikely as the aggregate is coated with binder. It refers to documented evidence that leachate or runoff from RAP storage is not problematic.

Sampling and testing

QIP 129 refers to the practice, occasionally used in the USA, of obtaining samples from the road pavement, prior to milling, in order to prepare mix designs specific to the material being recycled. That practice is not likely to be used in Australia where all asphalt mix design and asphalt process control is based on sampling and testing of processed RAP.

A well-executed sampling and testing plan for RAP is necessary to assess the consistency of the RAP stockpiles and to obtain representative properties for use in mix designs.

Sampling at least one set of tests per 1,000 tons of RAP is stated to be the best practice. A minimum of 10 tests should be performed on a RAP stockpile to yield good statistics for consistency analyses. Some agencies allow for a reduced testing frequency if the consistency of the materials properties for the stockpile can be demonstrated.

The testing frequency depends on the category of RAP and the amount of RAP that is to be used in the mix. For most mix designs, the data needed is:

- binder content of the RAP
- gradation of the aggregate recovered from the RAP
- consensus properties of the aggregate recovered from the RAP
- the RAP binder properties (for high RAP contents, i.e. more than 15%).

In some cases, additional aggregate tests may be necessary. For example, if the RAP is to be used in a surface mix for high-speed traffic, some agencies may require tests to evaluate the aggregate polishing characteristics. Typically, aggregate source properties such as Los Angeles (LA) abrasion and soundness are not necessary as it is unlikely that the coarse aggregates in the RAP would have come from sources not originally approved by the state agency.

Techniques for obtaining representative samples and test methods are described in QIP 129 and FHWA (2011).

A 3.2 Europe

According to the European standard for reclaimed asphalt (EN 13108-8:2005), the content and type of any foreign matter in the RAP – i.e. materials other than natural aggregate not derived from asphalt material _ must be documented. The RAP material is then categorised according to the content and material type, as detailed in the document. Identification of the feedstock should include the supplier, designation of the material, and date and time of delivery. Feedstock shall be traceable from the identification and material property declaration.

The binder type, binder properties and binder content of the RAP material must also be documented and declared. It must indicate whether the binder is a paving grade bitumen, modified bitumen or hard grade bitumen, or if the RAP contains a modifier additive. If the binder is paving grade, the RAP can be classified according to the penetration, softening point or viscosity at 60 °C, as described in the standard. If it is not a paving grade binder, then a declaration of the nature and properties of the binder based on available information must be made to evaluate its suitability.

The mean grading of the aggregates shall be documented and declared. The standard details the requirements for the grading and the sieves to be used. Also, to be declared is the source of the RAP, the type and properties of the aggregate, and the homogeneity of the feedstock.

Sampling and testing requirements are also stated. The number of samples to be tested is the quantity of the feedstock in tonnes divided by 500 tonnes, rounded upwards with a minimum of five. If low percentages of RAP are to be added (i.e. less than 10% in surface courses or 20% in base and binder courses), the frequency of testing is reduced to once per 2 000 tonnes, and a single sample per batch of feedstock may be specified.

A 3.3 United Kingdom

The use of RAP (referred to as reclaimed asphalt, or RA, in the UK) in the manufacture of asphalt is well established in the UK. Primarily, mixed sources of RA are used as in basecourse asphalt while the use of RA in wearing course is typically limited to no more than 10%.

The Transport and Road Research Laboratory (TRL) Road Note RN43 *Best practice guide for recycling into surface course* (Carswell et al. 2010) refers to a limited survey of asphalt manufacturing plants in the UK. The survey revealed that between 10% and 20% of plants had a capability to include between 10% and 15% of RA, up to 20% of plants had a capability to include more than 30% of RA, whilst the remainder could only accept up to 10% RA, if any at all.

TRL RN43 specifically addresses the issue of recovery and re-use of high-quality, polish-resistant aggregates from thin wearing course asphalt layers. The use of proprietary thin asphalt surfacings developed under the Highways Authority Product Approval Scheme (HAPAS) has been a growing trend in the UK, while high-quality aggregates have become a dwindling resource.

It is recommended in RN43 that wearing courses and base asphalt layers be milled separately. Any assessment of materials for recycling as a wearing course must consider potential contamination from surface dirt or unsuitable materials such as tar binders. Guidelines are provided for ensuring integrity in the classification of individual stockpiles and protection from moisture ingress. Further processing of RA may not be necessary when the proportion of RA to be added does not exceed 10%. Higher proportions of added RA may require crushing and/or screening to ensure a uniform product.

Mechanical properties of aggregates may be assessed from original production records (if available) or appropriate testing. Binder recovered from RA is tested for penetration (bitumen binders) or rheological properties (PMBs) in order to determine an appropriate binder blend for the recycled mixes.

Carswell et al. (2010) concluded that, with the RA management practices outlined in RN43, the inclusion of 10% RA in thin asphalt wearing courses could become routine, while larger amounts may be used where conditions are appropriate. Good RA management practices should also be applicable to the use of RA in lower layers as well as providing a basis for reducing restrictions on the use of RA in the wearing course.

A 3.4 Japan

The National Asphalt Pavement Association Information Series IS 139, *High RAP asphalt pavements: Japan practice – lessons learned* (NAPA 2015b) provides an excellent insight into the use of high proportions of RAP in Japan as an outcome of a US-industry study tour undertaken in 2014.

Significantly, asphalt producers in Japan have achieved an industry average of 47% RAP in the manufacture of asphalt compared to an average of 20% in the USA (NAPA 2015b).

Effective manufacture of mixes containing up to 60% RAP, and more, has been achieved through:

- a focus on quality (reducing variability), including processing of RAP (fractionating) and covering of stockpiles
- pre-heating of RAP to drive out moisture and soften the RAP binder
- the use of rejuvenating agents and other mixing best practices to achieve desired mix characteristics.

RAP is commonly sourced as chunks and slabs rather than pavement milling. Crushing, screening and stockpiling are undertaken in closed facilities to minimise moisture. RAP is generally screened into two sizes, minus 13 to 5 mm and minus 5 mm.

RAP quality is judged by three criteria:

- binder content ≥ 3.8%
- penetration of recovered binder ≥ 20 penetration units (pu) or samples of the compacted RAP must have an IDT coefficient < 1.70 MPa/mm
- per cent passing the 0.075 mm sieve: ≤ 5.0%.

Batch mixing plants, rather than continuous (i.e. drum) mixing plants are common. To ensure effective blending of RAP and virgin materials, the RAP is usually preheated and may be blended with rejuvenator in a separate pugmill before adding to the asphalt mixer.

Blending charts based on the measurement of binder penetration are used to determine the grade of virgin binder or proportion of rejuvenating agent. High RAP proportions generally require the use of rejuvenating agent. With increasing quantities of RAP containing PMBs, an indirect tensile test has been developed to measure the properties of the recycled asphalt blend as an alternative to the penetration based blending charts.

A 3.5 Asia

The Road Engineering Association of Asia and Australasia (REAAA) recently commissioned the preparation of a compendium on the state-of-the-art regarding current practice in the recycling of pavement materials in the Asia-Pacific region. The work was led by a Working Group on Pavement Maintenance and Rehabilitation set up by the Japan Road Association (JRA) under its Design and Construction Sub-Committee. It worked with REAAA Technical Sub-Committee TC-2 (Pavements) to manage the Committee's activities, commencing with the compilation of a *Compendium on pavement maintenance and rehabilitation* (REAAA 2017a). The report on the current status of pavement recycling in the region is due for publication before the end of 2017 (REAAA 2017b).

In the summary below, the percentages shown in brackets, refer to the percentages of the surveyed countries e.g. '(91%)' means 91% of the surveyed countries. Also, 'base layers' refer to the pavement granular base layers and not the asphalt basecourses.

The main findings of the study were as follows:

- Recycling of pavement materials is widely carried out in the REAAA member countries. Either plant or in-situ recycling is adopted in Australia, Indonesia, Japan, Korea, Malaysia New Zealand, the Philippines, Singapore, Taiwan and Thailand, whilst cold mix recycling is practiced in Brunei.
- Both plant and in-situ recycling is conducted in Australia, Japan, New Zealand and Thailand.
- The dominant reasons for recycling are 'saving new resources' (91%) followed by 'environmental considerations' (73%) and 'lack of new resources' (36%).
- Plant recycling is mainly adopted on national highways (64%) and local roads (73%). New Zealand, Singapore and Thailand accept reclaimed asphalt pavement (RAP) on expressways.
- Sixty-four per cent (64%) of the countries use reclaimed asphalt pavement (RAP), in which existing asphalt waste is mixed with new materials at the recycling plant and then used as an asphalt layer in new projects. RAP is also used in base layers in some countries. RAP is used in asphalt and/or base layers in Japan, Korea, New Zealand, Singapore, Taiwan and Thailand.
- Among the seven countries who use RAP in asphalt layers, Australia, Japan and Thailand are thinking of revising their guidelines. The Philippines is the only country that is considering a revision for the use of RAP as a base layer.
- All of the seven countries (Australia, Japan, Korea, New Zealand, Singapore, Taiwan and Thailand) who use RAP for asphalt layers have guidelines for the appropriate use of this technology. Four out of the six countries who use RAP in base layers are preparing guidelines.
- Specific technical problems encountered at the recycling plant include difficulty in quality control of RAP materials, the use of an appropriate index for judging the suitability of RAP for recycling, and the difficulty in extracting bitumen from modified asphalt materials.
- In terms of the use of RAP in the in-situ recycling of base layers – which is employed in six countries – technical standards are available. However, not all countries have standards for the use of RAP in asphalt layers.
- In terms of specific technical issues, Korea and the Philippines have concerns about quality control of RAP materials with Korea suggesting that quality control was recognised throughout the region as the key to the successful application of RAP.
- There are concerns in Taiwan that adding a higher percentage of RAP could create potential problems in terms of performance and durability.
- The recent popularity of modified bitumen and porous asphalt mixes in Japan has led to a reduction in the use of RAP in that country. This is because it is hard to assess aging levels in modified asphalt mixes from extracted bitumen. In addition, porous asphalt mixes differ from conventional dense-graded mixes in aggregate gradation and the level of modified bitumen.

A 3.6 South Africa

The Southern African Bitumen Association (SABITA) *Technical Recommendations for Highways TRH 21 – Hot Mix Asphalt Recycling* (SABITA 2009) provides a guide to RAP management practice in South Africa.

Road agencies in South Africa have been slow to adopt significant quantities of asphalt recycling. The purpose of TRH 21 is to encourage the greater use of recycling through a better understanding of the principles of recycling and design procedures, supported by details of a number of case studies. Guidelines for the reclaiming, processing and management of RAP and the manufacture of asphalt mixes are provided with reference to international best practice.

A 4 DISCUSSION

The literature review identified elements of diversity in RAP management in a range of jurisdictions both in Australia and internationally, but it is noted that there is great commonality. In most cases, diversity is driven by the requirements of the relevant road agency.

The use of RAP in the manufacture of HMA is well established in Australia, particularly in the major metropolitan areas where a ready supply of RAP has enabled the development of protocols for RAP management and asphalt mix design based on some 30–40 years of past experience.

Some of the points of difference in both Australian and international practice, include:

- identification of source materials
- the use of designated, discrete stockpiles for RAP obtained from different sources
- combining RAP from different sources
- processing and fractionation of RAP
- permitted size of stockpiles at processing sites and asphalt mixing plants
- covering of stockpiled RAP
- the maximum proportion of RAP used in different types of asphalt mixes and applications
- inspection and test requirements.

Identification, separation and combination of materials from different sources

In Australia, almost all RAP is used as a combination from mixed sources provided that appropriate controls are applied to avoid contamination from unwanted materials before processing of RAP into a reasonably uniform, blended product.

In Australia, asphalt is almost invariably manufactured with materials complying with the relevant state or local road authority specifications. Aggregates, in particular, can typically be used with confidence if they meet basic soundness requirements. Some caution must, however, be applied where materials such as binders with high proportions of crumb rubber or non-standard aggregates (e.g. slag) are encountered.

In the UK, and to a lesser extent in the USA, separate milling and recovery of wearing course materials is sometimes undertaken in order to recover polish-resistant aggregates for recycling back into wearing course mixes. TRL Road Note 43 (Carswell et al. 2010) makes particular reference to the recovery and re-use of these materials in thin wearing course layers.

Some road agencies in Australia do not allow any RAP to be used in dense-graded asphalt wearing course mixes. All Australian state road agencies exclude the use of RAP in OGA and SMA. These policies could be reviewed, taking into account factors such as the proportion of RAP being obtained from existing wearing courses and the utilisation of RAP inventory. Fractionation into sizes suitable for incorporation into OGA and SMA is also feasible provided the polishing resistance of the coarse aggregate is known and complies with specification requirements for these mix types.

It is recognized, however, that the creation of separate stockpiles of RAP for different applications would have a significant impact on storage space as well as the need to change asphalt mixing plant material feeds.

Processing and fractionation

At the most basic level, RAP must be crushed and/or screened to ensure a maximum size no greater than the size of asphalt being produced. Processing must also ensure the RAP is a free-flowing material. Further crushing and screening into separate fractions can also be applied, particularly where higher proportions of RAP are being used.

It is important to avoid excessive breakdown of aggregates during processing. Excessive fines in the processed RAP can be a limiting factor in the proportion of RAP that can be used when meeting combined grading targets of the manufactured asphalt.

Detailed guidelines for the processing of RAP are provided in NAPA QIP *Best practices for RAP and RAS management* (NAPA 2015a).

Stockpiling

The two major points of difference in specifications and practice in Australia are the requirements for single stockpiles in place of continuously replenished stockpiles, and the covering of stockpiles.

Victoria is the only state in Australia to allow continuously-replenished stockpiles. This is permitted for basic RAP proportions only (e.g. up to 10% RAP for heavy duty wearing course and up to 20% RAP for heavy duty basecourse), and not allowed for 'high RAP' mixes. All other states require separate stockpiles, typically a maximum of 500 or 1000 tonnes. These designated stockpiles are then sampled and tested prior to use.

Continuously replenished stockpiles require regular sampling to monitor variability. The experience in Victoria is that, with suitable processing techniques (light crushing and screening), variability is maintained within reasonable limits. This finding is consistent with the recommendations in NAPA QIP 129 (NAPA 2015a) as referred to in Appendix A 3.1.

Some Australian states require stockpiles to be covered or placed in covered bays. This may be considered good practice as excess moisture can increase drying cost as well as inhibit heat transfer between the RAP and the virgin materials. The remaining states have no mandatory requirements and leave it to the asphalt manufacturers to assess the benefits of placing under cover compared with the risks of uncovered stockpiles.

Other widely recognised elements of good practice include paving and drainage of stockpile areas, mixing of incoming materials to reduce variability, and the use of stockpile construction techniques to minimise segregation and avoid excessive consolidation.

Inventory management and allowable proportions of RAP

A primary aim of Austroads Project No. TT1817 – *Maximising the re-use of reclaimed asphalt pavement* (Austroads 2013, 2015 and 2016) is to facilitate increased usage through greater confidence in the design and performance of asphalt mixes containing higher proportions of RAP. The reports generated to date outline the tools required to manage the binder blend (virgin binder plus RAP binder) so that high RAP content mixes show comparable performance to virgin mixes. However, these tools need to be translated into specification requirements that ensure the road agency has confidence that the contractor is in control of the properties of their mixes.

The report of the North American study tour visit to Japan (NAPA 2015b) provides a particular insight into what can be achieved in increasing the proportion of RAP to levels well beyond that currently adopted in Australia and USA. High levels of RAP are enabled through a combination of RAP management procedures, asphalt mix design and asphalt mixing plant modifications.

Note, however, the result of the recent survey of the usage of RAP in REAAA member countries and the statement that the popularity of modified bitumen and porous asphalt mixes in Japan has led to a reduction in the use of RAP in that country. This is because it is hard to assess aging levels in modified asphalt mixes from extracted bitumen. In addition, porous asphalt mixes differ from conventional dense-graded mixes in aggregate gradation and the level of modified bitumen.

It is important, however, to consider issues of inventory management, as well as the proportion of RAP used in different mix types, in any proposal for high RAP mixes. As pointed out in the NAPA guidelines (NAPA 2015a) referred to in Appendix A 3.1, it may be undesirable to use very high proportions of RAP for a selected few projects (together with the additional testing and process controls involved) if it leaves an inadequate supply of RAP for more regular usage. An appropriate balance should be considered in relation to the amount of available RAP and the most effective application of that available resource.

Reliable data on the amount of RAP available from various sources in Australia and the amount being used in the manufacture of HMA is difficult to obtain.

In 2011, Hyder Consulting prepared a *Construction and demolition waste status report* for the Department of Sustainability, Environment, Water, Population and Communities (Hyder Consulting 2011) based on a wider ranging report, also prepared by Hyder consulting on *Waste recycling in Australia* (Hyder Consulting 2012).

Unfortunately, the data in those reports, collected from various agencies, is obscured in a number of jurisdictions by not recording asphalt separately from other masonry materials (bricks, concrete, etc.).

Anecdotal information from some asphalt suppliers suggests that they are maintaining a comfortable balance between the amount of RAP available to them and the amount being currently used.

On the other hand, interpretation of data from the Hyder Consulting report, along with other anecdotal reports, suggests that there are various sources of RAP that are not being fully and effectively used. Limitations on the use in HMA include those imposed by road agencies on the allowable proportion of RAP, asphalt mixing plant capability and poor recovery procedures, as well as alternative recycling uses.

Poor recovery procedures can result in RAP being contaminated with other materials such as unbound base materials, concrete, soil, etc.; they are suitable only for use as a lower grade base material or as clean fill.

Alternative recycling applications include mixing of crushed and screened RAP with bitumen emulsion or foamed bitumen binder RAP to produce a cold mixed bitumen bound material with properties approaching that of an asphalt mix, or used as a type of road base, either directly, or mixed in with other granular materials.

In a scoping study conducted for Main Roads WA, Andrews (2013) reported that asphalt sourced from recycled planning or slab asphalt which is subsequently crushed has a greater value in other applications than as an inclusion with concrete (e.g. as aggregate replacement in new asphalt or as a bituminous stabilised ‘cold mix’ product).

A 5 CONCLUSIONS AND RECOMMENDATIONS

A 5.1 Conclusions

In addition to providing guidance on best practice and implementation, the outcomes of the literature review reinforce the importance of RAP management plans in the effective use of RAP.

Traceability

Traceability has two elements: the traceability of the source of the RAP, and the traceability associated with a particular set of test results, typically from a specific stockpile of RAP or statistical sampling scheme.

In most cases, where mixed sources of RAP are collected and processed into a blended product (which is common practice in Australia), it is not practical to assign traceability to a particular source of asphalt pavement. Traceability of this nature is sometimes used in overseas countries, either where the road agency requires separation of RAP from different sources, or where it is desired to recover designated materials, such as wearing course aggregates with specific properties for re-use in a comparable application.

With the increasing emphasis on renewal of wearing courses as a road rehabilitation strategy, and the conservation of high quality aggregate resources, traceability of source materials may become applicable in Australia for particular applications (such as situations where the road agency may want to specify a relatively high polished aggregate friction value (PAFV) aggregate for a high skid demand/high accident risk site). It will, however, require additional stockpile storage space and special handling protocols.

The more general form of traceability is records relating to the manufacture of asphalt using RAP from a particular stockpile or, in the case of continuously-replenished stockpiles, the results of monitoring and the variability of in-coming materials.

Traceability requirements are set out in most road agency specifications and included in manufacturer's quality plans.

In-coming RAP materials

It is essential that RAP does not contain road base material, concrete, coal tar, plastics, brick, timber, scrap rubber, etc. It must also be free from dust, clay, dirt and other deleterious matter.

Inspection of road pavements, and if necessary sampling and testing, prior to any milling, should be part of a RAP management plan. This can be part of their management plan when the asphalt supplier has control of the milling operations. Irrespective of who has the 'RAP management plan', the asphalt contractor is responsible to ensure the end product is homogeneous and free from contaminants.

Similarly, RAP from pavement demolition work must be inspected to ensure that it is not contaminated with deleterious materials before being processed. Any contaminated materials must be set aside for alternative recycling or disposal.

Processing and storage

RAP may be processed and stored at the asphalt plant or at a separate site that is either controlled by the asphalt supplier or by an independent operator. In either case, the general requirements are similar, although different limits may apply to the maximum stockpile size. For example, RMS places a limit of 500 tonnes on the size of stockpiles at the asphalt mixing plant but allows stockpiles of up to 1 000 tonnes at the processing site.

Control of maximum size and grading

The first step in processing is usually screening to remove oversize material. Screening may also be continued to separate the RAP into two or more separate fractions, typically a minus 10 mm fraction and a coarser fraction.

Oversize material is then crushed and rescreened. As noted in the discussion on processing and fractionation, it is important to select and manage the crushing process in order to minimise crushing of aggregates and generation of excessive fines.

The processing operation must be managed to ensure that each fraction is suitably processed to ensure a uniform, free-flowing blend of material that is consistent in grading, binder content and moisture content.

Handling and transport

Moving of processed RAP from the location where it is screened and crushed provides a further opportunity to improve consistency. Using the loader to dig into the RAP stockpile at the processing unit at different locations around the pile, and remixing loads while building the stockpile at the asphalt mixing plant, can again be used to reduce variation.

Stockpiling

Processed RAP must be stockpiled separately to incoming unprocessed RAP and asphalt plant waste.

Stockpiles should be placed on a paved, free-draining surface and constructed to shed water or, preferably, covered or placed in covered bays.

Handling procedures used in construction and the recovery of stockpiled RAP should be carried out in a manner that minimises segregation and assists in remixing of materials during recovery.

Generally, stockpiles are limited to a maximum of 500 or 1000 tonnes except where continuous replenishment is permitted. It is considered good practice to limit the processing and stockpiling of RAP to the quantities required for short-term usage and to use it on a first-in-first-out basis in order to ensure that the RAP remains free-flowing.

Inspection and test plans

In most cases, the minimum requirements for inspection and test plans are specified by the road agency. As a minimum, each stockpile must be tested for grading and binder content. Alternatively, where RAP is being added to continuously-replenished stockpiles, regular testing should also be undertaken on in-coming RAP materials as well as the RAP in the stockpile. In Australia, using continuously-replenished stockpiles is generally limited to relatively low RAP content mixes (up to 10% RAP for heavy duty surfacing sources and up to 20% for heavy duty basecourses). Characterisation of binder properties is also required for higher RAP contents. The minimum frequency of testing of binder properties may depend on the proportion of RAP in the asphalt mix as well as variability of the RAP material. Where the RAP content does not exceed 15% of the asphalt mix, characterisation of the RAP binder properties is generally not necessary as the impact of the RAP binder on the binder blend is normally negligible. For situations where the particle density of RAP aggregate is unknown and the percentage of RAP to be included in an asphalt mix exceeds 15%, the RAP should also be tested for maximum density so that the impact of any variance in this property on the volumetric properties of the mix can be evaluated.

Traceability is an essential requirement of all sampling and testing programs. Process control charts and statistical analysis are useful tools for determining variability and action limits for adjustment to asphalt manufacturing process control.

Auditing

General requirements for quality assurance and auditing are set out in Austroads *Guide to pavement technology: part 8: Pavement construction* (Austroads 2009).

Auditing is a systematic, independent and documented process for obtaining records and other information and evaluating it objectively to determine the extent to which the policies, procedures and/or requirements are fulfilled.

Audits may take the form of quality system audits, quality audits, product quality audits, or technical procedure audits. It may be undertaken by an auditing team from within or outside the organisation. Audits should be conducted by a qualified auditor in accordance with AS/NZS ISO 19011 (supersedes AS 3911.1).

An audit can take the form of an audit of technical procedures, including elements of traceability and the inspection and test plans referred to earlier, or a quality audit involving samples taken and tested by an authority nominated by the road agency.

A 5.2 Recommendations

The following amendments to TMR specification requirements are proposed for the management of high-RAP-content dense-graded asphalt mixes:

- Binder blend:
  - Contractor to document their process control procedures for the management of the binder blend in their Asphalt Quality Plan.
  - Insert guidelines in MRTS30 for the management of the binder blend based on the outcomes of Austroads Project TT1817.
  - Include a clause in MRTS30 to allow the use of rejuvenating agents in asphalt mixes containing high RAP contents.
- Replace the current ‘performance period’ requirement for progressing to a higher RAP approval level with audit addressing the following issues:
  - Implementation of the contractor’s RAP management plan (including management of the binder blend and visual monitoring of RAP for the presence of foreign and/or deleterious materials).
  - Plant capability (i.e. demonstrate the asphalt plant can produce conforming asphalt at the RAP approval level being requested).
- RAP properties:
  - Replace the requirement in MRTS102 for testing RAP aggregate for strength and durability with:
    - a requirement that the RAP aggregate must be hard, sound and durable
    - a visual check for the presence of foreign materials.
  - Include the following requirements in MRTS102:

- RAP aggregate must be hard, sound and durable
- the contractor to nominate a binder content and production tolerance for the processed RAP
- periodically test the process RAP for maximum density.

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APPENDIX B PLANT TECHNOLOGY AND REQUIREMENTS FOR THE MANUFACTURE OF HIGH RAP CONTENT ASPHALT MIXES

B 1 INTRODUCTION

B 1.1 Purpose

This section of the report focuses on the plant requirements that are necessary for the manufacture of asphalt mixes containing more than 15% RAP. A literature review was conducted to investigate the capability of various asphalt plants in Queensland to incorporate high percentages of RAP (> 15%) into asphalt mixes and the results of this investigation are presented herein.

B 1.2 Background

One of the benefits of using RAP in HMA is to recycle the residual binder as well as the aggregates. However, there are limitations with how far the variable aged binder (different level of oxidisation that has been taking place) can undergo further heating to produce dry and heated RAP (Austroads 2016; Hunter, Self & Read 2015).

Since the booming of recycling industry in the 1970s, various techniques have been developed to heat and dry RAP in asphalt plants. The early concerns of the practitioners were centred around the sustainability and the performance of the RAP incorporated in HMA mixes. RAP had been successfully incorporated in asphalt mixes around the world, confidence was established regarding the application of RAP. As the result, the main focus, especially in the US literature, was around minimising the environmental impacts of RAP application. Various technologies have been developed to address the hydrocarbon vapour or the 'blue smoke' problem of the RAP recycling plant facilities. The outcome was the development of new drying and processing technologies such as counter-flow drum mixers to accommodate higher RAP content in the HMA production without introducing higher hydrocarbon emissions (European Asphalt Pavement Association (EAPA) 2007; Newcomb, Brown & Epps 2007; Newcomb, Epps & Zhou 2016).

RAP is generally heated either by superheated virgin aggregate, together with the virgin aggregate or in separate facilities (German Asphalt Pavement Association 2008). Typically, the RAP heating process in asphalt plant facilities is based on two methods (NAPA 2015):

- conductive heat transfer
- convective heat transfer

Conductive heat transfer

Conductive heat transfer takes place when there is a temperature gradient within a solid or static fluid medium. The conduction energy is transferred from higher temperatures to the lower temperatures. It occurs when superheated virgin aggregates are in contact with cold and damp RAP aggregates. Conductive heat transfer is typical of batch plants and counter flow drum mixers.

Convective heat transfer

Convective heat transfer occurs by movement of fluids (gas and liquids). In case of an asphalt plant, it takes place when RAP is exposed to the hot gas steam in the dryer. Convective heat transfer is typical of conventional aggregate dryers and traditional parallel-flow drum mixers.

This report discusses process for incorporating RAP into asphalt using different asphalt plant configurations.

B 2 METHODS OF INCORPORATING RAP INTO NEW ASPHALT MIXES

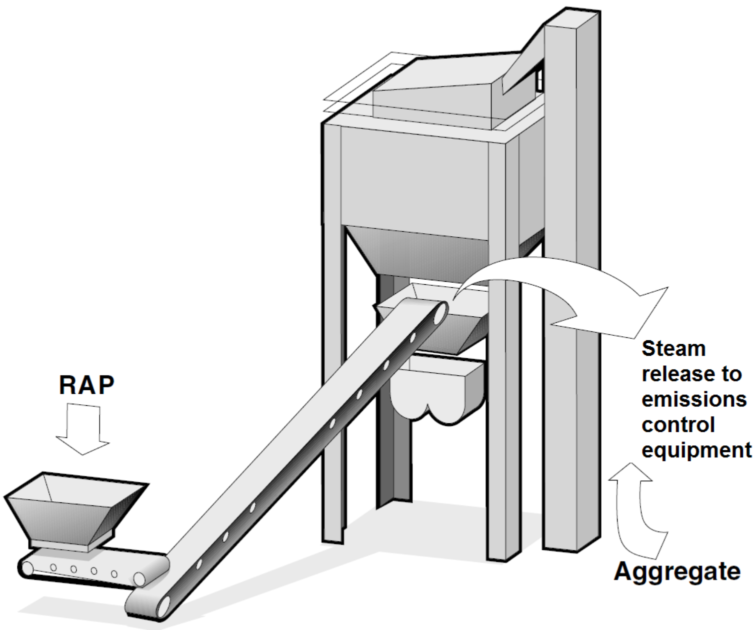
B 2.1 Weigh Bucket Recycling Technique

Also known as the Minnesota method, this is probably the first RAP recycling approach which was attempted in a batch plant facility. It was successful in producing state-approved quality mixes in the US (FHWA 1997).

In this technique, RAP (cold and wet) is added to the weigh hopper in addition to the already super-heated virgin aggregates. The heat transfer starts in the weigh hopper when the RAP is being added and continues in the pugmill during the dry mixing process. The temperature of the virgin aggregates should be adjusted so that it contains sufficient heat to evaporate the excess moisture of the RAP aggregate. From a practical perspective, this operation has to be within the operational heat capacity of the asphalt plant (Figure B 1).

A major concern with direct heating methods of the RAP material is a possible change in the RAP binder properties/rheology due to excessive heat exposure (over oxidisation) during the drying and mixing process. To address this issue, indirect heating techniques and separate heating arrangements have been developed. More details of these techniques are discussed later in Appendix B 2.9.

Figure B 1: Weigh bucket recycling technique (NAPA 2007)



NAPA (2007) published a guide that indicates the virgin aggregate temperature required to drive out moisture in the RAP and achieve the desired final product temperature. It is reproduced here in Table B 1.

In calculating the temperatures listed in Table B 1, a temperature loss of 6.6 °C (20 °F) between the dryer and the pugmill is assumed. The shaded cells in the Table reflect excessively high temperatures that may not be practically viable/achievable due to the mixing plant limitations such as the fabric filters in the bag house which are not designed for long exposure to continuous excessively high temperatures.

Table B 1: Required virgin aggregate temperature

RAP content (%)	RAP moisture content (%)	Recycled mix discharge temperature (°C)			
		104	116	127	138
10	0	121	138	152	163
	1	127	143	154	168
	2	132	146	157	171
	3	138	149	163	174
	4	141	152	166	177
	5	143	157	168	182
20	0	138	154	168	182
	1	146	160	177	191
	2	154	168	182	196
	3	163	177	191	204
	4	171	185	199	213
	5	179	193	207	221
30	0	157	174	191	207
	1	168	185	202	218
	2	182	199	216	232
	3	196	213	229	246
	4	210	227	243	260
	5	224	241	257	274
40	0	179	199	218	238
	1	199	218	238	257
	2	218	238	257	277
	3	243	260	279	299
	4	260	279	299	321
	5	285	302	321	341
50	0	210	235	257	282
	1	241	268	288	310
	2	271	293	318	343
	3	302	327	349	374
	4	338	360	379	404
	5	366	391	413	438

Source: NAPA (2007).

Similar guidelines for choosing the appropriate temperature can be found in European (German) literature. Figure B 2 provides suggested temperature adjustments based on the RAP percentage and moisture content, and the target temperature of the final HMA product (German Asphalt Pavement Association 2008). TL Asphalt-StB 07 (the asphalt construction working group of the road and transport research organisation in Germany) suggests Table B 2 for the required increase in virgin aggregate temperature for various RAP content (Asphalt Construction Working Group 2008).

Figure B 2: Required virgin aggregate temperature at specified asphalt mix temperatures (German Asphalt Pavement Association 2008)

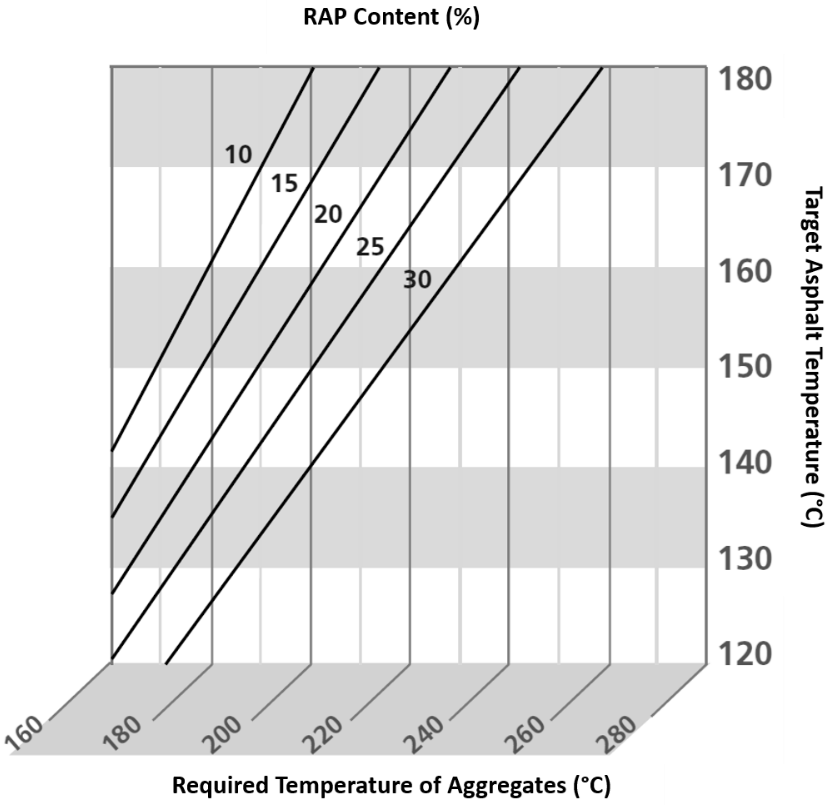


Table B 2: Required increase in virgin aggregate temperature for various RAP content

RAP content (%)	RAP moisture content (%)					
	1	2	3	4	5	6
10	4	8	12	16	20	24
15	6	12	18	24	30	36
20	8	16	24	32	40	48
25	120	20	30	40	50	60
30	12	24	–	–	–	–

Source: Asphalt Construction Working Group (2008).

When the wet and cold RAP is introduced to hot virgin aggregates in the pugmill, a large amount of steam is released. A significant amount of steam and dust is carried by the dry virgin aggregate, requiring the weigh-box and the pugmill to be enclosed and vented to the air pollution control system (primary collector in the exhaust system). Typically, the weigh-box and the pugmill are connected to the primary collector in the exhaust system. If the duct is kept open, considerable amount of air is drawn from the weigh-box and the pugmill, which can adversely affect the production capacity of the dryer as air volume in the dryer decreases.

Normally a damping system which consists of a large, single-bladed, butterfly-style damper is used to control the ventilation. The damper is electrically controlled by an air cylinder. When the RAP is being introduced into the weigh-box, relays on the control panel to open the damper. Once the heat transfer is complete, timers close the damper. The plant operator can adjust the timers to achieve optimum results. By upgrading the exhaust fans to an oversized one, additional flow can be generated to assist with drafting the tower during the heat transfer when RAP is introduced.

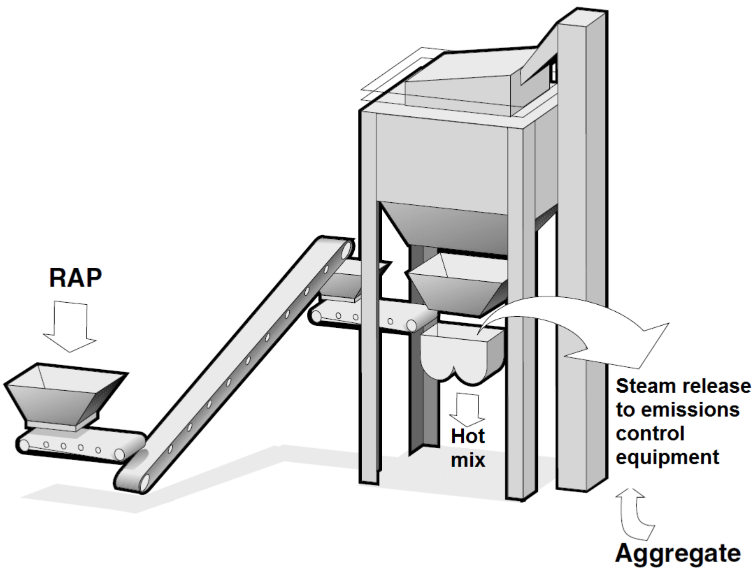
In practice, the RAP content rarely exceeds 25–30% with the mixer heat transfer method. One reason for this is that the moisture content of the RAP material is typically in the range of 3 to 5%, which means the virgin aggregate temperature should be elevated to temperatures that can be in excess of 315 °C (600 °F). At such high temperatures, it will be difficult to maintain the mixing and dryer efficiencies. Also, the filter fabric in the baghouse collectors are typically limited to around 200 °C (400 °F) of continuous service temperature. The fan capacity may also reduce at excessively high temperatures (FHWA 2011).

Some literature has reported lower practical RAP percentages achieved by this method which is more in line with typical Australian experience (10–15%). This RAP content can be increased by 5 to 10% by increasing the baghouse and the air system size or introducing a separate baghouse to vent the stream generated during the RAP drying (AMMANN 2017).

B 2.2 Pugmill Recycling with Separate RAP Weigh Hopper

Figure B 3 illustrates schematic setup of a batch facility with a separate RAP weigh hopper. By introducing a separate weigh hopper for the RAP material, the batch cycle time can be reduced since the RAP aggregates are weighed separately to virgin aggregates and bitumen.

Figure B 3: RAP into pugmill via separate weigh hopper (NAPA 2007)

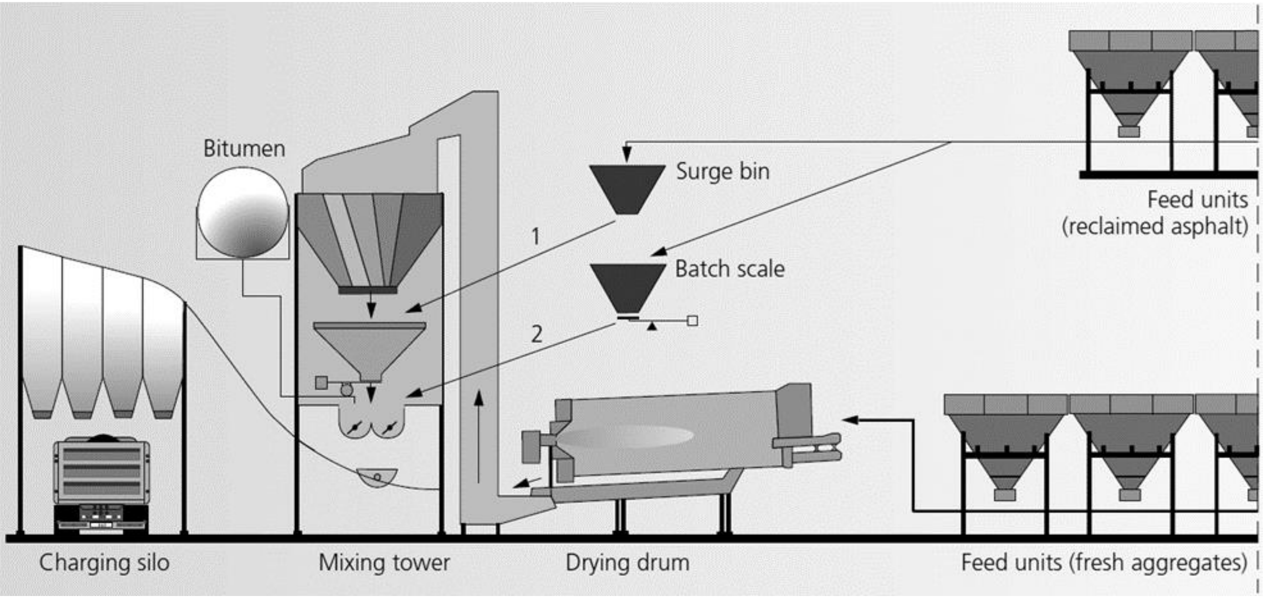


This approach has the same heat transfer mechanism (as the weight bucket recycling technique), hence has the same steam release and practical high temperature limitations as the weigh bucket recycling technique. The main advantage of this method is an increase in production rate during long production runs of HMA due to a slightly shorter batch cycle time. A high-speed slinger conveyor, a chute or a high-speed screw conveyor can be used to convey RAP to the pugmill from the weigh hopper.

Schematic configurations of the weigh bucket and the pugmill recycling plant facilities are illustrated in Figure B 4 with process lines 1 and 2, respectively.

There are reports that up to 30% RAP (at 3% moisture) material can be recycled into HMA with this technique (AMMANN 2017).

Figure B 4: Weigh bucket (1) and pugmill recycling (2) processes in an asphalt plant facility (German Asphalt Pavement Association 2008)



B 2.3 Bucket Elevator Recycling Technique

Another batch facility recycling approach is to introduce the wet and cold RAP to super-heated virgin aggregates when exiting the dryer and entering the bucket elevator; this is also known as hot elevator (Figure B 5). This approach is gaining popularity due to its relatively simple procedure. It also provides an alternative to the excessive steam generation (also referred to as steam explosion) in the mixer heat-transfer method.

In this method – and because the heat transfer between the virgin aggregate (super-heated) and wet RAP material is occurring on a continuous basis in the buckets as the virgin aggregate and the RAP are transferred to the screening deck – the steam will continuously be carried away by the ductwork covering the bucket elevator. Therefore, there will not be a sudden accumulation of steam/gases (Santucci 2007).

To ensure the correct ratio of RAP and virgin aggregates, scales are installed on the belt conveyors feeding the virgin aggregates into the dryer as well as the RAP feeding conveyors into the bucket elevator.

The following two methods can be used to control the aggregate gradation for the mix production:

1. The RAP is added to the outlet of the drying drum or onto the hot elevator (process lines of 1 and 2 in Figure B 6). The RAP and the virgin aggregates are screened on the screen deck at the same time and the blended mixture is then fed into hot bins in the tower. Hot bins need to be sampled for gradation and binder content determined by the binder extraction test. Once the typical aggregate gradation and the RAP binder content of each hot bin is known, the amount of additional fresh binder and the hot bin percentages can be calculated to achieve the target final grading and the mix design. For the first method a consistent RAP supply in terms of binder content, gradation and particle size are assumed.

2. The weigh box injection (screen bypass) method is more common than the first method (process line 3 in Figure B 6). With this method, in continuous flow facilities such as drum mixers, gradation is controlled at the cold bins feeding the dryer. The blend of RAP and virgin aggregate is stored in a single bin in the tower and weighed as a composite mixture in the

weigh hopper. Belt feeders with variable speeds with control over each feed bin is required in this method.

With the second approach, up to 20% RAP can be accommodated in the plant facility, the primary limiting reason is that RAP has a relatively short time to dry before it passes the screens and is stored in the RAP/virgin aggregate bin. If higher percentages of RAP are introduced it is likely that the aggregates will not get dry and the wet aggregate can clog the screens.

Figure B 5: Bucket elevator RAP recycling (NAPA 2007)

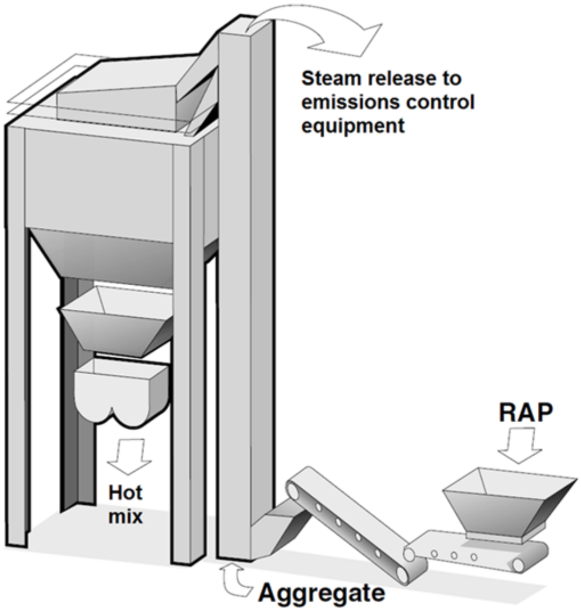
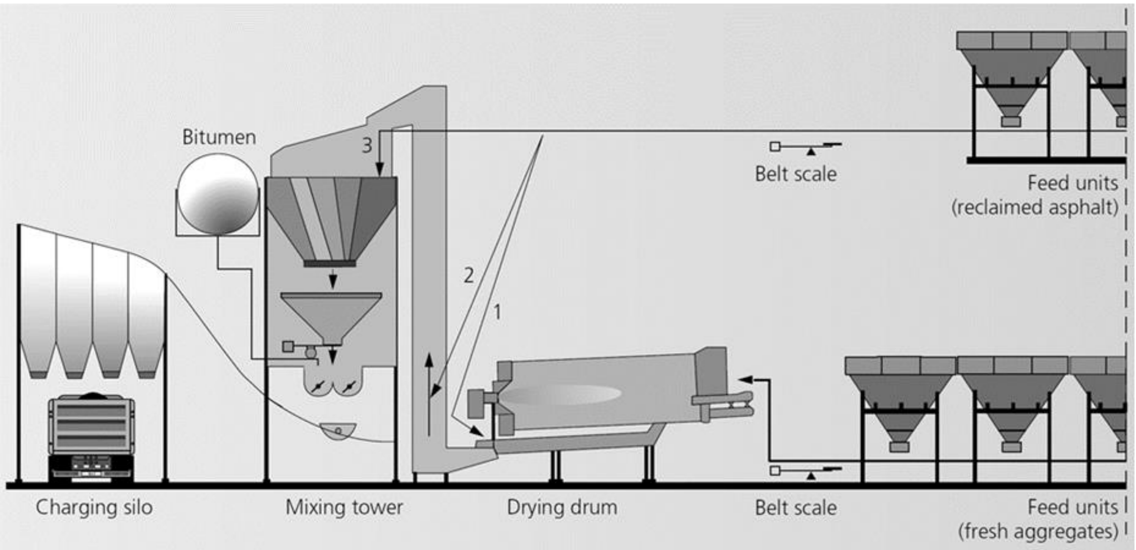


Figure B 6: Batch mixing plant – RAP addition to the dryer drum outlet (1), RAP addition to hot elevator (2) and RAP addition to screen bypass (3) (German Asphalt Pavement Association 2008)



B 2.4 Bucket Elevator Recycling Technique Introducing RAP into Heat Transfer Chamber on Dryer

The main aspects of this approach are similar to the bucket elevator method, the main difference being the addition of a heat transfer chamber (collar) on the dryer so that the heat transfer process can start at the dryer shell, hence allowing higher percentages of RAP to be introduced (Figure B 7). Alternatively, RAP can be added to the burner end of the dryer via a slinger conveyor and then transferred to the hot buckets Figure B 8). HMAs with RAP content of up to 40% has been reported to be successfully produced with the setup illustrated in Figure B 8 (German Asphalt Pavement Association 2008).

Figure B 7: RAP into dryer with bucket elevator (NAPA 2007)

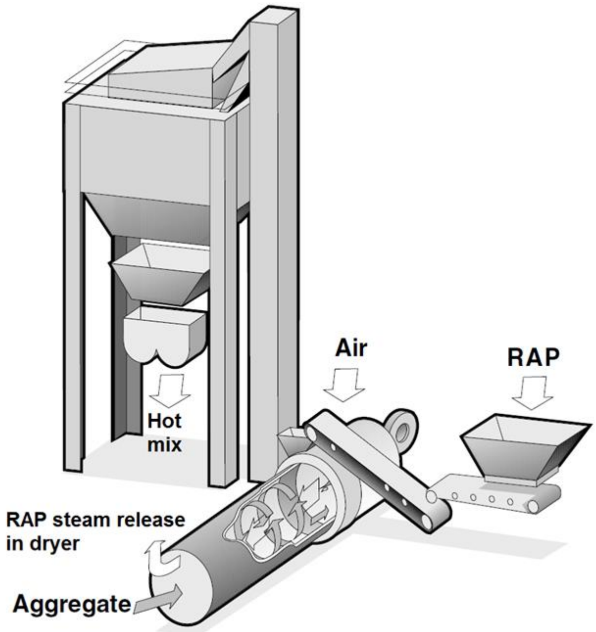
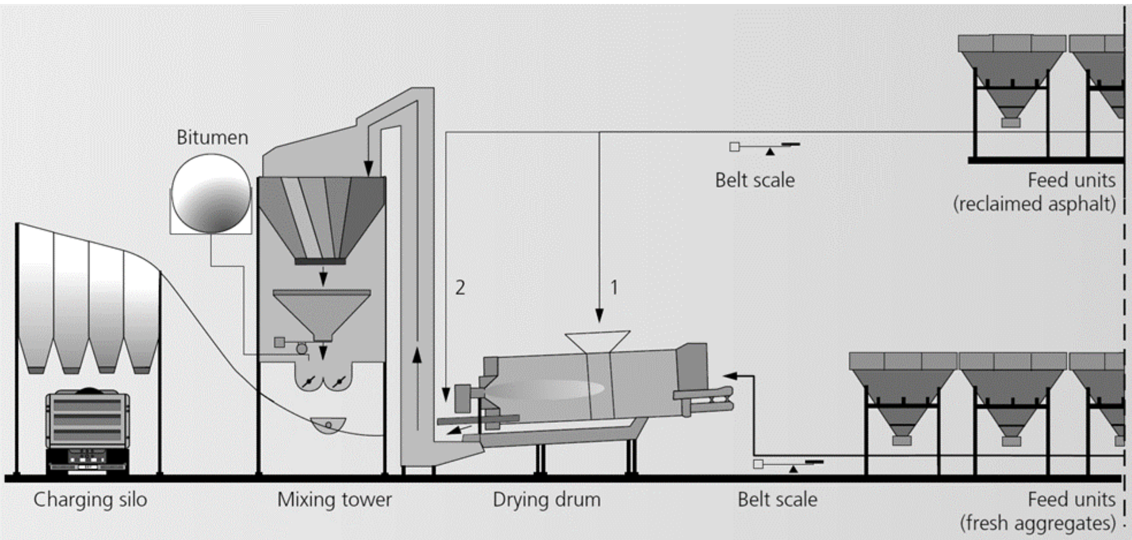


Figure B 8: Batch mixing plant – dryer drum central feed system (1), RAP addition to dryer drum via front wall on the burner end (2) (German Asphalt Pavement Association 2008)



B 2.5 RAP Dryer Recycling Technique

This method uses a separate convective heat transfer (parallel drum) to dry RAP material. It is widely used in Western Europe. While mixes with up to 80% RAP can be achieved through this technique, the typical RAP content is normally confined to 50% in the US (Figure B 9).

Once the RAP aggregates are heated in a typical parallel-flow dryer, they are transferred into a separate heated storage bin and weigh hopper similar to the aggregate weigh hopper in the batching plant. The RAP is treated as an additional aggregate; it is added directly into the pugmill where they are mixed with virgin aggregates and fresh binder. A high-speed screw conveyor, a chute or a belt conveyor can be used to transfer RAP from the RAP weigh hopper to the pugmill.

The steam and the hydrocarbon containing gases produced during the convective heat transfer of the RAP are exhausted to the virgin aggregate dryer where the combustion destroys hydrocarbons. The capacity of the burner on the primary (virgin aggregate) dryer to receive steam and hydrocarbon laden gases of the RAP can pose a practical limitation to the amount of RAP that can be incorporated into the new mix.

In Germany, a similar separate drums setup is used to produce as high as 80–100% recycled RAP asphalt mixes. The RAP material is heated to 130 °C to limit the carbon emissions and preserve the RAP binder. This approach can be implemented both in the form of a batching plant (Figure B 10) or a continuous mixing facility (Figure B 11) (German Asphalt Pavement Association 2008).

Figure B 9: RAP dryer system (NAPA 2007)

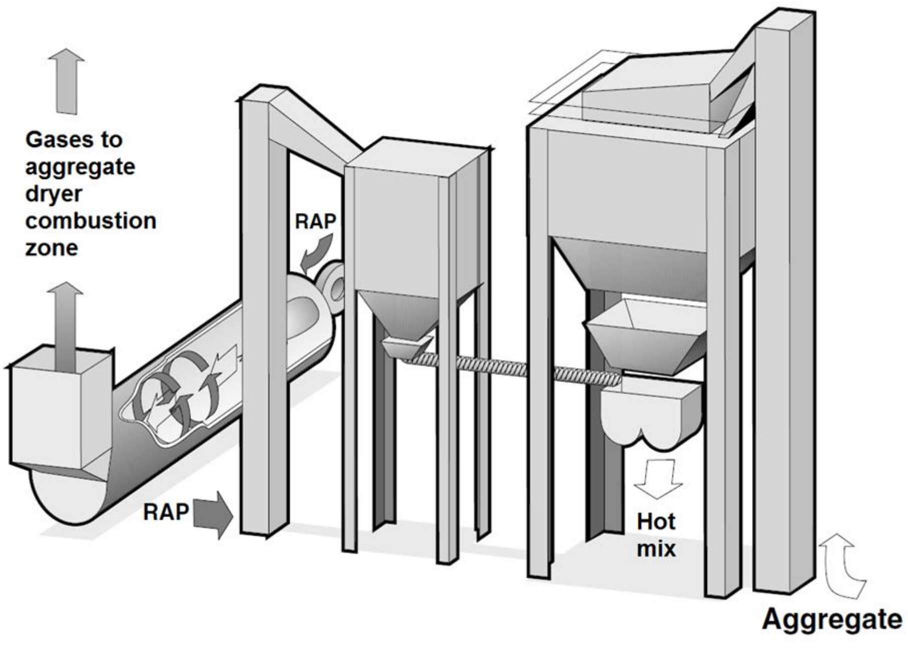


Figure B 10: Batch mixing plant – addition of RAP to aggregate scale (1), addition of RAP to mixer (2) (German Asphalt Pavement Association 2008)

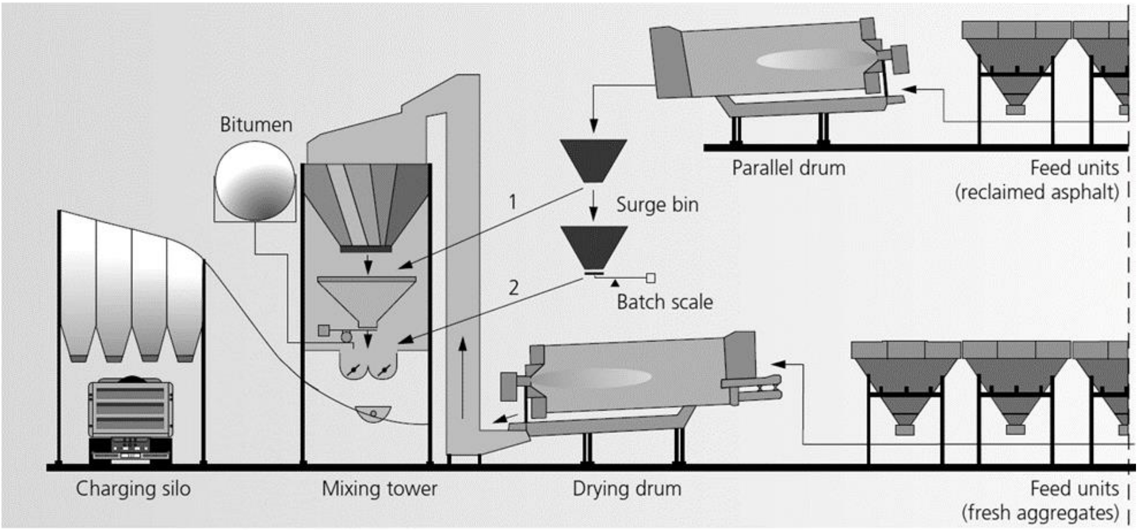
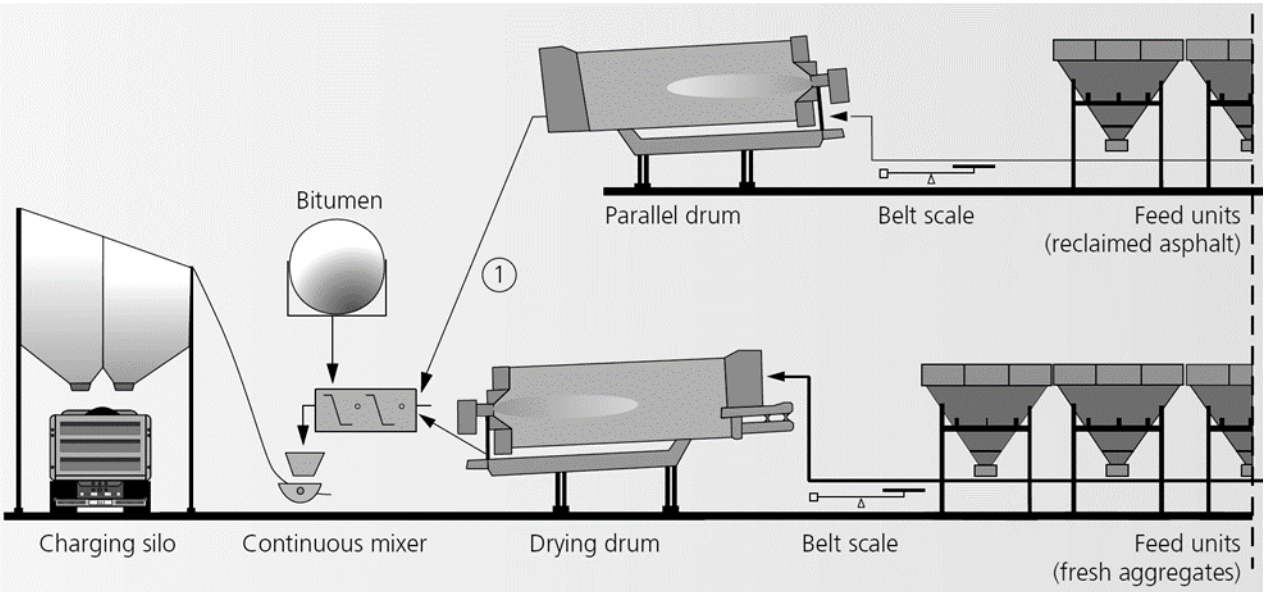


Figure B 11: Continuous mixing plant – downstream continuous mixer (German Asphalt Pavement Association 2008)

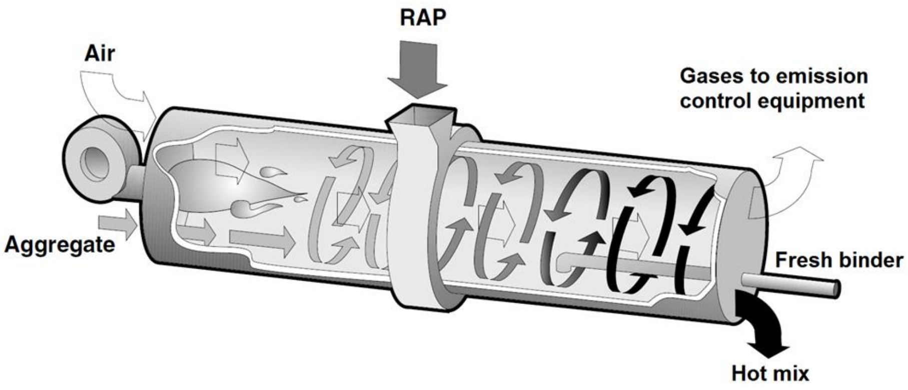


B 2.6 Parallel-Flow Drum Mixer

Parallel-flow drum mixers are a simple yet effective and continuous method of asphalt production that gained popularity in the US in the early to mid-1970s. In this method, virgin aggregates are heated convectively and introduced where the burner is. The aggregate then travels in the same direction as the exhaust gases (parallel-flow). Fresh binder is added at the discharge end of the dryer where the temperature is lower.

It is estimated that approximately 1 500 parallel flow drum mixers were manufactured between 1972 and 1992 in the US. Over time, several adjustments were made to this setup to accommodate RAP recycling; perhaps the most common approach with parallel flow drums is the mid-drum entry approach (Centre RAP Ring) (Figure B 12). In this approach RAP is added to the drum/dryer for heating and mixing with virgin aggregates approximately in the middle of the drum. The purpose of this is to prevent the covering binder of the RAP aggregate from being excessively heated and damaged/burnt. However, exposure of both the RAP and the fresh binder to naked/direct flames which will adversely affect the properties of the mix binder is still one of the major drawbacks of this approach (SABITA 2009).

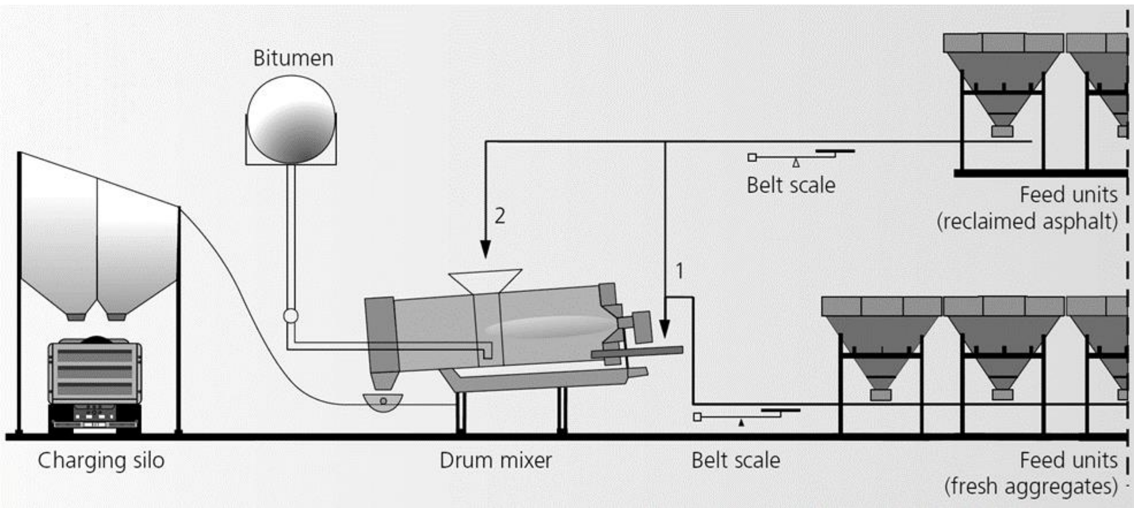
Figure B 12: RAP in parallel-flow drum mixer (NAPA 2007)



With more restrictive emission control regulation being introduced in the US in recent years, either the RAP percentage or the final mix temperature should be limited with the conventional recycling approaches. This required some innovation within the asphalt plant industry to produce high RAP content (25%) mixes without compromising the gaseous emissions. The outcome was plant facilities that had enhanced capability to recycle more RAP material into HMA.

The general plant configuration of a continuous mixing plant is shown in Figure B 13.

Figure B 13: Continuous mixing plant – heating of RAP together with aggregates (German Asphalt Pavement Association 2008)

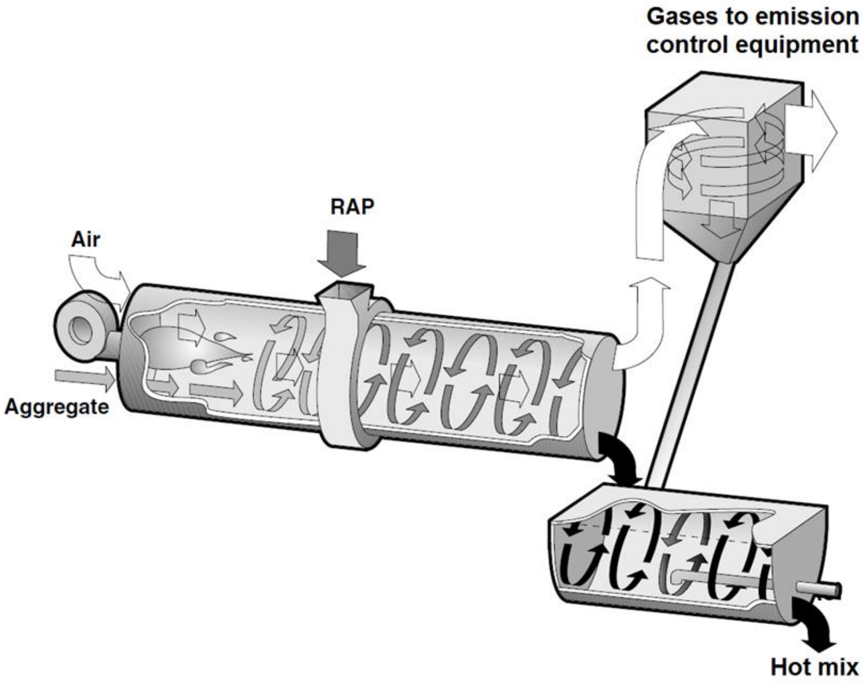


B.2.6.1 Parallel flow dryer with RAP collar and continuous mixing device

One approach to lowering the carbon emissions of drum plant facilities is to introduce a continuous mixing device (rotating mixing drum or a continuous pugmill also known as after-mixer) to a parallel flow dryer. By isolating/separating where the fresh binder is mixed with the aggregates, carbon emissions can be reduced/lowered. However, since the RAP aggregates are still being added to the dryer where the heat transfer occurs convectively, hydrocarbon constituents would still be present in the gas stream. The intensity of the carbon emissions depends on the RAP content and gradation, dryer length, burner type and flights setup, etc.

A primary collector is typically added to the pollution unit to collect the dust particles of the air stream and return them to the mixing area (Figure B 14).

Figure B 14: RAP in a parallel-flow dryer and continuous mixer (NAPA 2007)



B.2.6.2 Parallel flow drum mixer with RAP collar and isolated mixing area

This type of drum is similar to a dryer with a separate mixer, except for the fact that it has an integrated mixing device welded to the dryer which rotates with the dryer (Figure B 15).

The gas stream is vented from the dryer prior to the aggregate/RAP mixture entering the mixing area. In some designs, the mixing area is vented back to the combustion area of the dryer. Since the heat transfer process is mainly convective in this method, there will be some hydrocarbon constituents present in the gas stream which may be variable from job to job.

This method and the methods following, require a primary collector to be connected to the dryer to collect and return large dust particles back to the mixing area, typically with a screw conveyor.

B.2.6.3 Parallel flow drum mixer with counter flow RAP drying tube

This design is a minor modification of the previous design. In this approach, RAP is introduced in the cooler side of the dryer and travels against the gas stream. It is then mixed with the virgin aggregate in the mixing area of the dryer (Figure B 16). The heat transfer is a combination of conduction and convection both from the gas stream and the superheated virgin aggregate. Since the fresh binder is shielded against direct exposure to the gas stream there is a significant drop in the carbon emissions in this method.

Figure B 15: RAP in parallel-flow drum with isolated mixing area (NAPA 2007)

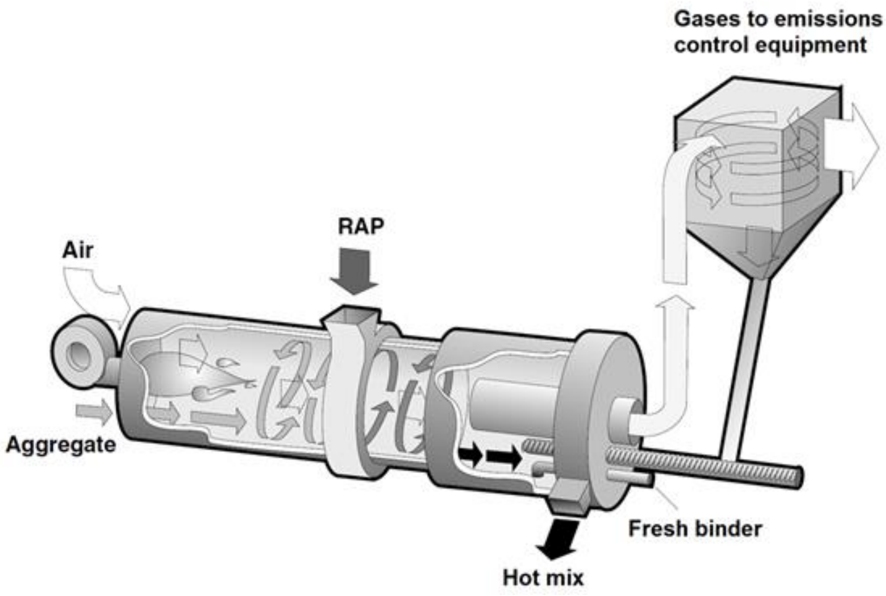
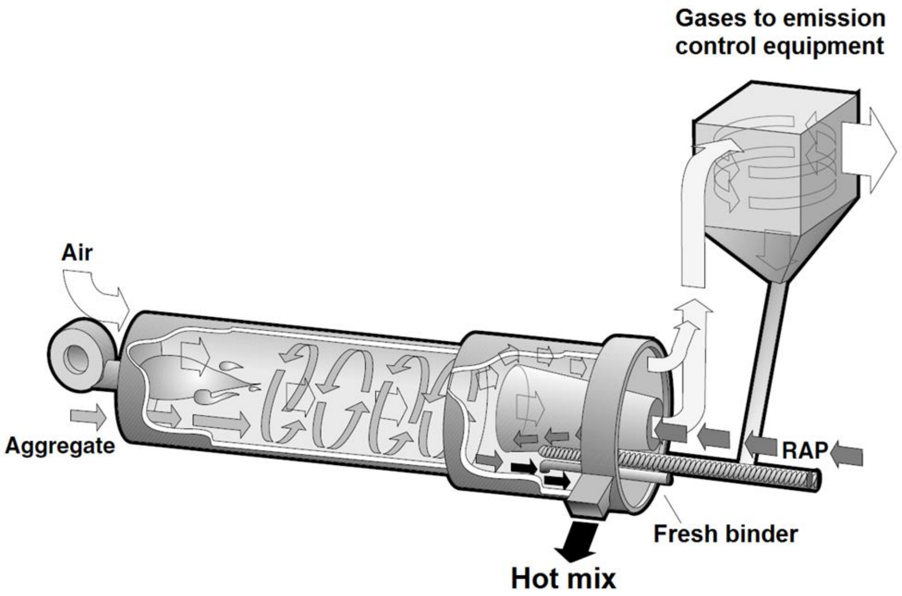


Figure B 16: RAP in a drum mixer with counter-flow drying tube (NAPA 2007)



B.2.6.4 Parallel flow dryer with RAP introduced in continuous mixing device

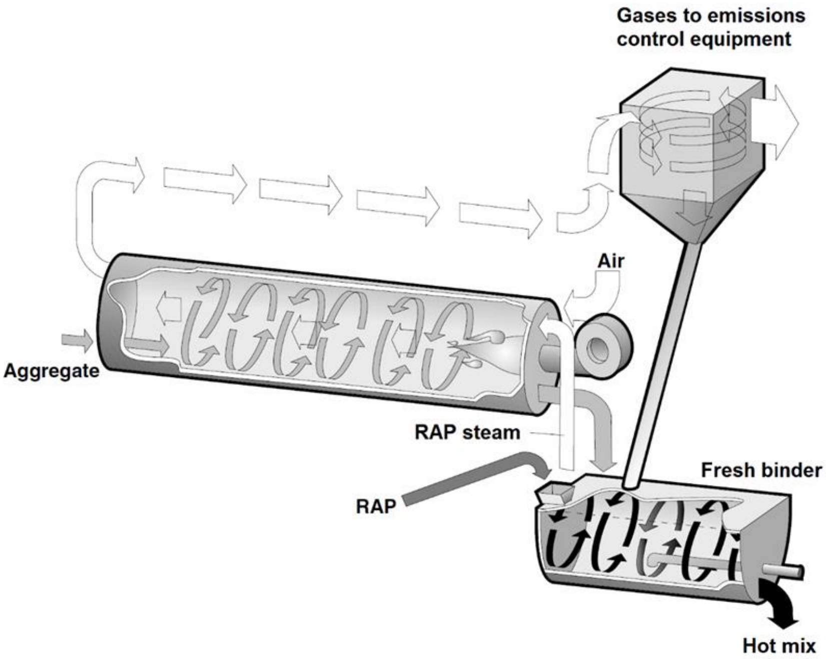
This setup uses a separate continuous mixer. The virgin aggregates are superheated in the parallel flow dryer and the RAP aggregates are heated conductively in the mixer when mixed with the virgin aggregates (Figure B 17).

For the conductive heat transfer to occur between super-heated virgin aggregates and the RAP, some physical space is needed in the mixing area, with the RAP content limited to the available space in the mixer. The released steam from the heat transfer process is typically directed back to the combustion area of the dryer to burn the hydrocarbon constituents, hence lowering the carbon emission.

Another limiting factor to incorporate higher percentages of RAP in this method is the pollution control unit of the facility. Temperatures above 200 °C (400 °F) will damage the fabric filter collectors in the baghouse; this will impose a limitation on the temperature that the virgin aggregates can be superheated. One way to address this issue is to bring in some fugitive air to cool down the collector during operation. To compensate for the air loss in the dryer, a larger exhaust can be installed on the facility. There is no need for this modification for lower RAP contents as less virgin aggregate temperatures are required.

Wet-scrubber collector equipped facilities do not need this modification either. However, the air flow can be reduced in wet collector systems at elevated temperatures. Depending on the high temperature exhaust fan capacity this can potentially affect the production rate.

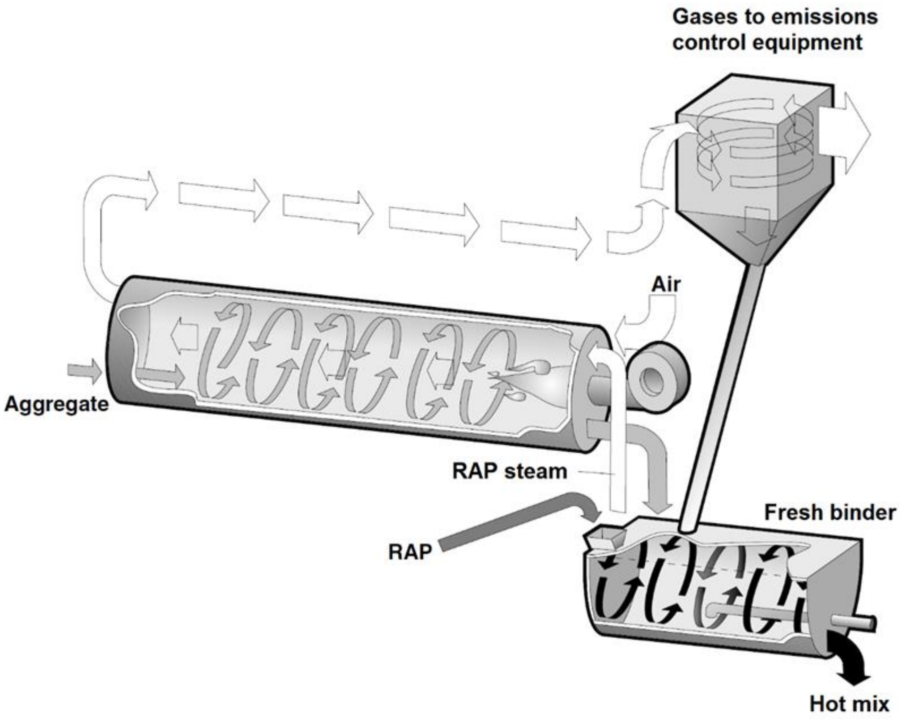
Figure B 17: Parallel-flow dryer with RAP added in continuous mixer (NAPA 2007)



B 2.7 Counter Flow Dryer with RAP Introduced into a Continuous Mixing Device

By implementing a counter flow dryer (where the aggregates travel against the gas flow) the practical limitation of the baghouse operation in excessively high temperatures can be eliminated. This is because the cooler damp aggregates enter the dryer where the hot gases are exiting. As a result, the exit gas temperatures to the baghouse operational temperature range can be lowered. This method utilises a separate mixing area where RAP aggregates are directly added. The RAP content can still be limited depending on the length of the mixing device which determines the required mixing duration for the heat transfer process between superheated virgin aggregates and RAP material. Similar to the previous techniques, the generated steam during the heat transfer is directed to the combustion area to burn the hydrocarbons (Figure B 18).

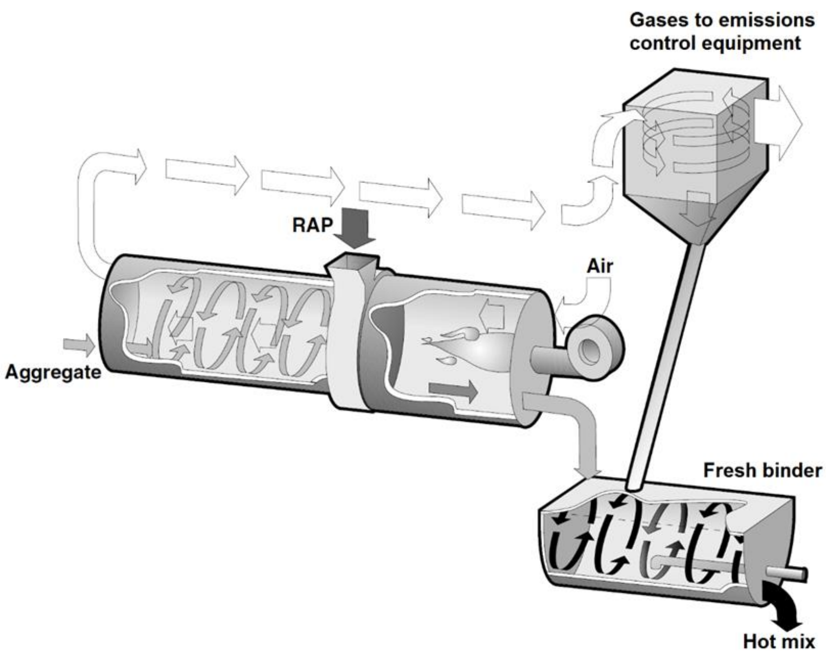
Figure B 18: Counter-flow dryer with RAP added in continuous mixer (NAPA 2007)



B.2.7.1 *Counter flow dryer with RAP introduced in the aggregate dryer*

In this method, a heat exchange chamber is introduced to a counter-flow dryer. As the RAP is heated conductively it has a longer time to mix with the virgin aggregate. Since it is heated closer to the hottest part of the dryer shell, higher RAP percentages can be recycled. The RAP steam is vented to the aggregate dryer with the virgin aggregate steam (Figure B 19).

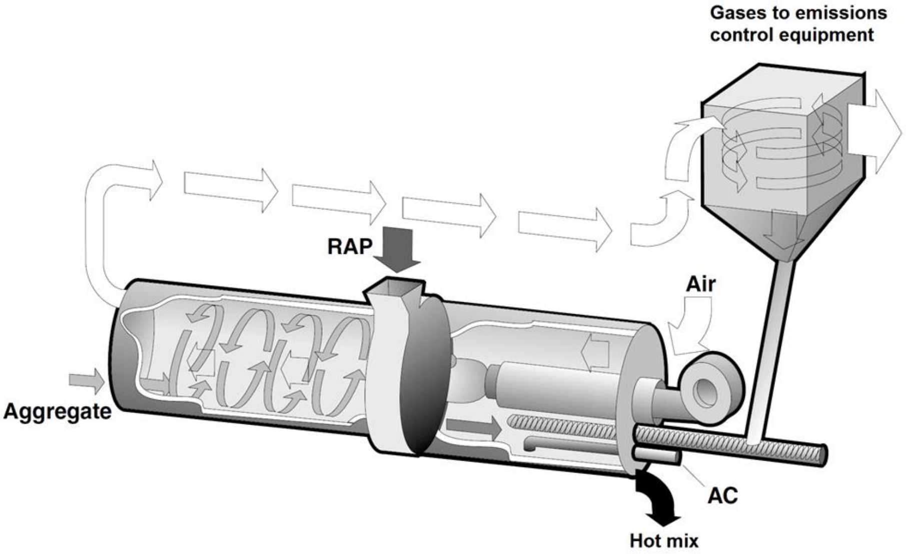
Figure B 19: RAP added in counter-flow aggregate dryer (NAPA 2007)



B.2.7.2 Counter flow drum mixer

In a counter flow drum mixer, a continuous mixing device is made part of a counter flow dryer. In this method virgin aggregates are heated convectively, and RAP aggregates are heated conductively. The heated virgin/RAP aggregate, fresh binder, recycled fines from the primary and secondary collectors and other additives are then mixed in the mixing area which is attached to the dryer shell and can rotate with it (Figure B 20).

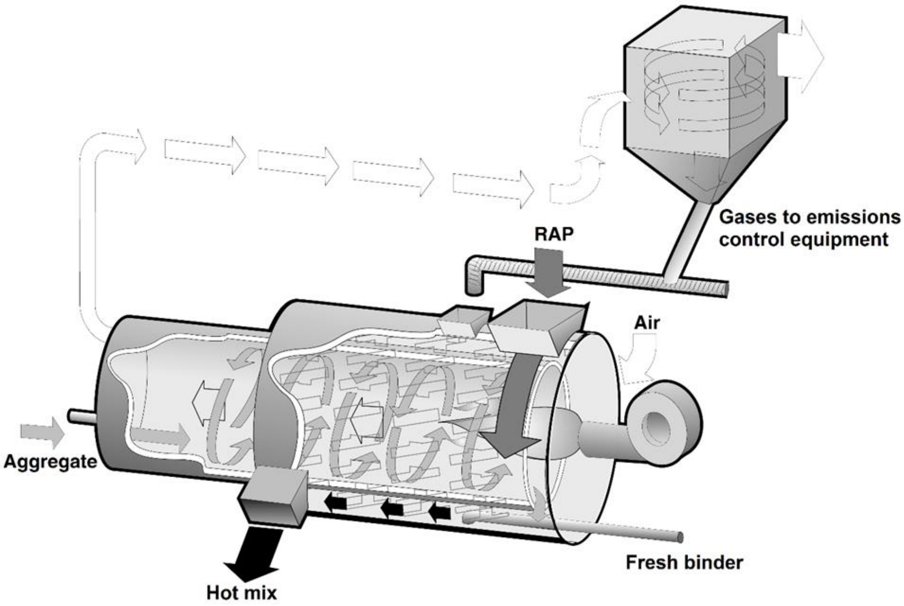
Figure B 20: RAP in a counter flow drum mixer (NAPA 2007)



B 2.8 Double Drum (Unitised Counter Flow Dryer and Continuous Mixer)

This set up is a combination of a counter-flow aggregate dryer and a continuous pugmill mixer. The mixing paddles are fixed to the outside shell of the aggregate dryer. Once the virgin aggregates are passed through the counter flow dryer they are fed into the mixer which is the outer shell of the dryer. The aggregates are then lifted up by the mixing paddles and moved toward the top of the shell where RAP aggregates are introduced and mixed with the virgin aggregates. The recycled fines collected from the air pollution control unit are also added at this stage. The RAP will benefit from the additional conductive heat transfer from the dryer (the combustion area of the dryer). When the RAP and virgin aggregates are mixed, fresh binder, other liquid additives or bulk material are added and mixed to produce the final product which is discharged close to the feed end of the dryer (Figure B 21).

Figure B 21: RAP added in unitised dryer/mixer (NAPA 2007)



B 2.9 High RAP Percentage Specialised Facilities

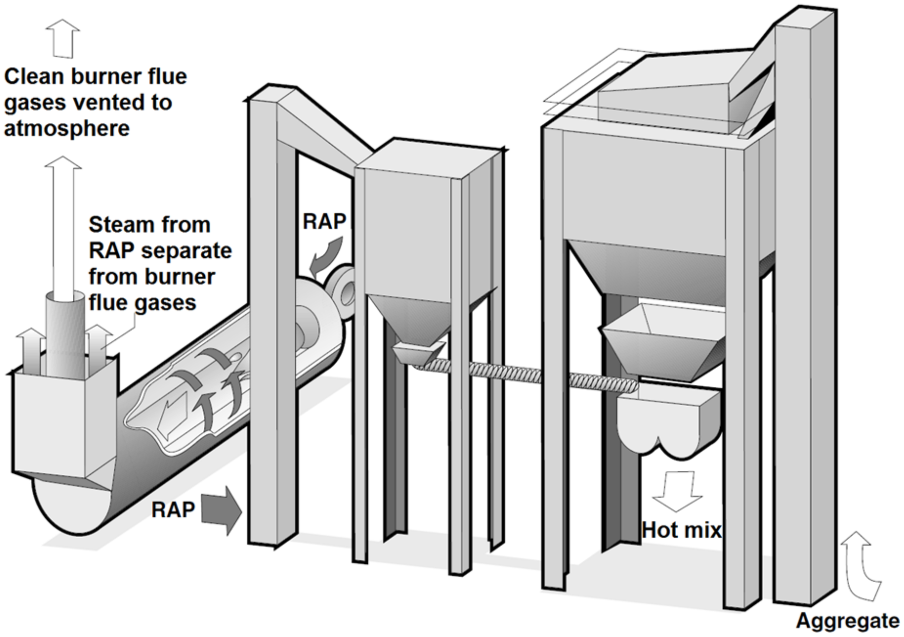
Two mainstream approaches can be found in the literature that are used by industry to implement more than 50% RAP which is normally the practical limit for most of the conventional recycling facilities reviewed before.

B.2.9.1 Indirect heat transfer methods

As the title indicates, the RAP is heated conductively via flues or tubes that take the exhaust gases of the burner through the dryer. By passing RAP between the flues, indirect conductive heat transfer will occur. Due to the indirect nature of the heat transfer, the hydrocarbon emissions are fairly minimal with this approach. The emissions would mainly consist of steam sourced from drying RAP and standard combustion emissions from the dryer burner depending on the efficiency of the burner (Figure B 22). The heated and dry RAP can then be directed to a batch or a continuous flow facility to blend with virgin aggregates and the fresh binder and produce the final mix product. Also, once the RAP is heated, it can be mixed with rejuvenators and binder conditioners to achieve high RAP content mixes (up to 100%).

However, the gradation of the RAP may be a practical hurdle to achieving mixes containing 100% RAP. RAP material typically contains a high percentage of fine particles, which requires blending with some coarse virgin aggregate to bring the gradation to within the specification limits.

Figure B 22: Indirect heat transfer (NAPA 2007)



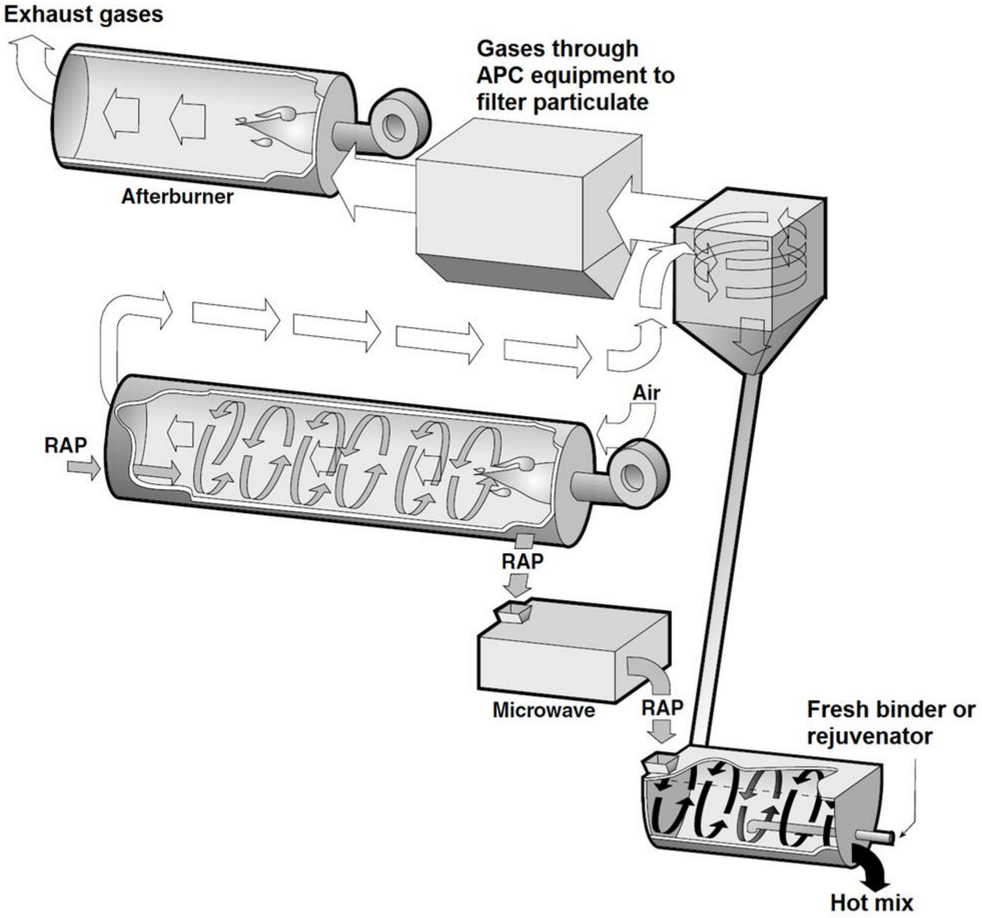
B.2.9.2 Microwave heat transfer technology

Another specialised facility that can be used to incorporate high percentages of RAP into asphalt (up to 100%) is the microwave technology. Similar to the indirect heat transfer method, RAP gradation may be a limiting practical hurdle to achieving 100% RAP.

In this method, RAP is heated convectively with either a parallel flow or a counter flow dryer, then entered into a microwave heater to raise the temperature to an elevated paving temperature (Figure B 23). The baghouse fabric filter collector is equipped with an additional part to remove the hydrocarbon constituents of the gas steam from the convective heat transfer.

The manufacture of asphalt using the microwave technology is currently proprietary; however, large tonnages have been produced in various states of the US with this technology over the years. There is no evidence to suggest that this technology is currently being used in Australia.

Figure B 23: Microwave heat transfer (NAPA 2007)



B 3 ASPHALT PLANTS CURRENTLY IN USE IN SOUTH EAST QUEENSLAND

B 3.1 General

A summary of the currently-registered asphalt plants located in South East Queensland (SEQ) is presented in Table B 3. Asphalt manufacturing plants outside SEQ have not been included as it is unlikely that plants located outside of SEQ will be able to source sufficient RAP to consistently produce mixes with higher than 15% RAP.

Table B 3: Summary of registered asphalt plants in south east Queensland

Company	Plant location	Plant make and model	Plant type	RAP capable	RAP introduction	Number of RAP feeders	Mix design[(1)]
Allens Asphalt	Caboolture	–	Counter-flow drum	Y	Feed belt to drum	1	N
Boral Resources	Charlton	Terex E300	Counter-flow drum	Y	Feed belt to drum	1	Y
	Redbank	Aztec T400	Double drum	Y	Feed belt to drum	2	Y
	Narangba	Mobile 7832	Counter-flow drum	Y	N/A	0	N
	Whinstanes	Armstrong Holland	Batch	Y	Bucket elevator	2	Y
	West Burleigh	D&G	Batch	Y	Bucket elevator	1	Y
	Toowoomba	ARAN	Batch	N	N/A	N/A	N
	Airport	Aztec	Double drum	Y	Feed belt to drum	1	Y
Brisbane City Council	Riverview	Gencor Titan 2000	Batch	Y	Pugmill via dryer	1	N
	Eagle Farm	Aztec	Double drum	Y	Feed belt to drum	1	N
Downer Infrastructure	Bli Bli	Ammann	Batch	Y	Pugmill via dryer	1	Y
	Archerfield	Ammann	Batch	Y	Pugmill via dryer	2	Y
	Strathpine	Armstrong Holland	Batch	Y	Pugmill via dryer	1	Y
	Gympie	D&G	Batch	N	Pugmill via dryer	N/A	N
Fulton Hogan	West Burleigh	–	Batch	Y	Bucket elevator	1	Y
	Ormeau	Aztec T300	Double drum	Y	Feed belt to drum	3	Y
	Toowoomba	Shin Saeng	Batch	N		1	Y
	Narangba	Benninghoven	Batch	Y		2	Y
RPQ/Trico	Swanbank	Aztec	Double drum	Y	Feed belt to drum	2	Y
	Swanbank	Benninghoven	Batch	Y		1	N
Suncoast Asphalt Pty Ltd	Brighton	Ammann	Batch	Y	Pugmill via dryer	1	N
Tropic Asphalts	Bells Creek	Benninghoven	Batch	Y		1	N

1 Does the plant have an existing registered mix design containing RAP?

Based on the literature review and a survey of currently registered asphalt plants, there appears to be a wide range of RAP capability in SEQ. Some plants are not currently configured to incorporate any RAP while other plants are capable of including up to 50% RAP in mixes (provided appropriate RAP management practices are implemented).

B 3.2 Discussion

Given the vast range of plant configurations and methods of incorporating RAP into asphalt mixes, the adoption of a prescriptive approach to specifying maximum RAP contents based on plant configuration/type does not appear appropriate. Adoption of an 'outcome' based approach to determine the allowable RAP percentages for particular asphalt plants appears more appropriate. To achieve this objective, the contractor would need to demonstrate to TMR that they are capable of producing conforming asphalt at the maximum RAP content to be adopted (up to a maximum of 40% for non-surfacing layers). This type of technical evaluation could be undertaken by TMR's Asphalt Mix Design Registrar as part of the asphalt mix design registration process.

B 3.3 References

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APPENDIX C RAP PROPERTIES TEST RESULTS

C.1 Laboratory Testing Details

This Appendix presents the laboratory test result of the RAP samples collected from three suppliers in SEQ. One of the suppliers produces two sizes of RAP; as a result, 48 RAP samples were prepared for sampling and testing. Aggregate gradings of the RAP material provided by the suppliers are presented in Figure C 1.

The binder was extracted according to Austroads Test Method AGPT/T191-15 (*Extractions of bituminous binder from asphalt*) (Austroads 2015a). In this method, samples are soaked in toluene to dissolve the binder. The binders are then extracted from the solution by evaporating the toluene in a Rolling Thin Film Oven (RTFO).

Once the binders were extracted, they were tested for their viscosity. Contractor A RAP samples (coarse and fine) for August, October, November and December 2016 and Contractor B and Contractor C RAP samples for August, September, October, and November 2016 were tested for full temperature/frequency sweep in the Dynamic Shear Rheometer (DSR) (Table C 1). Details of the temperature frequency sweep test are as follows:

- test temperature: 70 to 30°C (at 5 °C increments)
- oscillation frequency: 0.1 to 62.83 rad/s (5 points per decade)
- strain: 5%
- binder film thickness: 1 and 2 mm (1 mm for 25 mm diameter samples and 2 mm thickness for 8 mm diameter samples)
- binder sample diameter: 8 mm and 25 mm (70 to 50 °C tested in 25 mm spindles and 50 to 30°C in 8 mm spindles)
- number of test points: 1.

Due to time/budget constraints, the rest of the samples were tested according to the Austroads Test Method AGPT/T192-15 (*Characterisation of the viscosity of reclaimed asphalt pavement binder using the dynamic shear rheometer*) (Austroads 2015b). Details of the test settings are as follows:

- test temperature: 60 °C
- strain: 10%
- angular frequency: 1 rad/s
- binder film thickness: 1 mm
- binder sample diameter: 25 mm
- number of test points: 20 points (10 pre-conditioning points followed by 10 test points).

Although two different testing setups were used to test the viscosity of the RAP samples, it is believed that the difference between the measured viscosities is minimal. Details of the viscosity test results are illustrated in Figure C 2 and Figure C 3, and tabulated in Table C 2, and Table C 3 and Table C 4.

Table C 1: Details of the RAP binder viscosity test settings

Year	Month	Contractor A (fine)	Contractor A (coarse)	Contractor B	Contractor C
2016	August	✓	✓	✓	☹
2016	September	☹	☹	✓	✓
2016	October	✓	✓	✓	✓
2016	November	✓	✓	✓	✓
2016	December	✓	✓	✓	✓
2017	January	✓	✓	✓	✓
2017	February	✓	✓	✓	✓
2017	March	✓	✓	✓	✓
2017	April	✓	✓	✓	☹
2017	May	✓	✓	✓	✓
2017	June	✓	✓	✓	✓
2017	July	✓	✓	☹	✓
2017	August	-	-	-	😐

☹	No sample provided
✓	Samples provided - test completed
😐	Samples provided - testing in progress
(blue)	Tested only for viscosity @ 60°C (AGPT/T192)
(green)	Tested for full temperature/frequency sweep

Figure C 1: Aggregate grading charts of contractors A, B and C RAP

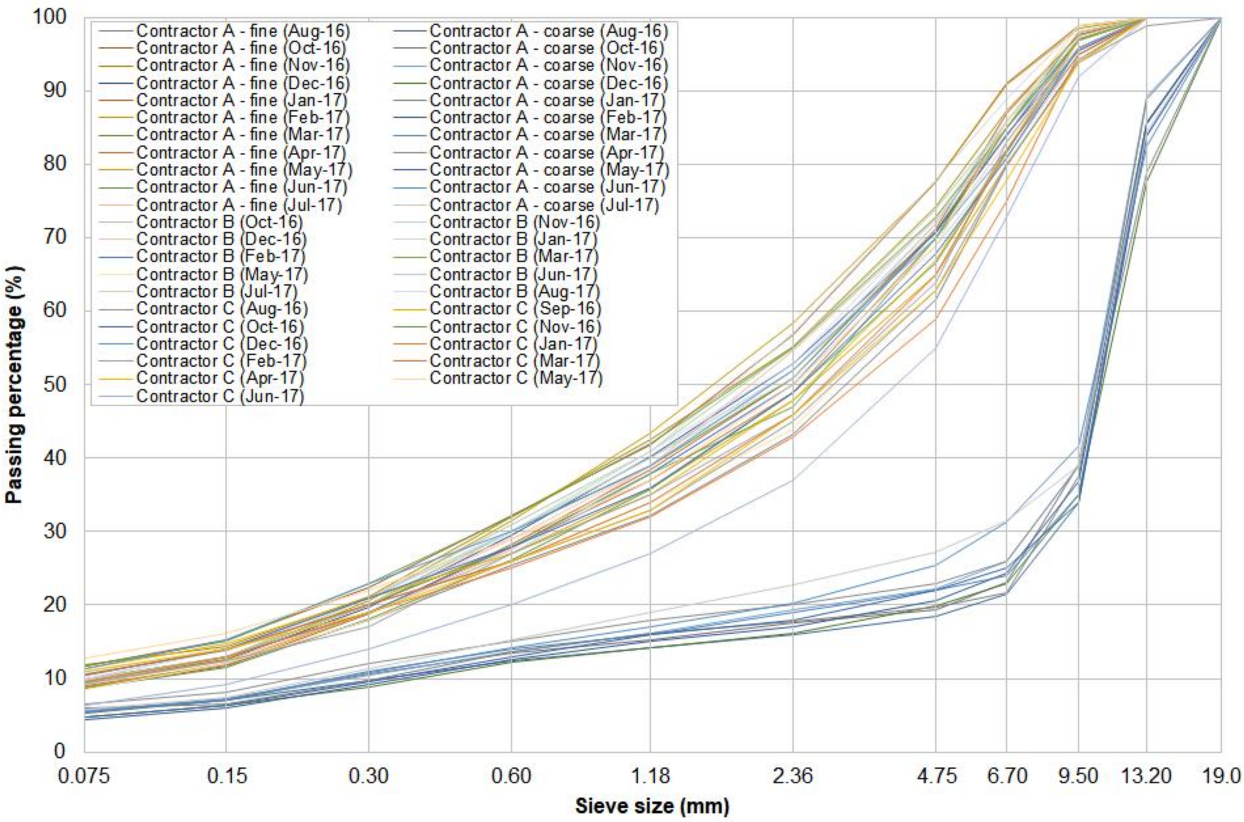


Figure C 2: Binder viscosity of contractors A, B and C RAP for August 16 to July 17 period

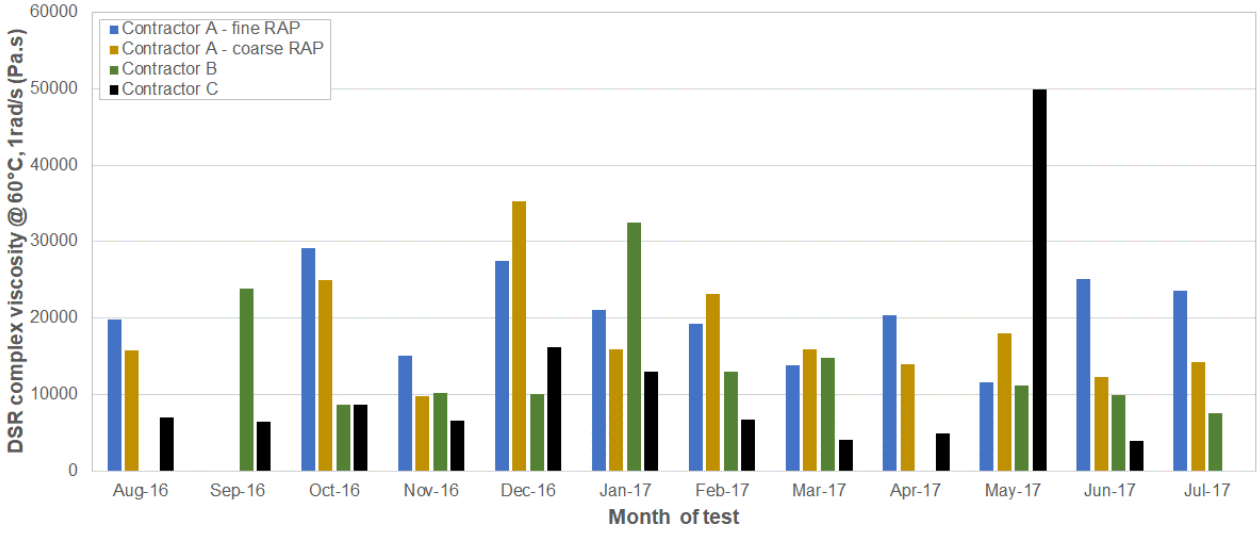
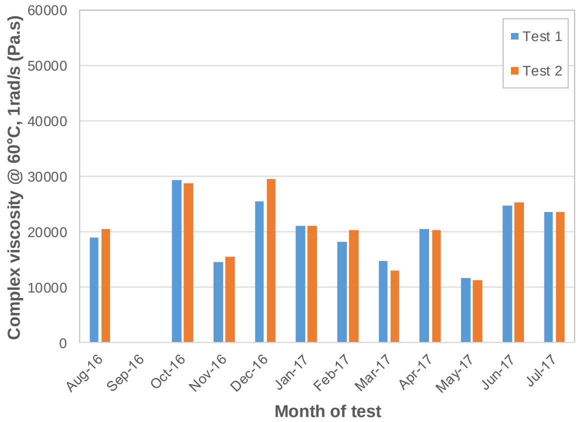
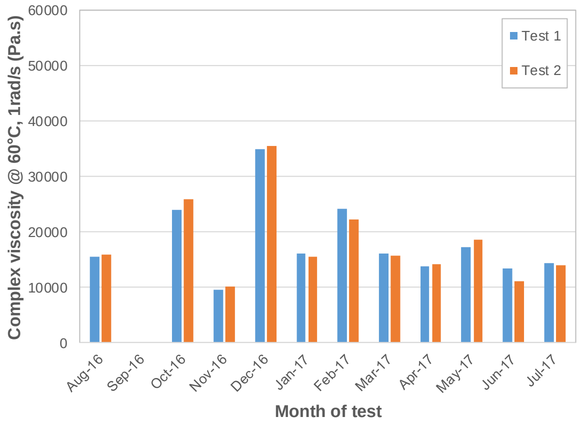


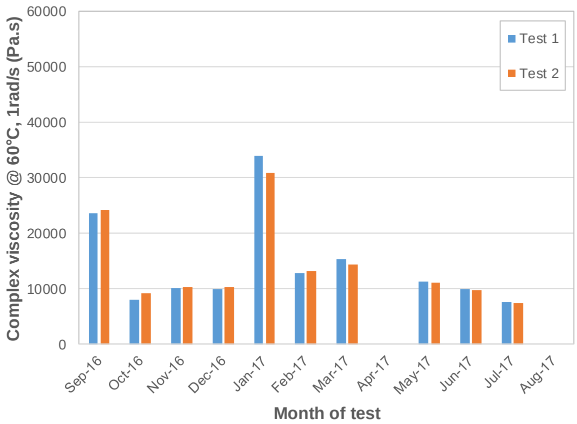
Figure C 3: Binder viscosity test repeatability of contractors A, B and C RAP



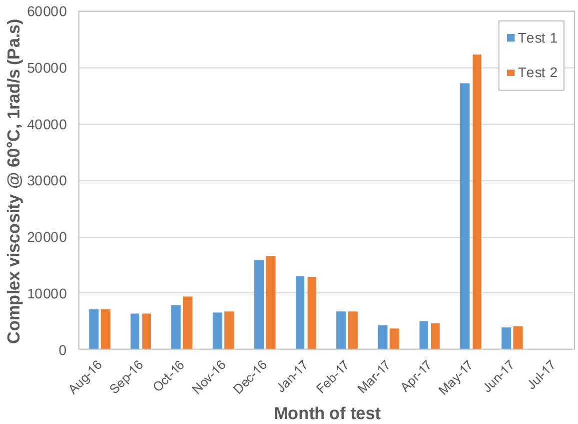
contractor A (fine RAP)



contractor A (coarse RAP)



contractor B



contractor C

Table C 2: Contractor A RAP details

Month-year	Sample ID	Date sampled	Viscosity (AGPT/T192)			Binder content (%)	Fine/Coarse
			Test 1	Test 2	Average		
Aug-16	4706	24/08/2016	19 040	20 470	19 755	4.42	Fine (10 mm)
	4705	29/08/2016	15 530	15 940	15 735	2.82	Coarse (14 mm)
Sep-16	–	Not sampled	–	–	–	–	Fine (10 mm)
	–	Not sampled	–	–	–	–	Coarse (14 mm)
Oct-16	4795	4/10/2016	29 410	28 780	29 095	4.51	Fine (10 mm)
	4794	4/10/2016	24 030	25 990	25 010	2.62	Coarse (14 mm)
Nov-16	4844	7/11/2016	14 470	15 580	15 025	4.83	Fine (10 mm)
	4843	7/11/2016	9468	10 060	9764	3.16	Coarse (14 mm)
Dec-16	4853	1/12/2016	25 430	29 470	27 450	4.59	Fine (10 mm)
	4854	1/12/2016	34 960	35 440	35 200	2.67	Coarse (14 mm)
Jan-17	4933	17/01/2017	21 118	21 100	21 109	4.14	Fine (10 mm)
	4934	17/01/2017	16 107	15 593	15 850	2.47	Coarse (14 mm)
Feb-17	4935	6/02/2017	18 169	20 342	19 256	4.57	Fine (10 mm)
	4936	6/02/2017	24 111	22 240	23 176	2.54	Coarse (14 mm)
Mar-17	5154	28/02/2017	14 745	12 966	13 856	4.45	Fine (10 mm)
	5153	28/02/2017	16 041	15 771	15 906	2.61	Coarse (14 mm)
Apr-17	5158	5/04/2017	20 533	20 303	20 418	4.15	Fine (10 mm)
	5157	5/04/2017	13 859	14 096	13 978	2.50	Coarse (14 mm)
May-17	5160	4/05/2017	11 744	11 293	11 519	4.42	Fine (10 mm)
	5159	4/05/2017	17 240	18 659	17 950	2.66	Coarse (14 mm)
Jun-17	5289	1/06/2017	24 805	25 399	25 102	4.13	Fine (10 mm)
	5288	1/06/2017	13 484	11 184	12 334	2.82	Coarse (14 mm)
Jul-17	5290	3/07/2017	23 546	23 563	23 555	4.61	Fine (10 mm)
	5291	3/07/2017	14 285	14 054	14 170	3.03	Coarse (14 mm)

Table C 3: Contractor B RAP details

Month-year	Sample ID	Date sampled	Viscosity (AGPT/T192)			Binder content (%)
			Test 1	Test 2	Average	
Aug-16	–	Not sampled	–	–	–	–
Sep-16	4793	21/09/2016	23 530	24 260	23 895	4.30
Oct-16	4789	14/10/2016	8021	9202	8612	4.00
Nov-16	4845	8/11/2016	10 160	10 360	10 260	4.25
Dec-16	4937	16/12/2016	9887	10 274	10 081	4.45
Jan-17	4938	9/01/2017	34 064	30 807	32 436	4.55
Feb-17	5281	21/02/2017	12 811	13 114	12 963	4.20
Mar-17	5282	13/03/2017	15 236	14 285	14 761	4.25
Apr-17	–	Not sampled	–	–	–	–
May-17	5283	8/05/2017	11 351	11 064	11 208	4.25
Jun-17	5284	9/06/2017	10 024	9681	9853	4.35
Jul-17	5285	13/07/2017	7632	7364	7498	4.25
Aug-17	–	21/08/2017	Test in progress			4.35

Table C 4: Contractor C RAP details

Month-year	Sample ID	Date sampled	Viscosity (AGPT/T192)			Binder content (%)
			Test 1	Test 2	Average	
Aug-16	4791	24/08/2016	7060	7047	7054	3.70
Sep-16	4790	16/09/2016	6433	6377	6405	3.95
Oct-16	4792	10/10/2016	7830	9438	8634	3.95
Nov-16	4846	7/11/2016	6526	6689	6608	4.60
Dec-16	4939	13/12/2016	15 904	16 532	16 218	4.35
Jan-17	4940	15/01/2017	13 001	12 837	12 919	3.95
Feb-17	4941	20/02/2017	6818	6711	6765	2..65
Mar-17	5155	12/03/2017	4288	3792	4040	4.05
Apr-17	5156	4/04/2017	5071	4755	4913	3.95
May-17	5286	30/05/2017	47 325	52 382	49 854	4.20
Jun-17	5287	18/06/2017	3885	4050	3968	2.90
Jul-17	–	–	–	–	–	–

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