The Circular Economy of Asphalt

EAPA Technical Review

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Summary

In the last years, sustainability and circular economy have become a top priority of the EU Administration, as well as most National Administrations across Europe. Considering that asphalt is a material easy to repair, 100% re-usable and recyclable, and that more than 90% of the European road network is currently surfaced with asphalt, it is clear that the European asphalt industry has the potential to become a key tool for Governments to achieve the most ambitious environmental objectives. The aim of this technical review is to present all the information related to the circular economy of asphalt, including technical information on preventative and repair techniques to extend the service life of asphalt, techniques to re-use and recycle it, environmental life-cycle benefits and the regulatory framework in Europe.

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1. Introduction

Roads are a vital part of modern life which most people take for granted. When we leave our home we need roads to go to work, to the shops, to school, to the cinema or to go on holiday. The goods and services we need are transported by road for at least part if not all of their journeys. In an emergency we rely on roads for the fire service, the ambulance and the police.

The European road network has been developed over centuries, with the majority of the roads having been constructed over the last 100 years, and is the Community's most valuable asset. It consists of 5.5 million Km and represents an estimated value of over € 8,000 billion [1], managed under local, regional and national responsibility. It is estimated that more than 90% of such network is currently paved with asphalt.

Asphalt is the road construction material of choice, due to its comfortable and safe ride, its value for money, speed of installation, flexibility in construction, performance and maintenance combined with excellent durability.

Asphalt has a key further attribute in that it can be 100% re-used without downgrading its functionality and is currently the most re-used construction material in the world.

Many other construction materials can claim recyclability but this often involves downgrading, for example as lower grade aggregate. Evidently, this can be also done with asphalt, as a last option.

Over the last years, road asset management has been switching from new construction to maintenance, leading to an essential change approach to resource optimisation. As it will be explained in this document, the asphalt sector has already achieved excellent figures of re-use and recycling and there is a proven track record of the satisfactory performance of roads containing this material. There is, however, scope to further widen the re-use and recycling to ensure that this resource and materials are fully valued and the embodied carbon within them is not wasted.

This document is intended to improve understanding of the re-using and recycling potential of asphalt and to encourage a more holistic approach to the maintenance of our road asset making use of the asphalt already in place in a planned, progressive structural maintenance system to keep the network sustainable for future generations.

2. What is Asphalt / how is asphalt made?

Asphalt used as a pavement material is mainly a mixture of mineral aggregate and fines cohesively bound with bituminous binders, with a binder content typically ranging from 3-7% by weight depending on the mix and application.

Aggregates used for asphalt mixtures are hard minerals selected for their physical characteristics and size classified for a specific asphalt mix design. They may be of natural origin such as crushed rock, gravel, and sand or artificial, such as blast furnace slag.

Bitumen are viscous hydrocarbons derived from refining crude oil. They are produced in different grades with specific engineering and physical properties relating to their viscosity, hardness, or brittleness at a specified temperature. They are sometimes modified with polymers to enhance the performance across a range of in-service temperatures of the asphalt mixes in which they are used.

One key physical attribute of bitumen is that it becomes softer and more fluid when heated and hardens again when it cools (thermoplasticity). Asphalt paving applications have been traditionally carried out at temperatures in the 140°C-160°C range. Nevertheless, the great developments in additives and foaming technologies achieved in the last years, are allowing the production at temperatures significantly lower, which is leading to reductions in the overall energy consumption and emissions.

Another key attribute is that even at ambient service temperatures, at which bitumen appears to be a solid, it retains some viscous flow and self-healing properties (viscoelasticity) when loaded. This means that asphalt can accommodate a degree of movement by foundations and under traffic with only microscopic but reversible cracking.

Different asphalt mix formulae, blends or "recipes," are used for the various paving applications. These formulae are engineered to meet the cost and service life objectives of the road owner.

Base mixtures provide usually the stiffer and thickest layers which act as the main load bearing element of a road structure.

Surface courses are used for the thinnest topmost layer and are designed to give the required characteristics for interaction with tyres including grip and skid resistance, evenness and low noise for driver comfort.

Binder courses are used at intermediate thicknesses between the base and surface courses to ensure an even running surface and to deal with load transfer of high traffic stresses.

Mixing of bitumen and mineral aggregates occurs in mixing plants designed to dry the mineral aggregates, proportion the aggregate fractions and fines and mix them with the binder in a heat-controlled environment.

The asphalt is transported from the plant to the paving site in covered insulated trucks. Transport distances vary and are only limited by the need to ensure the appropriate material temperature upon arrival at the paving site for workability for compaction. New technologies seek to extend these delivery and installation timeframes.

Trucks discharge the asphalt mix into a hopper on the paving machine. The material then is conveyed through the paving machine where it is spread across the width of the machine by an auger at the rear to the screed. As the auger distributes the material along the screed, the paver continues to move forward, so that the screed keeps the paving mat level and smooth.

The asphalt begins cooling rapidly at this stage and must therefore be compacted without delay to the required density and smoothness by rollers following the paver.

3. How asphalt gets deteriorated over its service life

Roads are designed with the understanding that over time there will be some cumulative deformation in, and wear or damage to, the bound asphalt layers in particular the surface course. It will therefore be necessary to periodically rectify these defects at the surface for road user safety. Sometimes the binder layer is replaced as well and very occasionally the lower bound pavement layers are also reconstructed.

In addition, roads are subject to attack from the environment from solar UV rays, oxygen, heat and cold. In particular, water can have seriously damaging effects. The freezing and freeze-thawing of water can rapidly accelerate such damage.

Water effects can be experienced at all levels in the pavement structure. Wet soils and over-saturated granular materials have very poor load bearing capacity. Variations of foundation moisture content can result in seasonal swelling and shrinking. All of these can lead to cracking and failure in the bound layers. It is therefore essential to ensure there is provision of adequate drainage and that this is also maintained as ultimately lack of foundation drainage can result in loss of support for the whole road structure.

If water penetrates into bound materials, between layers, down joints or through cracks, this can result in stripping of the binding agent from the aggregate and degradation to an effectively unbound granular material. If left unchecked, this can result in total disintegration of the pavement, particularly in winter after a period of freezing.

Bitumen ages slowly over time and involves a combination of complex chemical and physical processes including 'evaporation' of lighter oily components, which collectively lead to an observation of hardening of the binder. As it becomes harder and more brittle, it has less adhesion to aggregate and therefore is also more susceptible to damage and with less ability to recover or to resist normal stresses. The level of hardening varies depending on the mixture type (porous asphalt ages more rapidly than dense asphalt for instance) and the position in the asphalt (deep in the pavement or at the surface, exposed to direct sunlight/heat or more mild conditions).

Surface layers can suffer loss of skid resistance through the polishing action of traffic and closing up of surface texture. Deformation from all layers in a pavement will need to be corrected by relaying the surface. It is also important to maintain surface integrity to prevent water penetrating into the lower layers. Where studded tyres are used in winter, there will be a need to regularly replace material abraded from the surface.

Climate change may impact on any of the above mechanisms in the future with more extremes of flooding, storm rainfall, high and low temperatures.

Properly designed and maintained surface courses can be expected to last for 15-25 years. Pavement structural layers are usually designed to last for 30 to 40 years. Their condition should regularly be assessed and some significant strengthening or reconstruction anticipated as they approach the end of their design life. Even longer durability can be achieved for "long life pavements" ("perpetual pavements" as it is called in USA).

Asphalt pavements have an additional flexibility and adaptability in design and construction such that they can be simply overlaid (and /or widened) in order to increase strength and therefore traffic capacity (both volume and load). This may influence the construction strategy with a view to extending life and enhancing performance when increased funding becomes available.

4. The Circular Economy of asphalt

As introduced above, the managing and disposing of construction products when they reach the end of their service life are regulated under the umbrella of numerous national and European regulations, being especially relevant the Waste Framework Directive 2008/98/EC, in which a hierarchy was defined with the following order at the top: "prevention & repair" > "re-use" > "recycling" (Figure 1).

By following this hierarchy, the most sustainable strategy for asphalt roads is simply to prolong their service life, preserving the asphalt as long as possible in the road, thereby reducing the need to remove it at all. A pavement preservation or asset management strategy involving simple, timely and cost-effective surface treatments to retain the asphalt integrity before later more costly repairs or rebuilds makes economic sense. If a road is properly designed, constructed and maintained and lasts for twice as long, then 100% of the virgin materials which would have been used to reconstruct it have been preserved.

For the case of asphalt, and as it will be described in sections below, a wide range of techniques have been developed over the last decades to prevent damage or repair it when this occurs.

By using these techniques, it is possible to significantly extent the service life of the road surface and make the bottom structural layers practically perpetual. However, still nowadays, numerous Administrations prioritise the funding for new construction before the maintenance of the existing road assets, which in most cases lead in time to higher environmental impact and reconstruction costs.

When these preventative and repairing operations are no further effective, asphalt reaches the end of its service life, and it is ready to be reclaimed from the road.

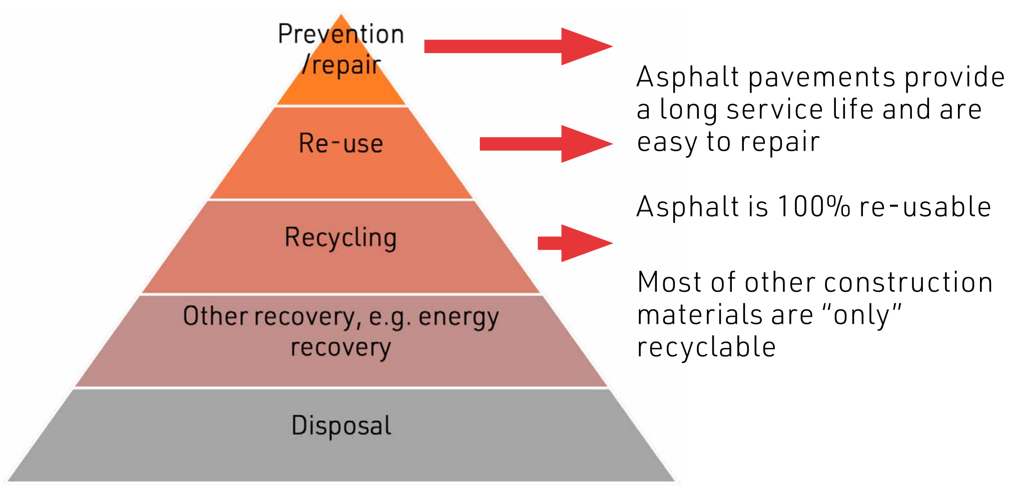

Figure 1. Waste hierarchy established by the Directive 2008/98/EC on waste

This reclaimed material is (in general) not suitable to be used straight away, requiring some intermediate processing (e.g., crushing, sieving, etc.). Hence, the Asphalt Product Standard EN 13108-8 "Reclaimed Asphalt" differentiates the concept of "site-won asphalt" (often-known as reclaimed asphalt pavement or RAP) from "reclaimed asphalt", as follows:

- **Site-won asphalt:**
  the material to be recycled, in the form of milled asphalt road layers or as slabs ripped up from asphalt pavements, or being asphalt from reject, surplus or failing production.

  Note to entry: These materials will require assessment and often processing before being suitable as a constituent material.

- **Reclaimed asphalt (RA):**
  the processed site-won asphalt, suitable and ready to be used as constituent material for asphalt, after being tested, assessed and classified according to this standard.

  Note to entry: Processing can include one or more of: milling, crushing, sieving (screening), blending, etc.

The Waste Framework Directive also defines the terms "re-use" and "recycling" as follows:

- **Re-use:**
  any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.

- **Recycling:**
  any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

By following these principles, EAPA proposes the following definitions:

- **Asphalt re-use:**
  operation by which reclaimed asphalt (RA) is added to new asphalt mixes, with the aggregates and the aged bituminous binder performing the same function as in their original application.

  Note: This is independent of manufacturing temperature, road layer, etc. Hence, it would include, for example, the manufacturing of cold mix asphalt from former warm or hot mix asphalt, as long as aggregates and aged bitumen keep respectively working as aggregates and binder.

- **Asphalt recycling:**
  operation by which reclaimed asphalt (RA) is used as foundation, fill or road material, with the recovered aggregate and bitumen performing a lesser (or alternative engineering) function than in the original application.

  Note: This means that, traditionally, the term "recycling" has been mistakenly used to also refer to "re-use" operations.

Figure 2. Asphalt re-use scenarios.

When asphalt is recycled, it is normally used as an aggregate in other construction products. These include aggregates for railway ballast and armourstone, but more usually as aggregates for unbound mixtures, such as sub-base and fill materials for civil engineering works or as unbound mixtures themselves. When recycled asphalt is used in other materials, there will naturally be quality limits and requirements in the specifications for the destination material, particularly relating to the retained binder content. Recycled asphalt can even be used as aggregate for concrete but clearly this does not exploit the inherent value of the bitumen content.

As detailed in the EAPA annual publication "Asphalt in Figures" [2] the total amount of reclaimed asphalt available for the industry in the European reporting countries in 2020 was 46 Mt. A great deal of these countries[1] also measured the percentages of the total RA available for the industry, which were "re-used" for the manufacture of new mixes, "recycled" as unbound road layers and other civil Engineering applications and used in other unknown applications or put to landfill. In these countries, 64% of the available RA was re-used and 33% recycled. This means that only 3% was used on unknown applications or put to landfill, which raises the asphalt sector to the top level of circularity (Figure 3).

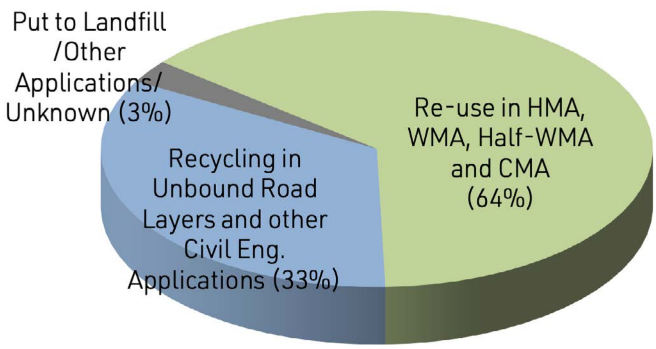

Figure 3. Application of reclaimed asphalt available in European countries providing data in 2020

Despite these exceptional figures (we must remember that most of other construction materials can "only" claim to be recyclable), different countries still classify site-won asphalt as "waste", requiring special handling procedures, which reduce efficiency and increase costs, until the established end-of-waste criteria are met (extended information on the regulatory framework in Sections below).

However, it was explained above that asphalt is a material 100% re-usable in the construction and maintenance of roads and 100% recyclable in other applications for several cycles. Therefore, no holder should intend (or be required) to discard this material. For these reasons, EAPA keeps encouraging Public Administrations and stakeholders to work towards the practical and regulatory scenario, in which "asphalt" is never considered "waste".

In addition, as more than 90% of the European road network is surfaced with asphalt, the European asphalt industry has the potential to become a key tool for Road Authorities and Governments to achieve objectives of the new Circular Economy Action Plan, such as:

- increasing re-used and recycled content in products, while ensuring their performance and safety
- enabling remanufacturing and high-quality recycling
- reducing carbon and environmental footprints
- restricting single-use and countering premature obsolescence
- improving product durability, reusability, upgradability, and reparability, addressing the presence of hazardous chemicals in products, and increasing their energy and resource efficiency.

5. Preventative measures to extend the service life of asphalt

By following the waste hierarchy of the Framework Waste Directive, the most sustainable strategy for asphalt roads is simply to prolong their service life, preserving the asphalt as long as possible in the road, thereby reducing the need to remove or recycle at all. A pavement preservation or asset

[1] Countries providing data are: Czech Republic, Denmark, Finland, France, Germany, Great Britain, Hungary, Ireland, Norway, Romania, Slovakia, Slovenia, Spain and Turkey

management strategy involving simple, timely and cost-effective surface treatments to retain the asphalt integrity before later more costly repairs or rebuilds makes economic sense. If a road is properly designed, constructed and maintained and lasts for twice as long then 100% of the virgin materials which would have been used to reconstruct it have been preserved – this supports the "reduce" element in the recycling hierarchy.

There are various preventative (non-structural) maintenance treatments for asphalt roads, some of which are outlined below.

- **Preservative sprays**
  Surface oxidation of bitumen is a key factor in asphalt degradation – oxidised bitumen is more brittle and susceptible to fatigue damage, and particularly so when it is heavily trafficked. Asphalt preservative sprays claim to 'reseal' asphalt surfaces by absorption into the top few millimetres of asphalts to prevent and reduce ongoing oxidation of volatiles from the bitumen and provide a membrane to protect from further environmental attack. To be fully effective frequent re-applications are often recommended, typically as soon as possible after initial asphalt installation (and at least when the material is still in good condition) and every 5 to 7 years thereafter. Some sprays also require the application of very fine aggregate in order to retain skid resistance properties.

- **Surface dressing**
  Surface Dressing is a long established highway maintenance technique. In simple terms it involves the spray application of a bituminous emulsion binder onto the existing road surface followed immediately by the even application of aggregate chippings to 'dress' the binder. Surface dressing seeks to seal the road surface against ingress of water, arrest the deterioration of the road surface and underlying road pavement structure and restore the necessary level of skid resistance to the road surface.

- **Micro & slurry surfacings**
  These materials are cold-applied, thin bituminous surface courses incorporating bitumen emulsion and fine graded aggregate with fillers.

  Slurry Surfacing is normally a single coat application laid mechanically or manually up to a dried film thickness of 6mm. Slurry surfacings are usually only appropriate for very lightly trafficked areas such as footways and cycleways and micro-surfacings for urban roads and those with relatively low volumes of commercial traffic (< 250 cv/d).

  Micro-surfacing incorporates a polymer modified bitumen emulsion and is often a two-coat application and can be laid mechanically or manually to a maximum dried film thickness of 15mm. These materials are usually referred to as Micro-Asphalts. Some Microasphalts have been designed for significantly higher traffic volumes than would be appropriate for slurry surfacings.

- **Thin surfacing**
  Thin asphalt surfacing overlays can also be considered as a preventative treatment, in addition to being a 'generic' construction option. If overlaid at less than 50mm there is not generally considered to be any significant additional structural contribution, but it does give increased scope for re-profiling larger areas of a road and improving road surface evenness.

Preservative treatments are generally applied in the thinnest layer possible in order to enhance cost effectiveness and reduce the need to adjust levels of, for example, gulleys, drainage and utility inspection covers, kerbs, crash barriers and other street furniture and not impinging on the headroom of over-bridges, cables etc.

Regardless of the effectiveness of preventative treatments and planned maintenance, all asphalt pavements have a finite life and a programme of progressive structural renewal will also need to be considered alongside to prolong the lifespan of the road in the long term. This may encapsulate widening or drainage works, partial reconstruction and thickening as necessary for increasing traffic and/or climatic demands. It is also possible to adapt and improve performance of existing upper layers through careful mixture design in order to meet changing pavement requirements, and for which the range of asphalt recycling processes can also make a contribution.

However, in some cases thick asphalt pavements can reach a state of structural equilibrium beyond which they are no longer observed to deteriorate – these are known as "perpetual" or "long-life" pavements. In this case, the only maintenance or performance improvement required will be in the upper layers of surfacing (binder and surface courses) to protect the indeterminate life base and foundation, presuming that adequate drainage etc. are already in place.

6. Repair techniques for asphalt roads

When damage is produced in an asphalt pavement, a number of possible repair treatments (for all types of pavement materials) are available, depending on the nature, size and depth of the defect, as well as the available budget of the road owner / operator. These can be applied as either reactive or preventative treatments, but the principles of their application are the same.

- **Patching and filling potholes – small areas of defects.**
  Potholes are typically 'small' areas (<300mm maximum dimension) and/or shallow (<50mm depth) defects in the surface course of a road, but if left untreated they will expand in both area and depth, often combining with other defects nearby to become more like 'trenches'. Their key characteristic is that they are areas of damage from which existing material has been lost or removed by traffic and/or water, or where the underlying structure has collapsed

  Sometimes as a matter of road user safety, potholes are filled temporarily until an effective permanent treatment can be put in place. These temporary repairs are carried out using asphalt mixes that have been specially designed to be workable for long periods of time for ease of application and compaction to profile. Full compaction is often not achieved without the action of traffic. The temporary filling of potholes alone will generally not address the underlying cause of the defect and will eventually re-appear, often just 'downstream' from an existing temporarily filled pothole.

  Permanent repair of potholes should be carried out as a patch. The intention of patching is to permanently restore the stability and ride quality of the pavement. Patching includes the repair of discrete areas of defective pavement, but not continuous lengths or full widths. This involves breaking out the material around the pothole, typically by a minimum of 150mm beyond the edge of the pothole or where defective material is found and to a depth such that the material below is still sound. The excavated area should have saw cut straight edges. All broken or excavated material must be removed from the area and the remaining hole swept clean and dried. All surfaces of the excavated area (including new interlayer faces) should be sprayed or 'painted' with hot bitumens or bitumen emulsions to ensure full bonding between the new and existing materials. Materials equivalent to (or one nominal size smaller) than those excavated in all layers will need to be compacted with equipment suitable to the size of the excavated area and to the same level as adjacent areas.

- **Inlay**
  Inlay treatments are similar to patch repairs, but carried out over a more extensive area, typically in or between wheel tracks but not to the full width of the pavement e.g. one (or part of one) lane of a multiple lane road. These areas are often associated with widespread cracking and/or excessive deformation in the line of the road (rutting) but also across the carriageway and are often associated with utility services or drainage paths or the route of heavy traffic. Inlays should be excavated and reinstated following the same principles as patches, but with the awareness that the material failure may be to a greater depth.

- **Planing and resurfacing**
  Pavements where the surface course and/or all or some of the binder course is to be replaced across its full width are considered to be 'resurfaced'. The most efficient method of removing materials is milling using specialist machinery as it can operate to a greater depth – such machinery can also be employed in excavation for inlays. Excavated areas should be

swept, also by larger machinery, and bitumen-based tack or bond coat applied to planed surfaces and exposed upstands e.g. kerbs, before laying new asphalt.

Materials used for inlays and resurfacing should be designed to restore initial properties or to deliver enhanced performance properties (or, as a minimum – "like for like") as necessary for changes in traffic type or volume at the same thickness as the material which has been milled off.

- **Overlay**
  Overlays are applied on top of existing pavement surface courses, where the structural integrity is acceptable but re-profiling is needed to improve riding quality or restore skidding resistance performance while adding thickness to the pavement to extend life. However, overlays less than 40 mm are not considered to add structural strength to the pavement. Special attention needs to be paid to road levels, particularly headroom under bridges and gantries, levels of crash barriers and other road furniture and drainage.

- **Full reconstruction**
  If the pavement is determined to have no residual service life and cannot be repaired, then full reconstruction will be necessary. The new pavement, foundations, drainage and materials will need to be designed to ensure that the new structure will perform adequately into the future. Existing materials should be removed for reuse.

Constituent materials in, and mixture design of, temporary or permanent pothole, patch repair, inlay, overlay or reconstruction materials should be appropriate in order to provide the required pavement performance for the area of application.

7. Re-use of asphalt at the end of its service life

7.1 A wide range of possibilities

When the preventive and repair operations are no further effective, asphalt reaches the end of its service life, and it is ready to be extracted from the road and prepared to be re-used.

The re-use of road materials has been practiced for decades. In this time, a range of techniques has been developed to provide an economically and environmentally suitable method for every type of project and location.

The production and laying of the new mix (containing or not material from the same road) is conducted once the milled surface has been prepared. The processes can be divided into two major methods: in-plant or in-situ techniques. These can be further sub-divided into hot and cold. In-plant (or off-site) re-use consists in removing the material from the site to a plant located elsewhere, which processes the reclaimed asphalt in order to re-use it either on the original project or on other projects. In-situ (or on-site) re-use allows the reclaimed material to be incorporated directly back into the new asphalt pavement under construction or maintenance.

The choice of process will depend on several factors, such as:

- Proximity of a suitable asphalt plant.
- Nature, quantity, quality and content of the reclaimed asphalt in the new mix.
- Amount and type of possible contaminants within the reclaimed material.
- Programmed duration of construction.
- Availability of space for interim storage of reclaimed asphalt prior to re-use.
- Engineering performance required from the new pavement.

A tentative decision tree to select the most appropriate technology can be seen in Figure 4. Nevertheless, this should be only seen as a first approach to the final decision. Each project has different conditions and each country different regulations and recommendations (e.g. end-of-waste criteria, limits for RA acceptance, etc.). Therefore, the final decision shall be always taken case by case.

For all options, there are a number of practical asphalt re-using issues, often related to binders in

RA, which need to be controlled, as follows:

- *Variability of binder content in reclaimed asphalt* –
  which can generally be addressed by homogenising the RA feedstocks (either in screened sizes or as "all-in" RA feedstock).

- *Hardness and level of 'recovered binder activation'* ,
  in other words how much of the old binder is participating in the new binder instead of just acting as black rock. For lower temperature systems, such as cold recycling, there is generally little to no participation of the old binder, but particularly in hot asphalt the binder will be re-mobilised during mixing and acting as binder, depending on the level of binder ageing. Binder mobilisation is particularly relevant in ensuring workability of new mixtures, but the volumetric contribution also needs to be carefully considered for performance.

- *Compensation for the ageing process in the design of the added virgin binder.*
  If all the aged binder is considered to be active, then the target binder content and grade can often be achieved simply by blending with softer virgin bitumens. In some severe cases, it may be required to partially recover certain properties of the aged binder by using additives, which ensure the appropriate performance of the final mix.

- *Re-usability of any polymer modified bituminous binders.*
  The most commonly used modifiers for bitumen, like SBS and EVA can be easily re-used as being thermoplastic they melt upon heating, even after ageing. Hence, the polymer can still have a substantial beneficial effect on the performance of the new mix. Nevertheless, it might also have significantly degraded, which would require the addition of extra polymer in the added binder (so-called PmB RC in countries, such as Germany, Austria and Czech Republic). For all these reasons, the presence of polymers in RA therefore needs to be qualified in the overall mixture design.

- *Re-usability of asphalt with legacy materials*, such as asphalt with Coal Tar or asbestos. While such products are no longer used, they can still be found in old road pavements and re-using them requires particularly special attention from start to finish from identification and assessment, to milling, transport, storage, disposal or mixing. In many cases it is better recommended to leave such products on the ground as disturbing them is likely to lead to more practical issues in trying to reuse them. If they are to be removed from the pavement, then the only alternatives that some countries consider to the disposal in approved landfills are the cold recycling (in-situ and/or ex-situ) and its treatment in specialised facilities able to separate the tar from the RA. Asphalt containing crumb rubber also needs special attention as there may be a tendency to add excess heat to overcome high viscosities during mixing, which could result in potentially hazardous fumes. Road owners have a fundamental Duty of Care in identifying the presence of potential contaminants in roads which they need to maintain, and therefore a key role to play in ensuring that such wastes or any secondary materials, do not enter the re-using stream. In cases, in which a new layer of asphalt is laid on top of a pavement containing hazardous materials, an adequate inventory must be produced, to ensure that in the future, only the suitable layers are milled.

- *Level of requirement:*
  The level of required performance for both the mix and its constituent materials changes, for example, depending on the type of pavement layer in which they are going to be placed. In order to optimise resources, it is recommended, when possible, to separate the material reclaimed from surface and bottom layers and use it respectively for the manufacturing of surface and bottom layers.

7.2 In-plant or off-site re-use

In-plant processes are employed when asphalt materials are excavated from the road and transported (even short distances) to processing units or plants in order to be used as an ingredient in new asphalt mixtures.

In plant re-using processes will generally provide

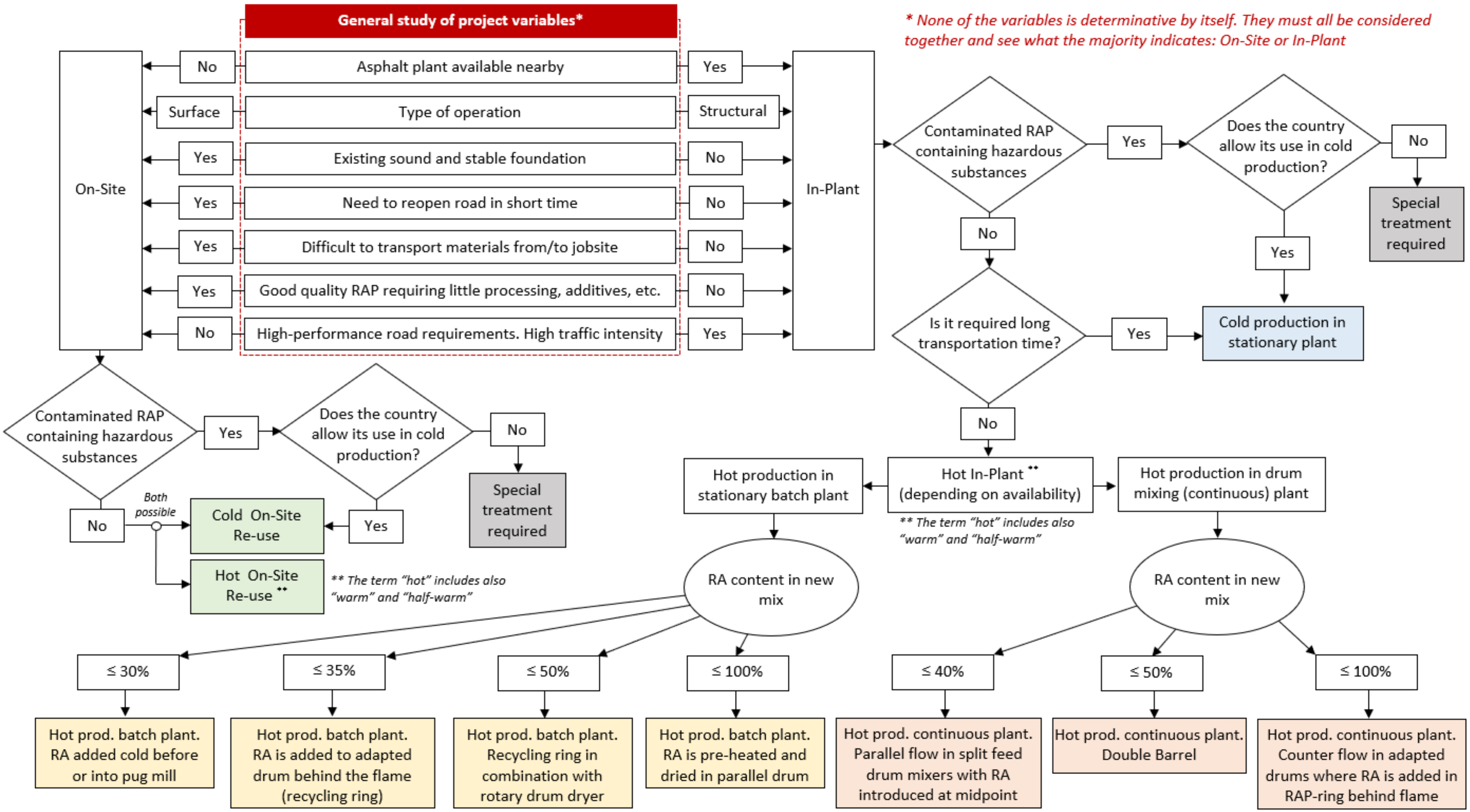

Figure 4. Tentative decision tree to select the most appropriate asphalt re-use/recycling technique

a greater level of quality control as these are more likely to take place at fixed plants where Factory Production Controls are already in place and can routinely monitor, for example, the crushing and screening of RA, assessment of RA feedstocks, and investigation of plants outputs.

In this process, careful assessment of reclaimed asphalt feedstock is necessary in order to ensure it is added in the right proportions to the new materials so as to deliver the necessary performance. This will include careful consideration of the amount and type of binder already present in the reclaimed materials, as well as the mechanical properties of the aggregates. In general, it can be broadly assumed that products, which are reclaimed from the roads, are suitable for re-use in new asphalt roads.

Amendments will generally be required to the production process to ensure that the addition of RA can be controlled to deliver final product quality and more care and attention is necessary as the content of added RA is increased, but for low volumes this should be quite routine. The RA is likely to be damp and the inherent binder may cause issues with blinding of screens if RA is heated, and potential release of fume if the RA comes into contact with the plant dryer flame.

It may even be possible to remix 100% RA only by blending single size RA feedstocks, but careful consideration is required to determine the need for additional added binder and/or additives to maintain workability and performance of the final mixture.

One of the prime considerations in successful asphalt mixing is to ensure that the binder evenly coats all the aggregate particles, and therefore the viscosity of the bitumen is critical. Reducing viscosity to make coating easier has generally been achieved by elevating the binder temperature, which if too elevated temperature impact properties with excessive ageing.

In order to reduce overall asphalt mixing temperatures, other technologies have been developed to enable this by reducing the viscosity of the bitumen binder without increasing temperature (Warm Mix Asphalt techniques). This equally reduces the need for super-heating of aggregates when using RA and in many cases can enable higher volumes of RA to be used.

- **Foaming processes**
  Foaming is achieved by carefully adding water and air to hot bitumen, resulting in a rapid but temporary expansion in volume of the bitumen, with an associated reduction in the binder film thickness. This enables the bitumen to coat the aggregates at lower temperatures and as such they do not have to be heated as well as dried. The aim of foaming processes is to achieve a volume of binder equal to the volume of aggregate, targeting an expansion ratio of 20. In case of RA, as only the virgin binder will be foamed, it may present some limitation as the volume of foamed binder is subsequently reduced par RA content.

  Other foaming technologies employ the inherent moisture, particularly in the fine aggregate fractions, as the water source for foaming the bitumen.

- **Emulsion processes**
  Reduced temperature mixtures can be also produced by using bitumen emulsions (a suspension of small bitumen globules in water) to reduce viscosity. In these mixtures the emulsion of bitumen and water is stable for longer than, for example, bitumen foam but the bond between them needs to be broken to ensure the bitumen coats and bonds the aggregates.

  Foaming and emulsion asphalt technologies may additionally benefit from the addition of cement or other hydraulic powders to promote early-life strength through chemical reaction with some of the water in the mixture. Such mixtures may be considered to be hybrid hydraulic-bituminous materials.

- **Additives**
  In some cases, additives are used in the presence of hot bitumen and/or aggregates, and result in a lower overall mixture temperature. Other chemical additives change the affinity between the bitumen and aggregate to promote adhesion.

7.2.1 Hot mix re-use technologies in stationary (batch) plant

The re-use techniques include "cold" and "hot" methods. For all methods the broken up material must be crushed and screened into correct sizes before further processing. Cold milling of asphalt pavements leads to material that can be used in the recycling process without further processing (crushing).

"Cold" methods refer to the addition of the reclaimed asphalt either at the discharge of the dryer into the hot elevator, or in the aggregates weighing scale, in these cases, the material is heated by the virgin aggregates before entering the pug mill (see figure 5) or directly into the pug mill. Here, the appropriate amount of new bitumen is added to the mixture according to desired end properties. It is important to avoid superheating of the added RA.

"Cold" methods imply recycling percentages of 10-40%, depending on the RA moisture content, the type of the plant's vapour extraction system, the RA quality in relation to the required specification, the new hot mix and the technical process limitations regarding maximum permitted temperatures.

Employing the hot method means that the RA is directly preheated (see figure 6). This method relies on an extra dryer (tandem TM drum). The RA is metered, heated and dried in the second drum and transferred via a buffer silo to the mixer.

Virgin aggregates are superheated in the first drum and conveyed to the pug mill mixer in the "cold" method above. The hot gases from the recycling drum are either directed to the first drum as secondary air near the burner or to the baghouse. Recycling percentages for the hot method are typically 30-80%, the upper limit being determined by the quality requirements of the mix specification in relation to the properties of the old asphalt.

For the continuous production of larger quantities of RA-containing asphalt, the RA percentages at the heating and mixing stages have to be kept in balance.

Another variation on warm re-use is feeding the RA into the dryer via a recycling ring (see figure 7). In this variation the virgin aggregates and the RA are introduced in the same drum but in two different places. The heating of the RA takes place behind the flame, ensuring that it does not overheated.

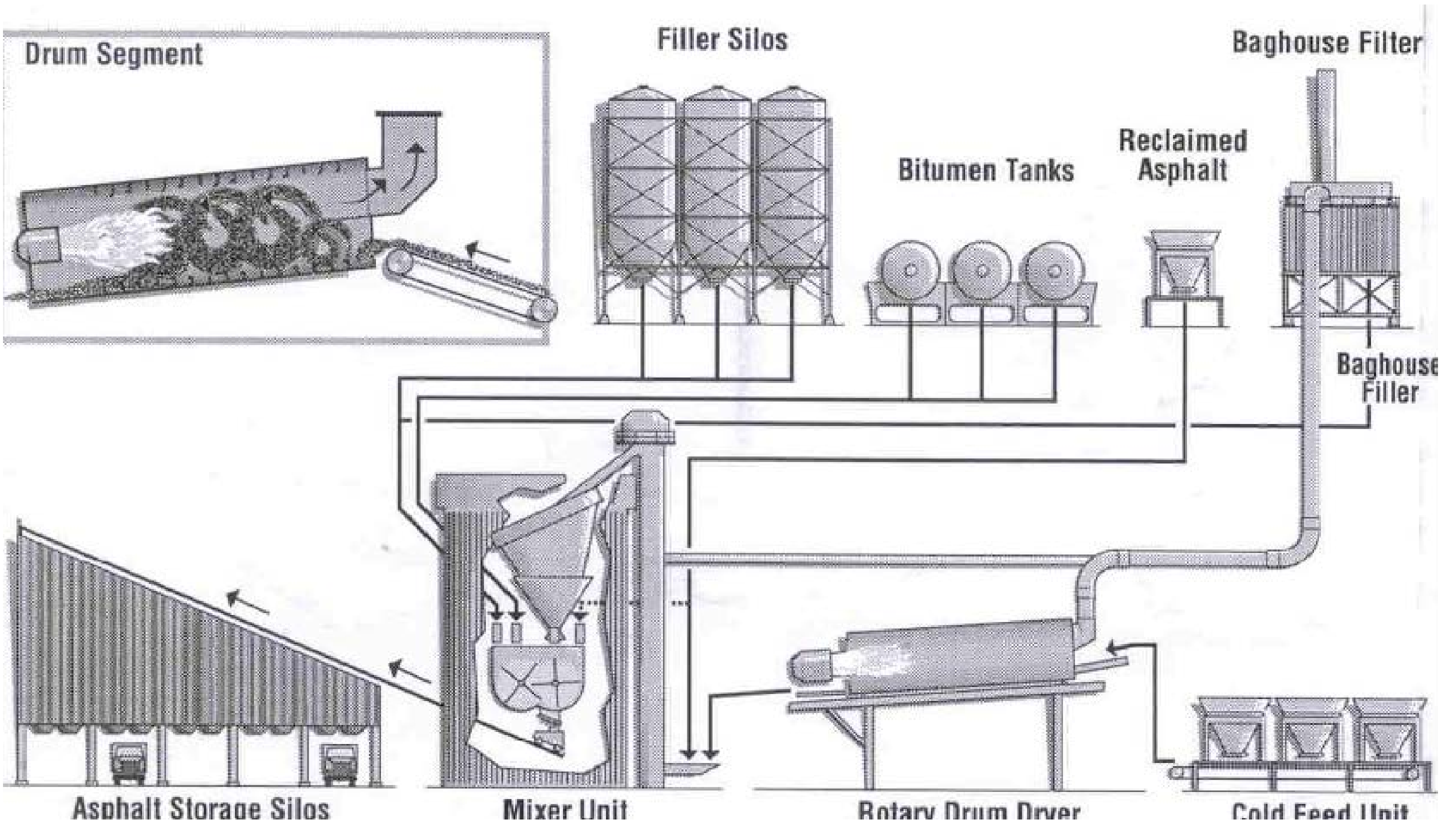

Figure 5. Batch mixing plant (cold RA method)

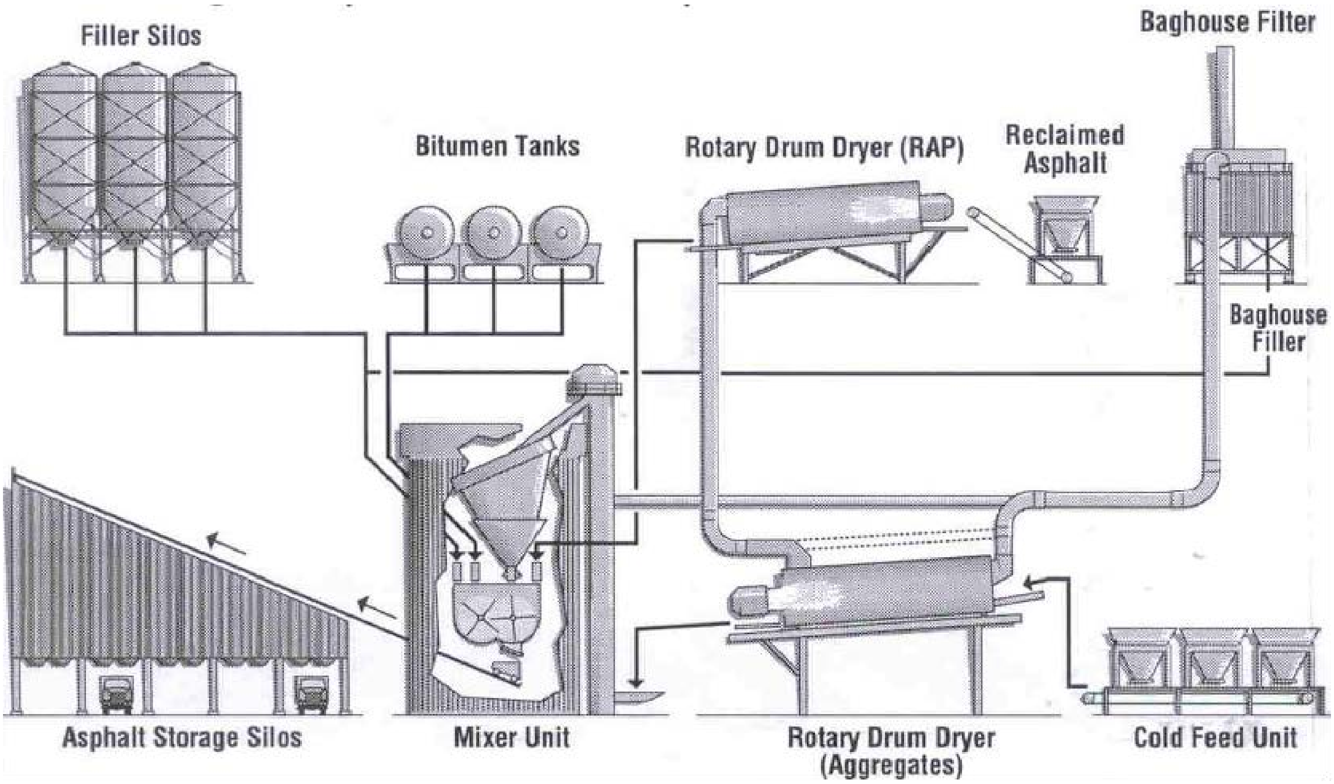

Figure 6. Batch mixing plant (warm RA method)

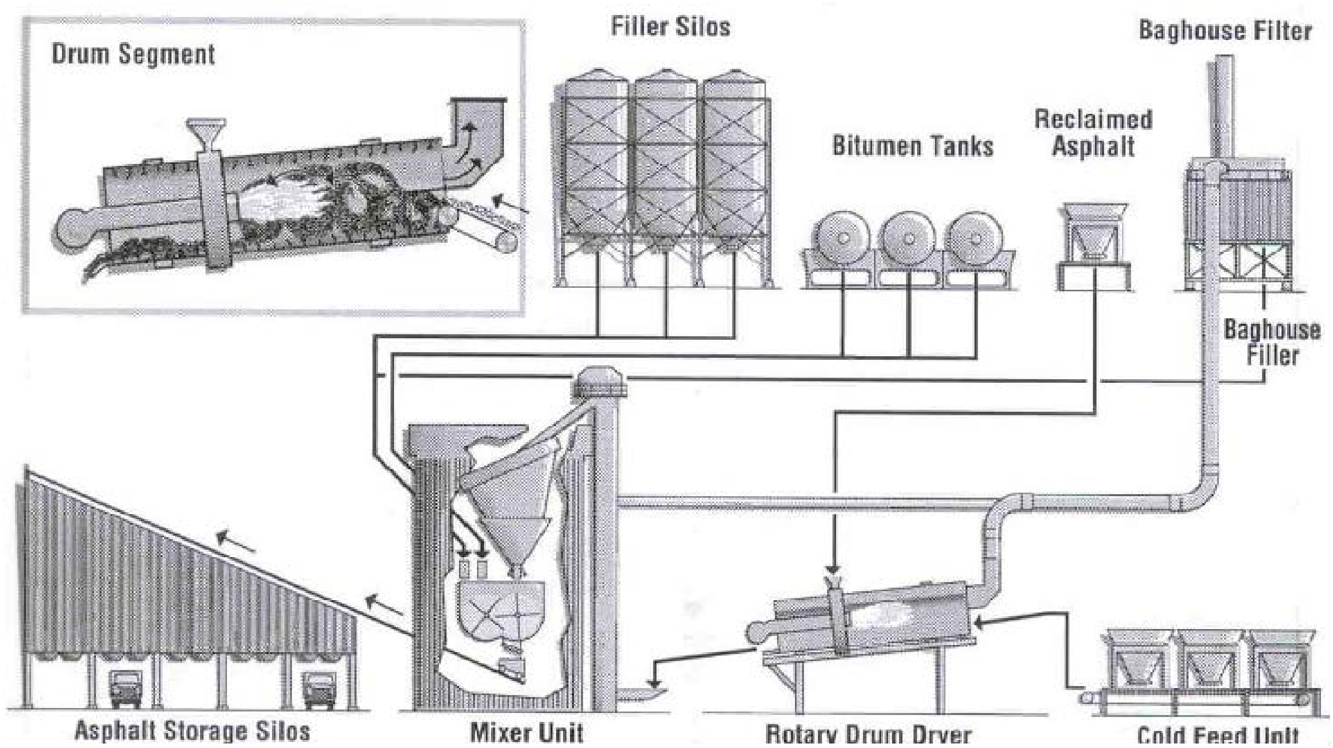

Figure 7. Batch mixing plant (recycling via recycling ring)

This method allows up to 35 % recycling.

It is possible to use a recycling ring in combination with a rotary drum dryer. In that case recycling up to 50% is possible.

7.2.2 Hot asphalt drum mixing (continuous) plants

Many recycling techniques have been developed throughout the years. This presentation mentions only the most successful ones. In a drum mixer, both the heating (and drying of aggregates) and the mixing (of aggregates, filler and bitumen) take place inside the drum.

Basically it is possible to identify three different methods of heating recycled material before the bitumen is added: depending on the type of drum mixing: parallel follow, counter flow or Double Barrel™.

The most common design for drum mixers today (parallel flow) uses both the direct flame heating and superheated aggregates principles. In so-called split feed drum mixers the processed reclaimed asphalt is introduced at about the midpoint ("RA ring") of the parallel flow drum (see figure 8): both the superheated virgin aggregates and the hot burner gases heat the bituminous material.

Another method is the counterflow mixer. Counterflow mixers differ from traditional parallel flow plants in that the flow of hot burner gases and aggregates occur in opposite direction (see figure 9). Technically the counterflow principle enables a reduction of the exit gas temperature, and an improved environmental performance through less heating of the recycled asphalt.

Virgin aggregates are introduced at one end of the drum (opposite burner) and RA is introduced into the drum about midway ("RAP ring"). The burner nozzle is extended so long into the drum that preheating of recycled material takes place behind the flame before entering the mixing zone. Consequently bitumen and recycled material are never in direct contact with the flame and heated gases. Under optimal conditions this process allows up to 50% recycling.

Double Barrel™ plant: figure 10 shows a Double Barrel™ drum mixer. The system consists of an ordinary revolving counterflow drum surrounded

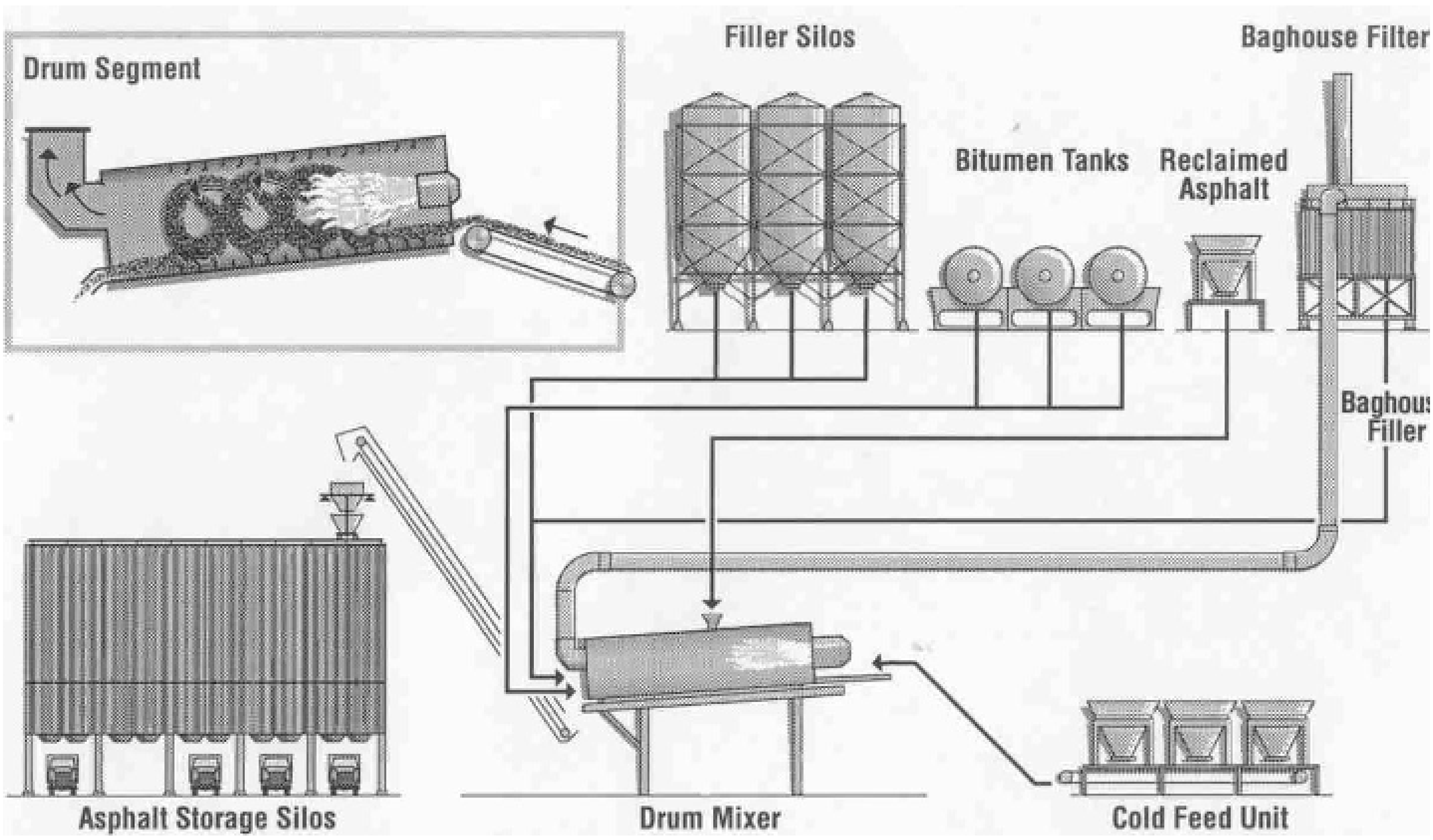

Figure 8. Drum mixing plant (with RA)

by a fixed outer drum. Recycled material is introduced in the outer shell outside the hot gas stream. The virgin material is dried and superheated in the inner drum. It then enters the outer drum by falling through openings in the inner drum. Virgin aggregates then travel in opposite direction to be mixed with injected bitumen and recycled material. Mixing thus takes place in the space between the two drums through blending flights mounted on the exterior shell of the inner drum.

Other techniques of indirect flame heating principally comprise arrangements with heat exchanger tubes preventing the mixture of reclaimed asphalt and virgin aggregate from coming into direct contact with the flame.

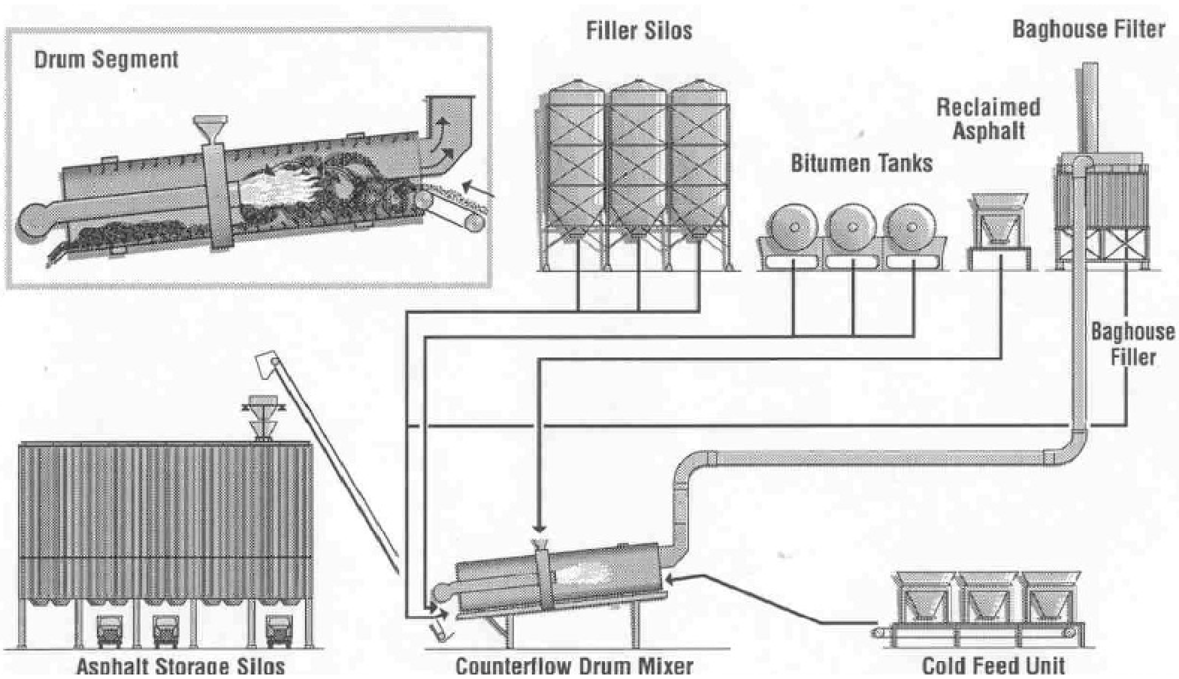

Figure 9. Counter-flow drum mixer plant

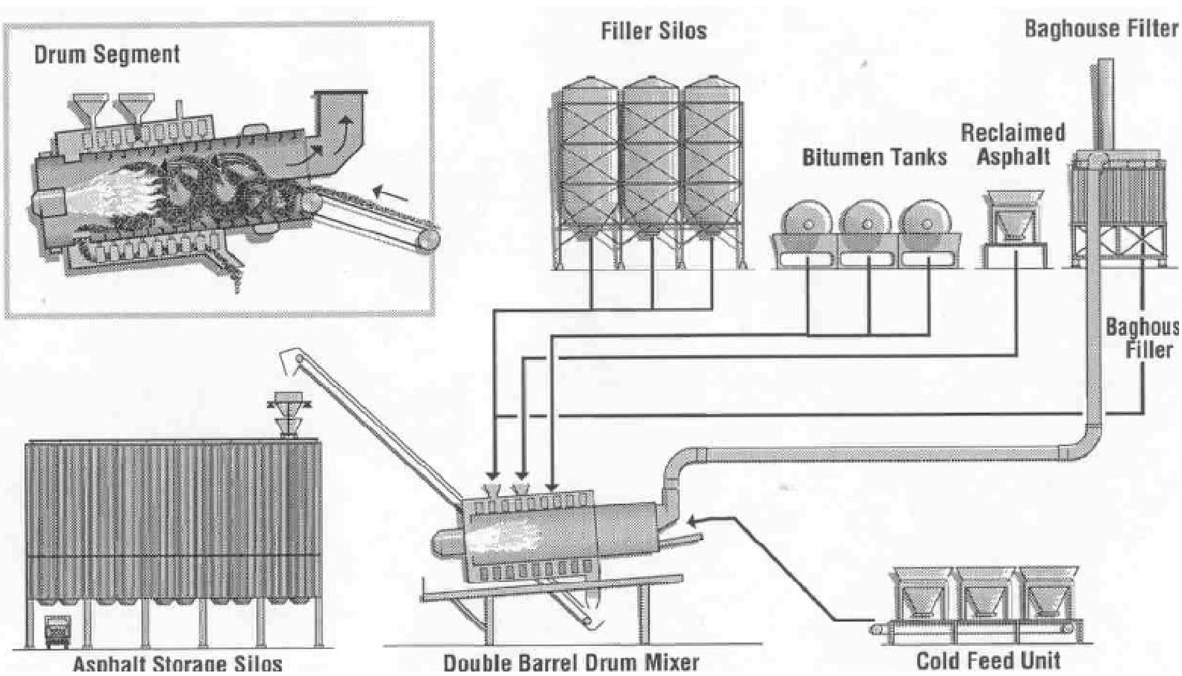

Figure 10. Double Barrel drum mixer plant

7.2.3 Cold mix re-use technologies in a stationary plant

The cold mix technology in an off-site central plant is a recent development that had been successfully used for several years already.

Reclaimed asphalt is returned to off-site plants with the same controlled crushing and screening process as for hot mix recycling, so as to produce a consistent feedstock the similar requirements of the feedstock for hot and cold mix plants make it feasible to operate both processes on the same location.

Two types of binder, foamed bitumen and bitumen emulsion, have been used combined with the recycled asphalt in a pug-mill. The methods are both able to accommodate over 90% of re-used asphalt producing materials at a low energy cost with an appropriate design life.

The final engineering properties may in some cases be inferior to that of hot mix, but in other cases when using end-product specifications can be at least equal.

The smaller number of components and less complex nature of cold mix plants have led to their successful adoption when needed in remote locations for short-term reconstruction programs.

7.3 In-situ re-use

Asphalt can be extracted and directly re-used in-situ, thereby reducing the need to transport materials from the site to other locations for processing. This has the benefit of reducing haulage movements of the materials to be re-used as well as associated transport emissions. There are a number of processes which can achieve this, using 'hot' and reduced temperature technologies.

7.3.1 Hot mix technology in in-situ re-use

The techniques are all similar in concept and require the use of special sets of equipment which have several brand or patent names, among them are Road train, Reshape, Repave and Remix (see figure 11).

- **Repave:**
  Repave-type processes are characterised by the heating and scarifying of the immediate surface of the road to approximately 20-30mm depth. This thin layer is then re-profiled and any material in excess of that required for the final line and level may be removed. This fresh asphalt material is laid on top of the scarified layer and these are compacted together. The process employs a highly specialised machine, typically of considerable length which may restrict areas on which it can be used. In addition, it tends to generate high emissions. The process will provide a new running surface, primarily to replace a surface which no longer has the required texture or skid resistance properties, but in which the existing surface course material is itself in good condition.

- **Remix:**
  The Remix process is similar to Repave, the main difference being that the existing in-situ material after heating and scarifying, is completely mixed with an appropriate amount of fresh material inside the machine itself. The newly mixed material is laid directly onto the hot, scarified, level surface by the machine. When asphalt recycling additives are needed they are added in the scarifying chamber before to be remixed with fresh materials. The new material that is mixed with the existing material from the road is designed so that the resultant blend will be suitable for the site conditions and comply with the appropriate specification.

The specialised nature of the plants and the size of economically viable contracts has widely limited their use across the European Union, however they are an important maintenance tool, where successfully established.

They all involve the part removal or scarification of the existing pavement to a controlled depth: then they heat and mix the RA, to which bitumen and/or virgin aggregates can be added, before laying back the reclaimed mixture.

Among their advantages there is the reduction in site-won asphalt transportation to an off-site processing facility and the rapid re-opening of a new road surface with improved riding qualities to traffic.

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7.3.2 Cold mix technologies in in-situ re-use

The same two techniques that have been successfully adapted for off-site plant recycling were originally developed for in-situ recycling using specialised plants.

The bitumen emulsion-based system involves the scarification, bitumen emulsion mixing and compaction of RA before overlay with a new wearing course. The foamed bitumen process requires the use of an improved milling machine, which pulverises the existing pavement in a hood that also acts as a chamber in which the bitumen is foamed, and mixing takes place. The recycled pavement is then spread ready for compaction and the application of a new running surface (Figures 13 and 14).

The processes both allow for the rapid reconstruction of existing pavement and a significant reduction in the quantity of material removal from the site for reprocessing elsewhere.

In some areas and particularly the Nordic countries, the oil gravel process is used to reconstruct in-situ pavements in remote locations where plants are not available either

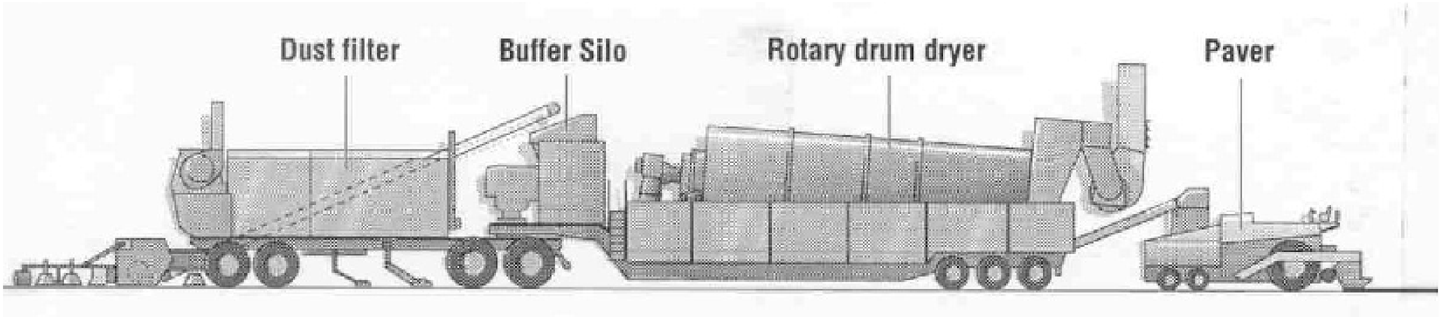

Figure 11. Asphalt recycling travelplant

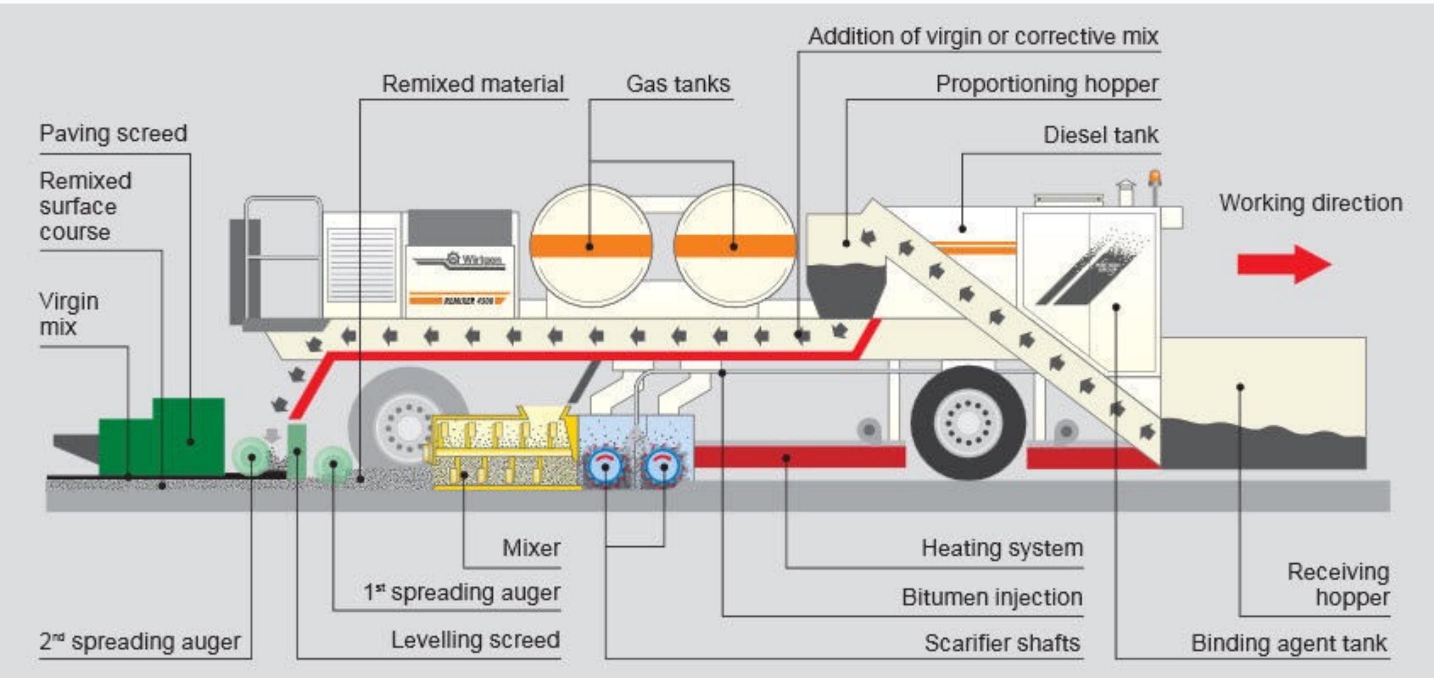

Figure 12. Example of remixer commonly used in Europe

for hot mix production or cold mix recycling.

- **Retread:**
  The Retread process is carried out to a greater depth than Repave or Remix, typically around 75mm. The road is cold-scarified and the materials homogenised with fresh aggregate and/or binder in the machine before being relaid to full depth. As this is a cold process, the materials may also require the addition of an asphalt recycling agent / emulsion in order to enhance the workability before compaction in a relatively thick layer. Retread is likely to be appropriate for in-situ cold re-use of base or binder layer materials prior to being overlaid with fresh surface layer. In some cases it may even be possible to Retread both the surface and binder layer together, if specifications and surface characteristic permit it.

- **Foamed bitumen and emulsion in-situ processes / full-depth re-use:**
  These processes reconstruct the entire road or haunches to a depth of 150mm to 350mm and involves mixing the existing material in-situ with new binders to form a uniform and strengthened structure.

  After initial milling to the required depth, the resultant surface is compacted and trimmed. Any excess material is removed before recombining the bulk of the existing materials with emulsion or foamed bitumen. Sometimes, hydraulic binders are also added creating Hydraulically Bound or Cement Bound mixes (HBM and CBM) of 100% RA aggregate, similar to the ex-situ 'hybrid' materials, such that the pavement design may also need to be considered differently, particularly if it is to be heavily trafficked.

During the process the road materials are not removed from the site and the sub-grade is not exposed, thereby reducing the risk of soft spots.

Once the re-mixing is completed, the material is again compacted, and the surface shaped by a grader to the required levels. Finally, the surface is often coated with surface dressing or micro-surfacing (e.g bituminous emulsion and sealing grit) after which it can be subjected to traffic if necessary. Depending on design requirements, a final surface course can be laid appropriate to site conditions.

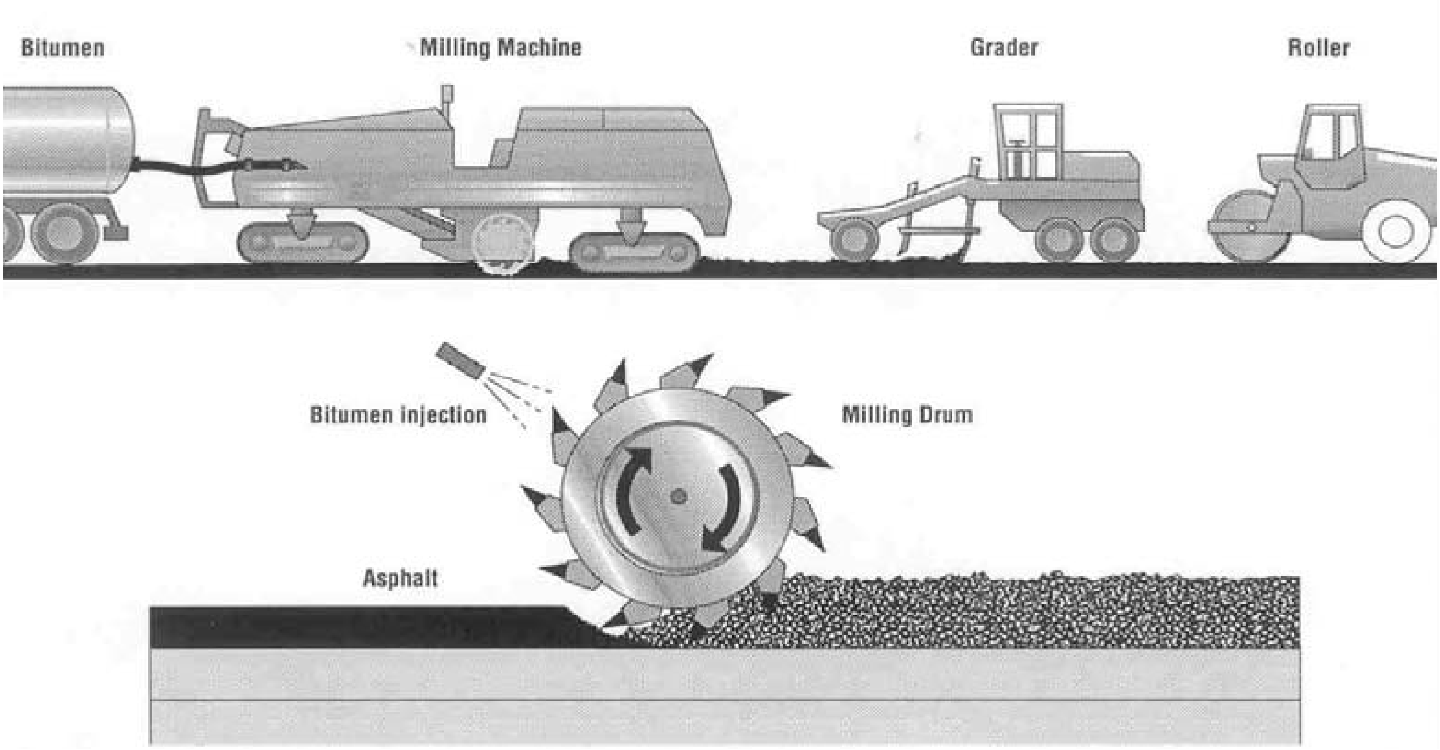

Figure 13. Cold-mix recycling without paving screed

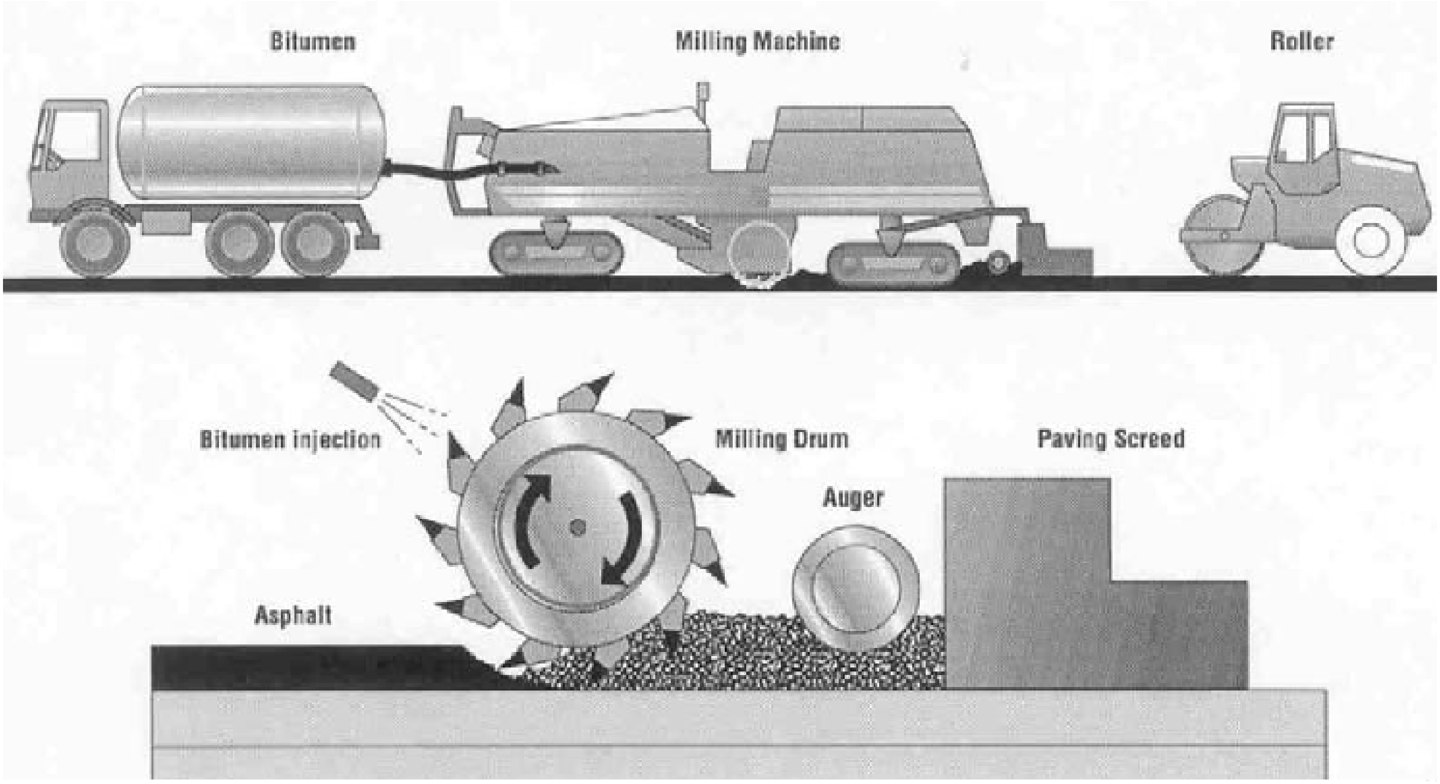

Figure 14. Cold-mix recycling with paving screed

The key assumption in determining the suitability of in-situ processes is that as the materials in the road have been already determined as appropriate for road construction then there is likely to have been little change in their mechanical performance and can continue to be used in that road.

In-situ processes generally address non-structural or surfacing issues such as the need to re-profile or re-shape a road or return surface characteristics (in combination with new surface layer materials) and where there is an existing sound and stable foundation. Full-depth re-use will address structural issues and also permit strengthening.

In some cases cold in-situ processes may be preferred where the existing road materials are or may be contaminated e.g. with road tar or other minerals and chemicals and therefore hot in-situ and/or ex-situ processes are not possible due to waste, environmental legislation and practical constraints.

7.4 Asphalt re-use / recycling agents

While the reuse of reclaimed asphalt with standard bituminous binders up to 30% addition rates is regularly successfully achieved, new challenges are arising. Over recent years, more polymer modified and harder grade bitumens have been used in asphalt production and therefore reclaimed asphalt based on them may not be adequately reused in the same way. At the same time, environmental and economic drivers demand the maximisation of the reuse of reclaimed asphalt by increasing its percentage into new mixes. In this context, an important development was the so-called asphalt re-use / recycling agents, which EAPA defines as:

- **Asphalt Re-use / Recycling agent:** family of products used in the manufacturing of asphalt mixes containing reclaimed asphalt to act on the aged bituminous binder and help to meet the requirements/specifications of binder and asphalt mixes.
  Note: The term "Rejuvenator" has been often used to refer to some of these products.

It is important to highlight that this definition, as such, encompasses a big family of commercial products available in the market, each of them with different properties and producing different effects on the aged binder and final mix. For example, while some products affect only rheological properties (e.g. viscosity, penetration or softening point) others are able to act on the chemical composition and properties of the aged binder. Hence, they can be classified into three categories, as follows:

- *Plasticizer effect / lower viscosity* :
  As recycling agents are physically in the form of an oil, their addition always results in a reduction in the viscosity (of the fraction of maltenes) of aged bitumen. In this way the viscosity of the recycling agent + the aged bitumen + the new bitumen finally reaches the appropriate viscosity in the mixture. This effect can be seen as a softening of the old binder. At the same time, a lubrication effect or reduction of friction (lubrication) can also occur, because the addition of a liquid product improves by its wettability the workability of the aggregates in the mix.

- Compensating effect in the chemical composition (maltenes / asphaltenes ratio):
  The recycling agents from petrochemicals are rich in aromatics and thus restore partially the balance in the generic composition (SARA fractions) of an aged binder by enriching the fraction of maltenes.

- *Dispersing effect*
  Certain recycling agents act as dispersants and are therefore able to break the interactions/associations between the asphaltenes present in large quantities (due to oxidation).

Recycling agents may come from a variety of sources and chemical compositions. In addition, in certain cases, e.g., when the RA content is reduced, also soft bitumen can be a good solution to re-adjust the chemical composition and recover some of the mechanical properties of the aged binder contained in the RA.

Based on previous considerations, it can be concluded that there is not an optimum re-use / recycling agent for all the cases of asphalt mixes containing RA and, in general, it will not be advisable to simply select the cheapest solution. On the contrary, the selection of the product will require a comprehensive study and will depend on a series of mix design parameters (e.g. RA content, quality and stiffness of the aged binder and characteristics of the new mix) as well as on the level of performance required for the final pavement (i.e. not the same for highways than for low-traffic secondary roads).

Asphalt producers are responsible for their product, and they declare the performance of their product in accordance with the requirements of the Construction Products Regulation in conjunction with European Standards (often referred to as "CE marking"). For this reason, it is very important to evaluate the efficiency of asphalt re-use agents in the end by testing the relevant properties of the final asphalt mixture for the intended use and ensure that the beneficial effect lasts over the service life of the new mixture. In addition, the selected asphalt re-use / recycling agents, must ensure good-quality performance to meet the obligations of the intended use and the contractual conditions, good health & safety conditions for workers and low environmental impact (e.g. not compromising re-usability / recyclability at the end of the next service life).

Due to the relevance of this technology in the current times, EAPA published in 2018 a guidance document with recommendations for the correct use of these products [3]. This document provides the asphalt industry position regarding potential benefits and underlying conditions for using asphalt re-use / recycling agents in an effective way to optimise the re-use of RA in asphalt production. Among other things, the document also details how to:

- Characterise the bitumen of the reclaimed asphalt
- Characterise the bitumen extracted from the reclaimed asphalt blended with the re-use agent
- Select the appropriate re-use agent
- Determine the optimum amount of re-use agent
- Characterise compacted asphalt specimens containing reclaimed asphalt and re-use agent

7.5 Milling and complementary jobsite operations

Before milling the existing pavement, preliminary checks must be carried out to identify and protect underground utilities, water pipes, manholes, etc.

The milling and extraction of the existing asphalt is conventionally done by crawler or wheel milling machines. These machines crush the material into finer material of a maximum gradation of 50mm. Larger pieces of material are manually removed. The operating width of these machines is usually about 2 m, which makes normal to undertake works on one road lane before moving sideways to the next lane. An overlap of around 10 cm is advisable to prevent that un-milled gaps between lanes remain in the process. Special attention must be put when milling in bends or near manholes and other structures, as un-milled gaps are more likely to happen. If this is observed, a backhoe can be used to finalise the job.

From the point of view of the re-use of materials, although there is some controversy regarding the degree of re-use that aged bitumen from RA can have, in the case of aggregates its degree of use is 100%. The only limitations can be given by an inadequate extraction of site-won asphalt during the milling process. Thus, if it is necessary to re-use the aggregates of the wearing course to be demolished by milling, this demolition process must be done with sufficient care so that the aggregates of the wearing course are not mixed with those of the binder layer, since the latter usually have worse properties in terms of PSV and Los Angeles abrasion test.

Therefore, in order to achieve the maximum degree of re-use of the RA, it is necessary that the milling process is carried out selectively and that the materials obtained are stored and classified appropriately.

For the particular case of cold on-site recycling, before the milling operations, cement can be manually or mechanically distributed on the existing surface, in appropriate proportions per unit area, as required by the mix design. Water and bitumen emulsion or foamed bitumen can be directly supplied to the distribution device of the milling machine by a tank truck, although some milling machines can directly load binder tanks.

The extension of the new mix (containing or not material from the same road) and the first phase of compaction is conducted right after the milling process.

Finishing is next carried out by a grader. Material segregation must be avoided in this operation. The desired compaction can be then achieved by using an 8 to 15 t tire roller and at least 10 t road roller with the longitudinal and cross-sectional shape in place. A vibrating roller is preferable when the thickness of the final base course is over 20 cm.

In case of using cold asphalt techniques, and in order to prevent percolation by rainwater and/or drying of the new layer, emulsified asphalt is quickly used to make a seal coating. After that, in cases requiring opening the road on the same day, a rough course of sand can be sprayed, preventing the material from sticking to vehicle tires. When different layers are being made, it is recommended that laying of the surface or binder courses is performed in a short time after lower recycling works have been completed.

7.6 Quality management

Like in all works conducted on-site, there is a possibility of quality deviations, which require the careful observation and quality testing during construction. Standard tests should be conducted to verify that the materials and equipment used are appropriate, as well as verifying that the requisite standards are met. Quality and product management is autonomously conducted by the contractor so that pavement qualities and products that meet the requirement of the design document can be empirically built.

In addition, the RA stockpiles also need special attention to ensure the homogeneity of the final mix. According to the European Product Standard EN 13108-8, the test frequency to determine the number of samples (n) for testing shall be taken from the following table.

Table 11. Minimum frequency for testing the reclaimed asphalt

Level	Tonnes/test
X	500
Y	1000
Z	2000

Where *(n)* equals the quantity of feedstock divided by the test frequency. The level should take into account the source of the reclaimed asphalt, its intended use (mix group and type) and the intended addition percentage and may be defined in documents relating to the application of asphalt products.

The number of samples (n) shall be tested for determining the properties and requirements necessary in section 4 of the Standard, i.e. foreign matter, type of binder, binder properties, binder content, aggregate grading and particle size of reclaimed asphalt.

When required, the homogeneity of the feedstock shall be declared, from the variability of the percentages of coarse and fine aggregates and of fines in the reclaimed asphalt, the binder content of the reclaimed asphalt and either the penetration, the softening point or the viscosity of the binder recovered from the reclaimed asphalt.

When a measure of homogeneity is necessary it shall be expressed as the maximum range or standard deviation of the test results of the required number of test results explained above.

In addition, the European Product Standard EN 13108-20 "Type Testing", states that the Type Test Report shall demonstrate that all constituent materials, including any reclaimed asphalt, conform to the appropriate requirements as required in the relevant product standards. Regarding changes in reclaimed asphalt, it also says that a new Type Test Report shall be required if changes in the properties of the reclaimed asphalt (as described in the relevant parts of EN 13108-8:2016, Clauses 4 and 5) result in a change to the performance levels or classes of the mix formulation as declared in the Type Test Report. This may be the result of variations in reclaimed asphalt feedstocks to those initially considered.

Finally, the European Product Standard EN 13108-21 "Factory Production Control" also states that incoming constituent materials shall be inspected and tested using procedures detailed in the quality plan and to a schedule complying with the requirements of this Standard. Results of tests carried out by the supplier may be used if the supplier's quality plan is called up in the manufacturer's quality plan. The required inspections of materials in storage shall be maintained to establish that no deterioration has occurred. For this, Table 12 is given.

8. As good as new

The fundamental requirement for producing asphalt materials including RA and recycling roads themselves by any of the mentioned techniques is that the resultant material / road have the same or improved properties compared to virgin asphalt and existing roads. Re-used asphalt can continue to contribute to circular economy at the top of the waste hierarchy, before being "down-cycled" and recycled into other applications (although after several re-uses this may eventually be appropriate). In an ideal world, RA would also be "up-cycled" into a higher value or performance application.

It is highly unlikely that aggregates in RA will be significantly affected by ageing in use and reprocessing for re-use, and having been previously used satisfactorily in a road it is more than likely that they will remain satisfactory after re-use activity.

More consideration however, needs to be given to the binder in the site-won asphalt, from its aged hardness (penetration) and viscosity to the volumetric contribution of previously coated aggregates. This is particularly important when

Table 12. Minimum inspection and test frequencies of reclaimed asphalt feedstock

Inspection/test	Purpose	Frequency
Organoleptic check of feedstock	For comparison with normal appearance with respect to grading, and shape. To check that feedstock is free from excess foreign matter.	Each day of asphalt production when using RA.
Moisture content	Process control	As indicated by the quality plan

considering the addition of high levels of RA and/or the use of reduced temperature technologies, as the binder may be "inactive" and simply contribute in the new mix as part of a "black rock" (still with certain thermoplastic and viscoelastic characteristics).

It is of great importance for asphalt producers to understand the nature of the site-won asphalt, which they intend to re-use. Road owners and clients therefore have an important role to play in maintaining accurate inventories of their networks in terms of constituting materials and where and when they were laid. This can also help identify 'legacy' materials but will also assist in making appropriate maintenance treatment decisions.

9. Carbon savings from the re-use of asphalt

In general, the use of RA in new asphalt mixtures has potential to reduce the environmental impacts, when compared to similar bituminous mixtures made with only virgin raw materials.

However, the industry takes great care to ensure that in doing so they do not negatively distort all the theoretical environmental advantages. Some considerations may include:

Higher manufacturing temperatures for effective mixing of the new and aged binder was traditionally necessary. This problem, especially affecting mixes with high RA content is nowadays minimised through the reduction of moisture in the RA stockpile, the use of energy-efficient asphalt plants, use of asphalt "recycling" agents and/or the utilisation of low temperature asphalt technologies.

When recycling agents are used, the embedded environmental impacts are considered.

Appropriate material characterisation, mix design and execution are implemented when using RA.

From the point of view of sustainability assessment, everything related to the durability of the materials can have a significant impact. When appropriate process and mix design is used, there is no difference between the durability of mixes with and without RA [4-6]. Some projects have even demonstrated longer service life on full scale accelerated experiment (LCPC carrousel) [7].

A more efficient use of resources can be achieved from selective milling operations and classifying the RA according to the nature of the aggregate and the type and quantity of bitumen.

Care is taken to ensure that site-won asphalt does not contain polluting materials that may jeopardise Health and Safety and/or the future recyclability of the new mixture. Examples of this problem are tar, asbestos, or some secondary materials containing hazardous compounds. Appropriate material characterisation and risk assessment are necessary.

Reclaimed asphalt can be used to produce hot, warm and cold mixtures. The selection of the best option for a given source of RA must be done carefully by an asphalt technologist, with the objective of optimising production efficiency and results.

Reduced hauling distances may have a remarkable positive effect on the LCA of the new mixes, due to savings in the emissions of the transport vehicles. Enhancing sustainability can be achieved by minimising transport distances.

Previous considerations lead, on many occasions, to the need of advanced material characterisation, mix design and execution techniques, which can cause reductions in asphalt plant productivity and require additional investments. This is a great effort that the asphalt sector started already decades ago and is nowadays more important than ever, due to current environmental policies.

10. Reclaimed asphalt is environmentally safe

Several countries in Europe have Regulations dealing with the potential for release of dangerous substances into groundwater or the atmosphere. Bound asphalt mixtures have been tested as monolithic structures and identified not to leach substances from within its structure. Asphalts are in fact used as linings for landfill facilities to prohibit leaching and bitumen waterproofing sealants and membranes are used for reservoir liners and dams as well piping in direct contact with drinking water.

The industrial production processes involved in asphalt production are also closely regulated across Europe to prevent excessive emissions to the environment through the burning of fuels and fumes from hot materials. Similarly, occupational exposure limits are in place to protect the health of the workforce and others in close proximity to production facilities and installation operations.

Recycling of asphalt by whatever means is clearly a sustainable approach to 'waste' management, however it must be carried out responsibly with particular respect to the environment in which it is to be applied. Of particular concern is the legacy of tar binders in existing road pavements. Until the mid/late 1980's tar from the coal production process was used as a binder in asphalt mixtures. It was subsequently established that coal tar contains potential carcinogens in the form of Polycyclic Aromatic Hydrocarbons (PAH). In their cold and solid state in pavements they do not represent a threat to human health or the environment. When heated, those PAHs can be reactivated and released with subsequent risk to health and the environment. Materials containing tar must therefore be carefully managed to ensure it does not enter the "hot recycling" stream.

However, asphalt also has a role to play in dealing with the legacy of tar in roads. Asphalt can effectively be used to encapsulate tar-contaminated materials reclaimed from old roads during their maintenance. It is vital that such encapsulation is carried out using cold asphalt recycling techniques, typically employing foamed bitumen or bitumen emulsion technologies, either in-situ or ex-situ at asphalt production facilities. As noted above, when bound into an asphalt mixture, the potential risk of leaching is minimal.

11. Regulatory framework for asphalt re-use

11.1 European Standards

As has already been demonstrated, asphalt is 100% recyclable back in o asphalt. For this reason, it was appropriate for asphalt materials intended for re-use by many of the methods above to be classified to a European Standard for inclusion in materials specified under other European Standards. For Reclaimed Asphalt Planings that Standard is part of the family of European Asphalt Standards themselves, namely EN 13108-8.

EN 13108-8 requires producers handling RAP materials for inclusion in other materials under EN 13108 to assess the suitability of that material as feedstock into the asphalt mixing plant. This will include the size, shape, particle size distribution, aggregate type, binder content and grade in the RAP. In addition, because RAP is often associated with mixed sources of construction and demolition waste, it is necessary to determine the level of contamination by other materials (e.g. uncoated aggregate, soils, concrete, ceramics, plastics, wood etc.). Quality control limits in EN 13108-8 determine which, and the levels to which, contaminants will need to be separated out of the feedstock to ensure best compatibility with the new asphalt. Ideally, all contaminants will be removed before being assessed for suitability as RAP.

Provision is made in all the EN 13108 standards to ensure the appropriate quality and performance level of materials produced including RAP to EN 13108-8. Aggregates in RAP should conform to the aggregates Standard, EN 13043, and bitumen (generally) to EN12591. This is particularly important in the case of asphalt intended for use in surface courses where aggregate properties such as Aggregate Abrasion Value (AAV) and Polished Stone Value (PSV) are vital for safety. For this reason it is currently generally permitted to include higher percentages of RAP into base and binder course materials (typically 30%) than in surface courses (typically 10%). These percentages have been exceeded in many applications and will continue to rise, particularly as better records and control of RAP feedstock from clients is achieved and mixing technology develops.

The EN 13108 family of Standards include specific procedures for calculation of the amount and grade of fresh binder required for a new asphalt mixture of the correct binder content and grade when RAP from known feedstocks is added. The resultant required aggregate additions can also be calculated by simple blending programmes. Properties of mixtures containing RAP should also be Type Tested to EN 13108-20, and additional requirements for factory production control of mixtures and feedstock are found in EN 13108-21.

11.2 End-of-waste criteria for site-won asphalt

11.2.1 General framework

The frame document at European level is the Directive 2008/98/EC on waste (Waste Framework Directive), which defines "waste" as "any substance or object which the holder discards or intends or is required to discard".

In 2018, the European Commission approved a Circular Economy Package, which includes four directives to be implemented by Member States within a two-year period. One of the directives (2018/851) in this Package amended the Waste Framework Directive, urging Member States to improve their waste management systems into the management of sustainable material, to improve the efficiency of resource use, and to ensure that waste is valued as a resource. Among other areas of focus, the amendments addressed:

- Measures to prevent waste generation, inter alia, obliging Member States to facilitate innovative production, business, and consumption models that reduce the presence of hazardous substances in materials and products, encourage the increase of the lifespan of products, and promote re-use.
- The handling of municipal wastes.
- Incentives for the application of the waste hierarchy, such as landfill and incineration charges or pay-as-you-throw schemes.
- Measures to encourage the development, production, marketing and use of products suitable for multiple use that contain recycled materials, and that are, after having become waste, suitable for re-use and recycling.
- Measures to promote the re-use of products constituting the main sources of critical raw materials to prevent those materials from becoming waste.
- Minimum operating requirements for extended producer responsibility schemes.

As asphalt is in general a material 100% re-usable and recyclable, its use would clearly contribute to the achievement of all previous principles. However, the definition of waste has not changed, and it is precisely its interpretation, which can be a barrier for the further re-use and recycling of reclaimed asphalt in many European countries.

11.2.2 Different interpretations in different European countries

The general interpretation applying to asphalt in most of European countries is that the owner (i.e. Road Administration, Public Agency, Ministry, Municipality, etc.) intends to remove the material from a given road before a further construction/ maintenance operation but without having any specific purpose or intention for its further use. Therefore, the definition given by the Waste Directive automatically applies and the material is classified as "waste". Although then, the contractor typically becomes the new owner, the classification does not automatically change.

Such classification involves the application of a waste regime, which can make difficult the use of reclaimed asphalt in the manufacturing and maintenance of roads or into other applications of civil engineering. In addition, the handling of this material becomes more complex, for example due to increases in testing frequency or limitations on maximum storage capacity, storage time, applications, etc. This normally results in lower efficiency and higher costs. In other words, these regulations can themselves be a barrier for the circular economy in paving engineering.

In some countries, such as Spain, the only alternative is to use the extracted material straight back on the same road through the implementation of on-site re-use and/or recycling techniques. With this approach, only the exceeding material, which is not immediately used and consequently needs to be transported away, must be handled as waste.

On the other hand, the waste classification is reversible in some other European countries, which have recently established (or are in the process of establishing) legal mechanisms to change the classification of site-won asphalt, from "waste" to "product" or "by-product". In these cases, the change of legal status usually happens when the site-won asphalt is processed into reclaimed asphalt (i.e. through cleaning, crushing, sieving, etc.) and as long as a series of "end-of-waste" criteria are met.

Unfortunately, these criteria can significantly vary from country to country, depending on specific national regulations. In addition, as this is a hot topic related to European priorities, most National Administrations across Europe are nowadays developing new legal documents, which makes the current European legal framework extraordinarily complex and under constant revision.

In countries, such as Germany, the end-of-waste criteria can even vary significantly inside the country, depending on the National, Regional or Municipal Administrations undertaking the project. Thus, it can be found that, while for some of these Administrations the milling process is enough to reach the end-of-waste status, others even charge contractors and asphalt plants for storing "waste". In Germany, a wide range of tests, such as binder content, ring-and-ball or aggregate composition are being already undertaken to optimise the RA content in the new mix. Nevertheless, this extensive assessment is not enough to declare the material as non-waste by a great deal of Administrations, requiring that besides processing operations (crushing, sieving, etc.) site-won asphalt must be analysed with much higher frequency (every 500 tonnes) than any other raw material, which can significantly increase costs.

The problem in other countries is that they do not have a clear policy, being necessary to assume possible interpretations of existing documents, which can change depending on the situation. In these countries, companies argue that site-won asphalt can meet aggregate standards, so as soon as it gets milled and loaded into the track, it can be considered as a "product" (as an aggregate mixture product). However, when an asphalt plant uses this material as an "asphalt component", the status of the material changes again, which can produce new issues. In addition, there are certain applications, such as utility works (e.g. laying pipes or cables along urban street pavements), which require the extraction of asphalt that is not normally assessed. Therefore, this must be considered as hazardous waste.

11.2.3 Steps forward

An increasing number of countries are establishing regulations, which clearly state when site-won asphalt can stop being classified as waste, based on well-defined principles.

A good example is Czech Republic, which in 2019 published the public edict No. 130/2019 Col. In this, it is stated that, if the owner of the road is able to declare that the asphalt layers to be milled or deconstructed are not hazardous (e.g. by identifying the PAH content), the extracted material can automatically be declared as a "by-product". In addition, a declaration is required, stating that the material will be treated in a mixing plant or by a recycling company with the purpose of using it as a by-product. It is not required that all the material is used at once or on the same road. Instead, it can be stockpiled and used over the following years, as necessary. Product Standards like EN 13108-8 and EN 13242 apply in order to turn the site-won asphalt into reclaimed asphalt for re-use into asphalt mixtures or recycled as aggregate for other applications.

This huge step forward has also advantages for the Administrations. For instance, it contributes to the objectives and measures proposed by the Waste Framework Directive and the amending Directive 2018/851 mentioned above. In addition, the non-declaration of site-won asphalt as waste avoids the need of an extra budget for waste handling, storage, processing and/or disposal.

A similar case is Italy, where the site-won asphalt ceases to be classified as "waste" if it meets a series of simple and well-defined criteria, included in the Decree of 28 March 2018, No. 69, Art.3. by the Ministry of the Environment and Land and Sea Protection.

Examples of other countries, which have recently advanced their national regulations in this direction are Belgium and The Netherlands.

12. Circular economy through the recycling of other waste materials into asphalt

Although the strong EU policy on Circular Economy can facilitate the use of reclaimed asphalt for the construction and maintenance of new roads, it can also boost a series of initiatives aiming at introducing a wide range of different by-products and waste materials from other sectors into asphalt. In this sense, EAPA has been warning over the last years, about the negative consequences that some of these products may produce into asphalt, especially in terms of quality/durability, environmental impact and health and safety of workers/operators [8].

The use of some waste materials and by-products into asphalt, could even endanger its re-usability and recyclability at the end of its service life. Therefore, and despite seeming paradoxical, the use of such materials could contradict the principles of circular economy, as it would make necessary to dump into a landfill, a material that otherwise would be 100% re-used and/or recycled several times.

For these reasons, by-products or waste derived materials, offered to the asphalt industry must only be incorporated into asphalt if it can be demonstrated through a Risk Assessment process, that now and in the future, there will not be disadvantages with respect to health and safety, environmental impact, end-of-life re-use, value for money, technical performance and competitiveness of asphalt solutions.

13. Conclusions and recommendations

The well-appreciated benefits of asphalt and asphalt roads can be replicated time and time again by re-using and recycling this essential construction material. Asphalt is durable, easy to repair, 100% re-usable and recyclable as itself and with continually developing and innovative technologies, the scope for circularity will continue to increase.

Due to all the considerations gathered in this document, asphalt roads are valuable assets and a sound investment for future generations. Asphalt re-use is proven successful technology, environmentally sound, economical and contributes to conservation of natural resources.

Optimising and maximising the re-use and recycling of reclaimed asphalt clearly makes sustainable sense in delivering the roads of the 21st century and beyond.

Unfortunately, there are still historical misconceptions of "new" being better than "re-used" and the application of regulations (e.g. Waste Framework Directive) has led some countries not to facilitate the transition of site-won asphalt from "waste" category to "secondary raw material". This is often translated into special operating procedures, which can reduce efficiency and increase costs.

The asphalt industry continues to work to ensure that, as long as it is technically and economically viable, a proper road maintenance must be carried out to maximise the service life of our road networks, prevent waste generation and minimise the depletion of new resources. After that, the re-use of existing asphalt shall always be the first option and its recycling the second. Therefore, there should be no intent (or requirement) to discard this valuable material. In other words, "asphalt" should never be considered as a "waste".

Finally, the asphalt industry must avoid the use of products, by-products and waste materials from other sectors, which may endanger asphalt fundamental properties, such as its own circularity.

With the aim of helping producers and contractors to achieve previous goals and maximise the circularity in the road sector, EAPA recommends the following practices:

1. **To adequately manage asphalt with legacy materials.** Examples of these can be coal tar or asbestos. While such products are no longer used, they can still be found in old road pavements and seeking to re-use them requires particularly special attention from start to finish from identification and assessment, to milling, transport, storage, disposal or mixing. Road owners have a fundamental Duty of Care in identifying the presence of potential contaminants in roads which they need to maintain, and therefore have a key role to play in ensuring that such wastes or any secondary materials, do not enter the re-using stream.

2. **To prevent the introduction of waste materials and by-products from other industries, which could compromise fundamental characteristics.** Alternative components proposed to the asphalt industry must be only incorporated into asphalt if it can be demonstrated through a Risk Assessment process, that now and in the future, there

will not be disadvantages with respect to circularity, health and safety, environmental impact, value for money, technical performance and competitiveness of asphalt solutions.

3. **Optimum design for optimum performance.** When RA is added to the mix, the durability of the material can be affected in different ways. Hence, the determination of the rutting resistance alone will be, in general, not enough. Other performance characteristics (e.g. cracking and fatigue resistance, impact of ageing, etc.) must be also assessed and controlled from the mix design. In addition, mix design and manufacturing process must be undertaken with focus on enabling the re-usability and recyclability of the new mix, once it reaches again its end-of-life.

4. **To maximise homogeneity in RA feedstocks.** Some effective measures are:

   - To cover stockpiles and place them on paved surfaces
   - To recover and test the RA binders to evaluate their properties with sufficient frequency
   - To fraction RA and equip plants with multiple RA feed bins

5. **To minimise moisture in the RA.** Keeping the RA with minimum moisture content is crucial to reduce the need of superheating the virgin aggregate for indirect heating of the RA, which means increases in production rates. To obtain this, it is important to use as little water as possible in crushing operations and keep the stockpiles and bins covered. It is recommendable to pre-heat the RA to drive out moisture before adding to the mixer. When possible, a separate drum for drying and pre-heating RA will be used (the so-called parallel heating method) (Figure 15).

Figure 15. Parallel drum for RA

6. **To compensate the ageing process in the design of the added virgin binder.** The target binder content and properties (e.g. penetration value at 25 °C, softening point temperature or rheological properties) can often be achieved by simply blending with one grade softer virgin bitumen. However, in some cases, it may be required to recover the lost properties of the aged binder by using additives, which ensure the appropriate performance of the final mix. These are known as asphalt re-use (or recycling) agents and recommendations are included in the EAPA Guidance document on the use of rejuvenators in hot and warm asphalt production [3].

7. **To undertake high-quality manufacturing processes.** The execution of high-quality mix manufacturing and on-site construction operations can create greater impact on the pavement performance and durability than advanced mix design tools or complex material testing methods. Hence, especial care must be put on these operations over the whole process, including RA milling and processing, storage, mixture production paving and compaction. Some improvements in asphalt plant may include longer virgin aggregate and RA mix times, high shear mixing, and storage time, which may facilitate the softening and blending of the RA binder.

8. **To ensure re-usability of any polymer modified bituminous binders.** The most commonly used modifiers for bitumen, like SBS and EVA, can be easily re-used as being thermoplastic they melt upon heating, even after ageing. Hence, the polymer can still have a substantial beneficial effect on the performance of the new mix. Nevertheless, it might also have significantly degraded, which would require the addition of extra polymer in the added binder (so-called PmB

RC in countries, such as Germany, Austria and Czech Republic). For all these reasons, the presence of polymers in RA therefore needs to be qualified in the overall mixture design.

9. **To optimise energy efficiency.** Fumes can be treated, and hydrocarbon odour can be eliminated by using after-burner technology. Thermal oxidizers can be used to handle emissions from the RA dryer. A significant part of the heat energy can be recovered by ducting hot gasses to the virgin aggregate dryer.

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