A study on Lower Temperature Asphalts Commercialisation in the UK
The Carbon Trust’s mission is to accelerate the move to a sustainable, low carbon economy. It is a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, it advises governments and leading companies around the world, reinvesting profits into its low carbon mission.

The UK Government’s Regional Growth Fund (RGF) financed this report. The Regional Growth Fund supports eligible projects and programmes that are raising private sector investment to create economic growth and lasting employment. Since its launch in 2010 it has invested £2.85 billion to help local businesses grow and take on more staff across England.

Author:
John Walch
Analyst, Carbon Trust
john.walch@carbontrust.com
Executive summary

The report presents a general review of the use of lower temperature asphalts (LTA) and the drivers and barriers to their commercialisation. Its principal purpose is to help educate interested stakeholders who are not necessarily experts in these products and technologies. It should also be of value to policy makers who are looking for a useful introduction to the topic.

Asphalt is mainly used in the transportation sector for paving roads, but also for a variety of other applications such as airfields and runways, footways and cycleways, ports, landfill caps, construction site working platforms, and roofing. Asphalt is made of two main components; aggregate and bitumen. 85% of the total worldwide bitumen production is used as the binder in asphalt for paving, 10% for roofing applications, and the rest for secondary uses [1]. Conventionally, asphalt is produced at temperatures above 140°C and denoted as hot mix asphalt. Responding to global energy, environment, and health and safety drivers, lower temperature asphalts have been developed by industry to reduce the “carbon footprint” of asphalts and contribute to improving workers’ conditions. Lower temperature asphalts are often semi-qualitatively divided into a range of “warm”, “half-warm”, and “cold” mix asphalts depending on the absolute asphalt production temperature, or the degree of temperature reduction. Of these descriptive technologies, warm mix asphalts (WMA) currently appear to be the most likely to be adopted in the UK to widely replace hot mix asphalt.

Today, LTA technologies are well-established and understood. Numerous laboratory tests and field trials have confirmed the performance of LTAs in the short and medium term, and asphalt manufacturers agree that its long term performance could be at least equivalent to its hot counterpart. However, LTA remains a young technology in comparison to conventional asphalt lifetimes and certainty of its long term performance is often perceived as the main risk by the Highway Authorities and Local Authorities.

Even so, LTA technologies have been shown to have one or more of a number of advantages, including:

- Reduced energy consumption;
- Lower emissions, fumes and odours;
- Improved compaction and workability;
- Possibility of higher reclaimed asphalt (RA) percentage in mixes;
- And ability to pave in colder weather.

The suite of European Standards for asphalts and the national guidance documents for their implementation do not absolutely prohibit the use of lower temperature asphalts in the UK, but equally do not provide specific guidance on their use. For example, the European Standards have requirements for maximum temperatures but there are no minimum temperature requirements. However, whilst lower temperature asphalts may be used in the UK, most of the current specifications and pavement designs are written based on knowledge of hot mix asphalt performance. As a result, it may be a more lengthy and involved process to design, specify and procure lower temperature asphalts, possibly discouraging their use.

In the USA, the use of lower temperature asphalts is increasing rapidly; LTA production now represents about a third of the total asphalt production and it is expected to keep growing in the coming years with no significant barrier to adoption. The technology development and adoption was catalysed by government programmes such as “Every Day Counts” and the involvement of the National Cooperative
Highway Research Program (NCHRP), which played a crucial role to address technical barriers, knowledge dissemination, and provide visibility on the technology. In addition, the bonus offered to asphalt manufacturers achieving a certain level of compaction played an important role to accelerate LTA’s growth. State agencies have also been very proactive to trial lower temperature asphalts and gain confidence in the products’ performance. In the USA, it is considered that LTA improves conditions for achieving performance and long life.

In Europe, more and more companies are now equipped for producing LTAs with different processes and are undertaking studies and trials. However, the adoption of LTAs remains very slow. Asphalt specifiers are looking for proof of long term performance, which means that more time may still be required to confirm lower temperature asphalts have similar performance as hot mix asphalts.

Government incentives seem to play a major role in accelerating the uptake of LTA. France has seen a fast increase in LTA production in the four years to 2013, achieving 14% of their total asphalt production in that year. The uptake was catalysed by a mutual and voluntary agreement between the state and industry, making the technologies visible and encouraging their use. One of the agreed targets for the industry is to achieve 30% of LTA by 2017. Similarly, the use of LTA increased quickly in Norway following the establishment of a bonus by the government when asphalt production temperature is at least 25°C lower than conventional asphalt.

In the UK, there are currently no incentives to drive the uptake of lower temperature asphalts by Local Authorities. Nevertheless, an increasing number of Local Authorities are showing interest in using the products.

From discussions with several organisations, there is a clear consensus that LTA usage is growing and it is expected that its use will become routine in Europe. However, the adoption is still slow in most countries. Below are some proposed recommendations that emerged from this study to encourage the technology’s commercialisation in the UK:

- Removing qualitative definitions of asphalt such as “cold, half-warm, warm” from specifications would be useful to eliminate potential artificial barriers to innovation.
- Lower temperature asphalts are often not well known to specifiers and effort should be made to increase the products’ visibility and benefits through more trials and reports.
- There is a need for a competent authority to develop specifications and design guidance and make them readily available to Local Highways Authorities and contractors.
- The US story encourages the building of collaborative multi-organisational working groups to accelerate the development, fundamental understanding and release of guidance and specifications, which are essential for the wide adoption of LTA.
- The Government should incentivise the uptake of lower temperature asphalts by incorporating financial or regulatory incentives.
- Asphalt specifiers could gain confidence in using lower temperature asphalts if more information is provided on successful stories around the world. More field trials in the UK are also needed to enhance confidence and documentation on the trials’ results should be compiled and disseminated.
Acknowledgment

We would like to thank the following organisations for providing information that helped to build this case study: Lafarge Tarmac; Nynas; Norfolk County Council; Mineral Products Association; Greater London Council; Highways Agency; Cormac; The National Center for Asphalt Technology; The National Asphalt Pavement Association; The European Asphalt Pavement Association; MAXAM Equipment; Arizona Department of Transportation; Eurobitume; Deutscher Asphaltverband; Veidekke; and BAM Group.

We would also like to thank Cliff Nicholls from the Transport Research Laboratory and Malcolm Simms from Mineral Products Association for reviewing the document.
1. Introduction

Where do road paving emissions come from?

The following pie chart shows an example of the total carbon footprint allocation for the construction of roads between manufacture of materials, asphalt production, site machinery, and transportation. Typically, about 60 kg of CO₂ are emitted per tonne of asphalt produced and laid. Whilst the proportion of emissions in each category is very variable and depends on the type of project, asphalt processing is clearly the single most carbon intensive process per tonne of asphalt installed. It is followed by bitumen processing (depending on the bitumen content of asphalt – usually 5%) and transport. Asphalt processing accounts for about 44% of the total carbon footprint of asphalt from extraction to installation [2]. Hence, there is a strong incentive to develop low carbon manufacturing technologies. The industry came up with two major strategies to mitigate emissions from asphalt production: reducing asphalt mixing temperatures and the increased use of reclaimed asphalt.

Exhibit 1: Total carbon footprint allocation for a typical road pavement project [2], [3].

The asphalt sector emitted about 530,000 tonnes of CO₂ in 2013 from the manufacture of 19 million tonnes of asphalt [4].
What is asphalt made of?

Asphalt mixtures are primarily composed of aggregates and bitumen (sometimes called asphalt binder):

- **Aggregates**
  Hard, inert granular mineral materials, such as crushed stone, gravel, and sand, providing most of the load bearing characteristics of the mix. Aggregates make up 90-95% of the asphalt mixture by weight [5].

- **Bitumen**
  Dark brown to black, sticky substance produced by refineries during petroleum processing. Bitumen is a thermoplastic material, meaning that it will liquefy without decomposing when heated and solidify when cooled. It binds the aggregate particles into a cohesive mixture, hence often named binder. Sometimes, polymer-modified bitumen is used instead of conventional bitumen. Bitumen makes up approximately 4-8% of the asphalt mixture by weight [5].

![Exhibit 2: Structural asphalt layers of a road [6].](image)

An asphalt road is generally made of several layers of different materials. Starting at the road surface, the first layer is called the surface course. The second layer is the binder course and the lower bound layers are the base. For a good bearing capacity of the whole road structure, it is important that there is a good bond between all the bound pavement layers [7]. The surface course constitutes the top layer of the pavement and should be able to withstand high traffic and environment-induced stresses. The binder course is placed between the surface course and base courses to reduce rutting (surface depression in the road) by combining qualities of stability and durability. The base is intended to effectively distribute traffic and environmental loading in such a way that underlying unbound layers are not exposed to excessive stresses and strains [7]. A wide range of products are available for each of these layers, such as asphalt concrete, mastic asphalt, porous asphalt, etc., with different properties.
What are lower temperature asphalts?

Lower temperature asphalts (LTA) describe a group of products produced with technologies which allow a reduction in the temperatures at which asphalt mixtures are produced and placed. It is the result of constant efforts in the asphalt industry to combine energy savings and environmental benefits, as well as improving construction efficiency and working conditions at comparable performance. Decreasing the temperature of material production appeared as a logical approach to achieve these goals. The equipment used for producing and transporting lower temperature asphalts is basically the same as for hot mix asphalt (HMA), although there may need to be some modification to the mixing plant depending on the specific process or technology. It is reported that low temperature asphalt technologies can lead to energy savings ranging between 10-40%, although it can be higher with some processes.

Despite their benefits, lower temperature asphalts are still only used in relatively small quantities in many countries, mainly because the products have not been around long enough to provide enough confidence to specifiers. However, more and more manufacturers are now equipped to produce LTAs and Local Authorities are increasingly willing to trial the products.
Classification of asphalts by mixing temperature

High production temperatures are traditionally needed to make the bitumen more fluid during mixing so as to completely coat the aggregate and also to have good workability during hauling, placement, and compaction. LTA technologies use water, water-bearing minerals, chemicals, waxes, and organic additives or a combination of techniques. The methods are applied to either the mixture or the bitumen to enable production of mixtures at lower temperatures. These technologies allow the bitumen to remain fluid at lower temperatures (i.e. decrease its viscosity) during mixing in order to completely coat the aggregates.

Classification of asphalts by mixing temperature only has given rise to the evolution of several terminologies. These may include an element of both quantitative and qualitative description, but when considering LTAs it is important to evaluate the reduction in temperature as well as the final output temperature (or boundaries implied by them).

- **Hot Mix Asphalt (HMA): above 140°C**
  The traditional process for producing asphalt is for aggregate and bitumen to be heated and mixed while hot to completely coat the aggregate with bitumen. The ingredients are heated (or added) above about 140°C (the actual temperature depends on the mixture type and grade of bitumen) during mixing and protected from heat loss during transport by insulated truck. The asphalt mixture then undergoes placement (where it is spread on the roadway by an asphalt paving machine) and compaction (where it is compacted by a series of asphalt roller machines). The mixture then cools to form the specific element of the asphalt pavement [5].

- **Warm Mix Asphalt (WMA): 100-140°C**
  As shown in Exhibit 5, warm mix asphalt relates to asphalt produced at mixture temperatures reduced to roughly between 100°C and 140°C [10]. With WMA, temperatures are lower during mixing and remain lower during trucking, placement, and compaction.

  Note: WMA is sometimes used as a general term for the range of technologies that reduce the temperature needed to produce and compact asphalt mixtures for the construction of pavements (here referred as LTA).

- **Half-Warm Mix Asphalt (HWMA): 60-100°C**
  If the resulting temperature of the mix at the plant is roughly between 60°C and 100°C, the mix has been considered as a half-warm mix [10].

- **Cold Mix Asphalt (CMA): Unheated aggregates**
  Cold mix asphalts are mixed using unheated aggregate and bitumen emulsion or foamed bitumen [10]. As for warm and half-warm asphalt, cold asphalt can be used for any structural layers. It is typically used for repairing potholes and other small defects in roads or for specific applications. It provides a way to make road repairs quickly because it can be applied right from the container without heating. However, cold mix asphalts tend to require time to cure to their design strength.
From 0°C to 100°C, heat is used for drying or driving water out from the aggregates. At 100°C, vaporisation occurs and the energy is used to turn water into steam. Finally, the heating step heats dried aggregates to the required mixing temperature.
2. Lower Temperature Asphalt Production Technologies

There are many processes and products that can be used to achieve a reduction in temperature, but generally lower temperature asphalts technologies can be separated into three main categories. A list of most often reported lower temperature asphalt technologies is given in Appendix 1.

- **Foaming technologies**
  The foaming effect is one of the most commonly used LTA technologies due to its cost-effectiveness. Foaming techniques can be divided into water-based and water-containing mineral additives or techniques. The water-based technology requires the injection of small amounts of water into the binders or in the asphalt mixing chamber, thus creating a large volume of foam when the water evaporates in the binder. Consequently, the volume of the binder will be enlarged and the viscosity will be diminished momentarily by the foaming action in the binder, which improves coating and workability. This technique can enable a temperature reduction of the asphalt mix of about 20°C to 40°C [12]. Foamed bitumen technology can be adapted and used for half-warm and cold mix asphalt production and therefore achieve greater temperature reduction.

- **Organic additives**
  Wax and fatty acid amide are the most commonly used organic additives in LTA. The organic additives reduce binder viscosity when heated above their melting point, which enable manufacturing of bitumen mixes at lower temperatures. Organic additives typically give a temperature reduction between 20°C to 30°C [12].

- **Chemical additives**
  Different chemicals can be provided which are suitable for different applications. Chemical additives include emulsification agents, surfactants, and polymers to improve coating, mixture workability and compaction. In particular, chemical surfactants improve the ability of the bitumen to coat the aggregate particles at lower temperatures rather than reduce the bitumen viscosity. Chemical additives typically reduce the mix and compaction temperatures by about 20°C to 40°C [12]. However, some technologies allow greater temperature reductions. Bitumen emulsion technologies typically allow the lowest mixing temperatures (cold mixes).

Lower temperature asphalts can offer the same performance whether it is made using foaming technologies or additives. The choice between the various production techniques largely depends on the asphalt manufacturer’s preference between an initial capital investment to modify the plant or buying additives, which also depends on the plant’s characteristics such as its geometry or its age. However, many of the additives have a significant carbon footprint and their use may diminish, or even negate, the sustainability argument for lower temperature asphalts. Other criteria such as national regulations can sometimes favour a technique over the other.
3. Characteristics of Lower temperature Asphalts

Advantages

Lower temperature asphalts are driven by three major benefits: (1) lower emissions during production and laying (which benefits the workers’ environment), (2) reduced energy consumption (which lowers fuel use and carbon emissions), and (3) increased mixture workability (which improves the ease of placement and compaction efficiency). These advantages have different impact depending on the region. Hence, the incentives to choose LTA over HMA can vary a lot between countries.

- **Lower emissions**: The occupational health of the workforce must be protected. Lower mixing and paving temperatures minimise particulate, fume and odour emissions and creates cooler working conditions for the asphalt workers. This will be increasingly important as emission regulations are getting stricter. Some countries, for example the USA, have set regulations or targets to reduce emissions thus encouraging the use of LTA.

- **Reduced energy consumption**: Energy is an important cost for producers’ business. The energy and cost saving potential of producing LTA is an incentive, particularly when energy costs are high, e.g. fuel oils in comparison to natural gas. If energy costs are already low then the relative savings may be not enough to compensate for any capital investment needed to make equipment changes. Nonetheless, reduced energy use will result in less carbon emissions.

- **Improved workability**: Improved workability enables improvements in general compaction efficiency and therefore durability [13]. It therefore also has the potential to reduce the risk of inadequate material performance associated with cool weather paving and compacting stiff mixes.

While lower emissions and reduced energy consumption appear as the main benefits, they only make a strong business case for LTA adoption in certain scenarios. Increased workability, however, makes a good business case for widespread LTA technology adoption because this benefit offers cost and risk reduction (i.e. offers improved compaction efficiency and equivalent durability to hot mix asphalt).
**Exhibit 6: List of all potential advantages of lower temperature asphalts.**

<table>
<thead>
<tr>
<th>Potential benefits of LTA</th>
<th>Economic</th>
<th>Operational</th>
<th>Environmental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher proportion of reclaimed asphalt in mixtures possible ¹</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced energy consumption</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Reduced emissions of CO₂, as well as reductions in SO₂, VOC, CO, NOx and dust ²</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Less ageing of binder during the production and paving, thus improving longevity of pavement service life ³</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longer haul distances due to possibility to pave at lower temperature ⁴</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Cold weather paving. As the difference between the ambient temperature is smaller for LTA than HMA ⁴</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved working conditions for the paving crew because of lower paving temperature</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Improved workability because of lower bitumen viscosity at paving temperature ⁵</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improved compaction possibility, which is achieved through the reduction in viscosity of binder ⁶</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Similar or better performance ³</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less nuisance to public near production and work sites as emissions of fume and odour are reduced</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Less wear on asphalt plant</td>
<td></td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Reduced time of pavement cooling because of lower initial temperature</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

Detailed explanation is given for some of the above points:

1 **Increased proportions of reclaimed asphalt (RA)**

In LTA, the lower mixing temperatures means that the virgin asphalt binder would not be as “plant aged” as in an HMA and, therefore, an increase in RA could be possible before the resulting mixture would be too stiff, with the potential for early cracking [14]. The amount of RA has been limited in HMA by many highway agencies in the USA because of concerns that at higher amounts of RA addition the asphalt mixture would be too ‘aged’ after production [15]. In some cases, it was estimated that the financial benefits of higher RA content with LTA can compensate for the cost of the LTA technology.
Reclaimed asphalt is another strategy to significantly reduce the embodied asphalt carbon footprint as it replaces primary aggregates and binder. In the UK, between 4 and 5 million tonnes of RA were available in 2013. This is equivalent to a quarter of the annual UK asphalt production. Figures for RA in Europe are given in section 3.2.

Reduction of emissions, fumes and odours
Working conditions are improved with LTA. Both at the production plant and on the construction site, workers inhale far less fume, and the working environment is not as hot. Comments from workers have been highly positive [5].

Exhibit 7: Heavy fumes and steam from a road-roller working with HMA in winter conditions [16].

Exhibit 8: Comparison of fumes released by hot mix asphalt at 160°C and warm mix asphalt at 120°C [17].
This reduction is particularly important in tunnels, where ventilation is reduced. As a rule of thumb, the release of fume is reduced by around 50% for each 12 °C reduction in temperature [12]. Details on the emission reduction of plant stack emissions of specific compounds reported in the literature for WMA and HWMA are given in the following table. Note that the actual reductions vary based on a number of factors, such as the fuel used, and should be considered on a case by case basis.

Exhibit 9: Emission reduction for WMA and HWMA [10]:

<table>
<thead>
<tr>
<th>Compound</th>
<th>Reduction range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>20% to 40%</td>
</tr>
<tr>
<td>SO₂</td>
<td>20% to 35%</td>
</tr>
<tr>
<td>VOC</td>
<td>Up to 50%</td>
</tr>
<tr>
<td>CO</td>
<td>10% to 30%</td>
</tr>
<tr>
<td>NOₓ</td>
<td>60% to 70%</td>
</tr>
<tr>
<td>Particulate</td>
<td>20% to 55%</td>
</tr>
</tbody>
</table>

Apart from improved working conditions, the reduction of CO₂ is particularly attractive to mitigate greenhouse gas emissions. Exhibit 9 shows the average carbon emissions for each step in the asphalt lifecycle.

Exhibit 10: Indicative lifecycle carbon emissions for the production of one tonne of asphalt [2], [3].
Please note that these numbers are indicative only and vary with factors such as the distances from quarries to the asphalt plant and to the paving site. Carbon emissions from the production of asphalt (mainly drying, heating and mixing) also depend on the processes and types of asphalt produced.

3 Improved longevity and better performance of asphalt
Whilst it is acknowledged that claims of enhanced performance and durability have been delivered elsewhere due to less ageing of binders during production and paving, some specifiers wish to see evidence of this more locally. Even though LTA has only been used on UK road for a short period, asphalt manufacturers generally agree that its performance can be at least similar to its hot counterpart.

4 Cold weather paving
In paving projects, the greater the temperature difference between the asphalt mix and the outside temperature, the faster the mix cools. Faster cooling can adversely affect durability, as when asphalt cools it becomes stiffer and less workable, which them can prevent sufficient compaction being achieved. Relative to HMA, LTA cools more slowly allowing LTA to be successfully placed in lower temperatures. As a result, LTA extends the paving season into periods when day (and night) temperatures are lower.

Low temperature asphalt technologies may also permit asphalt mix to be hauled for longer distances. This advantage is particularly useful when working in remote areas with no asphalt plants nearby.

Exhibit 11 shows the workability gain when lower temperature asphalt technologies are used but heated up to hot mix asphalt temperatures (point B). The increase in workability can be translated into additional time to work with the mixture before it becomes too stiff. Point A is an example when similar workability is achieved at lower temperature (typical use of LTA production technologies).

Exhibit 11: Relation between temperature and workability of asphalt.
Please note that the relationship between temperature and workability has been assumed to be linear on this graph. The relationship is variable depending on the type of mixtures, the air temperature, and various other factors. Similarly, the additional time will vary depending on these factors.

Workability has an inverse relationship with viscosity and is closely linked to compaction and durability.

5 Improved workability
Reducing bitumen viscosity usually results in better workability and a less “sticky” mixture. While this benefit is difficult to quantify, it is reasonable to assume that, a more workable mixture will be paved more efficiently as the equipment will use less energy to lay down the material. All other things being equal, improved workability can result in higher quality construction.

4 Compaction improvement
Appropriate compaction is critical to well-performing pavements and one measure of compaction is density. LTA can be employed as a compaction tool that can help achieve the necessary density and improve pavement performance goals. Achieving density requirements is particularly important to contractors in the USA because most asphalt paved on Federally-funded highways is accepted and incentivised based on density and evenness. Additionally, because LTA can make compaction easier, cost savings may be achieved by reducing time spent compacting the mix.

Use of Reclaimed Asphalt (RA)

As mentioned above, lower temperature asphalts can be used as one of the main techniques allowing an increase in the amount of RA recycled back in mixes without affecting the asphalt performance. The use of RA for the production of new asphalt is very attractive because it can provide a financial benefit through sustainable re-use of finite resources, particularly the available bitumen.

Exhibit 12: Percentage of the new hot and warm mix asphalt production that contains reclaimed material in Europe [2012] [18].
Germany and the Netherlands have the highest recycling rate of available reclaimed asphalt in Europe. No accurate data was available for the United Kingdom, but it is widely thought to be in excess of 85%. Outside of Europe, the USA is also very active in recycling asphalt; the asphalt industry remains the country’s number-one recycler by recycling reclaimed asphalt at a rate over 99% [19].

Note that not all reclaimed asphalt is used to produce new hot and warm mix asphalts. It is also used in cold mixes for all the pavement layers and can also be used as an aggregate for base or sub-base construction, or for other uses such as in concrete and other materials.

In the UK, virtually all asphalt is recycled and most of it is reused back into hot asphalt. Some small volumes are not hot recycled because they contain high tar (PAH) content, which is classed as hazardous waste, and must therefore only be cold recycled or otherwise safely managed or disposed of.

*Exhibit 13: Available reclaimed asphalt in Europe in 2012 [18].*

The amount of RA available can be reflective of the overall level of highway maintenance activity of the country.
Cost

Assuming the reclaimed asphalt content is the same in hot mix asphalts and lower temperature asphalts, then materials and production costs are affected by two main factors: (1) fuel consumption and (2) cost of additives and/or plant modifications [15].

[1] The fuel consumption mainly depends on two factors:

a. For every 10°C reduction in temperature, fuel consumption is reduced by 3-4%. This equates to around 0.25 kg fuel per tonne of asphalt produced, which becomes increasingly significant with increasing costs of fuel [14].

b. A reduction in the amount of moisture that is removed from the incoming aggregate also reduces fuel consumption. Indeed, a great deal of energy is spent drying aggregates by evaporating water, whereby the latent heat of evaporation of water requires five times the energy of raising the same mass of water from 0°C to 100°C. As a result, substantial energy savings can be achieved if the mixing temperature remains below 100°C [20]. For every 1% reduction in moisture, fuel consumption is reduced by approximately 10% [15]. This benefit is only valid for cold and half-warm mix asphalts, as warm mix asphalt is produced at temperatures above 100°C.

In LTA production, these two effects often work together. The total reduction in fuel consumption typically ranges between 10-40%, although it could be higher with some processes (see Appendix 1). The energy savings mostly depends on how much the production temperature was lowered and what kind of fuel is used. Note that other parameters can also influence the fuel consumption, such as burner efficiency, heat loss through the stack, production rates, etc. Additional inefficiencies can be introduced by frequent switching from hot mix to LTA production from the need to heat up the plant for hot mix and waiting for it to cool down for LTA. Longer runs of production at consistent temperature are more efficient (for both hot mix and LTA).

[2] The materials and production costs are such that, while LTA mixtures offer savings from reduced fuel consumption, it may not be enough to immediately offset the cost of the initial investment (in the case of the water-based process technologies) or the ongoing cost of additives [15]. Among the LTA technology options, water-injection foaming systems typically have the lowest cost per tonne. These systems however require the installation of mechanical equipment and some modifications to the plant’s control system. The early water-injection foaming systems cost around £50,000. At 2014 prices, other water-injection foaming systems that have entered the marketplace cost as little as £20,000 installed [21]. Many producers will depreciate capital expenditures such as this over five to seven years [21], so the cost benefits must be recovered in a similar timeframe.

LTA additives are reported to increase mix costs by approximately £1.30 to £2.20 per tonne [21].

Additional savings may theoretically be realised when analysing the life cycle of asphalt, as LTA potentially has better long term performance. Other benefits such as increased use of RA or extended-season paving may also provide economic and efficiency incentives.
Performance

In recent years, there have been a large number of field validation trials of LTA technologies established all over the world by private industry and road agencies. In May 2012, more than 160 documents had been identified in a literature search of LTA technologies reporting field trials of some form or another in the USA, Canada, Europe, Asia, South Africa and Australasia [22]. Of the references sourced, only about 20% provided sufficient information for them to be classed as validation or implementation trials. Most were development or demonstration trials established to evaluate a product or process in general terms only [22].

Many studies show that the performance and the in-service characteristics of LTA mixes are equivalent to those of the traditional mixes, and frequently even better [12]. The European Asphalt Pavement Association reports several reasons for the good performance of LTA. As a result of improved workability, a higher compacted density can be achieved. This higher density may reduce the long-term in-service hardening of the bitumen by preventing the ingress of water and oxygen. Lower production temperatures can also decrease the ageing of the bitumen during the production stage, which can additionally improve the thermal and fatigue cracking resistance of the asphalt [12].

Construction

In almost every aspect, the same methods of construction (i.e. paving and compaction techniques) are used for lower temperature asphalts as for hot mix asphalts. As mentioned in the list of advantages of LTA, the compaction window of this product is potentially larger than that of conventional hot mix asphalt, which means that more time is available to compact the asphalt layer. In addition, the level of effort required to compact LTA can be less than that required for HMA [23].

As the temperature of LTA is lower than HMA, the temperature ranges for initial and final rolling will likewise be lower than for HMA but will also depend on factors such as binder and LTA technology type, layer thickness and ambient weather conditions [23].

The decision on how soon after paving to open the newly paved LTA to traffic is influenced by various factors such as ambient weather conditions, traffic loadings, asphalt layer thickness, mix temperature, and binder properties [23]. Guidance on this should again be sought from the LTA producer.

Weaknesses

Exhibit 14: List of perceived weaknesses of lower temperature asphalts.

Weaknesses

- Young technology compared to hot mix asphalt (compared to required performance life)
- Lack of knowledge and understanding of long term durability
Although several studies have confirmed the short and medium term performance of LTA, more time is needed to observe substantially aged LTA on the road and bring confidence about the product. In the USA, accelerated pavement testing (APT) has been performed to provide a quicker indication of long term performance and has shown that LTA has at least similar performance to HMA.

Many asphalt buyers and contractors may often feel they are not informed enough about the product. There is a need for increasing knowledge sharing and collaborative design guidance to provide more clarity on the product’s characteristics and performance.

**Conclusions on chapters 2 & 3**

Lower temperature asphalt production technologies are now relatively well-established and better understood. LTAs are either produced through foaming techniques or using additives. In both categories, there exist several different technologies to produce LTA and hence offer different temperature reductions and carbon savings.

Numerous laboratory tests and field trials have confirmed the performance of LTA in the short and medium term, and asphalt manufacturers agree that its long term performance can be at least equivalent to its hot counterpart. However, LTA remains a young technology in comparison to conventional asphalt lifetimes and certainty of its long term performance is often perceived as the main risk by the Highway Authorities and Local Authorities.

Even so, LTA technologies can have a number of proven advantages, including:

- Reduced energy consumption;
- Lower emissions, fumes and odours;
- Improved compaction and workability;
- Possibility of higher reclaimed asphalt (RA) percentage in mixes;
- And ability to extend paving and compaction windows and seasons.

Confidence in lower temperature asphalts’ performance varies between countries. Two detailed case studies on the use of LTA in the USA and in Europe are provided in chapters 7 and 8.
4. Market Barriers

**Market barriers perceived in 2010**

In 2010, Carbon Trust commissioned Atkins as part of the Industrial Energy Efficiency Accelerator (IEEA) programme to identify the barriers to uptake of lower temperature asphalts in the UK. The study was based on consultations (workshops and questionnaires) with industry players (consultancies, suppliers, and contractors). Eighty-four people answered the questionnaire completely, which resulted in the twenty barriers listed in Appendix 2 [24].

Three workshops were organised (London, Birmingham and Glasgow), each comprising four sections. The key areas addressed and solutions found are presented in Appendix 3. Main findings from the workshops show the roads sector is conservative in its nature. Traditional hot mix asphalt is preferred as people are familiar with the product, which has a proven lifetime performance. The cost and service longevity emerged as the key barriers to be addressed. Participants also mentioned the need for guidance offering clarity and better understanding of the technology as a key requirement for lower temperature asphalts’ adoption [24].

However, the 2010 report indicated that a fairly high proportion of delegates would consider low temperature asphalt as an alternative if its cost and performance are proved to be similar as hot-mix asphalt.

**Where are we now?**

*Exhibit 15: The situation today with respect to the top five market barriers identified in the 2010 study.*

<table>
<thead>
<tr>
<th>Top 5 barriers identified in 2010</th>
<th>The situation in the UK today</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Evidence of performance</td>
<td>Although some countries have been using LTA for more than 10 years, it remains a new technology with respect to conventional asphalt’s lifetime. In particular, the technology is still under-utilised in the UK. Nevertheless, the use of LTA is now slowly increasing as the industry has become more familiar about its presence and performance. All lab tests and field trials to date suggest LTA performance and durability are similar or better than that of HMA. Asphalt suppliers and research organisations are increasingly confident about understanding LTA’s durability.</td>
</tr>
<tr>
<td>2 Knowledge and understanding</td>
<td>In recent years, many studies have been published on lower temperature asphalts in a number of countries. In addition, new trials made on various types of road have been documented and specifications are now being developed to include lower temperature asphalt technologies. In the USA, lower temperature asphalts are now widely accepted and guidance</td>
</tr>
<tr>
<td>3 Design guidance</td>
<td></td>
</tr>
</tbody>
</table>
documents have been released. In Europe and in the UK, an increasing number of documents are being released to help understand these new products.

<table>
<thead>
<tr>
<th></th>
<th>Affordability</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Affordability is not seen to be the same level of barrier to adoption. Today, lower temperature asphalts are often sold at the same price as conventional asphalt. They could even become slightly cheaper as demand and production increase.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Specification</th>
</tr>
</thead>
</table>
| 5 | Lower temperature asphalts are increasingly being used, but current pavement designs and specifications are written around hot mix asphalt. However, these specifications will need to be modified to become applicable to the various categories of lower temperature asphalts. Very little modification may be required for warm mix asphalt, with increasing modification anticipated for half warm mix and cold mix asphalts [11].

As part of a recent project to produce lower temperature asphalts, Lafarge Tarmac and Carbon Trust commissioned TRL to investigate overcoming this barrier and develop a model for national specification for lower temperature asphalts. TRL developed this based on the European standards for hot asphalts and the findings from that project. The new document, “Specification for Low Temperature Asphalt Mixtures”, may assist designers and specifiers to employ LTAs with greater confidence. The publication and launch of the model specification by the project team in 2013 was seen as a step towards the market advancement of lower temperature asphalts [25].

More information on Standards and Specifications is given in the next chapter.

Based on the table above, the lack of evidence and understanding of lower temperature asphalt’s durability seems to be the main barrier remaining today. Other barriers will need to be, have been or are being considered and addressed, such as pavement design criteria.
5. Standards and Specifications

Overview

This section presents an overview of the asphalt standards at a European level, and how these relate to the UK’s national specifications. These specifications are critical to help local authorities choose materials with the right performance requirements, to define job specifications and contract specialist contractors to carry out the work.


- **Standards**
  These provide a common technical language and understanding in producing and testing the performance of products. In the European Union, the European Committee for Standardisation (CEN) coordinates the national standards institutes of the EU and EFTA countries. CEN brings together delegates from the member states to try to achieve a European consensus on the various standards.

- **National guidance**
  At a national level, member states may produce national guidance documents on the details of the type of mixtures they want to use, but which should be compliant with the CEN standards. In the UK, PD 6691 and PD 6692 provide guidance on the use of the two European asphalt standards series, respectively BS EN 13108 for materials and BS EN 12697 for testing, which are published by the British Standards Institution.

- **National specifications**
  Specifications list the materials and equipment to be used, layer thicknesses, and the site and laying conditions. In the UK, these are primarily defined in the Specification for Highway Works and the Design Manual for Roads and Bridges by the Department for Transport and for use by other national and local highway authorities and by the Ministry of Defence specifications for airfields. British standards Institution also publish Standards related to the installation of materials.

These Standards are Specifications are subject to ongoing review at a European and National level, with significant revisions due for publication in 2015 and 2016.
European asphalt standards

Asphalt product standards

The European Standard series EN 13108 cover the asphalt products’ essential characteristics [26], and these should be implemented in all member states. Asphalt manufacturers need to ensure that their products are compliant with the EN 13108 requirements. In the UK, European Standards for asphalts first came into force on 1 January 2008 and the previous standards, BS 4987 and BS 594, were withdrawn in December 2007. The European standard series for “Bituminous mixtures” EN 13108 do not preclude the use of lower temperature asphalts [12]. Temperature ranges are given for each paving grade of bitumen, and there is a statement that “The minimum temperature of the asphalt mixture at delivery shall be declared by the manufacturer”. Requirements for minimum temperatures were deleted by corrigenda to the Standards in 2009 [11]. The standards also contain provisions for dealing with mixtures containing additives, subject to demonstration of equivalent performance [12]. The next revised edition of the Product Standards is anticipated to be published in 2016.

Bituminous testing standards

The standard series EN 12697 covers different “test methods for hot mix asphalt”. In total, there are in the region of 50 published testing standards, plus working drafts of methods under development [27]. These standards are used to measure binder content, particle size distribution, stiffness, temperature, etc. which are applicable to hot mix asphalt but many of which are equally applicable to lower temperature mixtures. The title of the series is “Bituminous mixtures — Test methods for hot mix asphalt” but are going to be retitled “Bituminous mixtures — Test methods” as parts are revised. It is anticipated that some new test methods will be necessary for LTAs.

Declaration of performance and CE marking

The EU Construction Products Regulation, which came into force on July 2013, requires manufacturers to provide a Declaration of Performance (DoP), with the aim of providing customers with the essential characteristics of the product the manufacturer wants to put into the market. The DoP is written when the product is covered by a harmonised standard (hEN) or a European Technical Assessment (ETA) [28]. In the case of bituminous materials, the corresponding standards are EN 13108.

Manufacturers use CE marking to identify that the product is in compliance with the European Standard and is consistent with the Declaration of Performance (DoP) made by the manufacturer. Therefore the manufacturer assumes the responsibility for the conformity of the construction product with the declared performance [28]. All asphalt in the UK must comply with one of the BS EN 13108 series and be CE Marked as required by the Construction Products Regulations. If an EU member state wishes to introduce a new product Standard, the approval of the European Commission will be required as it needs to be compliant with the Construction Products Regulation.

The Highway Authorities Product Approval Scheme

Although most highway construction materials are covered by European norms, not all of these have received a mandate from the commission and hence cannot be CE Marked. The Highway Authorities Product Approval Scheme (HAPAS) was set up in 1995 by the Highways Agency, the County Surveyors
Lower Temperature Asphalts – Pathway to Commercialisation

Society (CSS) and the British Board of Agrément (BBA). It targets innovative proprietary highways related products and systems that are not CE marked [26] or where demonstration of non-CE Mandated characteristics is required. Lower temperature asphalts are unlikely to be covered by HAPAS, since they are primarily the subject of CE marking and equivalent to hot products.

National guidance documents and specifications

All of the EU member states must adopt the European Standards for asphalt, but their practical use in each state is done at a local level. Hence, each member state may publish National guidance or application documents, which may outline preferences for mixtures and properties across the wide range of climate and traffic conditions found across Europe.

Guidance on the use of “BS EN 13108 Bituminous mixtures – Material specifications” (PD 6691 Asphalt)

In the UK, the British Standards Institution (BSI) published national guidance document PD 6691:2010 on the use of the EN 13108 series. PD 6691 includes guidance on materials, performance classes according to mixture characteristics (e.g. temperature, air voids content, stiffness etc.), as well as a series of Appendices containing example specifications for asphalt concretes, hot rolled asphalts and stone mastic asphalts [26].

The Highways Agency or Local Authorities can then write their works’ specifications based on the national guidance documents. Contractors should then procure materials from manufacturers which comply with the European Standards requirements, as evidenced by CE Marking.

Guidance on the use of “BS EN 12697 Bituminous mixtures – Test methods for hot mix asphalt” (PD 6692 Asphalt)

A second Guidance Document, PD 6692, provides advice on the application of the test methods for hot mix asphalt which are included in the EN 12697 series. PD6692 lists details of the sample preparation and test methods which are relevant to the UK [26]. Most of the test methods for asphalt are based on national test methods from European countries, including UK test methods specified in British Standards [29].

National regulation for road pavement

European Standards relate to the performance of a product as manufactured, meaning that they do not cover the materials’ installation.

National regulations cover the methods of transport, laying and compaction of bituminous mixtures [26]. The BSI has published the standard BS 594987:2010 “Asphalt for roads and other paved areas – Specification for transport, laying, compaction and type testing protocols”, which covers the following topics [27]:

- Transport, delivery and discharge on site
- Preparation works on site
- Laying the asphalt
This UK standard BS 594987 recommends minimum material delivery temperatures and temperatures prior to rolling, and specifies minimum rolling temperatures for hot rolled asphalt mixtures and for designed asphalt concrete mixtures (between 75°C and 90°C depending on the paving grade bitumen) [26]. It also indicates that different temperatures might be applicable when using modified bitumen or additives. The requirements of BS 594987 draw on best practice and are also included in Series 900 of the Specification for Highway Works [26].

UK Specification for Highway Works

The Highways Agency, Scottish Government, Welsh Assembly Government and the Department for Regional Development Northern Ireland publishes the Specification for Highway Works (SHW), which covers most asphalt procurement and installation in the UK. The SHW contains the requirements for the work and materials to be used in constructing and maintaining the UK trunk road network.

“Series 900 - Road pavements – bituminous bound materials”, describes the material requirements for bituminous surface, binder and base courses, including [30]:

- Reclaimed asphalt characteristics
- Placing and compaction of bituminous mixtures
- Hot rolled asphalt base and binder course (recipe mixtures)
- Testing of bituminous mixtures
- Weather conditions for laying of bituminous mixtures
- Durability of bituminous materials - saturation ageing tensile stiffness (SATS) test

Published specifications can pose potential design constraints, in which case authorities may seek to work beyond the limits of existing specifications. If a highway authority wants to use products that are out of the specifications, it is possible to file a “Departure from Standard” to the Highways Agency, which subsequently evaluates the document. This is to be welcomed, but it is important that the correct governance procedures are in place so that risks can be well managed and value for money maximised.

Local authorities

Local authorities do not have to follow the Specification for Highway Works, as only trunk roads are required to be designed according to these. For all other roads, the decisions on the choice of specifications and their incorporation into design lies in the hands of the local highway authorities [31]. For example, Norfolk council bases parts of its specifications for road pavement on the German Stone Mastic Asphalt surface course specifications.
Impact of asphalt regulations on lower temperature asphalts

This study has highlighted that the European Standards and national guidance documents do not prohibit the use of lower temperature asphalts in the UK. Lower temperature asphalts can be CE Marked. The UK specifies maximum temperatures but there are no minimum temperature requirements. In addition, Highway authorities can develop or adopt specific Declared Standards, which reinforces that the barriers for the adoption of lower temperature asphalts are not regulatory.

The key decision-makers in the procurement process of road and highways work in the UK is summarised in the following figure. More details on the procurement process of asphalt by local authorities is given in the next chapter.

Recommendations

From discussions with industry players, it has been recommended to remove primarily qualitative definitions of lower temperature asphalts such as “warm, semi-warm, cold” from standards and specifications to eliminate potential artificial barriers to innovation. Similarly, it was recommended to transform BS EN 12697 – “Bituminous mixtures - test methods for hot mix asphalt” by removing the qualitative definition [hot-mix] into: "test methods for asphalt”.

Whilst lower temperature asphalts can be used in the UK, most of the current specifications are written around hot mix asphalt. To incentivise and simplify the adoption and procurement of lower temperature asphalts, specifications for hot mix asphalt should be modified to become applicable to the various categories of lower temperature asphalts. This process has started to happen with the Transport Research Laboratory (TRL) who published models for lower temperature asphalts’ specifications in 2013 [11]. TRL does not have a mandate to write specifications, but it can be used by road owners to help them writing them.

Further investigation into the application of LTAs in pavement design methods and standards is probably necessary, particularly for those technologies which need time and/or curing regimes to achieve the necessary post installation and/or in-situ performance. Test methods and protocols for curing may also be required.
6. Asphalt Procurement Process in the UK

Road owners have a statutory responsibility for highway maintenance. That responsibility extends to the design of the highway structure itself, specification and detailing of maintenance strategies, including the materials or treatments to be used. The specification for materials may be compiled by a range of personnel such as in-house staff, private sector consultants, or joint venture personnel. The specification will then be used by contractors in order to bid for Works Contracts.

The typical procurement process of asphalt in the UK varies depending on local authorities, but we recognise three major procurement methods:

1) The local authority runs its own production facilities and installation teams. As a result, the local authority would generally deliver the work via in-house teams and not rely on external contractors for the paving of its roads. However, their own resources can be in competition with other providers for the supply and installation through a tender process.

2) The local authority has good knowledge of asphalt and is an expert procurer. It does not rely on specialist design or procurement service providers and works directly with the asphalt producer. In England, only a small number of local authorities still have this expertise.

3) The local authority is not involved in the choice of asphalt and relies on one or several service providers, which will be in charge of every step of the process. The local authority may contract with the asphalt producer directly and others providers are then involved in the decision process. Some local authorities will specify the requirements they want for their roads to a certain extent with the contractors.

Exhibit 18: The procurement process of asphalt in the UK.
Local authorities subcontracting the procurement of asphalt, typically involves a three-step process:

1. Design specifiers
2. Specifier contractors
3. Specialist contractors

Note that there are many procurement models and the process could involve less or more than three contractors. In this model, design specifiers would generally be choosing between different types of hot mix asphalt and also make the decision on hot mix asphalt versus lower temperature asphalts. However, alternatives may be proposed by other contractors in the chain.

Whilst there are many players involved in the buying process, contractors are sometimes set up in effective joint ventures. The table below shows an example of two regions of London covered by contractors set up in joint ventures. Contractors for London are selected by Transport for London, which has divided the city into four areas:

<table>
<thead>
<tr>
<th>Central area</th>
<th>Joint venture between Colas, Volker Highways and URS (CVU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North West area</td>
<td>Joint venture between Conway and Aecom</td>
</tr>
<tr>
<td>North East area</td>
<td>Ringway Jacobs</td>
</tr>
<tr>
<td>South area</td>
<td>Enterprise Mouchel</td>
</tr>
</tbody>
</table>

**Exhibit 19: List of asphalt contractors for the four London areas defined by Transport of London.**

**Highway Authorities**

The Highways Agency is the Highway Authority for all trunk roads and the vast majority of motorway mileage in England. Transport for London is the Highway Authority for main routes in London, except for sections of the M1, M4 and M11 motorways which come under the jurisdiction of the Highways Agency. All other roads are the responsibilities of Local Highway Authorities [32].

The Highways Agency has divided the UK in 14 areas for the management and procurement process of their activities. The majority of the Highways Agency’s services are delivered through Main Contractors. HA tender Asset Support Contracts (ASC) for the maintenance and improvements of the roads. The selected contractors suggest which materials to use in the road depending on the site conditions and required maintenance works. The Highway Agency uses 5-year contracts, with an optional 2-year extension based on performance.

Long term performance is the main risk seen by the Highway Agency, which requires a 5-year warranty. However, the Highway Agency would generally accept an asphalt manufacturer providing a similar or longer warranty for lower temperature asphalts. We could see an increasing number of projects using lower temperature asphalt products in the future as asphalt suppliers start to provide similar warranties for lower temperature asphalts.
Lower temperature asphalts are not included (but also not explicitly excluded) in the European standards series that the Highway Agency works with. As a result, a “Departure from Standards” is usually necessary for projects using lower temperature asphalts (see Chapter 5). Whilst it can be used this way, it is a costly and lengthy process for contractors, who are therefore often reluctant to get engaged in that process. Better Specifications would greatly simplify the process and encourage the use of lower temperature asphalts.

The Highway Agency has recently undertaken, in collaboration with industry, a demonstration section with lower temperature asphalt using foaming technology to pave over 100 metres of the A5. The objective is to evaluate the product’s installation and durability, which is seen as the main barrier. Initial performance evaluation has shown positive results but monitoring is needed to validate long term performance. CO₂ savings were estimated between 13% and 16% cradle-to-gate using the AsPECT carbon footprint tool.

**Contract length**

The procurement of asphalt is a continuous process as minor repairs and maintenance are needed all the time to prevent catastrophic failures. Hence, local authorities typically sign long-term contracts with asphalt suppliers and contractors. For instance, Norfolk County Council signed a 10-year contract. However, contracts for highway maintenance and management financed through Private Finance Initiative projects can last much longer (more typically for 25 years). Portsmouth and Birmingham are typical of these contracts which started in 2004 and 2010 respectively, and will terminate in 2029 and 2035 [33]. The authority may also enter into a series of framework contracts for the provision of particular services with one or many providers. The maximum duration of a framework under European Union Regulations is 4 years, however, Transport for London has recently let four framework contracts for an 8-year period based on appropriate advice [33].

The procurement process can vary depending on the scope of the works required. For example, Cornwall Council, which controls the buying process centrally with its own strategic procurement team, selects the most cost-effective local supplier from the tender for requirements under 100 tonnes of asphalt, whilst any orders over 100 tonnes are priced through a mini competition exercise with appointed suppliers.

**Incentives to use lower temperature asphalts**

In the UK, there are currently no direct incentives from the government to encourage the transition to lower temperature asphalts. This could be done by incorporating financial or regulatory incentives, or simply sending messages to encourage its use. Unlike some European countries, there is no explicit driver to improve health & safety for workers specifically through the reduction of fumes and emissions.
Whilst local authorities are generally sensitive to climate change at a high level, emissions reduction does not often influence their choice of asphalt in a major way, but rather depends largely on two critical criteria: cost and performance. Even at a similar price, conventional asphalt is still chosen over lower temperature asphalts, as the latter does not have a proven track record of longevity yet. In general, local authorities are risk adverse to innovation, although a few proactive local authorities have trialled the technology in the past few years. Recently, the highway authorities in the West Midlands Alliance have pledged to use lower temperature asphalts in 20% of their works and will make use of the model specifications drafted by TRL.

Some local authorities take other approaches to reduce CO2 emissions of laying their roads. For instance, Norfolk County Council tries to minimise the time gap between the asphalt delivery to site and the moment it get laid on the ground (to reduce temperature loss).

More interestingly, the Highway Agency uses a point system, wherein the sustainability weighting could be increased to push lower temperature asphalts forward. So, whilst the type of asphalt is ultimately selected by contractors, the Highway Agency can influence the choice of the product.

**Conclusions on chapters 5 & 6**

This study has highlighted that the European Standards and national guidance documents do not prohibit the use of lower temperature asphalts in the UK, which can also be CE Marked. The UK specifies maximum temperatures but there are no minimum temperature requirements. However, whilst lower temperature asphalts can be used in the UK, most of the current specifications are written for hot mix asphalt. As a result, the lack of specification applicable for lower temperature asphalts may be slowing down their uptake.

Highway Authorities may have to complete a “Departure from Standards” for projects using lower temperature asphalts. Whilst it can be used this way, it is a costly and lengthy process for contractors, who are often reluctant to get engaged in that process. Similarly, the lack of specification makes the procurement task of lower temperature asphalts more complicated for Local Authorities and contractors.

To incentivise and simplify the adoption and procurement of lower temperature asphalts, specifications for hot mix asphalt should be modified to become applicable to the various categories of lower temperature asphalts. The next step is for a competent authority to develop the specifications and make them readily available.
Long term performance is the main risk seen by Highway Authorities. Lower temperature asphalts are often not well known and effort should be made to increase the product’s visibility through more trials, reports and guidance documents. The government can play an important role here to support the technology by encouraging its use.

There are currently no incentives from the government to encourage the transition to lower temperature asphalts. Local Authorities generally give little importance to the carbon footprint of asphalt compared to cost and performance. To change that, lower temperature asphalts could be incentivised by incorporating financial or regulatory incentives related to the performance enhancements anticipated.
7. Case Study:  
Lower temperature asphalts in the USA

Introduction

The use of lower temperature asphalts in the United States is increasing rapidly; it saw an increase of about 26% from 2011 to 2012 and 23% from 2012 to 2013 [19]. LTA production now represents about one third of total estimated asphalt mix production in the USA, and it is expected to grow as contractors and agencies gain experience and more states implement permissive specifications.

While additives were more popular when lower temperature asphalts started in the USA, today plant foaming is used most often with more than 87% of the market, additives accounting for only 13% of the market [19]. The main reason is the lower cost of foaming technologies, which only require an initial investment cost compared to expensive additives per tonne of production.

Exhibit 21: Production of lower temperature asphalts in the USA [19].

Lower temperature asphalts are expected to keep growing in the coming years. No significant barrier to adoption is seen.
Lower temperature asphalt development journey

Exhibit 22: The development journey of lower temperature asphalts in the USA.

European technology tours and first trials

The initial interest in LTA in the USA came from industry, which organised a tour in Europe (Denmark, Norway and Germany) in 2002 led by the National Asphalt Pavement Association (NAPA) to understand existing lower temperature asphalt technologies. The new clean air legislation introduced in 2000 was also a trigger to begin examining the performance and benefits of LTA.

Following the tour, interest in these technologies started to grow in the USA, with the first project starting in 2004. At the beginning, trial sections were evaluated to quantify and better understand the benefits
and barriers of the new technologies. At that time, only three technologies were available in the USA, whereas today, there are over 30 different technologies.

In 2007, the Federal Highway Administration (FHWA), which designated LTA as a focus area, organised another tour in Europe to investigate existing technologies. The team went to Belgium, France, Germany and Norway. It concluded that the USA has no long term barriers to LTA use. The key implementations goals included [35]:

- Development of an approval system for new LTA technologies. The approval system should be based on performance testing and supplemented by field trials.
- Implementation of best practices for LTA production for handling and storing aggregates to minimise moisture content, burner adjustment, and LTA in general or for specific technologies.
- Technology transfer of the information gained through presentations, articles, and reports.
- More LTA field trials with higher traffic. The field trials should be large enough to allow a representative sample of the mixture to be produced.
- Identify and track the factors affecting the economic viability of LTA. These include additive costs, plant modifications, asphalt costs, fuel costs, costs of emission compliance equipment such as low-NO\textsubscript{x} burners and fugitive emissions containment systems, and costs related to worker exposure.

Today, all aforementioned points have been or are being addressed.

**Government support**

While the government is not providing any benefits from using lower temperature asphalts instead of hot-mix asphalt, it provides some support for research and education. In particular, in 2005, the Warm Mix Asphalt Technical Working Group (WMA TWG) was established to discuss issues and share knowledge of lower temperature asphalts. The group is composed of individuals from the public and private sectors from organisations such as the National Asphalt Pavement Association (NAPA), the State Departments of Transportation (DOTs), the Federal Highway Administration (FHWA), the National Center for Asphalt Technology (NCAT), the American Association of State Highway and Transportation Officials (AASHTO), and others [36]. So far, three Best Practices guides have been published.

Other examples of support through research are:

- The National Center for Asphalt Technology (NCAT), based at the Auburn University and linked to NAPA, which has several research programmes for lower temperature asphalts.

- The National Cooperative Highway Research Program (NCHRP), which plan to support a total of eleven research projects (funding typically ranging between $0.5m and $1.5m) throughout the development journey of lower temperature asphalts. Completed NCHRP projects addressed LTA mix design, the potential moisture susceptibility of LTA pavements, and whether LTA and HMA pavements provide significantly different short and long term performance. NCHRP planned projects will address the short term laboratory aging of LTA for mix design and performance testing, characterisation of foamed asphalt for LTA applications, and the use of recycled asphalt (RA) and recycled asphalt shingles (RAS) in LTA [37].
In 2010, the government set the programme Every Day Counts, which was designed to focus on initiatives of proven performance. Through this initiative, the Federal highway Administration (FHWA) works with state and industry to deploy different new technologies. This was crucial for the development of lower temperature asphalts. A direct result was the recognition of lower temperature asphalt as a technology by the government, which encourages use of LTA and provides some visibility of the technology. In 2013, lower temperature asphalt was honoured with the Construction Innovation Forum’s NOVA Award for its engineering, economic, and environmental benefits [38].

The programmes set by the government played an important role for the commercialisation of lower temperature asphalts. They identified strengths and weaknesses of LTA, and focused on how to overcome these weaknesses. It was typically addressed through:

- Specifications and/or special provisions
- Education/training for contractors and local agencies
- Documentation of better performance to prove effectiveness
- Capability of the technology to be used in all types of mixes

These various government programmes for lower temperature asphalt evaluation brought confidence to use the technology. In addition, guidance and specifications have been developed to encourage and facilitate its use. In Europe, examinations mostly depend on private companies which means there are a less independent review of different lower temperature asphalt technologies.

**Proactivity of state agencies**

Several states have been very proactive in trying LTA. States including Alabama, California, Missouri, Nebraska, Ohio, and Virginia have constructed and investigated the pavement quality of lower temperature asphalt test-sections. These tests compare different LTA technologies, and use a variety of means to predict their ultimate performance. Although it is too early to perform any full lifecycle evaluations, agencies have been able to discover a lot about LTA, and gain confidence to move ahead [39].

*Exhibit 23: Estimated percent by state of total production using LTA in 2013 [19].*
**Incentives**

**Incentives for lower temperature asphalts’ suppliers**

The two main incentives for lower temperature asphalts’ suppliers are the energy saving of producing LTA and compaction benefits, which make LTA easier to construct. LTA also reduces fumes, odours and emissions, hence being more environmentally-friendly and improving the working conditions for the paving crew. The possibility to use more reclaimed asphalt (RA) provides another significant economic advantage.

The economic advantage is what boosted LTA uptake in the USA. Apart from energy saving, suppliers also receive a bonus if asphalt compaction is higher than a certain level. Since LTA offers improved compaction, contractors used the bonus to finance modifications to produce LTA (in the case of foaming technologies). Compaction is closely linked to durability, fatigue, and other technical characteristics. This bonus indicates the government perceives better long term performance can be achieved with better compaction, hence using LTA.

Interestingly, foaming techniques can be used for both hot mix asphalts and lower temperature asphalts. Foaming techniques can help to achieve the desired compaction of asphalt, in addition to saving energy in the case of LTA. The equipment purchased by suppliers to produce LTA through foaming can therefore be used for HMA as well.

**Incentives for lower temperature asphalts’ buyers**

In the USA today, it is generally accepted that LTA improves conditions for achieving performance and long life, thus creating a significant incentive for buyers. LTA is sold at the same price as HMA. However, as production increases prices might potentially drop.

Buyers’ incentives also include operational advantages, in particular an extended paving season and longer paving distance. Lower temperature asphalts are particularly useful in very rural areas with no producer nearby as LTA can be hauled over a longer distance (but typically when LTA technology is used at HMA temperatures).

Environmental benefits, in particular reduction in CO₂ emissions, but also reductions in SO₂, VOC, CO, NOₓ and dust, encourage the product’s uptake as well.

**Performance**

**Conclusions so far**

Short term performance has been demonstrated. In general, LTA has similar or even better performance than hot mix asphalt. No long term comparison is possible today as older trials are nearing 10 years in the USA, compared to a typical lifespan of 15-20 years for hot mix asphalt. However, many people believe that long term performance is not an issue, although it cannot be confirmed until empirical observations are made. Several accelerated pavement tests have been undertaken since 2006 to provide confidence about LTA’s performance. For example, the National Center for Asphalt Technology (NCAT) in Auburn and the University of California Pavement Research Center (UCPRC) conducted accelerated loading
studies using the Heavy Vehicle Simulator (HVS). This means that rather than constructing a test section on an actual road, pavement is constructed in an environment where it can be subjected to exceptionally high loads, simulating years of service in a short time, although not the change in properties resulting from ageing. These trials have involved the production of the mixes, the construction of test pavements, and the monitoring of field performance, including detailed (within-pavement) response-to-load data. Extensive laboratory studies of both field and laboratory samples were also carried out and recommendations made regarding the implementation of LTA into current HMA mix design procedures.

Conclusions from these tests have shown no indication that warm-mix influences long-term rutting and has suggested that the performance of LTA pavements is at least equivalent to that of HMA.

Exhibit 24: Heavy vehicle simulator testing a section of lower temperature asphalt at the California’s Research Pavement Center [40].

Testing of state agencies

As mentioned above, state agencies have undertaken several tests to evaluate LTA’s performance. Typically, a new technology is tested on a road section that needs repair. It is then inspected in place or sampled for laboratory analysis. An extensive two-year comparison of LTA techniques in Virginia showed that it was performing comparably to hot mix asphalt, and that certain warm mix technologies might be slowing the detrimental aging process of the asphalt binder [39]. A combination laboratory and field study in Nebraska showed that LTA pavements were rutting at the same rate as hot mix, and predicted from lab data that there would be no expected failures during a 20-year service life. Similar tests are being conducted across the country to further increase the understanding of this material [39].

Some states, like California and Ohio, have used the accelerated loading technique to investigate lower temperature asphalts. Experience with California’s heavy vehicle simulator (HVS) showed some increased moisture content and increased initial rutting of warm mix compared to hot mix asphalt. However, the moisture content was still within reasonable limits, and the rutting behavior evened out over the long term. In Ohio, warm mix showed a higher tendency to consolidate under heavy loads, but this had a relatively small effect on total consolidation. In both cases, warm mix pavements were of similar quality to control hot mix sections [39].
Conclusions and lessons for the UK

This case study shows a very positive story for the development of lower temperature asphalts. From 2009 to 2013, lower temperature asphalts grew from 5% to 33% of total asphalt mix production in the USA, and is expected to keep growing in the coming years with no significant barrier to adoption.

The investigation and development of lower temperature asphalt technologies was pushed by both industry and the government. Organisations from the public and private sectors have worked together to bring LTA to commercialisation stage, notably through the LTA Technical Working Group. The technology development and adoption were catalysed by government programmes such as Every Day Counts and the NCHRP, which played a crucial role to address technical barriers, knowledge dissemination, and provide visibility on the technology. As a result of these programmes and working groups, guidance documents and specifications have also been developed to encourage and facilitate the use of LTA.

Whilst energy saving and the reduction of emissions were the initial motivations for LTA, the compaction bonus offered to asphalt manufacturers played a central role to boost LTA’s growth. State agencies have also been very proactive to trial LTA and gain confidence in the product’s performance. In the USA, it is generally accepted that LTA improves conditions for achieving performance and long life.

In the UK, most asphalt manufacturers have also developed LTA technologies, some of them receiving government funding. However, the number of projects is comparatively few. The US story encourages to build multi-organisational working groups to accelerate the release of guidance and specifications, which are essential for the wide adoption of LTA.

The case study has shown that government incentives play a central role to accelerate LTA’s growth. The UK would benefit a lot from a government mechanism to incentivise the production or use of LTA, such as the compaction bonus used in the USA.

Finally, there is a need for more proactive Local Authorities trialling LTA to gain confidence in using the product.
8. Case Study: Lower temperature asphalts in Europe

What triggered the development of lower temperature asphalts?

Although the USA is very active with lower temperature asphalts, the products were first used in Europe, where the oldest warm mix pavements can be found. LTA originated in Europe with the German Bitumen Forum in 1997 in response to the requirements for GHG reduction that were being adopted by the EU countries as part of the Kyoto treaty on climate change [41]. The reduction of emissions is the most important reason for the European asphalt industry to stimulate the use of LTA [12].

Exhibit 25: Development of lower temperature asphalts in Europe.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Germany raised concerns about asphalt fumes and developed LTA’s</td>
</tr>
<tr>
<td>1995</td>
<td>Shell patented WAM Foam &amp; undertook preliminary lab experiments</td>
</tr>
<tr>
<td>1997</td>
<td>First trials were performed between 1995 and 1999 in Germany and Norway</td>
</tr>
<tr>
<td>1999</td>
<td>Kyoto Accord</td>
</tr>
<tr>
<td>2000</td>
<td>German Bitumen Forum</td>
</tr>
<tr>
<td>1999</td>
<td>First application on a public road in Germany using the Aspha-min Zeolite system</td>
</tr>
<tr>
<td>2000</td>
<td>Euroasphalt &amp; Eurobitume Congress, Barcelona</td>
</tr>
</tbody>
</table>

Conclusions on the first field trials

The first countries to trial LTA were Germany and Norway. In Germany seven test sections and commercial applications of LTA were constructed between 1998 and 2001. The BAST (the Federal Highway Research Institute) has monitored the seven test sections. Based on laboratory and field performance data in all cases, the test sections had the same or better performance than the HMA control sections [35].

The table below synthesises the first trial results in Germany. Four LTA technologies were tested: Sasobit, Asphaltan-B, Aspha-min, and Subit. The sections were monitored for transverse profile, layer thickness, and surface condition during a 5-year evaluation period [35].
Exhibit 26: Results of the first trials with lower temperature asphalts in Germany [35].

<table>
<thead>
<tr>
<th>Section Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sasobit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasobit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphaltan-B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphaltan-B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphamin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Field Measurements**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rutting</strong></td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Post-compaction</strong></td>
<td>Equal</td>
<td>Better</td>
<td>Equal</td>
<td>Better</td>
<td>Better</td>
<td>Equal</td>
<td>None</td>
</tr>
<tr>
<td>densification</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cracking</strong></td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>-</td>
</tr>
</tbody>
</table>

**Laboratory investigations**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal stability</strong></td>
<td>Better</td>
<td>Better</td>
<td>Equal</td>
<td>Better</td>
<td>Equal</td>
<td>Better</td>
<td>-</td>
</tr>
<tr>
<td><strong>Low-temperature</strong></td>
<td>Equal</td>
<td>Equal or Better</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal or Better</td>
<td>Equal or Better</td>
<td>Very Good</td>
</tr>
<tr>
<td>performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Aging of the</strong></td>
<td>Equal or Better</td>
<td>Equal or Better</td>
<td>Equal or Better</td>
<td>Equal</td>
<td>Equal</td>
<td>Equal</td>
<td>Low</td>
</tr>
<tr>
<td><strong>binder</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Adhesion</strong></td>
<td>Equal or Better</td>
<td>Equal or Better</td>
<td>Better</td>
<td>Equal</td>
<td>Equal or Better</td>
<td>Equal or Better</td>
<td>Good</td>
</tr>
</tbody>
</table>

The oldest field trials in Norway were built in 2000 using the WAM-Foam process on two roadway sections. Rut depths were monitored over three years and it found that the rutting behaviour of the LTA mixes was similar to that of HMA [Larsen et al., 2004].

However, the picture is a little more complicated in Norway; the prevalence of studded tires leads to rutting problems. So far however, there is no indication that it is affecting warm mix pavements more than their hot mix counterparts [39]. The overall conclusion is that the WAM-Foam sections appeared to perform similarly to previous HMA overlays [10].

It was concluded that: based on the laboratory and short-term (3 years or less) field performance data, LTA mixes appear to provide the same performance as, or better performance, than HMA. Other studies have also shown that the performance and the in-service characteristics of LTA mixes are equivalent to those of the traditional mixes, and frequently even better [10].
Observations from American asphalt associations visiting Europe

Different tours were organised by American associations to investigate the first technologies developed in Europe, in particular;

Exhibit 27: American "Scanning Tours" visiting progress in lower temperature asphalts in Europe.

<table>
<thead>
<tr>
<th>Name</th>
<th>Date</th>
<th>Led by</th>
<th>Visited countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAPA European Scan Tour</td>
<td>2002</td>
<td>The National Asphalt Pavement Association (NAPA)</td>
<td>Denmark, Germany, Norway</td>
</tr>
<tr>
<td>FHWA European Scan Tour</td>
<td>2007</td>
<td>The Federal Highway Administration (FHWA)</td>
<td>Belgium, France, Germany, Norway</td>
</tr>
</tbody>
</table>

There is a consensus by both "Scan Tour" teams that LTA should provide equal or better performance than HMA. In Norway, six WAM-Foam pavement sections were viewed by the scanning team. The pavements generally appeared to be in very good condition. Some rutting was observed, but it was not attributed to the use of LTA technologies. In France, laboratory studies and field trials have been conducted on various LTA processes. The performance observed for LTA was the same for HMA. Finally, the same conclusion was reached in Germany. In addition to the German seven test sections presented above, several LTA additive suppliers presented performance data on a variety of trial sections, some of them on commercial projects. Again, the performance of the LTA was as good as or better than HMA.

The FHWA European Scan Tour team noted that the use of LTA in Europe was not as high as expected [in 2007]. Two reasons were suggested for this [42]:

- Oldest LTA sections were just exceeding the period of workmanship warranty. Contractors wanted to develop confidence in their long term performance before using them widely.
- In most cases, LTA still cost more than HMA at the time.

What are the incentives to produce and buy LTA in Europe?

In Europe, more and more countries are now equipped for producing LTA with different processes and undertaking studies and trials [10]. However, the adoption of LTA remains very slow. Asphalt buyers are looking for proof of long term performance, which means more time is required to confirm LTA has similar performance as HMA. Similarly, to confirm the carbon emission benefit of LTA over HMA, a full lifecycle analysis is necessary, which can be only be done once the lifetime of LTA is known.

A few European countries have been analysed to understand their position with respect to incentivisation of lower temperature asphalts. In particular, we looked at the first three countries which trialled the product; Germany, France and Norway.
Germany

First trials and commercial applications were constructed between 1998 and 2001 in Germany. German agencies, industry, and academia also jointly developed a “Merkblatt” or guidelines for the use of LTA [35].

However, today, lower temperature asphalt is still only a niche market. It is only used for specific applications, such as the paving of tunnels to avoid fumes, and the production of lower temperature asphalts remains very low. As opposed to other countries using foaming techniques, Germany developed and uses organic additives and zeolite (mineral additive). The use of additives is the only technique allowed in German specifications and regulations. Users of other lower temperature asphalt techniques do not benefit from the standard 5-year warranty for asphalt. As a result, foaming techniques were not developed in Germany like in other countries. Nevertheless, Germany is slowly approaching foaming techniques. The technology is still at research stage but some trials with foaming lower temperature asphalts are happening.

The use of additives for lower temperature asphalts did not meet a great success in Germany, mainly for two reasons: additives are expensive and are not believed to provide important carbon emission savings, and potentially with the opposite result. Whilst the emissions at the asphalt plant are reduced, additives require energy to be manufactured. As a result, the overall carbon saving is lower than what may be suggested by the reduction of mixing temperature.

Currently, there are no incentives or bonuses to encourage the production or use of lower temperature asphalts in Germany. Germany has taken a different approach by focusing mainly on recycling asphalt. The country has the highest recycling rates. New asphalts typically contain 50-60% of recycled asphalt and percentages higher than 90% recycled asphalt content have been tested. Today, almost all new asphalt contain reclaimed material, as shown in Exhibit 12. A second generation of recycling, consisting of recycling hard and oxidised bitumen that has already been recycled once, is even in advanced research stage.

France

In France, both laboratory studies and field trials have been conducted on various LTA processes. Laboratory studies have included gyratory tests for workability and estimation of field compaction, wheel-tracking tests for rutting resistance, Duriez test for moisture resistance, and fatigue tests. Workability for LTA tended to improve. The rutting resistance of LTA was the same as for HMA [35].

The Department of Eure-et-Loir in southwest of Paris examined LTA with Aspha-min zeolite and ECOMAC. The department decided to use LTA for its environmental benefits, improved working environment, and safety aspects (reduced steam if it rains while paving). Other reasons included longer haul distances, extending the paving season, and an expected longer lifetime [35]. The city of Paris also experimented with several LTA processes in the urban environment, including a dedicated bus lane. The city evaluated LTA technologies in response to calls from Parisians concerned about fumes and odours from paving projects [35].

Since then, the use of LTA has significantly increased and achieved 14% of the asphalt produced in France in 2013. The growth of LTA was boosted by “La Convention d’Engagement Volontaire”, a mutual and voluntary agreement between the State and French associations such as SETRA and USIRF [43]. This
agreement aims to preserve natural resources, improve energy efficiency, and limit greenhouse gas emissions. Particular areas of focus include progression of lower temperature asphalts and increase of reclaimed asphalt. The initial objective to triple the use of LTA from 2008 to 2012 has been largely achieved as the production increased over five-fold [43]. The goals of the agreement for 2017 are [44]:

- Increase the use of reclaimed asphalt to 15% (12% in 2012)
- Achieve 30% LTA out of the total asphalt production (7.5% in 2012)
- Increase innovation capacity & participation in new research

In France, the use of LTA is now more and more developed. The French association USIRF has also written a recommendation promoting LTA. A translated extract of this recommendation written by Jean Louis Marchand, then USIRF President, is given below [12]:

“The USIRF recommends the systematic use of lower temperature asphalts, except in special cases; such cases with specific technical constraints or in case of a motivated refusal of the road authority. The USIRF reminds that the stimulation of the use of lower temperature asphalts is one of the objectives of the voluntary agreement of actors in design, construction and maintenance of road infrastructure, road and urban public space signed in March 25, 2009.”

Furthermore, technical specifications are achieved with all lower temperature asphalt processes, and two French organisations, GPCR and IDRRIM, are currently preparing technical guides to explain and facilitate the use of lower temperature asphalts [43].

*Exhibit 28: Production of warm and hot mix asphalts in France [45]*.
France is also one of the leading countries for the use of cold asphalt. According to the European Asphalt Pavement Association, in 2013 the three leading countries in production of cold bituminous mixes were Turkey, France, and Switzerland, all three at levels far above other countries.

**Norway**

Norway stared investigating LTA around the same time as Germany. First lab testing occurred in 1998 and field trials started in 1999 with WAM-Foam. In particular, Norway developed foaming techniques for high quality asphalt pavement, which were then adopted by many countries, in particular the USA. The development of LTA was undertaken by the industry, Veidekke and Shell Bitumen. The authorities were sceptical due to the use of water, which usually leads to problems. However, conclusions from the first trials with LTA (offering a 30°C temperature reduction) showed similar quality and expected lifetime as hot mix asphalt.

The technology was introduced again in 2012 but this time pushed by the government. This decision came following a project in 2010 to study the consequences for asphalt workers’ health and the asphalt quality by doing 11 trial sections with 6 different techniques. The Confederation of Norwegian Enterprise’s “Working Environment Fund” granted NOK 1.3 million (£130k), which was crucial for the accomplishment of this project [46]. The results of the project showed, on average, statistically significant reductions in asphalt fumes of 58-67% (depending on the measurement method), at a mean reduction in asphalt temperature of 29°C. The study showed that the exposure of asphalt fumes was significantly lower when paving LTA compared to HMA [46].

Regarding quality monitoring, the focus was on the obtained void content, deformation resistance (wheel track values, initial rutting and evenness) of the pavement and water susceptibility of the mix. The quality follow-up so far has shown that warm mix pavements do not differ from hot mix regarding the relevant quality parameters. Until now there are no indications that LTA surface layers will have a shorter lifespan than the hot mix surface layers [46].
Today, Veidekke has 6 plants producing LTA, which corresponds to roughly 80% of Veidekke’s asphalt production. The main driver encouraging LTA production is a bonus payment of about €4 per tonne of asphalt, when produced at a temperature at least 25°C lower than conventional production (only for foaming technology). The bonus incentive established in 2012, which might give the investment a payback time of only one year, explains the fast growth of LTA since 2012.

The overall asphalt production in 2013 in Norway was 6.4 million tonnes, of which LTA production was 380,000 tonnes (5.9%), compared to 26,000 tonnes in 2012 (0.4%)

**Other European countries**

---

**Switzerland**
- Individual asphalt producers and contractors are promoting LTA technologies [12].
- In 2013, 870,000 tonnes of warm mix asphalt and 830,000 tonnes of cold asphalt were produced in Switzerland, making the country the second largest producer of lower temperature asphalts in Europe.
- Research project underway to include LTA in the standards [12].

**Sweden**
- In 2013, Sweden produced about half a million tonnes of LTA.
- Use of K60-method; a kind of LTA developed by Karl-Gunnar Olsson different from conventional foaming or additives techniques [12].

**Denmark**
- The company NCC is producing foamed asphalt.
- Paved a motorway in 2012 and obtained very satisfactory results.
- NCC has paved many other sections since then [12].

**Netherlands**
- Local authorities in the Netherlands use environment criteria in their bids to select asphalt. The point system was put in place by the government; CO₂ criteria weight can be up to 10%, thus increasing the chance to win tenders with LTA.
- Foaming technique is used to produce LTA, which is sold at the same price as HMA. Asphalt also typically contains a lot of reclaimed asphalt.
- Whilst the uptake of LTA remains slow today, BAM Group is planning to produce 0.5 million tonnes of LTA, representing over 5% of the asphalt production in the Netherlands.
- BAM Group is currently undertaking a project part-funded by the EU (Life+ LE2AP) with the goal to pave 1 km of road containing 80% reclaimed asphalt and produced at 80°C by 2016.

**Czech Republic**
- Preliminary national specifications for LTA published by the Czech Ministry of Transport in 2012.
- In 2013, an important road tunnel in Prague was paved using LTA.
- A couple of other research projects focusing on the development of LTA started in 2013 [12].
Which countries are leading the production of lower temperature asphalts?

Warm mix asphalt production

The market share of LTA in Europe is much smaller than in the USA. According to EAPA, France was the leading country for LTA production in Europe, followed by Great Britain, Switzerland and Scandinavian countries. Although no precise number are given for Great Britain.

The following table shows the production of LTA in 2013 by countries. Data has been collected by the European Asphalt Pavement Association. Here, warm mix asphalt is defined as having a production temperature between 100°C and 150°C. Hence, cold mixes are not included in this chart. However, the definition of warm mix asphalt is not harmonised internationally, so the range of production temperature characterising warm mix asphalt might differ a bit depending on the country. Note that Great Britain’s LTA production is indicated to be smaller than 1 million tonnes but no precise estimate is given.

Exhibit 31: Production of warm mix asphalt versus hot mix asphalt in Europe in 2013 [45].
Because of the many advantages of LTA, its usage is growing and it is expected that the use of LTA will become standard practice. The advantages with regard to the environment, the asphalt workers, the paving operations and the economic benefits also have to be brought to the attention of the politicians and the specifiers in road authorities.

**Cold mix asphalt production**

Cold mix asphalt is typically used for repairing roads or for specific applications. France, Turkey, and Switzerland are far ahead of other European countries in term of cold asphalt production.

*Exhibit 32: Production of cold bituminous mixes in Europe in 2013 [45].*

![Production of cold bituminous mixes in Europe in 2013](chart)

**Lower temperature asphalt adoption in Europe versus the USA**

The different LTA technologies used can explain one of the possible reasons why LTA has not grown in Europe as in the USA. Whilst techniques based on chemical and organic additives were initially mainly used in Europe to make LTA (e.g. in Germany and France), the USA mainly focused on foaming techniques. Both techniques offer similar performance, however foaming technology requires an initial capital investment usually ranging between $30,000 and $70,000 per plant, as opposed to additives which
typically add about $3 per tonne to the cost of asphalt, thus making these methods more expensive in the long term. Today, almost 90% of the US market uses foaming.

The difference between American and European criteria for asphalt performance also explains the popularity of LTA in the USA. Whilst local authorities in Europe wish to see proof of long term performance before buying a product, in the USA the main decision criterion is compaction. If the compaction of asphalt is met, the asphalt can be laid. Furthermore, from a certain level of compaction, a bonus is offered to asphalt manufacturers.

**Conclusions**

In Europe, lower temperature asphalt was developed mainly to reduce emissions. More and more countries are now equipped for producing LTA with different processes and undertaking studies and trials. However, the adoption of LTA remains very slow. Asphalt buyers are looking for proof of long term performance, which means more time is required to confirm LTA has similar performance as HMA.

Government incentives seem to play a major role in accelerating the uptake of LTA. France has seen a fast increase in LTA production in the last four years, achieving 14% of their total asphalt production in 2013. The uptake was catalysed by a mutual agreement between the state and industry, making the technology visible and encouraging its use. In Norway, LTA is increasing quickly following the establishment by the government of a bonus when asphalt production temperature is at least 25°C lower than conventional asphalt.

From discussions with several organisations, there is a clear consensus that LTA usage is growing and it is expected that its use will become standard practice in Europe.
9. Summary of Recommendations

Lower temperature asphalts are on the rise in Europe and in the UK. Most people agree that LTA will become standard practice in the future. However, the adoption is still slow in most countries. Below are some proposed recommendations to encourage the technology’s commercialisation.

- Removing qualitative definitions of asphalt such as “cold, warm, half-warm” from standards and specifications would be useful to eliminate potential artificial barriers to innovation. Although lower temperature asphalts can be used in the UK today, the current lack of specifications often requires that contractors must go through a lengthy process to procure LTA, discouraging them to select the product.

- Lower temperature asphalts are often not well known to specifiers and effort should be made to increase the products’ visibility and benefits through more trials and reports.

- There is a need for a competent authority to develop specifications and design guidance and make them readily available to Local Highways Authorities and contractors.

- The US story encourages the building multi-organisational working groups to accelerate the development, fundamental understanding, and release of guidance and specifications, which are essential for the wide adoption of LTA.

- The Government should incentivise the uptake of lower temperature asphalts by incorporating financial or regulatory incentives.

- Asphalt specifiers could gain confidence in using lower temperature asphalts if more information is provided on successful stories around the world. More field trials in the UK are also needed to enhance confidence and documentation on the trials’ results should be compiled and disseminated.
10. References


Appendix 1 – List of lower temperature asphalt technologies

Below is a list of most often reported lower temperature asphalt technologies [47]. Other technologies not listed have been developed as well. In addition, many companies listed below have since then developed new lower temperature asphalt products or sometimes renamed some of the old products.

<table>
<thead>
<tr>
<th>Product</th>
<th>Company</th>
<th>Description</th>
<th>Countries</th>
<th>Production temperature or [Reduction range] °C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foaming technology</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquablack WMA</td>
<td>MAXAM equipment</td>
<td>Water-based</td>
<td>U.S</td>
<td>Not specified</td>
</tr>
<tr>
<td>Double Barrel Green</td>
<td>Astec</td>
<td>Water-based</td>
<td>U.S</td>
<td>116-135</td>
</tr>
<tr>
<td>Low Energy Asphalt (LEA)</td>
<td>LEACO</td>
<td>Water-based, hot coarse aggregate mixed with wet sand</td>
<td>U.S, France, Spain, Italy</td>
<td>&lt;100</td>
</tr>
<tr>
<td>Low Emission Asphalt</td>
<td>McConnaug-hay Technologies</td>
<td>Water-based, hot coarse aggregate mixed with wet sand, combined with chemicals</td>
<td>U.S</td>
<td>90</td>
</tr>
<tr>
<td>Ultrafoam GX</td>
<td>Gencor Industries</td>
<td>Water-based</td>
<td>U.S</td>
<td>Not specified</td>
</tr>
<tr>
<td>WAM-Foam</td>
<td>Shell and Kolo-Veidekke</td>
<td>Water-based foaming process using two binder grades</td>
<td>U.S, Norway, Worldwide</td>
<td>100-120</td>
</tr>
<tr>
<td>Warm Mix Asphalt System</td>
<td>Terex Roadbuilding</td>
<td>Water-based</td>
<td>U.S</td>
<td>[&lt;32]</td>
</tr>
<tr>
<td>LEAB</td>
<td>Royal Bam Group</td>
<td>Water-based, mixing of aggregates below water boiling point</td>
<td>Netherlands</td>
<td>90</td>
</tr>
<tr>
<td>LT Asphalt</td>
<td>Nynas</td>
<td>Water-based binder foaming with hydrophilic additive</td>
<td>Italy, Netherlands, Worldwide</td>
<td>90</td>
</tr>
<tr>
<td>Advera</td>
<td>PQ Corporation</td>
<td>Water-containing technology using Zeolite</td>
<td>U.S</td>
<td>[10-30]</td>
</tr>
<tr>
<td>Aspha-Min</td>
<td>Eurovia</td>
<td>Water-containing technology using Zeolite</td>
<td>U.S, France, Germany, Worldwide</td>
<td>[20-30]</td>
</tr>
<tr>
<td><strong>Organic or wax additives</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasobit</td>
<td>Sasol</td>
<td>Fischer-Tropsch wax</td>
<td>Worldwide</td>
<td>[20-30]</td>
</tr>
<tr>
<td>Product</td>
<td>Manufacturer</td>
<td>Description</td>
<td>Location</td>
<td>Commercialisation</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------------------</td>
<td>-----------------------------------------------------------</td>
<td>------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Asphaltan A</td>
<td>Romonta GmbH</td>
<td>Montan wax for mastic asphalt</td>
<td>Germany</td>
<td>[20]</td>
</tr>
<tr>
<td>Romonta N</td>
<td>Romonta GmbH</td>
<td>Refined Montan wax with fatty acide amide for rolled asphalt</td>
<td>Germany</td>
<td>[20-30]</td>
</tr>
<tr>
<td>Licomont BS</td>
<td>Clariant</td>
<td>Fatty acid amide</td>
<td>Germany</td>
<td>[20-30]</td>
</tr>
<tr>
<td>3E LT or Ecoflex</td>
<td>Colas</td>
<td>Proprietary</td>
<td>France</td>
<td>[30-40]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical additives</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Evotherm ET</td>
<td>Mead-Westvaco</td>
<td>Chemical bitumen emulsion</td>
<td>Worldwide</td>
<td>[50-75]</td>
</tr>
<tr>
<td>Evotherm DAT</td>
<td>Mead-Westvaco</td>
<td>Chemical package with water</td>
<td>Worldwide</td>
<td>[45-55]</td>
</tr>
<tr>
<td>Evotherm 3G</td>
<td>Mead-Westvaco</td>
<td>Chemical package without water</td>
<td>US</td>
<td>[33-45]</td>
</tr>
<tr>
<td>Cecabase RT</td>
<td>CECA Arkema group</td>
<td>Chemical package</td>
<td>US, France</td>
<td>[30]</td>
</tr>
<tr>
<td>Rediset WMX</td>
<td>Akzo Nobel</td>
<td>Cationic surfactants and organic additive</td>
<td>US, Norway</td>
<td>[30]</td>
</tr>
<tr>
<td>REVIX</td>
<td>Mathy-Ergon</td>
<td>Surface-active agents, waxes, processing aids and polymers</td>
<td>US</td>
<td>[15-25]</td>
</tr>
<tr>
<td>Iterlow T</td>
<td>IterChimica</td>
<td>-</td>
<td>Italy</td>
<td>120</td>
</tr>
</tbody>
</table>
Appendix 2 – Market Barriers identified by Atkins

The final ranking for all twenty barriers is listed below (scored from 1 to 5) and classified in four sectors: Technical, Perception, Cultural and Organisational sectors [24]:

<table>
<thead>
<tr>
<th>Rank</th>
<th>Barrier</th>
<th>Score</th>
<th>Barrier sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Evidence of performance</td>
<td>4.40</td>
<td>Perception</td>
</tr>
<tr>
<td>2</td>
<td>Knowledge and understanding</td>
<td>4.18</td>
<td>Technical</td>
</tr>
<tr>
<td>3</td>
<td>Design guidance</td>
<td>4.15</td>
<td>Technical</td>
</tr>
<tr>
<td>4</td>
<td>Affordability</td>
<td>4.06</td>
<td>Perception</td>
</tr>
<tr>
<td>5</td>
<td>Specification</td>
<td>4.02</td>
<td>Technical</td>
</tr>
<tr>
<td>6</td>
<td>Impartial assistance</td>
<td>3.89</td>
<td>Technical</td>
</tr>
<tr>
<td>7</td>
<td>Personal views</td>
<td>3.68</td>
<td>Perception</td>
</tr>
<tr>
<td>8</td>
<td>Engineering skills</td>
<td>3.68</td>
<td>Cultural</td>
</tr>
<tr>
<td>9</td>
<td>Confidence of success</td>
<td>3.61</td>
<td>Cultural</td>
</tr>
<tr>
<td>10</td>
<td>Attitude to risk</td>
<td>3.57</td>
<td>Cultural</td>
</tr>
<tr>
<td>11</td>
<td>Benefits unclear</td>
<td>3.38</td>
<td>Perception</td>
</tr>
<tr>
<td>12</td>
<td>Absence of advocacy</td>
<td>3.36</td>
<td>Cultural</td>
</tr>
<tr>
<td>13</td>
<td>Regulator approvals</td>
<td>3.30</td>
<td>Organisational</td>
</tr>
<tr>
<td>14</td>
<td>Key action drivers</td>
<td>3.24</td>
<td>Organisational</td>
</tr>
<tr>
<td>15</td>
<td>Leadership views</td>
<td>3.23</td>
<td>Organisational</td>
</tr>
<tr>
<td>16</td>
<td>Priority for attention</td>
<td>3.12</td>
<td>Cultural</td>
</tr>
<tr>
<td>17</td>
<td>Proprietary processes</td>
<td>3.05</td>
<td>Perception</td>
</tr>
<tr>
<td>18</td>
<td>Procurement</td>
<td>2.95</td>
<td>Organisational</td>
</tr>
<tr>
<td>19</td>
<td>Logistical planning</td>
<td>2.86</td>
<td>Organisational</td>
</tr>
<tr>
<td>20</td>
<td>Organisation structure</td>
<td>2.75</td>
<td>Organisational</td>
</tr>
</tbody>
</table>
Appendix 3 – Summary of sessions 2 & 3 of Atkins’ report

Main findings: the industry is conservative by nature; fairly high proportion of delegates who would consider lower temperature asphalts as an alternative; issues of cost and service longevity emerged as the key barriers to be addressed [24].

- **Just what is it about traditional hot-mix asphalt that makes it so appealing and endearing to you?**
  1. Familiarity
  2. Proven performance
  3. Forgiving/repairable
  4. Availability
  5. Investment value

- **Describe your precious engineering performance requirements which are provided by traditional hot-mix asphalt –Base/Binder Course.**
  1. Durability
  2. Stiffness
  3. Impermeability
  4. Deformation resistance

- **Describe your precious engineering performance requirements which are provided by traditional hot-mix asphalt –Surface Course.**
  1. Skid resistance and texture. (Road user safety)
  2. Durability
  3. Ride quality
  4. Deformation resistance
  5. Impermeability

- **If asphalt were available with a lower carbon footprint and with similar precious features as hot-mix asphalt would you consider its use?**
  1. **As Base/Binder Course**
     - Yes (75%)
     - Perhaps (25%) – cost and life qualifying circumstances
  2. **As Surface Course**
     - Yes (42%)
     - Perhaps (58%) – cost, risk and life qualifying circumstances
### Barrier exploitation & addressing the barriers

<table>
<thead>
<tr>
<th>Rank</th>
<th>Barrier</th>
<th>Detailed issues</th>
</tr>
</thead>
</table>
| 1    | Performance and Serviceability | - Industry conservatism (risk)  
- Experience of failure  
- Former client experiences conditions future attitude  
- Availability and supply logistics  
- Technical forums -share evidence, successes and failures |
| 2 & 7| Engineering Knowledge    | - Reliability upon national Standards  
- Training, in depth, for the professional engineer  
- Client, elected members, procurement officers and non-engineers education  
- Poor dissemination and access to knowledge  
- Engineering confidence in materials and laying processes  
- Guidance documents – where to use and where not |
| 3    | Design guidance          | Not covered in sessions 2 & 3                                                                                                                                  |
| 4    | Affordability            | - Clarity of definition  
- Client design optineering  
- Works programming and logistics  
- Designs driven by initial cost rather than life cycle cost  
- Disclosure of true product cost  
- Stakeholder partnerships  
- Fear of blame – public accountability  
- Articulate the added value |
| 5    | Specification            | Not covered in sessions 2 & 3                                                                                                                                  |
| 6    | Expert Support           | - Fragmented and dwindling human resource  
- Absence of a forum cross industry sharing of knowledge especially Las  
- Lack of skills and technical knowledge  
- Possible mistrust between LAs/client and Contractor in respect of advice |
| 8    | Open Mindedness          | - Articulate the benefits  
- Empowerment – corporate commitment  
- Limited support from organisation/management – lack of champions/mentors  
- Fear of failure  
- Knowledge base – lack of good understanding impedes acceptance |
| 9 & 10| Confidence of success    | - Previous experiences condition client attitudes to risk  
- Limited funding environment creates caution as consequences of failure can be a constraint on innovation  
- Media – raises negative profile and doesn’t always provide solutions  
- Concern about use of some current materials and specifications |
Application potential

- **Indicate which layer in the road you consider the most likely for application of Low Carbon Asphalt.** This was subdivided into structural (base/binder) applications and surfacing.

  1. Most likely adoption of half-warm and cold asphalt to be in structural applications. For surfacing, half-warm scores more highly than cold asphalt which confirms the findings from the Session 1 analysis where the perceived risk is greater for surfacing applications.

- **What would it take to make you change from hot to half-warm asphalt?**

  1. Cost – modest or no increase/certainty
  2. Performance – prediction and longevity
  3. Guidance – clarity and understanding

- **What would it take to make you change from hot to cold asphalt?**

  1. Cost – modest or no increase/certainty
  2. Performance – prediction and longevity
  3. Guidance – clarity and understanding
  4. Logistics – production availability and works planning
The Carbon Trust’s mission is to accelerate the move to a low carbon economy. We are a world leading expert on carbon reduction and clean technology. As a not-for-dividend group, we advise governments and leading companies around the world, reinvesting profits into our low carbon mission – a unique and sustainable combination. Our vision is a vibrant, sustainable economy – with wealth and opportunity for those who take the lead.

- We advise businesses, governments and the public sector on their opportunities in a sustainable low-carbon world
- We measure and certify the environmental footprint of organisations, supply chains and products
- We develop and deploy low-carbon technologies and solutions, from energy efficiency to renewable power

www.carbontrust.com
+44 20 7170 7000

Whilst reasonable steps have been taken to ensure that the information contained within this publication is correct, the authors, the Carbon Trust, its agents, contractors and sub-contractors give no warranty and make no representation as to its accuracy and accept no liability for any errors or omissions. Any trademarks, service marks or logos used in this publication, and copyright in it, are the property of the Carbon Trust. Nothing in this publication shall be construed as granting any licence or right to use or reproduce any of the trademarks, service marks, logos, copyright or any proprietary information in any way without the Carbon Trust’s prior written permission. The Carbon Trust enforces infringements of its intellectual property rights to the full extent permitted by law.

The Carbon Trust is a company limited by guarantee and registered in England and Wales under Company number 4190230 with its Registered Office at: 4th Floor, Dorset House, 27-45 Stamford Street, London SE1 9NT
Published in the UK: April 2015.
© The Carbon Trust 2015. All rights reserved.