

Embedding Sustainability Strategies in the Transport Sector: Strategic Review

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Summary:

In recent years, the asphalt industry has become increasingly aware of its sustainability impact in surfacing, namely to the three key pillars, being Societal, Economic, and Environmental. This awareness is now driving the leading asphalt companies to research and develop new methods of asphalt creation to make the surfacing industry more sustainable for years to come, particularly as there are both internal and external drivers pushing for a change for the better, categorised thusly as normative, coercive and mimetic. This paper investigates the issues that today's leading asphalt-producing companies are facing and the solutions that are being adopted by these companies to overcome these challenges. The research methodology used was literature review from current real-world examples from leading asphalt suppliers and academic sources. Both proven and researched methods were selected to review and examine the factors resulting in sustainable solutions being implemented.

Keywords:

Asphalt industry, Sustainable Value Creation, Sustainable Solution, Challenges, and Triple Bottom Line.

Track 30: Sustainable and responsible business

Word Count: 6,188

Introduction

Whilst the Romans may have built the first roads around 410AD, today's surfacing industry came about in the 18th century when pioneering engineers like John Macadam improved road surfaces by covering them in layers of compacted stone (National Highways, 2024). Since then, road surfacing technology has continued to evolve, from the utilisation of hazardous tar-bound aggregate to the more recent recycled aggregate and 'foam' mix, a mix whereby hazardous material, such as tar-bound asphalt, can be incorporated into the new surface course (Tarmac, 2024); and energy-reducing asphalt, which can help to reduce carbon emissions created by construction projects (Heidelberg Materials, 2024).

This report will focus on the sustainability issues faced within the surfacing industry, how it is slowly starting to overcome the challenges faced and how future sustainability may be evolved via the use of four solutions, being recycled asphalt, use of single-use and waste plastic as well as biomaterials as an aggregate binder and the incorporation of smart technology. The report will then conclude with recommendations as to how future sustainability may be achieved.

Why the Surfacing Industry?

Compared to other sectors, surfacing has only recently gained an awareness of the necessity to change its ideals and attitudes towards a more sustainable future, with recognition of the impact

being in the very late 20th century. This is late compared to other industries and construction sectors which started looking into sustainable solutions as far back as the mid-19th century (Bergquist, 2017).

With such a large scope for improvement in sustainable engineering within the surfacing industry utilising various methods such as recycled materials, permeable surface and smart technology (Smart Surfacing Solutions, 2024), this sector is deemed to have a great opportunity and much potential to decrease the current impact on sustainability.

As this research focuses on surfacing, it will look at three of the main five layers that make up a typical road surface, which is the base course, binder course and surface course. A cross section of this can be seen in figure 1 (below). These three courses all include a binding agent called bitumen which is usually obtained from crude oil (Zahedi, 2022). Typically, the amount of bitumen used in road construction is around 7kg per metre squared for a depth of 6cm (Darbandizadeh, 2021). This would equate to 52.5kg bitumen needed for a full depth construction of 450mm of the three courses. If the whole of the UK road network needed to be re-surfaced at once, based on there being 245,700 miles of road network as of 2023 (Department for Transport, 2024), this would require 114bn kg bitumen to undertake the task, so it can be easily seen why this is a key area for sustainability.



Figure 1 – typical cross section of a flexible pavement (Mathew, T., 2015)

Due to crude oil being a fossil fuel, and therefore finite, asphalt companies are continuously looking at ways to move away from the use of traditional bitumen and utilise more sustainable methods of asphalt production. It must be noted that whilst the subbase course does contain bitumen, the percentage used is considerably lower compared to that of the three courses covered in this paper. This does not mean to say however that the solutions identified could not be applied to the subbase course.

Challenges Facing Asphalt Companies

There are a multitude of challenges that face the modern asphalt companies when it comes to improving their sustainability and reduction of impacts on the three pillars, being social, economic and environmental. One of the first areas of impact is the quarrying of materials to use in asphalt mix. The quarrying of stone means that resources are being depleted over time and not being replaced. In 2019 alone, circa 133.5m tonnes of sand, gravel and crushed rock was sold in England, 25% of which was for surfacing (Mankelow, J., Wrighton, C., Brown, T., Sen, M & Cameron, D., 2021). An overview of this can be seen in figure 2 below:

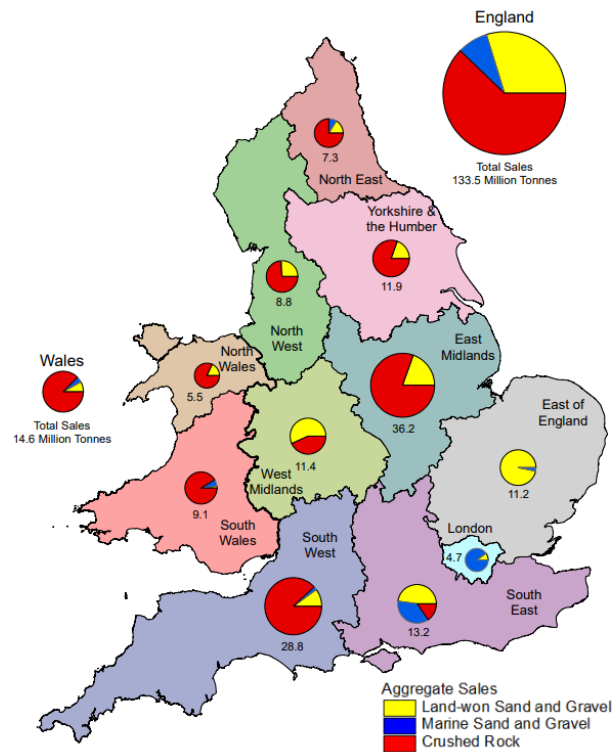


Figure 2 – Sales of sand, gravel and crushed rock for primary aggregates in 2019
 (Mankelow, J., Wrighton, C., Brown, T., Sen, M & Cameron, D., 2021)

Another area of focus is the creation of a lot of carbon emissions, not only from the extraction process within the quarry but also material processing, haulage to site and use of plant on site to lay the various asphalt courses. Figure 3 shows the breakdown of carbon emissions from plant, transportation and materials, with materials (i.e., aggregate), being the highest carbon emitter.

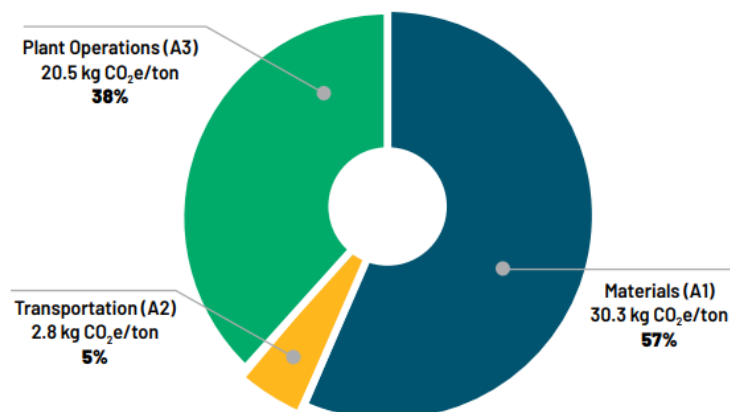


Figure 3 – Cradle to gate GHG emissions (A1-A3) (Shacat, J., Willis, R., Ciavola, B., 2024, 2024)

When looking at the surfacing elements alone, being base, binder and surface, typical carbon emissions by tonnage can be seen in table 1. The total kgCO₂e/t is calculated from direct and indirect sources which are emissions from the asphalt plant itself (Scope 1 - direct), and emissions from electricity consumption and the purchasing of goods and services, and distribution (Scopes 2 and 3 respectively) (Heidelberg Materials, 2024).

Product Category	Total kgCO ₂ e/t	Scope 1	Scope 2	Scope 3
Base Course	47	30	2	15
Binder Course	48	30	2	16
Surface Course	60	31	2	27

Table 1 – Typical carbon emissions by tonne of asphalt (Heidelberg Materials, 2024)

Further challenges are issues faced on construction projects or human error. This can lead to wasted loads resulting in additional haulage for returned loads and increase in landfill waste if the material cannot be recycled or used elsewhere. Such issues can include incorrect design, excess material ordering, improper handling and incorrect storage (Business Waste, 2024)

One final challenge is that of planned waste that could be considered hazardous (e.g., asphalt containing coal tar). Tarmac Contracting (2020) identified that this can be very expensive to dispose of – up to £150 per tonne – and requires special license for disposal.

Economic, social and environmental impacts of current practices

When undertaking research for this paper, the economic, social and environmental impacts of surfacing have been investigated. It can have both positive and negative impacts on the three pillars. Socially, the positive impacts are that when a road surfacing project is completed, it can lead to improved transport links, road surfaces tend to be quieter (though this is upon completion of the permanent road, rather than temporary surface) and an improvement in community links between cities and rural areas. Negative social impacts include frustration from members of the community when roadworks are being undertaken due to delays, noise pollution from the utilisation of plant breaking up old road surface, and concern over damage to vehicles from temporary road surface.

Positive impacts on the economic pillar are that improved roads allows better connection between businesses, suppliers and customers, there is a reduction in journey times increasing higher deliverance of goods and services, and an improvement in employment statistics from better connections to areas outside of cities. On the contrary, negative impacts can include loss of revenue to businesses during times of work whilst road closures are underway, there is a potential increase of council tax and business rates to offset cost of new road and maintenance, and an increase in waste products from old, excavated roads.

Finally, positive environmental pillar impacts include when recycled aggregate is used, this reduces CO₂ and creates less pollution, old, used quarries can be re-purposed for other things like stadiums or nature reserves (Thompson & Son, 2021), and an improvement in water drainage reducing risk of flooding to the surrounding areas. Some of the negative impacts include habitats being disrupted by quarrying activities, recycled methods are not yet fully understood or trusted, and there is an increase in air pollution from roads being constructed/maintained.

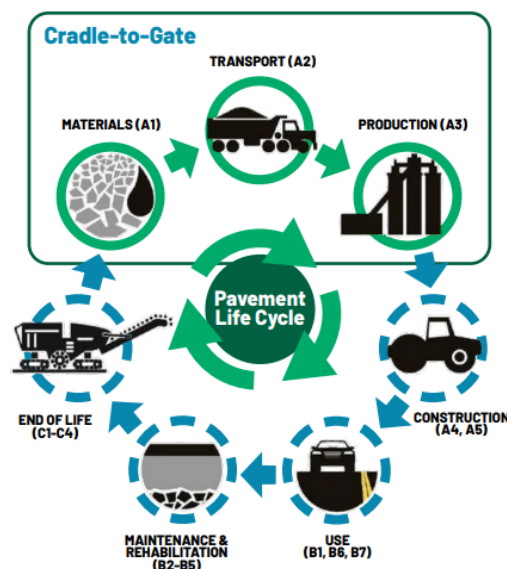
Current sustainability and environmental issues relating to traditional asphalt including the impact of quarrying

One of the current sustainability and environmental issues facing asphalt production is the high-water usage for quarrying of materials, material processing including washing, and the

production of binding agents to create final surface mix. Indeed, it is not just water that plays a key part in the issues that face the surfacing industry. There are many steps required to produce the final asphalt product as can be seen in figure 4. It is not simply just a case of extracting material and transporting it to its destination, but several steps from the quarrying of the material for processing, to construction usage, all through to end user (i.e., road users) and finally recycling for re-use elsewhere.

These number of steps also create high carbon emissions from material extraction, processing and haulage. Interestingly, haulage is usually overlooked in carbon monitoring due to difficulty in tracking. Whilst not impossible, if the haulier's fleet is their own, then trackers can be fitted to the vehicles to make emissions easier to track. Should the haulage be provided by an external company, however, the fitting of trackers may not be deemed favourable by the external company, consequently resulting in the emissions not being tracked.

Another issue being faced by the industry as mentioned previously is that the materials being removed from quarries is finite and not being replaced. Ultimately when one quarry is depleted, a new one must be sourced to ensure continuity in the provision of materials. The next part of this paper will review quarry impact further as part of this chapter.



*Figure 4 - Cradle to Gate Pavement Life Cycle
(Shacat, J., Willis, R., Ciavola, B., 2024)*

As well as the issues that relate to the asphalt paving itself, there is also the impact of quarrying. As identified earlier in this paper, materials make up the largest carbon emitter compared to operations and transportation. In recent times, there has been a realisation that the material in quarries is finite – one example is Midland Quarry Products (MQP) who are applying for planning permission to extend one of their quarries, located at Cliffe Hill in Leicestershire, due to the aggregate within that quarry predicted to reach total depletion in 2027 (MQP, 2019). By extending the quarry, this will ensure continuous material supply for many years to come. Ultimately this will result in disruption in eco-systems and surrounding areas from quarrying activities.

In comparison, Cliffe Hill can be considered a small quarry when compared to the largest quarry in the UK. Glensanda, a coastal quarry located in Scotland. covers an area of 1,800

hectares (Work-Tops, 2024). This equates to enough material extraction for 100 years (BBC, 2013). From this, it is evident that the industry focus is not on recycling. However, whilst the issues facing surfacing and asphalt production may be challenging, it is not entirely negative. Figure 5 shows the benefits that the quarrying industry brought to the UK in 2018

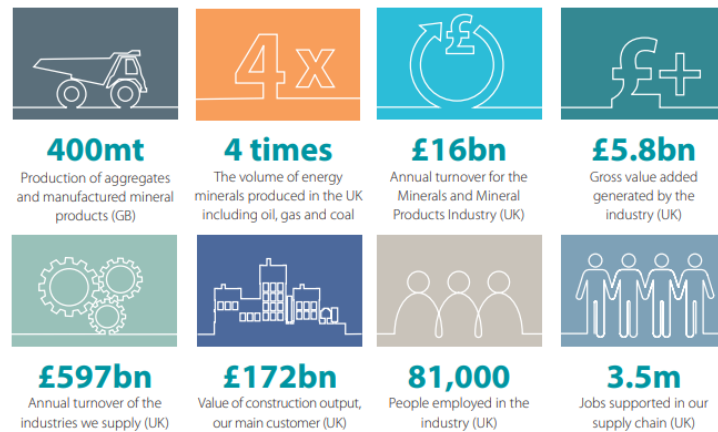


Figure 5 - At a Glance (2018) (Mineral Products, 2020)

Internal and external drivers for change

As the asphalt industry continues to realise the need for change, there are various drivers that also push the industry towards these positive changes. These can be classified as internal and external drivers. Below are some of the internal and external drivers for change for the three largest asphalt-producing companies, being Aggregate Industries, Heidelberg Materials and Tarmac.

Internal drivers for change usually come from within the asphalt companies themselves and include areas like finite materials in quarries, carbon savings from recycling, cost saving from re-purposing hazardous material, people and communities, water conservation and nature positive, planet, climate and net zero, circular and resilient economy, and safety and inclusivity.

The three main asphalt producers all follow similar principles which serve as their internal drivers for change as highlighted in their sustainability policies. Tarmac (2024) have four areas which are purpose, people, planet and solutions. Aggregate Industries (2024) policy covers four area also, which are climate, circular economy, water and nature, and people and communities. Finally, Heidelberg Materials (2024) categorise their commitments as net zero, safe and inclusive, circular and resilient, and nature positive. Whilst the companies all have their own policies, they all follow similar themes in focusing on their people, the environment, sustainable solutions and working more with nature to offset impact.

External drivers for change are just that – external to the asphalt companies. These are usually derived from government sustainability policies, habitats disrupted from quarrying, increase in air pollution from construction, environmental, social and economic impacts, public pressure and customer demand, technological advancement, increase in sustainability awareness, and United Nations global climate action.

The UK government has set out a sustainability policy specifically for road construction. Known as the strategic road network and the delivery of sustainable development, it dictates sustainable development principles that road construction companies must adhere to when undertaking construction. Some of these principles include reducing construction emissions

and net zero maintenance by 2040, focusing on improving multiple occupancy travel by incorporating more public transport and cycling routes, and an improvement on better connection links. It must be noted that alongside the 2040 directive mentioned above, there is also the driver to reduce road user emissions to net zero by 2050 (Gov.uk, 2022). Whilst this can be deemed a desirable target by the government, it could be perceived to be an impossible task for the road construction companies as they would not have impact on final road user choice of vehicle (i.e., petrol or diesel over electric) thus setting out what may be considered an impossible target.

A step towards a more sustainable industry – current and future solutions

As the asphalt industry strives to become more sustainable as time progresses, the three main asphalt producing companies have each created their own methods of mixing and laying that not only reduces carbon emissions but also incorporating recycled road surface into the mix thus reducing the amount of virgin quarried material required. Aggregate Industries (2024) now quite often utilise a mix called Foamix and Foamix Eco, both of which can be cold rolled, meaning it does not use heat for asphalt production but water instead.

Heidelberg Materials (2024) have created an asphalt mix classed as Energy Reducing Asphalt (ERA). They discovered that by utilising recycled material in the surface mix, carbon emissions are significantly reduced, as can be seen in figure 6. Another method of becoming more sustainable is by using old tyres to replace cellulose fibres normally used as a binder additive, a mix called Ultipave R that was trialled by Tarmac in 2021 on Otley Road in Bradford with much success (Tarmac, 2021).

The three major companies identified above are now all utilising similar methods of more sustainable asphalt production with their own names. Whilst each has its own specification, they follow similar attributes of the use of recycled material, innovation in sustainable asphalt production, improved health and safety from lower temperature laying, sustainable, adaptable in its use, and cost efficient.

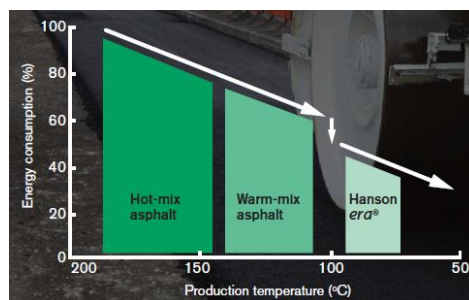


Figure 6 - Carbon reduction from era (Heidelberg Materials, 2024)

Whilst the industry is making good progress with the current asphalt mixes, four further potential solutions have been identified within this paper that could truly result in the asphalt industry becoming more sustainable, which shall be explored over the next four sections. These solutions are use of recycled aggregate including hazardous materials, use of single-use plastic in asphalt, use of smart technology, and use of biomaterials as a binding agent in asphalt.

Solution 1 – use of recycled aggregate including hazardous materials

This solution, known as reclaimed asphalt pavement (RAP), is a method that is widely used by many asphalt-producing companies. It works by recovering aggregate from old surfacing that is being replaced or decommissioned, then processed before being mixed with virgin material

from quarries to create a new surface mix. The implementation of this reduces the amount of virgin material required, thus reducing the amount of quarrying required (Aggregate Industries, 2024).

This is not being utilised as much as it could be and this may be due to current highways standards specifying that only a maximum of 10% recycled aggregate can be incorporated into a new mix (Wright, M., Zuo, W., and Bateman, D., 2020). This is because using RAP can reduce the durability of new surfacing and result in greater cracking, and more road maintenance. This was challenged by FM Conway in 2019, however, when they utilised an asphalt mix that included 50% RAP. This mix was successfully used on the M25 between J25 and J26 with FM Conway then looking to use it on future projects (F M Conway, 2024).

It has also been identified that in some instances, hazardous material, such as tar-bound asphalt, can also be recycled. Heidelberg Materials have achieved this as part of the reconstruction of the A66 near Darlington in 2017. Approximately 10,000t of hazardous material was re-purposed (Heidelberg Materials, 2024). Heidelberg Materials continue to use this process today as it results in the cost of waste management being reduced drastically. It costs on average £150 per tonne to dispose of tar-bound planings (Bottom, 2011) compared to the average of £10 per tonne for clean planings (Commercial Recycling, 2024). Overall, the use of RAP has proven to be a very effective way of re-cycling and re-purposing old material with the leading asphalt companies continuing to utilise it to this day.

Solution 2 – use of single-use plastic in asphalt

This is a solution that is somewhat being used by asphalt companies. The concept replaces traditional aggregate binding agents with recycled and waste plastic and tests have shown that even a small amount of plastic can improve stability, strength and durability of asphalt when used in the surfacing mix (Sasidharan, M., Torbaghan, M., & Burrow, M., 2019).

One surfacing project, based in Green Dragon Lane, Enfield (Hall, 2019) utilised a mix of polymer-modified asphalt and recycled plastic-bound asphalt with a successful outcome. The asphalt performed very similarly to commercial polymer-bound asphalt and saved 600kg waste plastic from incineration/landfill and a carbon saving of 1,416kg. The product used on this scheme is now being used internationally.

It doesn't stop there. Further development by PlasticRoad has resulted in the development of a road made entirely from recycled plastic (Barnett, 2021). Figure 7 (below) shows a cross section of a PlasticRoad panel. Developed in the Netherlands, it has been trialled initially as a thirty-metre-long stretch of bicycle path in 2018. It is a lightweight, hollow solution that has space for services as well as a drainage system. There are also sensors embedded in the plastic which provides feedback that can be used for future development, thus also incorporating smart technology into the solution.



Figure 7 – Segment of PlasticRoad (Caceres, 2023)

Solution 3 – use of smart technology

The use of smart technology is fairly new with use by some by asphalt companies, though not very common at the moment. Companies can use technology to create ‘Smart Road Materials’, meaning the use of asphalt which incorporates sensors to monitor conditions of roads in real time, allowing for better addressing of issues by local authorities due to the provision of data that can predict when maintenance may be needed (Smart Surfacing Solutions, 2024). This is done by data being transmitted to a data collection hub which, in turn, would then send the data to a database on a server to be analysed. This analysis can then be carried out either via human or artificial intelligence.

Smart technology can also be used to monitor material quality at the asphalt plant without human intervention, create self-cleaning equipment and monitor asphalt plant emissions (Woof, 2024). One example is Astec Digital (2024) who have created smart technology for ‘rock to road’ value chain as can be seen in figure 8. Their system covers every aspect of asphalt monitoring from the quarrying of aggregates using industrial automation, plant and mobile telematics, through to robotics and ultimately analytics, all via a connectivity suite. By utilising this system, the overall benefit is improvement in material quality and road maintenance.



Figure 8 - Rock to Road smart tech solutions (Astec Digital 2024)

Another area smart technology in road surfacing could benefit is via the charging of electric vehicles as they drive over the road. One country that has already started looking into this is the USA. Installed in Detroit, Michigan, the road was created by installing electromagnetic coils under the surface course, powered by the city's electrical grid. The coil then transmits energy to a receiver on the car's battery, charging it as it drives. The benefit of this would be reducing the amount of charging required and potentially even not needing charging points at all in the future (Paris, 2024). If implemented in the UK, this would be certainly beneficial in aiding the UK government to achieve the, albeit ambitious, target ban of petrol and diesel vehicles by 2035 (Podpoint, 2024).

Solution 4 – use of biomaterials as a binding agent in asphalt

In comparison to the other solutions investigated, this is a much newer concept which was trialled in January 2024 in Canada and is a solution which is also being investigated in numerous other countries as an alternative to traditional or plastic-based asphalt. It can include materials such as plants, cooking oils, and animal manure (Abdolla, 2024). A study and testing undertaken at Chang'an University showed that the addition of plant fibres resulted in stiffer asphalt binder at lower temperatures, as well as a decrease in the cracking resistance of the asphalt (Li, Z., Li, K., Chen, W., Liu, W., Yin, Y. & Cong, P., 2022)

Biodiffusion Technologies Inc and Dufferin Construction in Canada have developed a completely bio-based resin, made from forestry and agricultural products and is 100% non-toxic (CBC News, 2024). Figure 9 (below) shows the bio-resin and how it looks. It has been described as a similar consistency to 'Vegemite' and is a completely non-toxic solution to traditional bitumen binding agents (CBC News, 2024)

As this is a new technology within asphalt production, it may be some time before the industry recognises and starts to use this method due to not only extensive testing being required but also the current restriction on recycled asphalt being able to be used as identified in solution 1.



Figure 9 – Bioresin Sample (CBC News, 2024)

With the reluctance from local authorities in the UK being high regarding recycled asphalt, only a limited number have allowed the use of biomaterials to be trialled in the UK. Alongside Canada trialling a bioresin in early 2024, Tarmac (2022) have also produced a plant-based binding agent in their asphalt mix as part of the A452 resurfacing works in Birmingham. The mix enabled carbon savings of 6.5kg CO₂e per tonne of asphalt as well as carbon capture and storage, showing what could be considered a highly sustainable option for road surfacing.

These aren't the only two sources of bio-asphalt. Scientists at Wageningen University and Research in the Netherlands have developed a lignin-based ingredient for asphalt. Lignin is a residue product which is a structural component of plant cell walls, particularly found in wood and bark. Currently trialled on 25 different road types, the scientists found that application of lignin resulted in a significant drop in CO₂ emissions anywhere between 35-70% when replacing half the traditional bitumen binder (Gosselink, 2024).

Furthermore, another research team in Arizona University, USA, has developed a binder using liquefied algae that would replace traditional bitumen. The scientists discovered under laboratory conditions that the use of algae cuts the emissions and pollution produced from bitumen by 70% by selectively capturing harmful compounds prior to converting to volatile compounds. Further research is planned to see how it will react outside of laboratory conditions (i.e., on an external road surface) (World Bio Market Insights, 2024).

Additional research shows there are many more scientists and companies who are continuously looking at other bio-binders for use in asphalt production. With this being such a promising area of study, this may be the only solution that, when combined with recycled aggregate, could be the truest way of the surfacing industry becoming sustainable.

To enable appropriate decision making for more sustainable solutions, table 2 compares the four proposed solutions, highlighting the key benefits and drawbacks for each. The drawbacks are discussed later in this paper in the “Challenges within sustainable solutions” section.

Solution	Benefits	Drawbacks
Recycled Asphalt Planings	• Re-uses old asphalt that would have gone to landfill • Can re-use hazardous material • Results in a reduction of virgin material	• Planing out and processing of asphalt can be expensive • May be considered a lower-quality asphalt mix than virgin material
Single Use Plastic	• Can improve stability, strength and durability of asphalt • Full plastic solution lightweight and hollow for easier services installation and maintenance	• Chemicals in the plastic could leach into the environment • Finite availability of single use plastic meaning difficulty with maintenance
Smart Technology	• Higher road condition monitoring efficiency • Reduction of road defects from early notification • Potential for electric vehicle charging	• Costly to maintain • Concern of cyber attacks if software not updated regularly • Initial cost of implementation high
Bio-binders	• Natural solution that is biodegradable • Completely non-toxic solution to traditional bitumen binding agents • Can utilise materials such as plants, cooking oil and animal manure	• Chemical composition of binder may not be compatible with aggregate • Current length of degradation time unknown – roads may degrade faster than other solutions

Table 2: Comparison of Sustainable Solutions

Economic, social and environmental impact of sustainable solutions

Of course, the sustainable solutions investigated within this paper don’t come without their own impacts on the three pillars of sustainability. As discussed earlier in this paper, the three pillars are economic, social and environmental.

Socially, the positive impacts are that with plastic being implemented as an aggregate binder, it could promote the recycling of single-use plastics, consequently resulting in a cleaner community. However, many people have a mentality of ‘someone else will clean up after me’ attitudes towards waste and recycling therefore the promotion of recycling plastics more may not have as much of an impact as desired. Another benefit is that of health – an improvement in health may potentially be seen in not just the community but also surfacing workers if biomaterials were to be developed and implemented more. This is because there would be a significant reduction, if not eradication, of hazardous materials in the asphalt mix.

Another positive is the implementation of smart technology within the surface course. If implemented, it could, as identified, monitor road condition and reduce maintenance, thus reducing car maintenance and tyre replacement. The negative to this however is that there is a wariness of the use of smart technology and data capture. Socially, people are wary of their data being captured and sold therefore may not be in favour of smart technology, particularly in the near future. One final negative impact is that recycled asphalt tends to be considered lower quality of new asphalt mixes therefore may result in more vehicle maintenance from surface cracking and repairs.

There are also economic impacts, both positive and detrimental. Positively, if there is an increase in recycling, this may result in a decrease in income tax due to the community being tidier and fewer resources required to keep areas clean. However, it must be understood that plastic is finite, and as time progresses and alternatives to plastic are sourced, this will make road maintenance more difficult to undertake due to limited materials available, ultimately costing more.

Smart technology can also have a positive economic impact, as with it being able to monitor road quality and conditions in real time, this will decrease maintenance as roads will need fewer repairs. The negative impact from smart technology however is that it may be deemed very costly to implement as part of the asphalt laying process as well as data storage and processing. Additionally, if it is not kept up to date, the technology may be unreliable.

Lastly, a positive economic impact that sustainable solutions may have is the cost of recycled asphalt being lower than completely virgin mixes. This means that the cost of laying is ultimately cheaper, therefore may also reduce costs of new surfacing schemes. In contrast to recycled however is bio-solutions and the impact that, due to lack of testing and the method not yet being fully known, may result in more maintenance needed if the mix degrades quicker due to it containing natural resources, economically resulting in higher costs to maintain and replace.

The third pillar, being environmental, also has its own benefits and drawbacks from sustainable solutions. Recycling waste and single-use plastic can yield optimistic results in that the use reduces CO₂ and pollution from a reduction in plastic waste. It can also result in the environment looking better as well as a decrease in danger to flora and fauna from micro-plastics. Areas would also be cleaner due to waste reduction in the community. The opposite of this is the concern that chemicals from recycled plastic in the asphalt mix may leach into the ground and watercourses.

If biomaterials continue to develop these could also have a positive impact on the environment as it would mean more natural materials being incorporated into the mix than man-made thus reducing impact on plants and wildlife. Contrarily, this may not happen for a while as currently recycled methods are still not yet fully trusted, and with only 10% recycled material currently allowable in asphalt mixes, biomaterials will take some time before being incorporated. Recycled mixes also still need an element of virgin material therefore there will still be an environmental impact from quarrying.

Challenges within sustainable solutions

After investigating four different solutions that the surfacing industry could incorporate within asphalt mixes, whilst they bring many positive, sustainable ideologies, these don't come without their own challenges.

The first solution, recycled asphalt, has long been deemed a lower-quality asphalt mix compared to using virgin material. This results in an increase in cracking and reduction of road longevity (Rathore et al, 2019), in turn increasing the amount of maintenance and upkeep required to ensure smooth road surfaces for driving. The challenge posed here is how to create an asphalt mix that doesn't crack as much. Until such a time as a mix is developed and the amount of recycled asphalt is included, the permissible amount may stay at 10% thus still requiring aggregate quarrying. Additionally, emergency works, say following a traffic collision, won't allow time for a recycled mix to be sourced due to urgency therefore virgin material will still be utilised for a long time to come.

The challenge with the second solution, being plastic-bound asphalt, is the concern that chemicals in the plastic could leach out of the binder and into natural watercourses. As people become more environmentally aware, the addition of plastic to aggregate binder may be viewed negatively. Additionally, low temperatures degrade the cracking resistance of the asphalt (Xu, F., Zhao, Y., and Li, K., 2021) thus requiring more maintenance. Another challenge with plastic-bound aggregate is the finite availability of plastic. There may come a time when plastic is no longer available. Should this be the case, the challenge here would be to find a new asphalt mix that does not incorporate plastic.

The third solution, smart technology, also has its own barriers. Being a fairly new concept, not only the initial cost to install, but also the cost of the maintenance may be significantly high resulting in a reluctance to incorporate it. There is also the issue of ensuring there is enough storage available for the data collection from the monitoring of the asphalt production, plant, laying the base, binder and surface course, and maintenance of the road. There may also be a cybersecurity risk if the technology is not kept up to date (Farhadi, 2024).

Finally, biomaterials also come with their own challenges. Due to this being a newer solution than smart technology, it cannot yet be deemed certain that the chemical composition of biomaterials used would be completely compatible with the aggregate and therefore may degrade faster than traditional, recycled or plastic mixes. The use of biomaterials may also be costlier than traditional materials (Abdolla, 2024) as if it does degrade faster, would need more maintenance than other surfacing mixes. Many biomaterials are also still going through research and development phases as outlined in Solution 4, and whilst laboratory conditions yield very positive results, the same cannot necessarily be said when it comes time to use the mix in the real world as there can be many factors that may impact the effectiveness, such as weather.

These four solutions also share some common barriers to acceptance and application which are the cost impact, public acceptance and government/local authority approval. Except for RAP which is in wide use today and does bring an element of cost benefit from clients purchasing the asphalt plantings for use in projects, the other three solutions would need thorough cost benefit analysis carried out to determine the long-term financial advantage. As identified previously, rigorous testing would also be required to ensure British Standards are met, thus garnering trust from the public as well as government/local authority bodies.

Miller and Bahia (2009) define a sustainable pavement as:

'a safe, efficient and environmentally friendly pavement that meets today's transportation needs without jeopardising the ability to meet such needs in the future'

It could be argued that the challenges identified within the sustainable solutions do not fit Miller and Bahia's definition, therefore cannot be deemed truly sustainable options.

Conclusions and Recommendations

In conclusion, sustainability can certainly be seen to be changing the shape of the asphalt and surfacing industry gradually. However, given the many issues being faced, for example lack of trust in recycled methods, it is highly unlikely the surfacing industry will change any time soon. Indeed, great steps have already started to be taken by three of the major aggregate producing companies via the use of recycled asphalt and incorporating waste plastics, however without the backing of the local authorities and UK government, it will still take a considerable amount of time before sustainable methods completely overtake traditional quarrying and asphalt production.

To ensure changes become more definite, sustainable solutions to current traditional surfacing mix production, such as recycled plastics, smart technology and biomaterials will need to be invested in to allow continuous testing and improvement for future use. As well as investment, the methods should also continue to be utilised so that they gradually become more mainstream, and an increase in the amount of permissible recycled aggregate in a mix being increased from the current 10% as well as a greater inclusion of waste and single-use plastics.

In addition to the above, further research is also suggested into the use of biomaterials as binding agents in base, binder and surface course mixes due to plastics potentially becoming obsolete in future and needing to be replaced with other asphalt mixes. Smart technology should also be researched further as this could have great potential, particularly for road quality and maintenance.

By further developing recycling methods, smart technology and biomaterials, the implications of this would be a reduction in quarrying of virgin material, thus lessening impact on the immediate environment, as well as putting single-use plastic and agricultural waste to better use than direct to landfill, also resulting in fewer harmful materials being released into the environment. There may also be a decrease in road maintenance from smart technology implementation thus also reducing maintenance costs and council tax from improved and automated monitoring.

The above can only happen, however, if governing bodies such as the Environment Agency and the UK government themselves invest the time, funding and research into these areas as well as the major aggregate producing companies, or preferentially, a combination of all.

The overall recommendation would be to, in the short term, promote the use of recycled asphalt in use whilst other methods are researched and developed further. The three largest asphalt companies would be advised to also work with local authorities, the UK government, and each other to promote alternative methods of surfacing material production. Also, whilst any asphalt company would most likely prefer to be the first to normalise smart-technology or develop a completely bio-based surfacing mix, the leading companies should work together to develop the products further and promote their use in the UK. Once this has been done, then the companies could look to utilising the mixes overseas.

In the interim, this paper recommends the switching of current surfacing mixes to full plastic solutions, like Plastic Road, then once developed into a trusted product, look to then start combining with biomaterials. Once this mix is then tested and developed further, the surfacing industry should then look to decrease the amount of plastic used over time until the mix only incorporated 100% bio-based asphalt, as well as implementing smart technology to oversee quality and maintenance.

One final consideration that could be taken when developing biomaterials is the use of what is deemed to be invasive species in the UK, e.g., Japanese Knotweed and Giant Hogweed. If these plants were tested and identified to be a feasible part of the mix for sustainable surfacing, not only would this potentially result in the industry becoming more sustainable, but also aid in the eradication of these invasive species from UK shores.

Overall, whilst the asphalt industry realises it needs to change and has started to make some changes, there is still a considerable way to go before full sustainability can be reached, if ever.

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