Centre of Excellence
for Decarbonising Roads

CATAPULT
Connected Places

ADEPT
International Scan
A systematic review of low-carbon materials for use on roads in the UK

July 2024

Department for Transport

ADEPT LIVE LABS 2 Decarbonising Local Roads

Transport for West Midlands

North Lanarkshire Council

Amey

COLAS
WE OPEN THE WAY

Executive Summary

Key objectives

This report, a collaborative effort between Connected Places Catapult and a consortium led by Transport for West Midlands, North Lanarkshire Council, Amey, and Colas, aims to achieve a thorough, systematic review of both domestic and international markets for low-carbon materials in road construction. The primary objective is to understand the implications of integrating low-carbon materials and approaches within existing systems, providing insights into their potential impacts on infrastructure and sustainability.

Problem

Transport accounts for 27% of the UK's carbon emissions (Strategic Road Network Initial Report, 2023), making roads a critical sustainability priority. If we are going to decarbonise, we need to move away from a linear - take, make, waste - economy. The linear economy is characterised by the extensive use of virgin materials – in the case of roads, concrete, asphalt, and steel – which are often discarded through incineration or landfilling. This practice harms the environment and is also wasteful in terms of money and energy. The materials essential for road construction are particularly challenging to decarbonise due to the lack of clear technological solutions, highlighting the critical need to trial and evaluate innovative, less carbon-intensive materials and practices.

To address this problem, the Centre of Excellence for Decarbonising Roads (CEDR) has been established to develop and implement a comprehensive framework to identify, evaluate, and trial innovative low-carbon road materials, while fostering industry-wide collaboration and overcoming barriers to adoption within local authorities. CEDR is one of the four themes included in Live Labs 2, a three-year, £30 million, UK-wide programme funded by the Department for Transport that will run until March 2026, with a five-year subsequent, extended monitoring and evaluation period.

Recommendations

Reduce: Focus on minimising the construction of new roads by prioritising only the most essential projects. Innovative designs and materials should be employed to ensure that new roads require fewer resources, thus reducing their environmental footprint. The use of lighter, more durable materials and optimised structural designs can significantly decrease the volume of materials needed, conserving resources and reducing emissions.

Reuse: Implement preventative maintenance strategies that leverage technology to extend the life of existing roads. Utilising data from optical sensors (cameras, LiDAR and infrared) on modern vehicles, we can monitor road conditions in real-time, allowing for preventative and efficient maintenance. This approach ensures that roads last longer and remain in better condition, reducing the need for full reconstruction.

Recycle: Enhance the circularity of road materials by recycling as much of road infrastructure as possible. Develop systems that integrate waste streams from other sectors, such as mining and construction, into road material production. For example, converting construction waste and mining by-products into aggregates can significantly reduce the demand for virgin materials. This strategy not only bolsters the UK's supply chain resilience but also reduces landfill waste.

Rethink: Innovate with novel materials and approaches to advance sustainable road construction. Explore the development of self-healing materials, such as bio-concretes and geopolymers, that can repair themselves and thereby extend road life. Consider the potential of roads to serve as carbon storage sites or as mediums for restoring ecosystems and generating electricity. Collaboration with developers of autonomous vehicles could also lead to roads requiring less infrastructure, making them simpler and more sustainable.

Purpose

The shift towards sustainable road construction under the **"Reduce, Reuse, Recycle, Rethink"** framework offers many environmental, economic, and societal benefits:

Future climate change resiliency: Materials must be assessed for their resiliency to future climate conditions. This involves evaluating how materials will perform under changing climates, including increased rainfall, temperature fluctuations, and extreme weather events. Materials that demonstrate higher resilience will ensure the long-term durability and functionality of roads, reducing the need for frequent repairs and replacements that can be costly and resource-intensive.

Resource conservation: The focus on reducing the use of virgin materials and increasing the use of recycled content alleviates pressure on natural resources. This approach is particularly significant in managing the use of biomass and other materials that, while renewable, can be limited in availability and have competing uses.

Reduction of toxicological impact: Employing fewer toxic materials and innovative construction methods can significantly decrease the release of harmful pollutants, including microplastics. Roads designed with this in mind can reduce the degradation that contributes to microplastic pollution, thus protecting both terrestrial and aquatic ecosystems.

Economic efficiency and durability: Sustainable roads are designed to last longer and require fewer repairs, resulting in less potholes and other structural issues. This durability translates into lower long-term costs for communities, as the expenses related to frequent maintenance, repairs, and full replacements are significantly reduced.

Enhanced community experience and safety: Longer-lasting road infrastructure improves the daily commuting experience, enhances safety, and ensures that transportation networks remain robust and reliable. This stability is crucial for economic activities and quality of life, offering consistent and dependable access for all community members.

Supporting a circular economy: The strategic use of recycled materials not only reduces waste but also fosters a circular economy. By keeping materials in use for as long as possible and re-integrating waste back into the construction cycle, we minimise environmental impact and create a more sustainable economy.

Conclusion

These positive impacts collectively represent a substantial advancement in how road networks are conceptualised, constructed, and maintained, offering a model for sustainable development that benefits both the planet and its inhabitants. Creating a sustainable road network proves to be a win-win scenario – it's economically advantageous, reduces maintenance costs, provides a safer and more reliable experience for road users, supports wildlife and ecosystem health, and lowers emissions overall.

There are lots of systemic barriers that stand between us and decarbonisation, so we need to be bold and creative to overcome them to ensure a prosperous future for humanity.

ADEPT Live Labs 2

This report is the result of a collaboration between Connected Places Catapult and a consortium led by Transport for West Midlands, North Lanarkshire Council, Amey, and Colas. The partnership focuses on producing outputs that enhance decision-making and encourage the adoption of innovative materials and deployment processes in the construction of road and highway assets and the establishment of the Centre of Excellence for Decarbonising Roads (CEDR).

CEDR is one of the four themes included in Live Labs 2, a three-year, £30 million, UK-wide programme funded by the Department for Transport that will run until March 2026, with a five-year subsequent, extended monitoring and evaluation period.

Part of the ADEPT Live Labs 2 : decarbonising local roads programme, a three year £30million UK-wide initiative funded by the Department for Transport that aims to decarbonise the local highway network.

Connected Places Catapult

Our work underpins Connected Places Catapult work to connect people, places and businesses to a future of inclusive sustainable growth and prosperity. This project was led by the Human Connected Design and Design Futures Teams for their expertise in Foresight and Speculative Design.

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Introduction

Human activity has become the dominant influence on climate and the environment, defining a new geological era.

This is a useful perspective for examining one of our most ubiquitous and essential infrastructures: roads. Often considered the most important infrastructure in human history, roads have acted as the world's capillaries, connecting human societies for thousands of years. Traces of roadways over 5,000 years old still etch our landscapes, bearing witness to our lasting influence on the natural world.

In the UK, we have built most of the roads we will ever have, and so our challenge is to innovatively sustain and adapt our existing road network to meet the challenges of the future. Transport accounts for 27% of the UK's carbon emissions (Strategic Road Network Initial Report, 2023), they represent both a significant environmental burden and a pivotal opportunity for sustainable transformation. This reality prompts us to view roads not just as transport infrastructure, but as opportunities for significant environmental benefits, including carbon reduction, carbon storage, and large-scale habitat regeneration. This report investigates how roads, if left unmanaged, could significantly contribute to the planetary crisis. However, by reimagining road construction, they can become key vectors for advancing sustainable practices and minimising our environmental footprint in the construction sector and beyond.

The challenge of decarbonising roads presents both obstacles and opportunities. Notably, the most sustainable roads are those that are durable and long-lasting. These roads not only cost less to maintain but also provide the best experience for drivers. As we shift our focus toward maintenance and extending the lifespan of roads through efficient, preventive strategies, we find opportunities to build better and more cost-effective roads in the long-run. By using sustainable materials, promoting recycling and refurbishment, and incorporating features such as cycle paths and electrification of vehicles and maintenance processes, our road networks can improve in many ways.

Collaborative efforts, particularly between organisations like the ADEPT, DfT, Live Labs 2, the **Centre for Excellence for Decarbonising Roads** and local authorities, are crucial. As these partnerships pilot and implement sustainable materials and technologies across the UK, this ensures that advancements in road sustainability are not isolated to certain regions but are disseminated nationwide. By doing so, they not only lead in the development of sustainable road infrastructures but also indirectly contribute to green job creation and growth across all regions. This inclusive approach invites every part of the UK to participate in innovative activities, setting the stage for a future where all communities benefit from better, more sustainable roads. By doing so, the UK can ensure that its road network supports both human progress and the health of the planet.

This century's materials challenge

This diagram, sourced from the Global Resource Outlook 2024, illustrates the major materials challenge of this century. It emphasises the necessity to decouple societal progress – measured in terms of well-being and economic activity – from the environmental impacts associated with resource use. Historically, economic growth has been closely tied to resource exploitation, leading to widespread skepticism about the feasibility of achieving significant decoupling.

Despite technological advances and increased awareness, the practicality of completely severing this historical linkage remains a challenge. Achieving meaningful decoupling will necessitate a profound change. The report argues that we focus on maximising the value derived from materials already in circulation, emphasising the need to dramatically enhance our recycling rates, which remain disappointingly low.

Materials, such as those used in road construction – aggregates, asphalt, and concrete – represent one of the hardest sectors to address in terms of climate change. Unlike the energy sector or automotive industry, where technological solutions like renewable energy and electric vehicles are well-established and primarily require scaling and political support, the materials sector faces unique challenges. Innovation is required across multiple dimensions: developing new, eco-friendly materials that can match the durability and cost-effectiveness of conventional materials, redesigning processes to reduce emissions during manufacturing, and implementing vastly different systems and behaviours around the end of life of products. This complexity makes decarbonising the materials sector a multifaceted problem, where advancements must be made not only in technology but also in supply chain logistics, regulatory frameworks, and public acceptance.

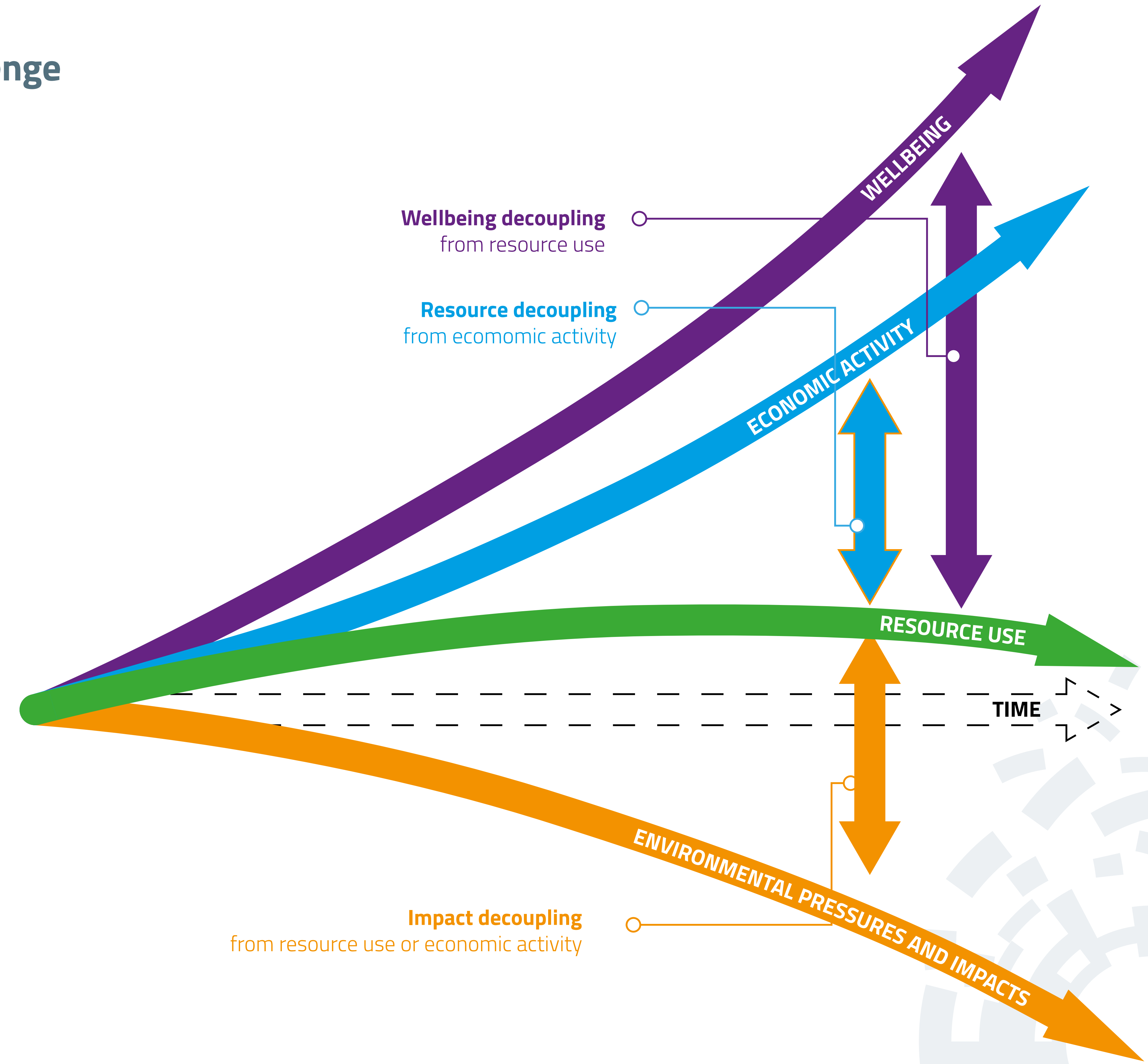


Figure 1.1: Global Resource Outlook,. 2024

Overview of Search Results

Introduction

This scan identified innovative and sustainable materials in the road infrastructure sector, cataloguing over 200 materials from various geographical regions. These materials were categorised based on their application in the infrastructure domain, ranging from pavements to bridges. This chapter provides an overview of the findings from the scan, highlighting the distribution of materials across different categories and geographies.

Methodology

1. **Keyword search:** We conducted keyword searches using a variety of search engines, and then followed links from sources we found to other articles and websites. A typical keyword search involved a combination of "sustainability adjective" + "technology" + "geographies" e.g. "bio-based" + "asphalt" + "Australia". A list of examples are available on page 12.
2. **Product catalogues + suppliers:** We also accessed Product catalogues and sustainable material specialist suppliers such as the Alex Fraser Group in Australia. Categories identified were Concrete, Steel, Pavements + Resurfacing, Surface Treatments, Winter Maintenance, Potholes + Patching, Kerbing, Aggregates, Bridges, and Road Accessories.
3. **Expert interviews:** We broadened our desk research to include interviews with the experts responsible for many of the innovations identified in our study. This was done to gain a deeper understanding of what constitutes effective standards for sustainable road design.

   During each interview, we requested additional recommendations for potential interviewees, which helped us further explore the intellectual discourse surrounding sustainable road design.
4. **Academic engagement:** Our Academic Engagement Team connected us with leading universities and research institutions. This granted us access to the latest studies and innovations in sustainable road materials, ensuring that our database is not only reflective of current standards but also anticipatory of upcoming technological advancements.
5. **Network:** Through our SME Team, we accessed a diverse range of businesses, gaining practical insights into the application and efficacy of low-carbon road materials. This direct engagement provided us with a practical understanding of market readiness and the scalability of emerging materials and technologies.

Future research

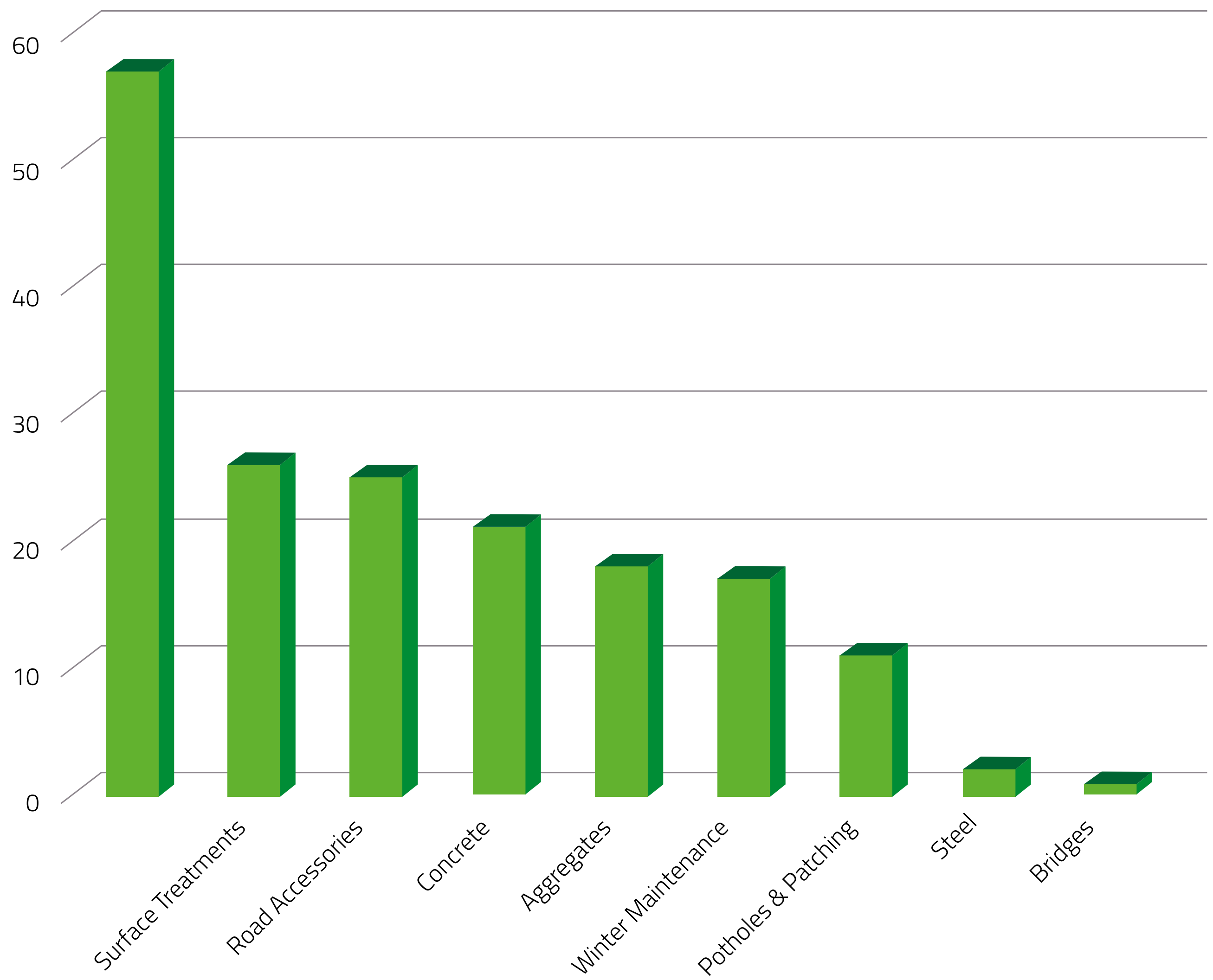
This scan has effectively mapped the current landscape of novel sustainable materials in infrastructure, highlighting the active regions and categories. The findings suggest several areas for future research to consider:

- Further research in underrepresented geographies such as South America and Africa.
- The scope of the search could be expanded to include sustainable materials from other sectors or industries.
- There were notably fewer results for low carbon steel, possibly because this technology is less mature and highly dependent on innovations in other areas, such as green hydrogen. Additionally, green steel is upstream from road construction; typically, road construction companies purchase steel products like signs rather than dealing directly with the steel itself, whereas they directly engage with asphalt and concrete as primary materials.

Results by category

The materials scanned were grouped into nine categories. Below is a breakdown of the number of entries per category:

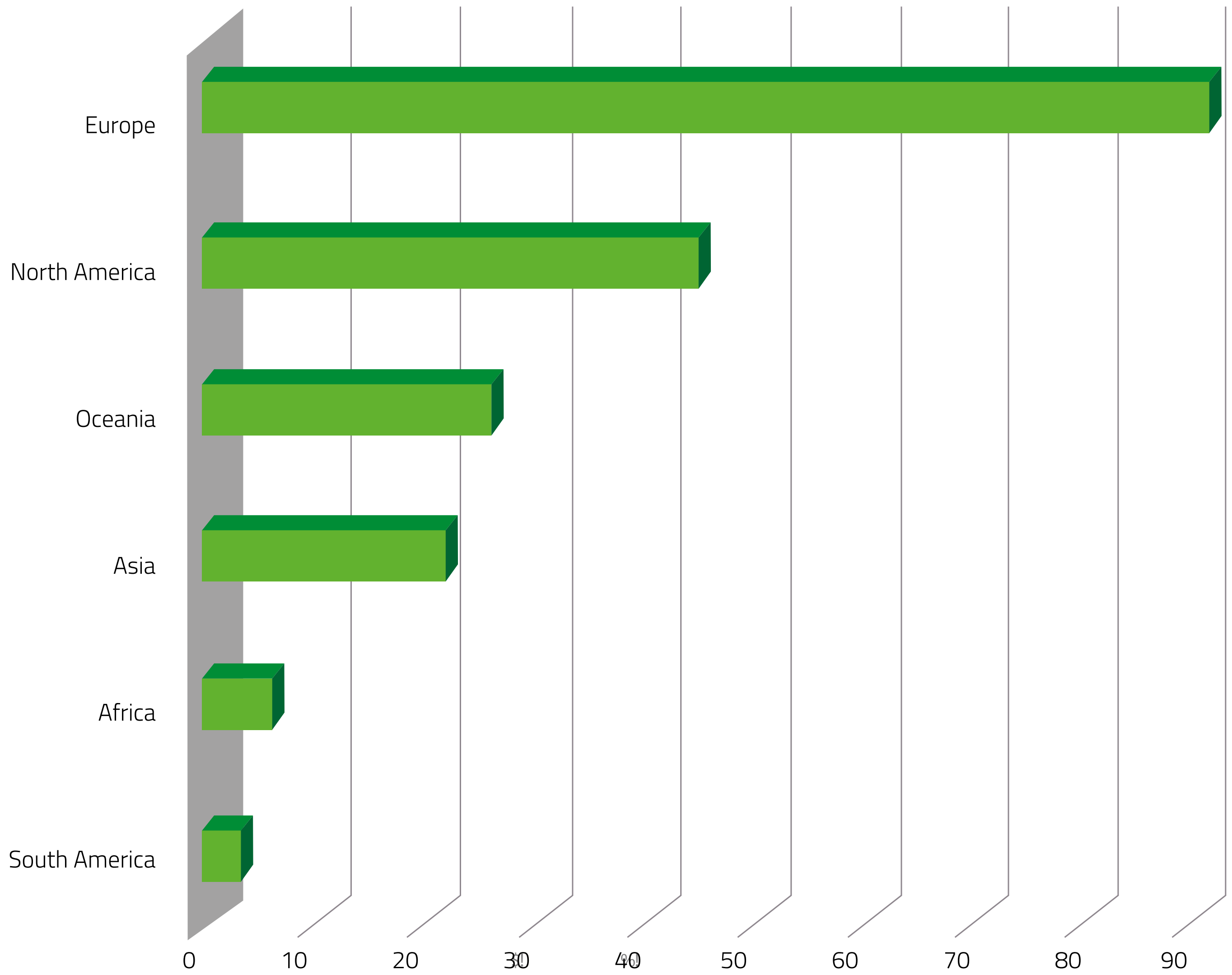
- Pavements and Resurfacing: **57**
- Surface Treatments: **26**
- Road Accessories: **25**
- Concrete: **21**
- Aggregates: **18**
- Winter Maintenance: **17**
- Potholes and Patching: **11**
- Steel: **2**
- Bridges: **1**
- Pavements and Resurfacing materials make up approximately **28.5% of all entries.**
- Categories such as Steel and Bridges are significantly less explored, with only **1.5% combined.**



Results by geography

The materials were also classified based on the geographic origin of the research or implementation:

- Europe: **90**
- North America: **44**
- Oceania: **25**
- Asia: **21**
- Africa: **5**
- South America: **2**
- Europe accounted for the most entries in sustainable materials for infrastructure, contributing **45% of the total entries.**
- North America and Oceania together account for approximately **34.5% of the entries.**
- Contributions from Asia, Africa, and South America are relatively lower, making up **20% of the total.**



Assessment Criteria

R Strategies as an assessment criteria for sustainable road materials

The R-strategies (Potting, J. et al.), originally conceptualised to promote a more sustainable and circular economy, are a hierarchy for evaluating environmental impacts and fostering resource efficiency. Rooted in the principles of the conservation of mass and energy, this framework serves as a guide for minimising emissions throughout a product's lifecycle. Within the domain of road construction – a sector traditionally characterised by significant resource related emissions – the R-strategies offer a systematic approach to evaluate sustainability interventions. By ranking strategies from rethinking design to recovering energy, the framework provides a robust structure for reducing the emissions associated with innovative materials and processes. In this chapter, we apply the R-strategies to the domain of road construction and maintenance, exploring how each strategy can be a frame for assessing the sustainability of road materials and processes.

Short Loops: R0-2

R0: Refuse

The "Refuse" principle in road construction underscores the importance of resisting new road projects unless they are critically necessary. This strategy encourages leveraging and enhancing existing infrastructure through maintenance and thoughtful upgrades instead of pursuing expansion. By refusing to expand unnecessarily, we can significantly reduce resource consumption and the emissions linked with the extraction and processing of raw materials. Additionally, this principle calls for a reevaluation of the materials used in road construction, advocating for the use of minimum viable materials suited to specific functions. For example, gravel could be used for parking lots and organic, semi-hard materials for bike lanes. This not only minimises the use of pavement but also enhances water management and helps preserve natural habitats. These materials are more permeable and less disruptive to the local environment, allowing for better rainwater absorption and reduced runoff.

R1: Rethink – multipurpose

The application of "Rethink" in road construction is more tenuous than in other cases as roads are already shared resources with often intensive use. However, multifunctional road designs can be explored, such as solar roads that both support traffic and generate energy. Additionally, roads can integrate features aimed at carbon sequestration, enhancing biodiversity, and managing stormwater. Rethinking also extends to the materials and processes of road construction and maintenance, emphasising the use of novel materials designed for durability and ease of recycling. For instance, there is potential for communities to collaborate in building or refurbishing 'lightweight' roads using less invasive methods and materials, such as cold mix asphalt-in-a-bag that simply requires water and can be applied without heavy, emission-intensive machinery. This approach not only reduces the carbon footprint associated with construction but also fosters community involvement and resilience in infrastructure development, ensuring roads are both durable and easier to recycle at their end of life.

R2: Reduce – efficiency and conservation

For road materials, "Reduce" is about minimising resource extraction and consumption, primarily through a conservative approach to commissioning new roads. It also encourages the adoption of lighter, more efficient materials that retain structural integrity with less mass. For instance, the use of geo-synthetics in roadbeds that stabilise surfaces while reducing the need for traditional fill materials.

Medium loops: R3-7

R3: Reuse – extending material lifecycles

In the road sector, "Reuse" could mean the standardisation of components for easy recovery and reuse. For example, the reutilisation of traffic signs and barriers in multiple locations, or the use of demountable and relocatable road structures, such as modular plastic roads, in temporary or changing urban settings (Highways Today, 2017).

R4: Repair – proactive intervention for sustainable longevity

"Repair", emphasises the significance of early detection and preventative repair to stave off the cascade of deterioration that results from minor damages left unaddressed. It is well-established that small, timely repairs can forestall extensive – and often costlier – damage, reducing both the financial and environmental toll (World Highways, 2015).

Emerging technologies in this space make use of the many sensors deployed on the roads via new cars which could regularly scan and assess the condition of road surfaces. With access to such technologies, road authorities could create a digital twin of the road network across the UK, transforming road maintenance from a reactive to a proactive task. Such a platform would enable precise monitoring and timely repairs, ensuring maintenance is performed exactly when and where it's needed, optimising the use of materials and labour.

R5: Refurbish – updating and upgrading

In contrast to "Repair" which fixes local faults in a road surface, "Refurbish" is the strategy that involves upgrading large portions of a road surface to extend its useful life and delay the need for complete replacement. In the context of road construction, refurbishment can take the form of applying rejuvenators and advanced surface treatments to existing roadways. Rejuvenators are specially formulated compounds that restore the original properties of asphalt binder, rejuvenating old pavement by improving its flexibility and reversing the effects of aging. When used in conjunction with surface coatings, which provide a protective layer and can seal small cracks, the combination effectively extends the useful life of the road surface.

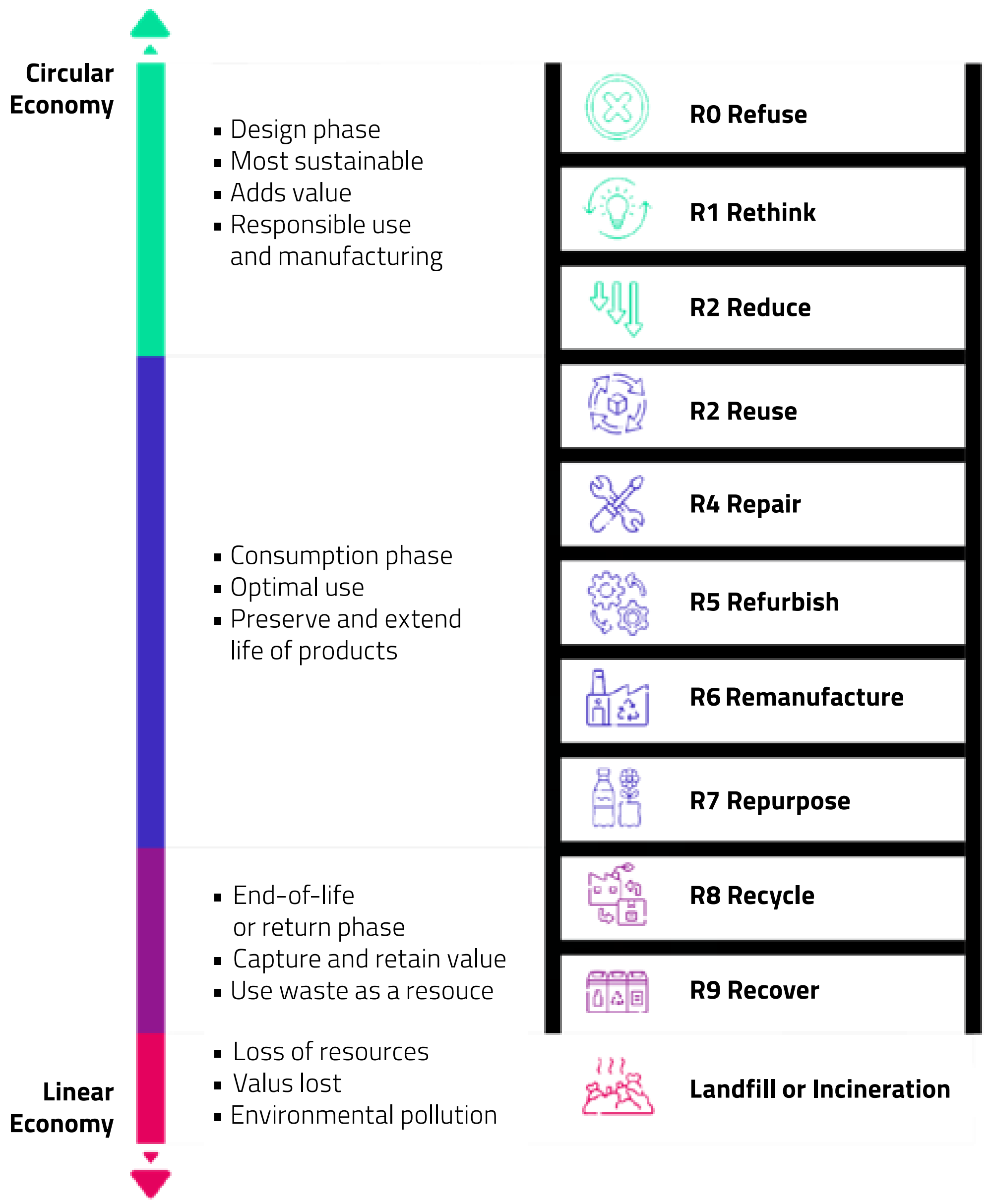
These interventions are less resource-intensive compared to full-scale reconstruction, reducing the demand for new materials and the associated emissions from their production and transport. By incorporating rejuvenators and surface treatments into regular maintenance schedules, the lifespan of road infrastructure can be significantly extended. This not only conserves resources and reduces waste but also aligns with the goals of a circular economy by maintaining the value of the infrastructure for as long as possible.

R6: Remanufacture – applying old parts to new objects

"Remanufacture" in road construction can also focus on reusing components like streetlights and curbs, which are often replaced during road upgrades. For example, old streetlights can be remanufactured to meet current energy efficiency standards and then reinstalled. Similarly, concrete curbs that are removed can be processed to correct any wear and then reused in new locations. This process not only saves resources but also reduces landfill waste. Implementing such practices allows asset managers to extend the lifespan of these materials significantly, decrease costs associated with purchasing new components, and reduce the environmental footprint of construction projects, aligning with the principles of a circular economy.

R7: Repurpose – innovating new uses

"Repurposing" involves finding new uses for road materials once they are no longer viable for their original purpose. This could involve using reclaimed asphalt shingles in sound barriers or converting decommissioned road materials into architectural features. A compelling example of this innovative remanufacturing is observed in the preparations for the Paris Olympics, where 350 lights, created using construction waste, were installed in the athletes' village. This initiative demonstrates a sustainable model for integrating salvaged materials into functional and essential infrastructure, thereby transforming waste into beautiful assets.



'Circularise', framework adapted from Potting et al. (2017, p.5)

Long loops: R8-9

R8: Recycle – closing the material loop

"Recycling" is already a well-established practice in the road industry, with reclaimed asphalt pavement (RAP) and recycled concrete aggregate (RCA) being used in new road construction. This approach focuses on maximising the recyclable content while ensuring that the recycling process itself is efficient and sustainable.

R9: Recovery – energy generation

When other strategies to repurpose road materials fall short, converting these materials into energy presents a final alternative before considering landfill disposal. This energy "recovery" can take various forms, such as pyrolysis, where organic material is decomposed at high temperatures in the absence of oxygen, transforming it into useful fuels like bio-oil, syngas, and char. Another method involves the conversion of these materials into synthesis gas (syngas), a versatile fuel that can be produced through gasification. While these processes contribute to managing waste and energy production, they also generate greenhouse gas (GHG) emissions. However, there is potential to mitigate these emissions through carbon capture and storage technologies, which can prevent the release of emissions produced during these processes. These measures add a valuable layer to the waste management hierarchy by extracting latent energy from road materials that would otherwise contribute to landfill volumes. Despite its advantages, this approach is considered the last resort within the principles of a circular economy.

Landfill – method of last resort

When all other strategies fail, we resort to landfill for the disposal of road materials, the least desirable option. This outcome is an acknowledgment of the current end-of-life scenario for materials that have not been designated for higher-value R-strategies. The disposal of road materials signify a failure to capture the remaining value of resources, resulting in the loss of embodied energy and the generation of greenhouse gases and pollutants.

Avoiding this scenario requires a change in the entire lifecycle management of road materials. To prevent road materials from reaching this final and least favourable stage, it is crucial to embed the principles of the circular economy into every phase of road design, construction, and maintenance. This involves prioritising strategies such as design for disassembly, maximising the use of recyclable and renewable materials, and developing robust markets for secondary materials.

The industry must advance research and innovation to find new ways to reduce, reuse, and recycle materials. To gather the evidence, demonstrate the benefits, and scale these practices, governments and policymakers play a vital role by incentivising sustainable practices and penalising landfill and incineration where avoidable. Addressing behavioural barriers is essential for a shift towards zero waste in road construction, which is not only a matter of environmental stewardship but also an economic opportunity to reduce costs associated with waste management and tap into the value of recovered materials.

The goal is to design out waste altogether, so that every material in road construction has a predetermined second life, ensuring that landfill and incineration become relics of an unsustainable past.

Complementary assessment criteria

While the R-strategies provide a useful framework for evaluating the sustainability of road materials, additional criteria are essential to ensure that these materials not only contribute to sustainability but are also market-ready, cost-effective, and capable of delivering high-quality, safe roads. This chapter explores several key assessment criteria that can complement the R strategies, helping local authorities in the UK to make informed decisions about which sustainable road materials to trial.

Carbon factor

The carbon factor, typically expressed in terms of grams of CO_2 equivalent per functional unit, is a value that represents the amount of carbon dioxide emissions associated with the production, use, and disposal of a material. Carbon factors help to quantify the direct contributions of a road material to greenhouse gas emissions. Materials with lower carbon factors are preferable as they produce less emissions.

Cost (upfront and lifecycle)

The cost assessment must consider both the initial upfront costs and the lifecycle costs of materials. While some sustainable materials may be more expensive initially, they might offer savings over time through reduced maintenance, lower energy costs, or longer lifespan. A comprehensive cost analysis helps in making a case for sustainable materials that are economically viable as well as environmentally beneficial.

Safety

Safety is paramount in road construction and maintenance. Materials must meet rigorous safety and compliance standards to protect the users of the roadways. This includes ensuring that materials can withstand typical loads and uses without posing risks of accidents due to material failure. Additionally, the safety profiles of materials during their production, installation, and disposal must be considered to protect road workers, road users and the public.

Technical readiness level

Technical readiness level (TRL) is a method used to evaluate the maturity of a technology. In the context of road materials, the TRL indicates how tested and proven a material is, from initial concept stages through to its full commercial deployment. High TRL materials have been extensively tested and are likely to be more readily accepted by the market. This market scanning program has focused primarily on higher TRL materials to ensure that outputs are ready for practical, real-world application by UK local authorities.

Environmental impact

Beyond carbon emissions, it is important to evaluate the broader environmental impacts of road materials, such as their effects on water quality, air quality, and biodiversity. This criterion assesses whether a material causes pollution, requires hazardous chemicals in its production, or disrupts local ecosystems. Selecting materials that minimise negative environmental impacts can help in achieving a holistic approach to sustainability.

Future climate change resiliency

Materials must be assessed for their resiliency to future climate conditions. This involves evaluating how materials will perform under changing climates, including increased rainfall, temperature fluctuations, and extreme weather events. Materials that demonstrate higher resilience will ensure the long-term durability and functionality of roads, reducing the need for frequent repairs and replacements that can be costly and resource-intensive.

By incorporating these assessment criteria alongside the R-strategies, stakeholders can ensure that the selection of sustainable road materials is balanced, considering environmental impact, readiness for deployment, economic viability, and safety. This approach will facilitate the adoption of innovative materials that are both sustainable and effective in meeting the demands of modern road infrastructure.

Decarbonisation Strategies

The big three

Efforts to reduce carbon emissions in road construction and maintenance are crucial for the UK to achieve net-zero. Decarbonising road materials entails adopting strategies throughout the lifecycle of the materials used in road construction. Concrete, asphalt, and steel are the three material categories responsible for the majority of emissions in road construction. National Highways has outlined strategies focusing on these materials, as their decarbonisation is key to reducing the environmental impact of road construction (National Highways, 2021). Local authorities can align with these strategies, promoting sustainable solutions by helping them gain widespread acceptance and achieve cost parity.

Concrete

Concrete production is a significant source of carbon dioxide emissions which are produced during the calcination of limestone in cement production. Strategies to reduce the carbon footprint of concrete include the use of alternative cementitious materials such as fly ash, slag, and silica fume. These materials can replace a portion of Portland cement in the mix, leading to substantial reductions in emissions. Additionally, advancements in concrete technology encompass both carbon capture and storage (CCS) techniques, which focus on capturing CO_2 emissions from cement production, and carbon capture, utilisation, and storage (CCUS), which not only captures but also reuses CO_2 in the production process. These innovations, alongside the development of self-healing concretes, enhance sustainability and extend the lifespan of the material.

- **ClimateCrete, a KAUST** (King Abdullah University for Science and Technology in Saudi Arabia) spinout based in Silicon Valley, is transforming the construction industry by making local desert sand suitable for concrete production, significantly reducing the reliance on environmentally damaging imported sand. Their technology re-engineers the smooth desert sand into concrete-ready aggregates at competitive costs, substantially cutting the carbon footprint of concrete by using less cement and eliminating sand imports.
- **Concrete4Change** is a Nottingham based startup advancing a technology for the construction industry that mineralises CO_2 within concrete. Their process involves mixing a CO_2-loaded carrier, made from recycled waste materials, with concrete. This carrier then gradually releases CO_2 into the concrete for permanent mineralisation. This method not only increases concrete strength but also reduces the amount of cement required, contributing to a reduction in the overall carbon footprint of concrete production.

Asphalt

For Asphalt, the focus is on energy consumption and the release of volatile organic compounds during production and laying. Warm and cold-mix asphalt technologies significantly reduce the temperatures required to produce and lay asphalt, thus cutting energy usage and emissions. The recycling of asphalt pavements is another effective strategy, decreasing the demand for new raw materials and the associated environmental impacts of extraction and processing.

- **VIATOP® Premium** developed by J. Rettenmaier & Söhne in partnership with Interchem Handels GmbH, is a pelletised blend of natural cellulose fibers and bitumen, used primarily in Stone Mastic Asphalt to enhance road durability and efficiency. The product streamlines the asphalt mixing process by ensuring quick and complete dispersion, thereby improving production throughput without requiring dry mixing time. Its application in a major highway project in Germany demonstrated a 30% increase in road lifespan, withstanding heavy traffic and reducing maintenance needs. VIATOP® Premium exemplifies an advancement in sustainable road construction by enhancing durability, operational efficiency, and economic viability.

Steel

The steel industry is currently exploring emerging technologies aimed at reducing emissions, although most of these are still in trial phase. The integration of electric arc furnace technology, which uses recycled steel scrap, has proven to reduce the energy intensity and carbon emissions compared to traditional blast furnaces, however they only work for recycling steel. The exploration of hydrogen as a replacement for coking coal in the direct reduction of iron ore in primary steel production is another pathway that is being actively researched and has the potential to revolutionise the industry with near-zero emissions.

- **Researchers at Rensselaer Polytechnic Institute** in New York have developed an alternative to traditional steel rebar, utilising hemp fibers encased in thermoplastic. This new **Hemp Rebar** avoids the corrosion issues associated with steel, particularly in salty environments, potentially tripling the lifespan of concrete structures and significantly reducing carbon emissions associated with frequent repairs and replacements. The production process, which involves bonding fibers with thermoplastics, allows the rebar to be formed on-site using a specially designed machine, promising to lower costs and construction time while being competitive with traditional materials.

R Strategies of the Circular Economy

- Reduce
- Reduce volume of new material

R0 Refuse

R1 Rethink

R2 Reduce

- Reuse
- Preserve and extend life of roads

R3 Reuse

R4 Repair

R5 Refurbish

R6 Remanufacture

R7 Repurpose

- Recycle
- Retain value from materials beyond their useful life in roads

R8 Recycle

R9 Recover

Pavements + resurfacing

Performance requirements: Pavements and resurfacing requires materials and processes that ensure durability, load-bearing capacity, weather resistance and occasionally drainage. The performance of these road components must meet stringent standards to handle varying traffic volumes, environmental conditions, and maintenance practices. Effective pavement and resurfacing materials must also prioritise longevity, safety, and cost-efficiency, while increasingly incorporating sustainable practices to reduce environmental impact.

- R2: Reduce **Energy:** Adopting materials such as warm-mix and cold-mix asphalt, which requires less energy, and therefore emissions, to produce.
- R1: Rethink **Renewable energy:** Transitioning to fully renewable energy sources for the production, transportation, and other processes involved in pavement material handling.
- R8: Recycle **Materials:** Utilising a higher percentage of recycled asphalt pavement in new mixes conserves raw materials and reduces emissions.
- R1: Rethink **Durability:** Making strategic choices in pavement construction and repair to optimise carbon savings. For example, using Polymer Modified Bitumen (PMB), which enhances durability and reduces the frequency of repairs, contributing positively to sustainability efforts.
- R1: Rethink **Sustainable binders:** Replacing bitumen with bio-based binders like lignin or using sealants derived from renewable sources.

- Carbon Crusher, a startup from Norway backed by Y Combinator, is developing a road repair technology involving a plant-based binder to recycle old roads. This method significantly reduces the carbon footprint of road repairs, to the extent that the roads effectively become carbon negative. The process involves using specialised machinery to grind the top layer of damaged asphalt or concrete, instead of bringing in new materials. The company then uses lignin, a byproduct from the paper industry commonly burned for energy in Norway, to bind the crushed material, effectively sequestering carbon captured by trees during their growth.
- TileGreen manufactures a patent-pending tiling brick made from non-recyclable plastic waste, transforming it into a carbon-negative building material that competes directly with traditional cement products. Their innovative process efficiently converts unrecycled plastics into durable building products such as paving tiles and roof tiles, while also ensuring these products are 100% recyclable and competitively priced with conventional materials. Featuring enhanced strength and durability compared to cement tiles, TileGreen's materials present a sustainable alternative for pedestrian walkways and cycle paths.

Key:
- Case Study
- R-Strategy

Surface treatments

Performance requirements: Surface treatments for roads extend pavement life, enhance skid resistance, and reduce maintenance costs. Performance requirements for these treatments include durability, weather resistance, and the ability to maintain their effectiveness under heavy traffic and varying environmental conditions.

Additionally, surface treatments must be compatible with existing pavement materials, quick to apply, and minimally disruptive to traffic.

- R1: Rethink **Bio-based polymers** for rejuvenating and sealing asphalt.
- BioSealcoat is a soy-based asphalt sealer that provides enhanced durability and resistance to chemicals such as gasoline and motor oil. Its use of UV-stable colourants helping maintain the asphalt's deep black colour for extended periods. BioSealcoat is free from forever chemicals, it has minimal odour during application, and is USDA Certified Biobased as it is derived from soybean oil. The product allows for rapid curing which facilitates traffic flow and can be applied with conventional sealcoating equipment without the need for heating, simplifying the application process and reducing safety risks.

Winter maintenance

Performance requirements: Winter maintenance of roadways demands effective strategies to ensure safety and accessibility during adverse weather conditions. This includes the ability to quickly respond to snow and ice accumulation, maintain traction, and prevent accidents. Performance requirements focus on the efficiency and environmental impact of de-icing chemicals and equipment, reliability of snow removal operations, and the minimisation of road and vehicle damage. Solutions must be cost-effective, minimise environmental degradation, and ensure public safety throughout the winter season.

- **R2: Reduce Smart salt management:** Using advanced weather forecasting and sensors to optimise salt spreading, minimising usage while maintaining road safety.
- **R1: Rethink Food waste de-icing:** Investigating the use of less corrosive and more environmentally friendly de-icing agents, such as beet juice or cheese brine mixtures.
- **BEET 55™ Liquid Organic Accelerator** is an eco-friendly de-icing agent made from sugar beet molasses, which serves as a sustainable and renewable resource. This product is blended with salt brine to enhance its ice and snow control capabilities, proving to be superior to traditional brines in performance and less corrosive by 75%. BEET 55™ not only reduces the need for salt usage by up to 50%, thus lowering operational and material costs, but it also minimises environmental impact and infrastructure corrosion. It is typically used to improve the efficacy of salt brine by reducing its freezing temperature.

Potholes + patching

Performance requirements: The performance requirements for pothole repair and patching focus on durability, rapid repair capability, and minimal disruption to traffic. Materials and methods must ensure a long-lasting repair that withstands environmental conditions and traffic stress. Effective pothole and patching strategies should also be cost-efficient, provide a seamless integration with the existing pavement, and maintain safety for both vehicles and pedestrians.

- **R2: Reduce Infrared technology:** Using infrared heaters for pothole repair allows for the existing asphalt to be reused, reducing the need for new material.
- **R1: Rethink Cold-mix asphalt:** Using energy-saving cold-mix asphalt applied at ambient temperatures. Most local authorities, including NLC, use materials like Viafix. Adding sustainable binders, RAP, or 'permanent' repair materials boosts durability and sustainability.
- **ARRES** is the world's first autonomous pothole repair robot, developed by tech company Robotiz3d and the University of Liverpool, is set to begin road testing in Hertfordshire. Named ARRES PREVENT, the robot uses AI imaging technology to identify and fill cracks in the road, preventing the formation of potholes by sealing out water. This pilot initiative, a collaboration between the University of Liverpool and Hertfordshire County Council's highway engineers, aims to revolutionise road maintenance by addressing defects in real-time. This approach could enhance the durability and safety of road surfaces by combating pothole formation during cold weather.

Please see page 45 for reference links

Figure 3.1: Ahead of the Paris Olympic Games, design firms Concepto and Studio 5.5 have installed 350 streetlights in the athletes' village, created from salvaged scaffolding poles and decommissioned lampposts as part of a broader initiative to reduce carbon emissions by 47%. This approach involves reusing materials in creative ways, demonstrating the power of design to generate value from so-called waste materials.

Road accessories

Performance requirements: Road accessories, encompassing elements like lighting, lane markings, barriers, and storm drains, play a critical role in road safety and functionality. Performance requirements for these components are multifaceted: lighting must provide adequate visibility while being energy-efficient; lane markings need to be durable and visible in various weather conditions; barriers should offer robust impact resistance without compromising the safety of vehicle occupants; and storm drains must efficiently manage water runoff to prevent flooding and minimise hydroplaning risks. Across all categories, materials and designs must balance longevity, maintenance ease, environmental impact, and compliance with stringent safety standards.

- **R1: Rethink Solar lighting:** Implementing solar-powered streetlights and traffic signs to reduce electricity consumption from non-renewable sources.
- **R8: Recycle Materials:** Using signage, bollards, and noise barriers made from recycled or repurposed materials, cutting down on both waste and emissions from new production.
- **R1: Rethink Novel materials:** Designing road accessories with innovative materials that have lower embodied emissions and optimise for better recycling, regeneration, disassembly and repair.
- **UK based startup Guerrilla** is developing a retrofittable device aimed at preventing urban runoff from polluting rivers and oceans. This innovative solution captures pollutants – including microplastics, toxic hydrocarbons, and heavy metals – from roadside drains during rain events, without the need for membranes, electricity, or moving parts. It is designed to be versatile and can be fitted into various sizes of existing roadside drains as standalone units that independently filter out contaminants while maintaining the drain's flow capacity. By addressing the problem of runoff, which accounts for 30% of all ocean pollution according to the US EPA, Guerrilla's technology offers a step towards preserving aquatic ecosystems and improving public health.

Aggregates

Performance requirements: Aggregates used in road construction must meet stringent performance criteria to ensure the structural integrity and longevity of pavements. Key requirements include high durability, resistance to abrasion and weathering, and the ability to withstand the loads and stresses from traffic without degradation. Aggregates should also possess proper gradation and size to provide stability and support for the pavement layers. Environmentally, the use of recycled and locally sourced aggregates is increasingly important to reduce the carbon footprint and support sustainable construction practices.

- **R2: Reduce Local sourcing:** Sourcing aggregates from local quarries reduces transport emissions. Additionally, using waste materials from these quarries as aggregate further enhances sustainability.
- **R3: Reuse Secondary aggregates:** Utilising waste products from other industries, such as slag from steel manufacturing, or mining waste, as a substitute for traditional aggregates.
- **O.C.O Technology Limited,** in collaboration with Repsol, is pioneering the creation of eco-aggregates through a process that captures CO_2 from industrial activities. Set to be produced near Repsol's Petronor facilities, these aggregates are made from CO_2 captured at the refinery and ashes from the incineration of municipal solid waste (MSW). The project aims to produce 56,000 tons of eco-aggregates annually, which will reuse 22,000 tons of MSW ashes and capture 2,200 tons of CO_2 each year, reducing the carbon footprint by sixteen times compared to traditional products. This initiative, funded by the EU Innovation Fund 2020, advances the circular economy by converting waste into valuable raw materials for the construction industry.

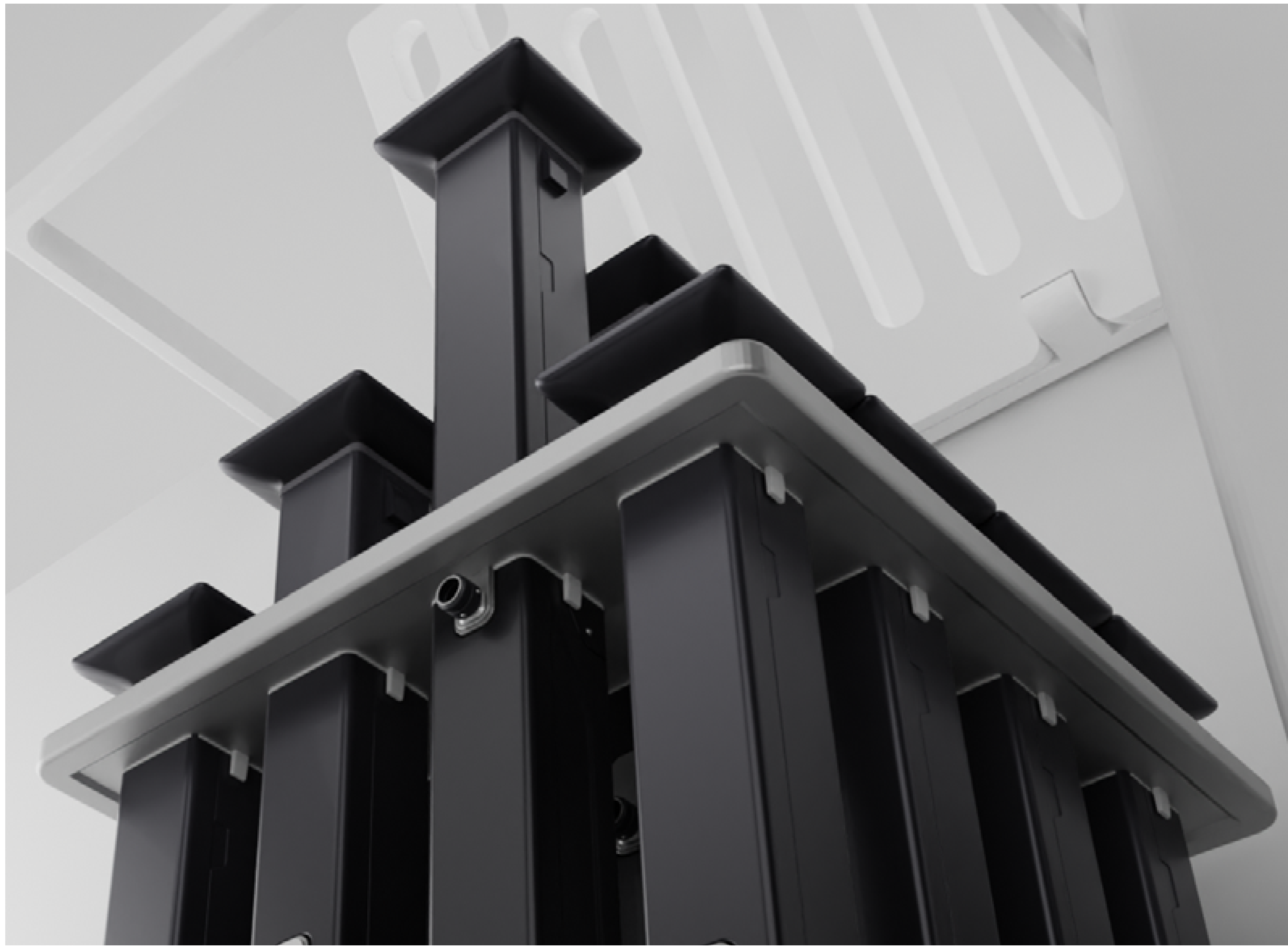


Figure 3.2: UK-based startup Guerrilla is developing a device that can be retrofitted to existing roadside drains to capture pollutants like microplastics, hydrocarbons, and heavy metals during rain events, functioning without membranes, electricity, or moving parts. This technology not only preserves drain flow capacity but also addresses urban runoff, which contributes to 30% of ocean pollution, thereby aiding in the protection of aquatic ecosystems and enhancing public health.

Bridges

Performance requirements: Bridges require rigorous performance standards to ensure safety, durability, and long-term functionality. Key criteria include structural integrity to withstand loads and stresses from traffic, environmental resilience against weather extremes and natural forces, and corrosion resistance to extend lifespan and reduce maintenance needs. Additionally, bridge designs must accommodate potential expansions and modifications, and integrate seamlessly with existing road networks.

- **R1: Rethink Low emission concrete:** Incorporating concrete with supplementary cementitious materials like fly ash or slag, which have a lower carbon footprint than traditional cement.
- **R1: Rethink Innovative design:** Enhance material efficiency through innovative design approaches, such as using lightweight structures or tensioned elements that reduce reliance on concrete and steel.
- **R1: Rethink Materials:** Incorporate advanced laminated wood materials like cross-laminated timber, which offer regenerative and structurally robust alternatives.
- **Arup's timber bridge** concept, developed in collaboration with Heijmans and Schaffitzel, represents a significant reduction in embodied carbon compared to traditional bridge design. Known as Bridges of Laminated Timber (BoLT), the design uses mass timber in road bridge construction, suitable for spans up to 25 meters, which are common in national networks. By focusing on renewable materials, the BoLT concept aligns with Rijkswaterstaat's 2030 emissions reduction goals and introduces a low-carbon alternative to traditional bridge materials.

  This innovative approach not only reduces the carbon footprint but also promotes longevity and potential reusability, embodying the principles of the circular economy.

Kerbing

Performance requirements: Kerbing, critical for road safety and water management, requires materials and installation techniques that ensure robustness, stability, and longevity. Performance criteria for curbing include resistance to weathering, vehicle impacts, and erosion. They must also maintain structural integrity and alignment over time, without requiring frequent maintenance. Additionally, kerbing should facilitate effective drainage and contribute to the aesthetic and functional design of roadways.

- **R8: Recycle Materials:** Using kerbs made from recycled plastic or rubber, which not only repurposes waste but also reduces the production of new concrete.
- **R1: Rethink Water permeability:** Installing permeable kerbing to manage stormwater and reduce the need for separate drainage systems.
- **KERBFIX,** is a combined kerb and drainage system (CKD) designed for modern infrastructure needs such as highways, car parks, and industrial developments. Manufactured from 70% recycled polypropylene, KERBFIX units offer efficient water intake through their design, ensuring quick drainage of large areas to protect surfaces from water run-off. Each unit is lightweight for easy installation and transport, measures 0.5 meters, and is available with various accessories. This system supports sustainable construction practices by using materials that are both recycled and recyclable.

Unintended Consequences

Consequential thinking is crucial in assessing the sustainability of environmental initiatives, as it involves considering the potential unintended effects of actions intended to be beneficial.

A poignant example is the wood pellet industry, which was originally developed to use waste from forestry operations as a renewable energy source. However, this initiative led to unforeseen consequences, including the large-scale harvesting of forests in British Columbia to meet the United Kingdom's demand for wood pellets. This scenario highlights the importance of thorough impact assessments and strategic planning to mitigate the negative outcomes of well-intended sustainable practices, ensuring that they do not inadvertently contribute to the problems they aim to solve.

Biodiversity loss

In many sectors, biomaterials are being considered as a strategy for decarbonisation. Yet, scaling their use in road construction requires careful consideration of their availability and true environmental impact. The potential for competition with other sectors for biomass is a challenge that must be addressed to ensure the road construction sector can leverage these materials without unintended consequences.

Risks

- **Resource consumption and emissions:** According to the Global Resource Outlook 2024, extraction and processing of material resources, particularly biomass, are major drivers of greenhouse gas emissions and particulate matter pollution, accounting for a significant portion of the triple planetary crisis.
- **Land use and biodiversity:** Biomass production is responsible for over 90 percent of biodiversity loss and water stress related to land use changes. The extraction and processing of material resources – including fossil fuels, minerals, non-metallic minerals, and biomass – are responsible for more than 55% of greenhouse gas emissions and 40% of health impacts related to particulate matter. When changes in land use are considered, the climate impacts increase to over 60%, with biomass making the largest contribution at 28%. (Global Resource Outlook, 2024).
- **Competition and scarcity:** With biomass already used in sectors like aviation, maritime, and plastics, there is a real risk of shortages and competition for land that could otherwise be used to grow food. If not managed carefully, the scale of potential demand in the road network could lead to increases in food prices, pollution, GHG emissions and biodiversity loss.

Mitigations

- **Resource efficiency:** Prioritise extending the life of existing road materials and recycling them before turning to new sources of biomass. This approach reduces the need for primary biomass and mitigates competition with agriculture and forestry.
- **Waste biomass utilisation:** Focus on using waste biomass for long-lasting applications in road construction. Employing biomass in cascades – where materials are reused in several products to maximise their lifecycle – is more efficient and sustainable.
- **Decentralised and sustainable sourcing:** As suggested by Bishop et al., 2022, the source of biobased materials is crucial for their sustainability. Utilising residues and side streams, potentially through decentralised production and biorefinery practices, can mitigate the environmental impact.
- **Innovative material solutions:** Explore the use of polymers with a high availability in waste streams.

Policy implications

- **Ongoing supply chain assessments:** To avoid outcomes like those seen in the wood pellet industry, continuous assessment of the biomass supply chain is crucial. This ensures that demand for waste streams does not inadvertently lead to primary biomass extraction.
- **Cross-sectoral collaboration:** Foster collaboration across sectors to optimise the use of waste streams and ensure policy coherence, supporting sustainable biomass use at scale.

The transition to biomaterials in road construction holds great promise for decarbonisation but requires a strategic and judicious approach. It is imperative to optimise the use of waste streams, foster cross-sectoral collaboration, and ensure that policies support sustainable practices to effectively scale biomaterials in a way that benefits the environment and society.

Biomass accounts for over 90 per cent of total land use related biodiversity loss and water stress (Global Resource Outlook, 2024)

Microplastics

As the road construction sector explores the use of recycled plastics to reduce its environmental footprint, it has become important to assess the potential impacts of microplastic pollution in the context of roads. These minute particles, ranging from less than 5mm in size to microscopic particles, have been shown to be toxic to animals and ecosystems. Road materials containing plastic components, such as recycled plastic composites and polymer-modified asphalt, have been shown to leech microplastics.

Microplastics have insinuated themselves into seemingly untouched corners of the planet – from Arctic ice to deep-sea trenches – highlighting their pervasive nature. Research is revealing that these particles can carry toxic additives, used in plastics manufacturing for colour, flexibility, or durability, into the environment. The impact on human health is not yet fully understood, but possible serious effects could arise if environmental levels continue to increase.

Risks

- **Presence and mechanisms:** Microplastics in plastic roads would originate from the breakdown of polymer-modified asphalts and other plastic materials. These particles can be separated from the road surface due to vehicle wear, weathering, and mechanical stresses.
- **Migration:** Once separated, microplastics can be transported to nearby water streams or other areas through increased precipitation, which may distribute them more widely. We know this from tyre and break wear pollution.
- **Scale:** Considering the length of roads worldwide, even a small amount of microplastics can have a large cumulative effect.
- **Future strain:** The shift towards heavier electric vehicles and SUVs may increase road wear and thus microplastic shedding. Additionally, the frequency and intensity of extreme weather events caused by climate change may increase the wear and tear of roads and distribute microplastics more widely.

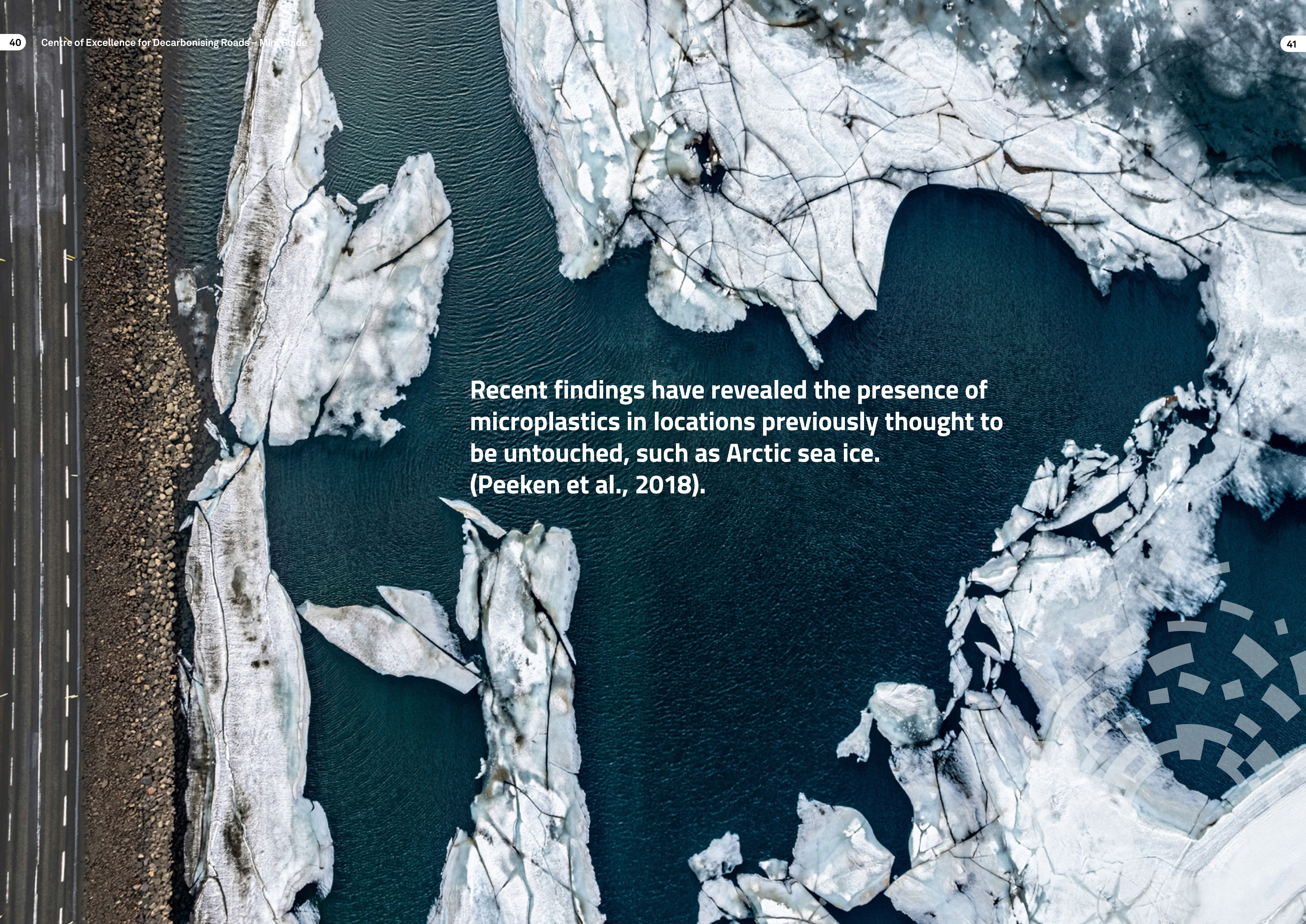
Mitigations

- **Material innovation:** There is a pressing need for materials that resist degradation and thus reduce microplastic shedding over time. This calls for rigorous research and development efforts and a re-examination of the materials we currently favour.
- **Particulate capture and recycling:** Implementing systems to capture microplastics before they enter the ecosystem is essential. Such systems could include improved street cleaning techniques and innovative filtration technologies at runoff sites and drains.

Policy Implications

- **Regulation of plastic use:** The type of plastics used in roads should be selected meticulously, potentially from high-value waste streams with proven provenance, like consumer electronics, to ensure durability and minimise microplastic shedding.
- **Policy guidance:** Policy must guide and govern the intersection of road construction and environmental stewardship, ensuring that the benefits of using recycled materials do not come at the cost of our planet's health.

As the road construction industry moves towards incorporating recycled plastics, it must navigate the challenge of microplastics with a responsible and evidence-based approach. Only through holistic and informed strategies can we construct roads that serve our infrastructure needs without compromising the environmental health we aim to protect.



Recent findings have revealed the presence of microplastics in locations previously thought to be untouched, such as Arctic sea ice. (Peeken et al., 2018).

Conclusion

The transition to low-carbon materials for road decarbonisation is a crucial step towards sustainable development. Implementing strategies under the 9R Framework can greatly limit reliance on virgin materials, enhance resource conservation, and mitigate the harmful impacts of traditional road construction. By integrating innovative materials and designs, road builders and custodians of the future can create resilient, long-lasting infrastructure that supports a circular economy.

Decarbonising roads presents challenges that require bold, creative solutions to overcome systemic barriers. However, the benefits we are looking to achieve through innovation are extensive: reduced emissions, lower maintenance costs, and improved safety and reliability for road users. Embracing these innovative approaches paves the way for a greener future and ensures the longevity and resilience of our infrastructure for generations to come.

Next steps

Local authorities

Local authorities are crucial for implementing low-carbon road materials. They should visit CEDR* to explore a database of novel materials and technologies assessed for reducing carbon emissions.

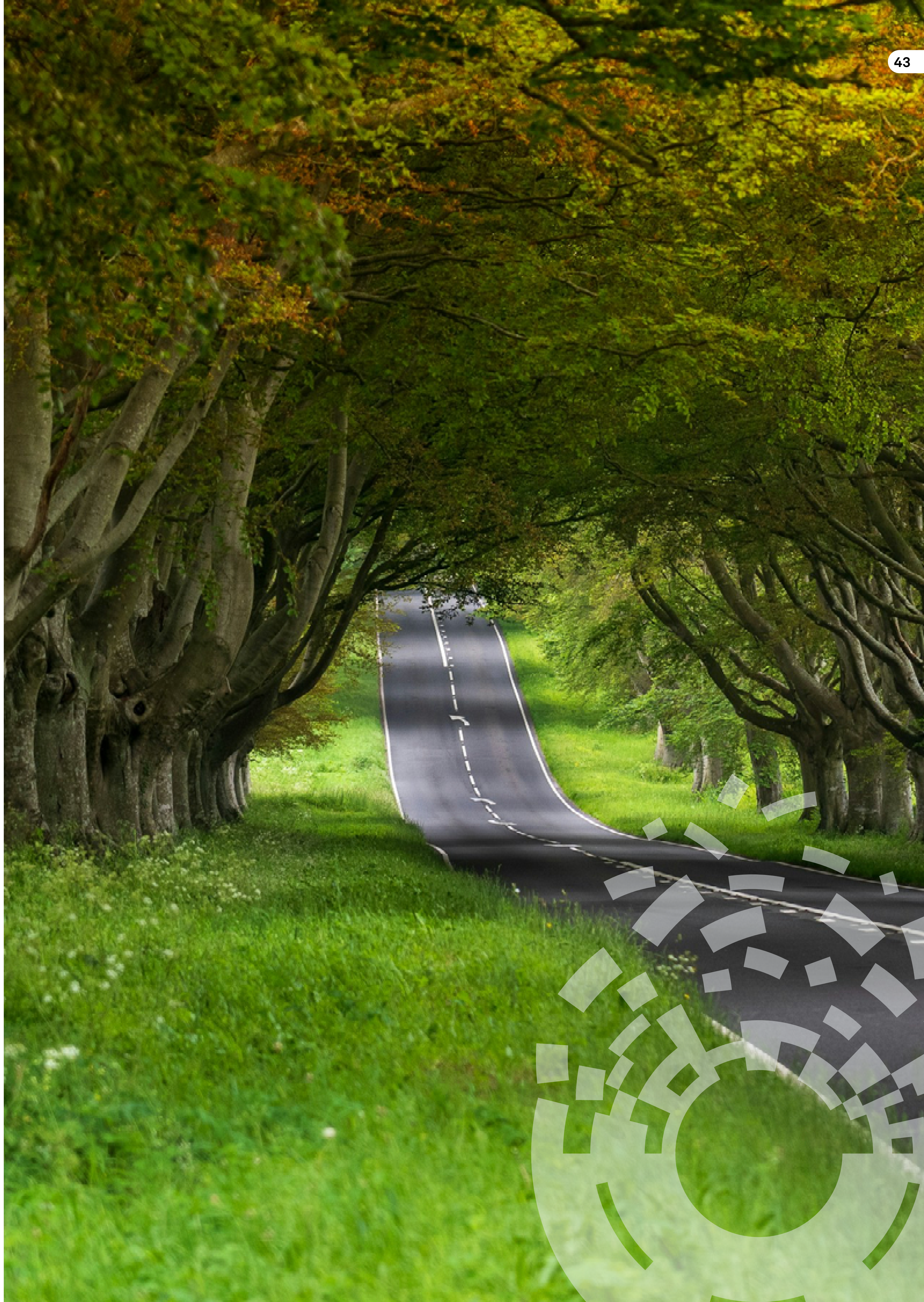
- **Explore database:** Access a database of novel low-carbon materials.
- **Identify needs:** Find materials that align with specific project requirements.
- **Assess feasibility:** Use tools to evaluate materials in various contexts.
- **Conduct trials:** Initiate pilot trials to test materials in real-world conditions.
- **Share findings**: Contribute experiences and data to the platform's knowledge base.

Material innovators

Material innovators are invited to submit their novel materials for assessment and trials through CEDR*. This platform offers a structured process for evaluating new materials and showcasing products to industry stakeholders.

- **Submit information:** Provide detailed descriptions, technical specifications, and environmental benefits of novel materials.
- **Participate in assessments:** Engage in testing and evaluation processes.
- **Gain visibility:** Featured submissions gain visibility and credibility.
- **Collaborate:** Create partnerships with local authorities and construction companies.

*Centre of Excellent for Decarbonsing Roads (CEDR): decarbonisingroads.co.uk



References

Tabaković, A., & Schlangen, E. (2016). Self-healing technology for asphalt pavements. Self-healing materials, 285-306.

Bruyninckx, H., Hatfield-Dodds, S., Hellweg, S., Schandl, H., Vidal, B., Razian, H., ... & Pfister, S. (2024). Global Resources Outlook 2024: Bend the trend-Pathways to a liveable planet as resource use spikes.

Material Economics. (2021). EU Biomass Use in a Net-Zero Economy—A Course Correction for EU Biomass.

Hale, R. C., Seeley, M. E., La Guardia, M. J., Mai, L., & Zeng, E. Y. (2020). A global perspective on microplastics. Journal of Geophysical Research: Oceans, 125(1), e2018JC014719.

Enfrin, M., Myszka, R., & Giustozzi, F. (2022). Paving roads with recycled plastics: Microplastic pollution or eco-friendly solution?. Journal of Hazardous Materials, 437, 129334.

Bishop, G., Styles, D., & Lens, P. N. (2022). Land-use change and valorisation of feedstock side-streams determine the climate mitigation potential of bioplastics. Resources, Conservation and Recycling, 180, 106185.

Salih, S. I. (2020). Self-healing of cyclic loading damage in asphalt mixtures (Doctoral dissertation, University of Nottingham)

Obaidi, H. I. A. (2018). Development of innovative pothole repair materials using induction heating technology (Doctoral dissertation, University of Nottingham).

Ajam, H. K. (2019). Effect of heating energy, steel fibres, bitumen types and ageing on the self-healing phenomena in hot mix asphalt (Doctoral dissertation, University of Nottingham).

Guo, F. (2021). Improving pavement networks through performance-based planning with optimal treatment strategies and management policies (Doctoral dissertation, Massachusetts Institute of Technology).

Highways Today. (2017, February 25). Prefabricated sustainable plastic roads: The future? Retrieved from https://highways.today/2017/02/25/prefabricated-sustainable-plastic-roads-future/

World Highways. (2015). The importance of road maintenance. Retrieved from https://www.worldhighways.com/wh8/wh9/wh10/feature/importance-road-maintenance

National Highways. (2021). Net zero highways: Our 2030/2040/2050 plan. https://nationalhighways.co.uk/media/eispcjem/net-zero-highways-our-2030-2040-2050-plan.pdf

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular economy: measuring innovation in the product chain (No. 2544). PBL Publishers.

ClimateCrete, a KAUST
https://climatecrete.us/

Concrete4Change
https://www.concrete4change.com/

VIATOP® Premium
https://www.jrs.eu/jrsAssets/docs/strassenbau/produktflyer/de/en/viatop-premium-productflyer.pdf

Hemp Rebar
https://www.dezeen.com/2022/03/15/hemp-rebar-low-cost-low-carbon-alternative-steel-design/

Carbon Crusher
https://www.carboncrusher.com/

TileGreen
https://tilegreen.org/

BioSealcoat
https://www.aexcelcorp.com/products/eco-friendly-traffic-paint/biosealcoat-sustainable-sealcoat-aexcel

BEET 55™ Liquid Organic Accelerator
https://bracorenvironmental.ca/beet-55/

ARRES
https://www.robotiz3d.com/arres-prevent/

UK based startup Guerrilla
https://theguerrilla.co.uk/

O.C.O Technology Limited
https://oco.co.uk/

Arup's timber bridge
https://www.arup.com/news/arup-consortium-develops-innovative-timber-bridge-design-for-dutch-highways-agency-rws/#:~:text=Arup%20has%20developed%20an%20innovative,highways-%20agency%20Rijkswaterstaat%20(RWS).

KERBFIX
https://www.hauraton.com/en/products/surface-drainage/kerbfix/

Example search terms

Product design advancements

- "durability enhancements in road material design"
- "weather-resistant construction materials for roads"
- "acoustic enhancements in road construction products"
- "cosmetic improvements in road surface materials"

Asphalt production optimisation

- "optimising asphalt production processes"
- "technologies for efficient asphalt manufacturing"
- "innovations in asphalt production optimisation"

Alternative and bio-binders

- "bio-binders for sustainable road construction"
- "alternative binders in asphalt production"
- "bitumen replacement technologies with bio-binders"

Recycled materials

- "using recycled materials in road construction"
- "aggregate replacements with recycled materials"
- "sustainable aggregates from recycled sources"

Self-healing roads

- "self-healing road technologies"
- "innovations in self-repairing asphalt"
- "development of self-healing road surfaces"

Autonomous road construction technologies

- "autonomous machines for road construction"
- "robotic road construction technologies"
- "automation in road building processes"

Electric equipment solutions

- "electric construction equipment for road building"
- "sustainable electric machines in construction"
- "battery-powered road construction equipment"

Smart compaction technologies

- "advanced compaction technologies for road construction"
- "smart compaction systems in civil engineering"
- "intelligent compaction equipment for better pavement quality"

Cold milling technologies & material recapture

- "cold milling techniques in road refurbishing"
- "material recapture solutions in road milling"
- "innovations in cold milling for road reconstruction"

Underground monitoring technologies

- "underground infrastructure monitoring technologies"
- "soil and geology monitoring solutions for construction"
- "advanced sensing for underground conditions"

Quality control and standardisation

- "quality control standards in road construction"
- "standardisation in civil engineering materials"
- "technologies for quality assurance in road building"

Critical road maintenance recovery

- "strategies for critical road maintenance"
- "emergency road recovery techniques"
- "rapid response solutions for road damage repair"

Road condition monitoring + intelligence

- "road condition monitoring systems"
- "intelligent road surveillance technologies"
- "smart sensors for road condition assessment"

EV and autonomous road solutions (IoT)

- "IoT solutions for EV-compatible roads"
- "infrastructure for autonomous and electric vehicles"
- "smart road systems supporting autonomous driving"

Value from roads

- "economic impact assessments of road infrastructure"
- "maximising value from road investments"
- "strategic management of road assets for greater ROI"

Critical maintenance monitoring

- "monitoring technologies for road maintenance"
- "critical maintenance tracking systems for infrastructure"
- "real-time monitoring

Pavements and resurfacing

- "sustainable asphalt innovations USA"
- "Europe recycled plastic road pavements"
- "advanced road resurfacing materials Asia"
- "Australia eco-friendly road resurfacing solutions"
- "Africa pavement recycling techniques"

Surface treatments

- "North America eco-friendly surface treatments for roads"
- "Europe advanced bituminous surface treatments"
- "surface preservation technologies South America"
- "Middle East innovative road surface treatments"
- "Asia road surface life extension methods"

Winter maintenance

- "Canada sustainable de-icing solutions"
- "Scandinavia environmentally friendly winter road maintenance"
- "Russia biodegradable road salt alternatives"
- "USA green de-icing technologies"
- "Japan innovative snow melting techniques for roads"

Kerbing

- "Europe recycled materials for road kerbing"
- "USA sustainable kerb construction"
- "Asia eco-friendly kerbing solutions"
- "Middle East innovative kerbing materials"
- "Australia green solutions for road edges"

Potholes and patching

- "UK innovative pothole repair materials"
- "USA sustainable road patching techniques"
- "Canada bio-based asphalt for road repairs"
- "India eco-friendly pothole solutions"
- "Brazil advanced road patch materials"

Aggregates

- "Australia recycled aggregates for road construction"
- "Europe sustainable aggregate sources"
- "USA eco-friendly road base materials"
- "South Africa alternative aggregates in road construction"
- "China green road construction aggregates"

Bridges

- "Japan green bridge construction materials"
- "USA sustainable materials for bridge engineering"
- "Europe recycled concrete in bridge construction"
- "Brazil innovative bridge materials"
- "Canada eco-friendly bridge construction techniques"

Road accessories

- "UK sustainable road accessories"
- "USA eco-friendly road signs and barriers"
- "Germany biodegradable road markings"
- "China green road safety products"
- "India eco-friendly materials for road infrastructure"

Glossary

- Using materials in **Cascades** involves the sequential use of materials in multiple products and applications to maximise their utility and lifespan before recycling or disposal. In cascading use, a material is repurposed at the end of each life cycle for a progressively lower-value application, thus extending its total lifecycle and reducing waste. This practice supports resource efficiency, minimises environmental impact, and contributes to a circular economy by keeping resources in use for as long as possible.
- **Composite materials** are engineered by combining two or more distinct materials, such as aggregates, polymers, and bitumen, to create a final product with different properties than the individual components. These composites are designed to enhance the strength, durability, and resilience of road surfaces. Common examples include polymer-modified asphalt and fiber-reinforced concrete.
- **Fugitive emissions** refers to gases or vapours that are unintentionally released into the atmosphere from industrial activities or facilities, other than through a stack or vent. These emissions can escape from equipment leaks, loose fittings, valves, flanges, or other parts of a process system, as well as from storage tanks, pipelines, or other infrastructure. Fugitive emissions are a significant source of air pollution and include substances such as methane, volatile organic compounds (VOCs), and other hazardous air pollutants, which can contribute to environmental and health problems. They are often difficult to detect and quantify, making their control a challenging aspect of environmental management.
- **Geo-synthetics** (in road construction) are man-made materials used in the stabilisation of roadbeds to enhance the structural integrity of roads. Geo-synthetics include a variety of products such as geo-textiles, geo-grids, and geo-membranes, which are used to reinforce the soil, provide drainage, and separate different soil layers. These materials reduce the reliance on traditional fill materials by distributing loads more evenly, controlling erosion, and improving the durability and lifespan of road surfaces.
- **The Overton window** refers to the range of policies or ideas, or in this case materials, that are considered politically acceptable or mainstream at a given time. In the context of road construction, applying the Overton Window concept can denote the exploration and integration of materials previously confined to pure research or used in unrelated industries like aviation and maritime. This approach suggests a shift in focus towards innovative materials that had never been traditionally considered for road construction, reflecting a broadening of acceptable and feasible options as technologies evolve and environmental considerations gain prominence.
- **Polymer-modified asphalt** is asphalt that has been enhanced with added polymers to improve its performance properties. These polymers, which can be elastomers like styrene-butadiene-styrene (SBS) or plastomers such as ethylene-vinyl acetate (EVA), enhance the asphalt's durability, flexibility, and resistance to deformations such as rutting and cracking. Some of these polymers may also be sourced from recycled plastics. This modification enables the asphalt to better withstand varying temperatures and heavy traffic conditions, making it highly suitable for road construction and maintenance.
- **Sub-base:** A layer of material in road construction that is placed directly under the base course. It is composed of lower quality materials than those used in the base course but still provides significant structural support and load distribution. The sub-base enhances the load-bearing capacity of the pavement, helps prevent deformation from the traffic loads, and improves drainage, preventing water from pooling and weakening the road structure.
- **Triple planetary crisis** refers to the three interconnected environmental emergencies facing the Earth: climate change, biodiversity loss, and pollution. This concept underscores the profound impact human activities have on the planet, emphasising that these crises exacerbate each other and pose significant risks to ecosystems and human well-being. The phrase is often used to highlight the urgency of coordinated global actions to address these critical issues through sustainable practices and policies.

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