Centre of Excellence
for Decarbonising Roads

TARMAC BIO HRA LIVE TRIAL EVALUATION REPORT

Live Labs 2 North Campus

This report presents the findings of a live trial evaluating Bio HRA, a biogenic binder within a Hot Rolled Asphalt (HRA) with 26% RAP included. Traditionally UltiPave Bio is a Stone Mastic Asphalt (SMA) product however for the purpose of this trial the bio-binder has been used with HRA. UltiPave Bio (HRA) demonstrated a reduction in embodied carbon emissions (A1-A5) than conventional HRA. Trial data demonstrates meaningful biogenic carbon savings, production readiness, and full compatibility with standard asphalt plant, laying, and compaction processes, minimising barriers to contractor uptake. To translate trial-level benefits into network-scale emissions reductions, the report recommends multi-year monitoring, formal third-party verification, and development of an Environmental Product Declaration. The findings support scale-up where material supply and verification resources are available.

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Executive Summary

This report evaluates a live trial conducted as part of the Live Labs 2 project, which aims to test innovative highway solutions to reduce carbon emissions, improve road performance, reduce maintenance needs, and enhance safety. This trial focused on the Tarmac Bio HRA (Hot Rolled Asphalt), described by the manufacturer as an asphalt biogenic binder which replaces a percentage of the conventional bitumen binder, whilst maintaining the durability and performance of the surface course. A biogenic binder is an asphalt binder derived from biomass such as plant oil or bio-residues such as vegetable oil residues. UltiPave Bio is a Tarmac Stone Mastic Asphalt (SMA) product, however for the purpose of this trial the biogenic binder from UltiPave Bio has been used within a mixture of HRA. For the purposes of this report this will be referred to as Bio HRA to avoid confusion. Tarmac also included 26% Reclaimed Asphalt Pavement (RAP) within the HRA mix.

Bio HRA was trialled as part of the Supersite Trial (a single stretch of highway trialling several materials and techniques) along Hirst Road in North Lanarkshire. Bio HRA was trialled as a surface course within section 5 of the supersite at a depth of 50mm, a control section of Hot-Rolled Asphalt (HRA) surface course was also applied to the supersite at a depth of 50mm to allow for direct comparisons to the business as usual (BAU) approach to surfacing for North Lanarkshire Council. The findings, limitations, and recommendations presented in this report aim to inform the potential rollout of Bio HRA across UK local councils.

This report assesses carbon emissions across cradle to construction lifecycle stages in accordance with EN 15804, covering product stages A1-A3 of this standard (raw material extraction, transportation to processing facilities and manufacturing) and construction stages A4 to A5 (transportation of the finished material to site and installation). EN 15804 classifies carbon and establishes a modular, transparent approach to lifecycle assessment that assigns emissions to defined stages. Using EN 15804 ensures that this live trial is consistent with the recognised European standard, follows accepted boundaries and allocation rules, and enables results that are comparable, auditable and consistent across products and projects.

The findings from the trial show that Bio HRA demonstrated a reduction in carbon intensity when compared to conventional HRA, with trial results showing 9.06 $kgCO_2/m^2$ versus 9.19 $kgCO_2e/m^2$ for baseline HRA (both applied at a depth of 50mm), signifying further carbon efficiency when applied under live conditions in North Lanarkshire. These carbon savings can be accounted to materially lower A1-A3 embodied emissions associated with the biogenic binder and the inclusion of 26% RAP within the HRA mixture.

These results confirm the carbon-saving potential of biogenic binders and demonstrate production readiness and compatibility with standard asphalt plant and laying processes, thereby reducing barriers to contractor adoption. To realise network-scale emissions reductions from these trial findings, multi-year monitoring is recommended, together with obtaining an Environmental Product Declaration or third-party verification.

Introduction

This Evaluation Report provides a high-level assessment of Bio HRA, an emerging sustainable material in highways, construction and maintenance, focusing on its environmental impact, product viability, and alignment with future infrastructure needs. Bio HRA is a biogenic additive which is added to conventional hot-rolled asphalt (HRA) to create an enhanced asphalt which offers increased durability and reducing maintenance requirements. A biogenic additive can be defined as a asphalt additive made from biomass derived, organic materials rather than conventional petroleum based, in the case of this trial the biogenic additive is sourced from bio-oils derived from biomass.

Live Labs 2 is a three-year UK-wide programme funded by the Department of Transport (DfT), with a five-year monitoring and evaluation period, focusing on how to decarbonise local highways infrastructure and assets. As part of this initiative, North Lanarkshire Council (NLC) are working alongside Transport for West Midlands (TfWM), to establish the UK Centre of Excellence for Materials Decarbonisation in Local Roads.

The Centre of Excellence will act as a central hub within Live Labs 2, supporting research, innovation, and best practices to accelerate low-carbon solutions in road construction and maintenance. By integrating findings from Live Labs 2 trials, the centre will drive sustainable advancements, enabling Local Authority Highway sectors across the UK to adopt more efficient and environmentally responsible materials and methodologies.

The purpose of this report is to present key findings from a comprehensive evaluation of sustainable materials, including their carbon intensity, potential application, and overall benefits by examining carbon appraisals, lifecycle benchmarks, and various factors such as scalability, compliance, durability and supply chain viability. The report aims to provide decision-makers with valuable insights into the material's capacity to meet sustainability goals while maintaining construction quality and durability. The evaluation will inform ongoing efforts to balance environmental considerations with operational efficiency in infrastructure development.

The carbon profiles of materials have been calculated using the Future Highways Research Group (FHRG) tool Carbon Leadership Profiler Toolkit (previously known as Carbon Analyser), a excel-based tool developed in collaboration with local highway authorities to provide a simple, standardised method for quantifying carbon emissions associated with transport and highways activities, and the OneClickLCA database where embodied carbon data is otherwise unavailable. All carbon profiles have incorporated a local and sector-wide baseline material to benchmark carbon savings. The UltiPave Bio (HRA) trial has been evaluated against conventional HRA.

The carbon evaluations for Bio HRA incorporate whole lifecycle assessments which consider:

- Embodied Carbon;
- Transportation emissions of materials and people;
- Operation of plant and equipment during construction period;
- Operational electricity, fuel and water emissions;
- End of life emissions including deconstruction and waste processing.

Feature	Description	Carbon Intensity	Product Prospects
Material Summary	**Description of material**	**Specific emissions data (CO_2e per unit of material)**	**Brief product potential overview**
Bio HRA – Tarmac	Bio HRA is traditionally a Stone Mastic Asphalt (SMA) product with includes the addition of a biogenic binder. However, for this live trial this biogenic binder has been added to Hot Rolled Asphalt (HRA) as this is the conventional surfacing material in North Lanarkshire. A biogenic binder is an asphalt binder in which a portion of bitumen is replaced with material derived from biomass such as plant oil or bio-residues. The addition of the biogenic binder is claimed to offer carbon savings in resurfacing projects while retaining the durability and constructability of conventional HRA. This biogenic binder can also include Reclaimed Asphalt Pavement (RAP) without effecting surface performance. In this live trial the HRA mixture included 26% RAP.	This product produced 9.06 $kgCO_2e/m^2$. When applied on the same stretch of road conventional HRA produced 9.19 $kgCO_2e/m^2$. Both surface course materials were applied at a depth of 50mm. Comparative carbon analysis in this trial showed a 1% reduction in A1-A5 (extraction to construction) lifecycle stage carbon emissions per square metre. However, the baseline HRA on the supersite contained 15% Reclaimed Asphalt Pavement (RAP) while Bio HRA contained 26%. To allow for a more complete comparison, carbon modelling of Bio HRA and HRA 0% RAP has been completed. This modelling demonstrated a 13% reduction.	It is considered that this product has a potential in the road construction and maintenance industry, particularly in projects prioritising sustainability. Bio HRA demonstrated 5.23% lower material-stage emissions and 21.86% lower construction-stage emissions than conventional HRA in this trial, confirming its ability to deliver reduced-carbon surfacing in live conditions. The results from this live support Tarmac's low carbon claims and demonstrate the products potential to be adopted within road maintenance in North Lanarkshire and other local authorities.

Methodology

Trial Design

The Bio HRA trial was designed to evaluate the performance, durability, and environmental impact of this material. The trial was conducted as part of the larger Supersite trial (a single stretch of highway trialling several materials and techniques) which focussed on testing innovative low-carbon surfacing materials and in-situ recycling techniques to evaluate their carbon savings and long-term performance under real-life road conditions.

Bio HRA was applied to section 5 of Hirst Road which had previously undergone cold in-situ recycling completed by Stabilised Pavement Limited (SPL), to assess the materials carbon savings while maintaining conventional HRA durability claims.

Carbon emissions have been assessed based on the whole lifecycle stages A1-A5 (extraction to construction) in accordance with EN 15804. EN 15804 is the European standard that defines the rules and reporting format for Environmental Product Declarations (EPD) for construction products, providing a consistent, audible framework for quantifying carbon impacts across a products lifecycle. These stages cover raw material extraction, transport to and manufacture at the factory, delivery to site and on-site installation, see Figure 1. This clear separation of stages enables precise attribution of emissions to each segment of the supply chain, helping to identify areas for potential reduction measures and ensuring comparability across all trials.

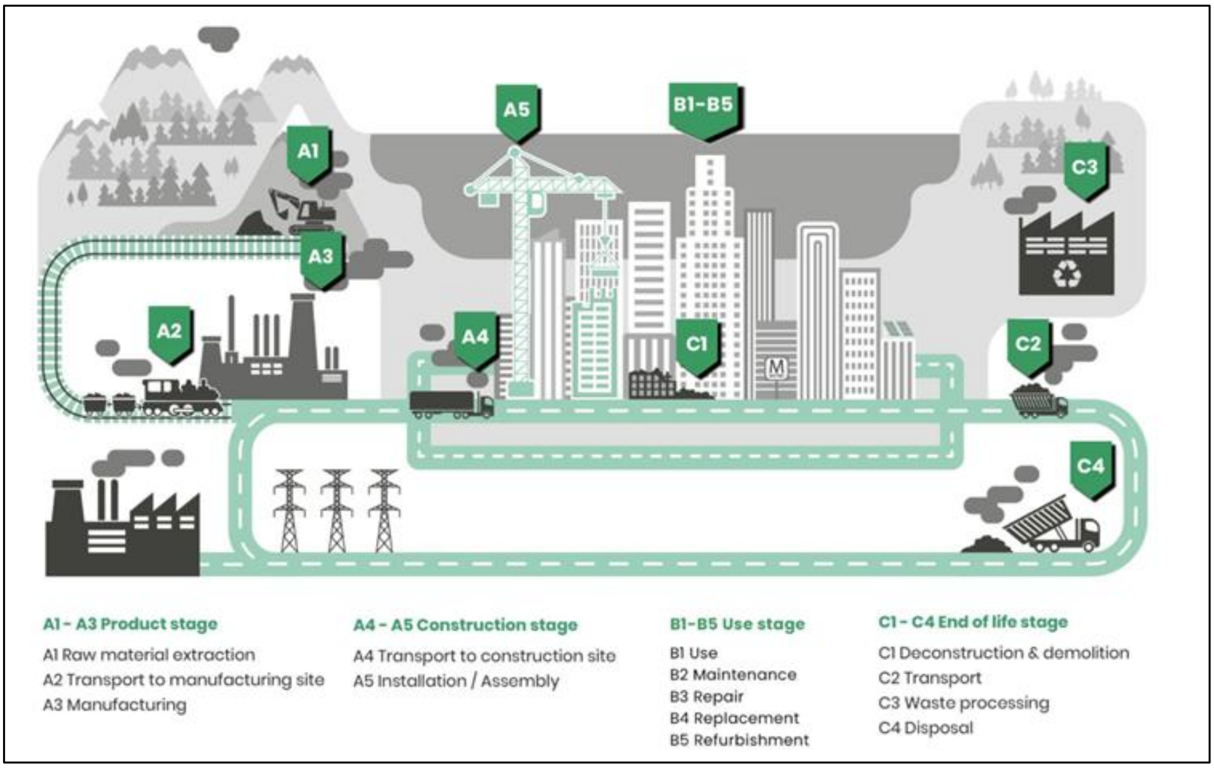

Figure 1: Carbon Lifecycle Stages[1]

[1] https://help.oneclicklca.com/en/articles/275901-life-cycle-stages

Site Selection

The trial sites were chosen based on the following criteria:

- **Traffic Volume:** The site was chosen as it experiences high numbers of both light and heavy vehicles allowing for the assessment of the material's performance under differing stress conditions.
- **Environmental Conditions:** The Supersite site was selected due to its varying weather conditions (e.g., temperature, humidity) to evaluate the surfacing material's resilience.
- **Surface Type:** Sites were all originally surfaced with Hot-Rolled Asphalt (HRA) and had severely deteriorated with time and use, requiring urgent maintenance.

Data Collection Plan

The following data items were collected to ensure a thorough evaluation during site trials:

DATA ITEM	UNIT(S)	RESPONSIBLE	LOCATION OF DATA	PURPOSE
Trial Location	Road name, Road Type (A, B, C), Coordinates of location of Bio HRA	Operational Staff	Site Diary	Technical comparisons
Conditions at the time of lay	Temperature (°C) Conditions (rain, dry, etc)	Operational Staff	Site Diary	Operational considerations and technical comparisons
Coring	Pen Softening Point DSR	University of Nottingham	Site Diary	Technical Evaluation
Road Surface Temperature	Temperature (°C)	Inspector	Site Diary	Technical Evaluation
Quantity	m^2 of Bio HRA used	Operational staff & Carbon Lead	Site Diary	Cost and Carbon Evaluations
Cost	£ for Bio HRA £ for conventional resurfacing	Amey Procurement and Suppliers	SAP	Purchase cost and whole lifecycle cost evaluation
Surface Characteristics	Length and Width (cm)	Carbon and/or Technical Lead	Site Diary	Technical and Carbon Evaluation
Operational Experience – ease of installation	Subjective – any concerns or benefits experienced by Operations Team	Project Manager to collect on-site data with Operations Team	Case Study in knowledge bank	Scalability Evaluation
Health & Safety	Ease of installation on-site Temperature required for installation	Operational staff and supplier information	Site Diary	Health and Safety Assessment
Operational Data	Time to complete (hh:mm)	Operational Staff	Site Diary	Operational considerations and carbon evaluation
Fuel Usage	Litres of petrol used Type of plant/fleet used (electric, diesel, model)	Operational Staff	Site Diary	Carbon evaluation

Table 1: Data collection plan

Trial Location Plan

The primary aim of the Supersite trials is to undertake a comparative analysis of surface courses with the current benchmark for standard practice used by North Lanarkshire Council, traditional HRA. There were a total of eight trial sections along one site (Hirst Road), with six surface courses and two binder courses on the main straight stretch of the carriageway and a further two surface course sections at junctions. Bio HRA was tested on section five of these sections. All trial sites were completed on one B classification of road (Hirst Road).

	BINDER COURSE			SURFACE COURSE			
TRIAL SECTION	**MATERIAL/METHOD**	**DEPTH (MM)**	**SUPPLIER**	**PRIMARY MATERIAL**	**INNOVATION**	**DEPTH (MM)**	**SUPPLIER**
1	In-situ Recycling	110	Colas	HRA	GiPave®	50	Iterchemica/ Holcim
2	In-situ Recycling	110	Colas	HRA	Styrelf bio-PMB	50	Total /Holcim
3	In-situ Recycling	110	Colas	HRA (warm mix)	HRA 35/14 Warm Mix	50	Holcim
4	In-situ Recycling	110	Colas	HRA	Traditional Surface HRA 35/14	50	Holcim
5	In-situ Recycling	4% CEM II and 4% calcined clay binder (150mm HBM recycled layer)	SPL	HRA	Bio HRA	50	Tarmac/ Holcim
6	In-situ Recycling	4% CEM II and 4% calcined clay binder (150mm HBM recycled layer)	SPL	HRA (warm mix)	HRA 35/14 Warm Mix	50	Holcim
Junction 1	Traditional Binder	60	Hochtief	14mm HardiPave	HardiPave®	40	Miles Macadam
Junction 2	Traditional Binder	60	Hochtief	14mm MilePave PMB	MilePave®	50	Miles Macadam

Table 2: Supersite trial information

Procedure

Site Preparation: The selected sites were cleaned, prepared and planed for the application of Bio HRA. Loose debris and water were removed to ensure proper adhesion.

Material Application: Roads were prepped as per manufacturer's instructions prior to the products application. Bio HRA was applied by Holcim via a paver following conventional HRA processes.

Monitoring and Data Collection: The trial sites were monitored over a period of 12 months. Data on surface condition, material performance, and environmental impact were collected at regular intervals.

Performance analysis: The performance of Bio HRA was evaluated based on criteria such as durability, resistance to traffic stress, and environmental impact. Comparisons were made versus traditional resurfacing to benchmark performance.

Data Analysis

The collected data were analysed to determine the effectiveness of Bio HRA as a surfacing material as an alternative to conventional HRA. Data analysis methods were used to evaluate the performance of Bio HRA versus a control section (HRA) along the same road. This analysis focused on:

- **Durability**: Assessing the longevity of the treated site and resistance to traffic and environmental stress;
- **Environmental Impact:** Evaluating the reduction in carbon emissions and use of recycled materials; and
- **Cost- Effectiveness:** Comparing the costs associated with Bio HRA, including material, application, and maintenance costs.

The embodied carbon factors for trialled materials have been built based on supplier product data and supported from carbon factors sourced from OneClick LCA where required. An Environmental Product Declaration (EPD) had not been produced for biogenic binder additive for HRA at the time of this carbon appraisal.

The reliance on supplier provided carbon emission factors may raise confidence issues due to limited transparency in the supplier's methodology however, Tarmac has shared the methodology and assumptions made and has calculated the emission factor in accordance with BSI PAS 2050:2011 and using the industry standard methodology for asphalt, the Asphalt Pavement Embodied Carbon Tool aspect v4.2. This higher level of transparency helps to mitigate potential uncertainty.

Carbon Appraisal

Carbon appraisal

Drawing on data collected through trials; a carbon assessment has been undertaken. Table 3 establishes the parameters of the model, defines assumptions and outlines product specifications.

ASSUMPTIONS	JUSTIFICATION
All transportation is undertaken via diesel HGV.	Based on standard modelling assumptions from similar schemes.
Design life of pavement surface is 40 years.	Based on PAS 2080 guidance [2]. At 40 years the binder course of HRA requires replacing.
Unit of measurement used is ‘$kgCO_2e/m^2$’.	Based on the best available data used to conduct carbon appraisals.
Traffic management activities were not included within this carbon assessment.	Traffic management differs between sites and local authorities so requires separate capturing, as part of standard practice.
Government emission factor transport, HGV, diesel 2025 was used to calculate A5 for plant when a specific emission factor is unknown.	Based on the best available data at the time of this carbon appraisal.
This carbon analysis does not incorporate planing out activities within this assessment.	This is a BAU activity therefore is not influenced by this innovative process.
Where specific machine hour carbon emission factors were unavailable emission factors have been selected based on average kW power, sourced from OneClick LCA.	Based on the best information available at the time of the carbon appraisal.
The emission factor for Bio HRA was supplied by the manufacturer, Tarmac.	Based on the best information available at the time of the carbon appraisal. Tarmac has calculated the emission factor in accordance with BSI PAS 2050:2011 and using the industry standard methodology for asphalt, the Asphalt Pavement Embodied Carbon Tool aspect v4.2.
Tarmac used Eurobitume’s 2025 carbon emission factor for bitumen[3], 530$kgCO_2e$/ tonne to calculate the emission factor for the biogenic additive.	This figure is the most recent bitumen emission factor and is considered the industry standard.
The emission factor used in this analysis is for BIO HRA 35/14 F SURF 40/60 DES H/S (UltiPave Bio HRA) and is specified to this mix and plant used in mixture.	Using an emission factor tied to the exact mix ensures the carbon emission reflects the specific binder type, aggregate grading, and additive content used in the product.
The RAP (reclaimed asphalt pavement) content of the material mixture is 26% and this is treated as reclaimed filler/aggregate within the carbon assessment.	Counting RAP as reclaimed aggregate/filler recognises avoided upstream extraction and processing emissions while still accounting for residual embodied emissions in the aged binder. Industry LCA guidance for asphalt commonly allocates RAP as a recycled aggregate stream within the material balance, which aligns with PAS-2080 approaches to recycled content.
Primary data from annual energy performance of individual Tarmac extraction and manufacturing sites and supplier information where available; where supplier data is not available, relevant information was sourced from trade bodies or the ICE database (Hammond & Jones, November 2019).	Incorporating supplier data where possible increases specificity and better represents supply chain variability. However, when this is unavailable using establishes sources such as trade body datasets and the ICE database provide widely accepted, audited baseline values for materials and processing, ensuring continuity and comparability between products and processes.
The carbon modelling for HRA with 0% RAP assumes equivalent material quantities and construction activities to those recorded for	This approach controls key variables, reducing modelling uncertainty and making the carbon impact of RAP omissions directly attributable.

[2] 2023-03-29-pas_2080_guidance_document_april_2023.pdf

[3] https://eurobitume.eu/wp-content/uploads/2025/03/EB-GWP-Report-to-LCA-4.0-2025.pdf

the supersite's HRA control section, ensuring a like for like comparison.	
The carbon emission factor for HRA containing no RAP was sourced via One Click LCA from an EPD for Hot Rolled Asphalt surface course mixture (HRA 35/14) manufactured by Roadstone Limited and awarded an EPD by Eco Platform in 2025 (EPD-IES-0020174).	EPDs are prepared and verified to EN15804 and ISO 14025 standards, which makes this emission factor suitable for lifecycle modelling. One Click LCA is widely used within the industry to source and apply verified EPD data in construction carbon models.

Table 3: Carbon appraisal matrix

Carbon Modelling

The carbon modelling for the trials was conducted using the Future Highways Research Group (FHRG) Carbon Leadership Profiler Toolkit to collect and analyse primary carbon data from the trials, detailing emissions from materials, transport, construction activities and equipment use. Using this information the tool generated carbon profiles that identified emission hotspots and using the toolkit's emission database providing verified emissions factors to improve data accuracy.

One Click LCA was also utilised in modelling to support the FHRG Carbon Leadership Profiler Toolkit due to its large database of emission factors supported by Environmental Product Declaration (EPD). The carbon emission factor for Bio HRA has been supplied by Tarmac. This value was calculated Tarmac's internal carbon calculator. Tarmac has shared the methodology and assumptions made and has calculated the emission factor in accordance with BSI PAS 2050:2011 and using the industry standard methodology for asphalt, the Asphalt Pavement Embodied Carbon Tool aspect v4.2.

Indicative results from carbon modelling for the Bio HRA works along section 5 of the Supersite on Hirst Road, expressed in $kgCO_2e$/tonne and $kgCO_2/m^2$. This presentation of emissions enables direct comparison across different surfacing materials, to highlight carbon-efficient options and support data-driven decision making for reduction strategies. Results are presented graphically in Figure 2, Figure 3 and Figure 4:

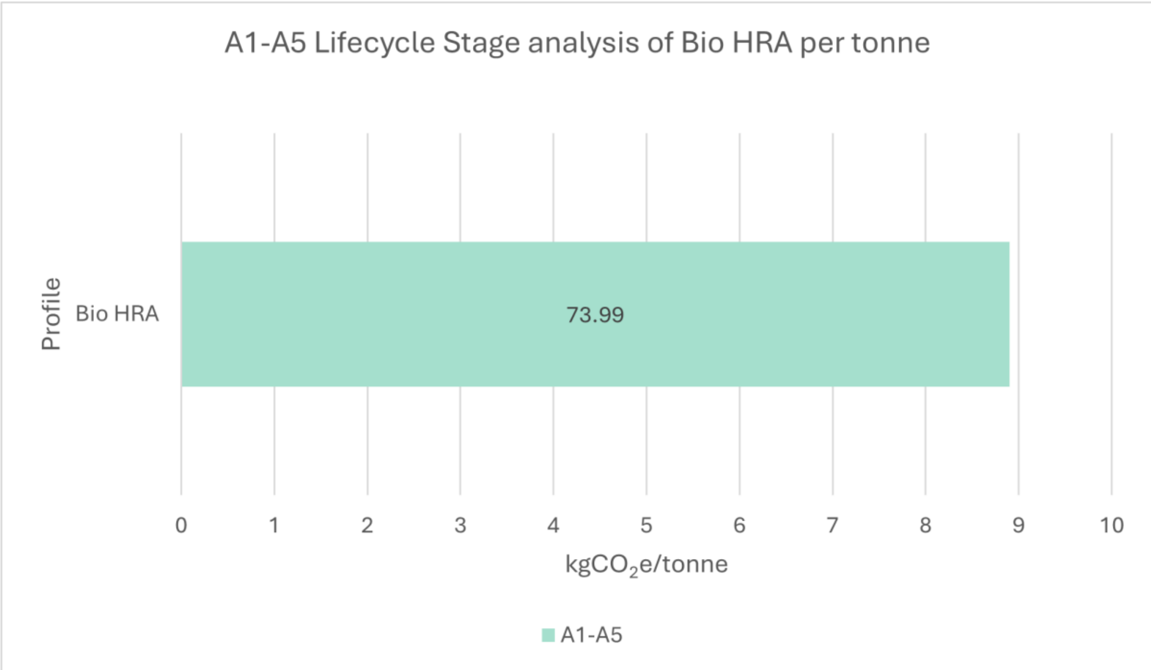

Figure 2: Carbon analysis of Bio HRA per kilogram (50mm depth)

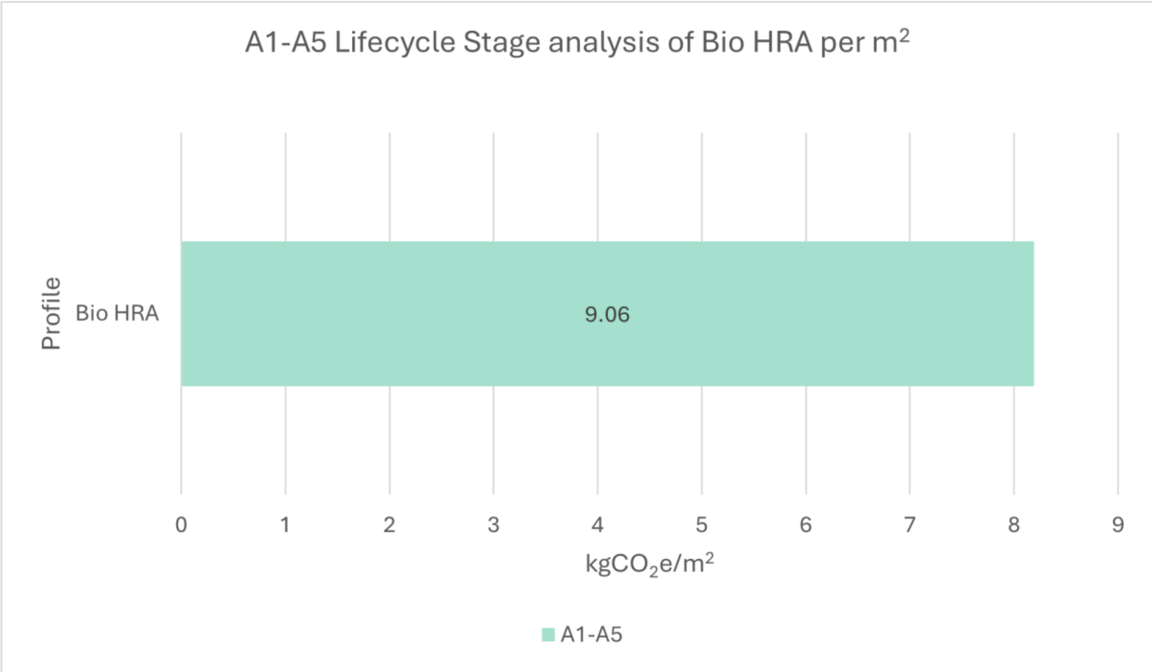

Figure 3: Carbon analysis of Bio HRA per meter squared (50mm)

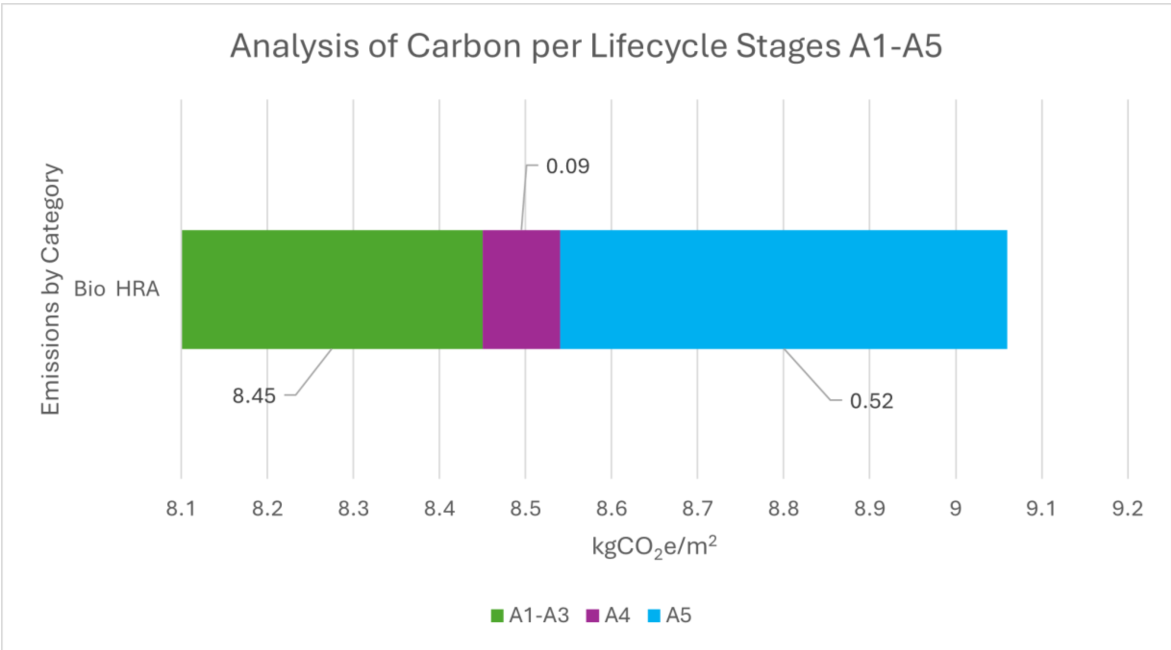

Figure 4: Lifecycle analysis stages A1-A5 of Bio HRA per m^2 (50mm depth)

Benchmarking

Until this trial, Bio HRA was yet to be used on North Lanarkshire Council highways . These trials are to allow for an analysis of the performance of Bio HRA in comparison to conventional HRA on the same road of the same traffic loads. This would be the business as usual option for re-surfacing if Bio HRA was not used. This allows for comparisons between Bio HRA versus BAU surfacing within the carbon analysis.

Comparative analysis results is presented graphically in Figure 5 and Figure 6:

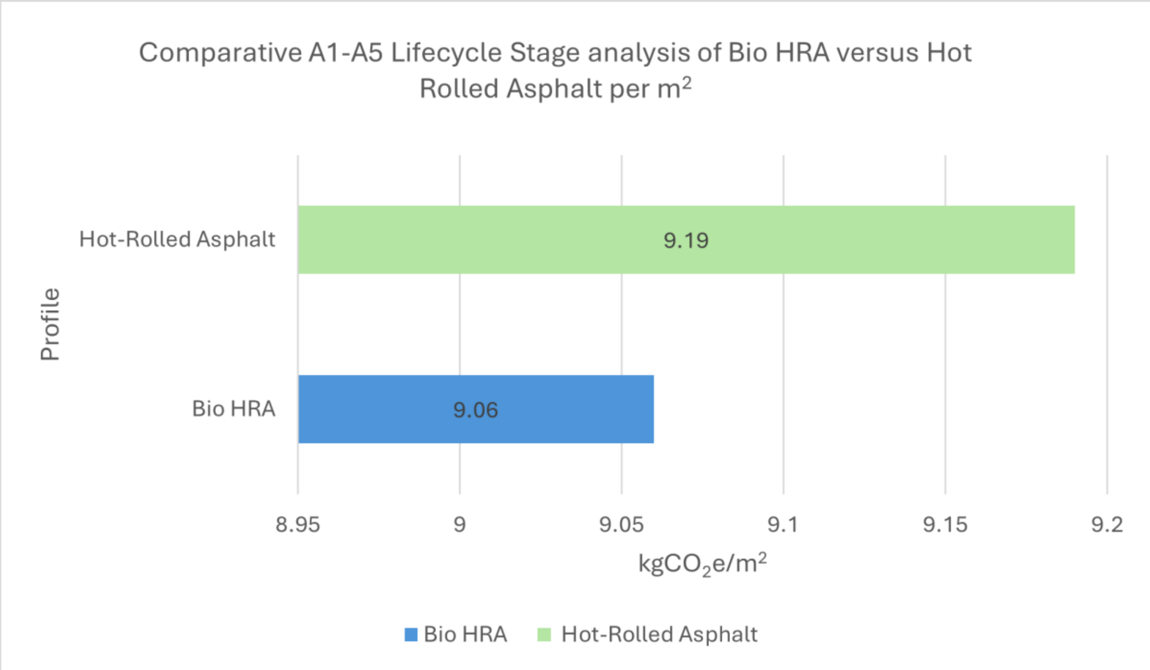

Figure 5: Comparative carbon analysis Bio HRA versus HRA per m² (50mm depth)

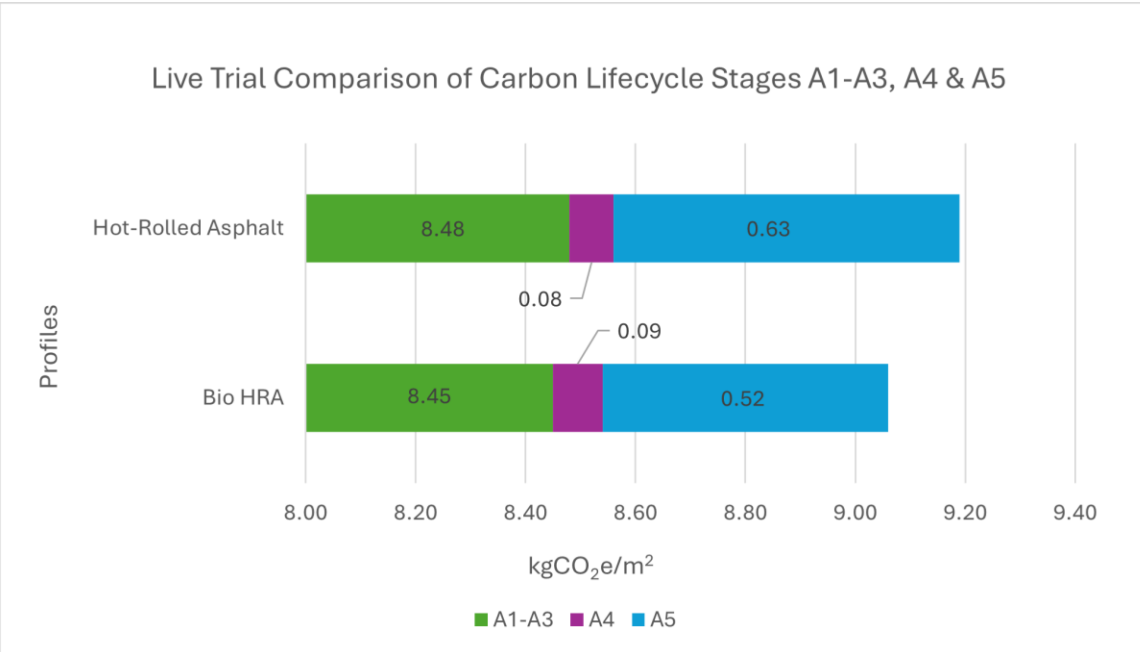

Figure 6: Comparative carbon analysis of BioHRA versus HRA, lifecycle stages A1-A5

The benchmark HRA control section on the supersite contained 15% RAP while the Bio HRA mix included 26% RAP. RAP content varies by Local Authority, dependent on specification and design. To provide a conservative, like-for-like comparison, Bio HRA has been modelled against an HRA baseline with no RAP content to demonstrate further potential carbon savings. Results from this modelling are represented graphically below in Figure 7:

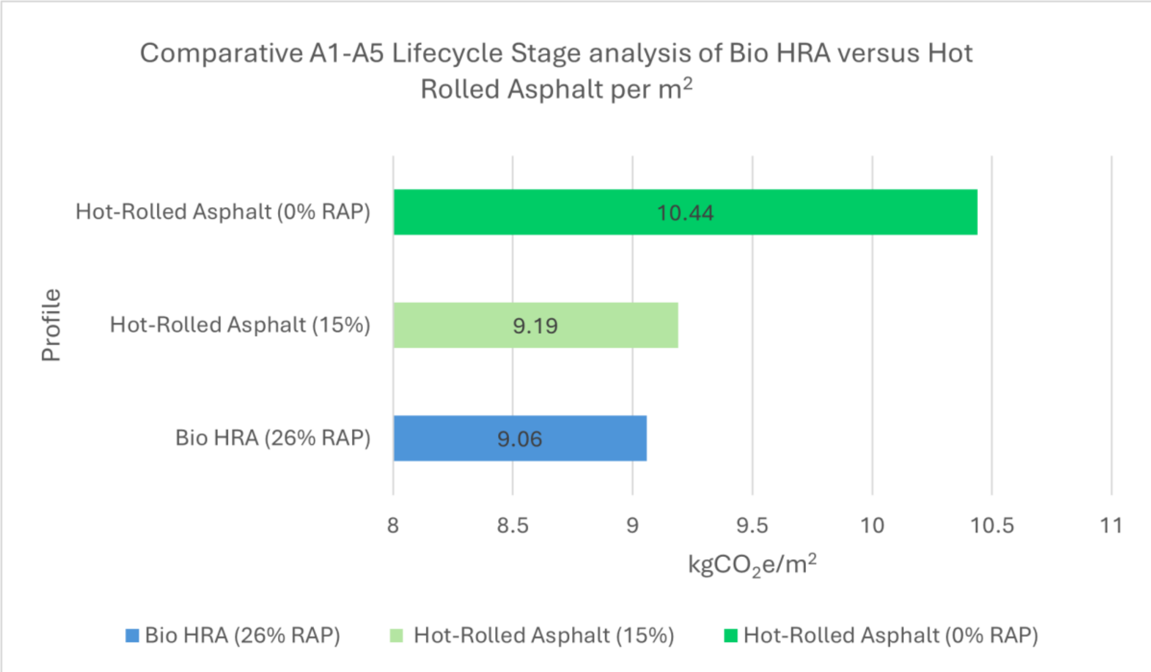

Figure 7: Comparative carbon analysis Bio HRA versus HRA with no RAP content per m^2 (50mm depth)

MATERIAL	COMPOSITION	APPLICATIONS	PERFORMANCE	INSTALLATION	SUSTAINABILITY
HRA	HRA is a dense, gap-graded bituminous mix comprising of a mortar, fine aggregate (sand), filler and bitumen. It is hot applied via a paver. Immediately after paving, the pre-coated high-PSV chippings are rolled into the hot mix to lock in a positive texture for skid resistance.	HRA is predominately used on high-speed and heavily trafficked roads where durable, dense, low-void wearing course is required such as motorways, A-roads, bus lanes, roundabouts etc.	The densely mortared matrix makes HRA impermeable and resistant to rutting and deformation under heavy loads. Its sharp chippings protruding from the surface maximises adhesion and increases skid resistance at even at speed. HRA can be susceptible to rutting if the mix or compaction is incorrect under heavy traffic but is the proven baseline with well-understanding of mix suitability.	HRA is supplied and laid on site at approximately 160-180 degrees. Laid using standard hot-mixing plant and standard paving/rolling practices for HRA. After initial compaction, pre-coated chippings are spread at a controlled rate and rolled in immediately to embed them into the mortar HRA has well-established specifications on procedures across the industry.	Traditional HRA can incorporate reclaimed asphalt pavement (RAP) percentages, though high fines and virgin bitumen grades often limit RAP rates to maintain mortar cohesion.
Bio HRA (26% RAP)*	Bio HRA contains bio-enriched bitumen (biogenic content blended in the binder). Traditionally Bio HRA is an SMA product however, for the trial in North Lanarkshire the bio-genic binder was used in HRA.	This bio-genic binder can be used on surfaces traditionally surfaced with conventional HRA. This includes heavily trafficked roads where durability, texture retention and high skid performance is required.	Bio HRA formulations reduce tyre/road noise and surface spray when compared with conventional dense surfaces, improving user comfort and safety. The bio-genic binder maintains HRA's impermeability and resistant to rutting and deformation under heavy loads.	The biogenic binder additive uses standard HRA laying and compaction procedures. While applied in a hot mix at this trial, the material holds potential to be used in warm mix asphalt.	The material can incorporate RAP within its mixture. The mix used on the North Lanarkshire site contained 26% RAP. The products increased durability claims holds potential to increase service life and reduce maintenance cycles, contributing to whole lifecycle carbon savings. The bio-genic binder has potential to be used in warm mix asphalt to further reduce carbon emissions.

Table 4 Bio HRA Appraisal

*All factors assessed as part of the appraisal of UltiPave Bio, as a biogenic additive for HRA has been built on supplier provided material and are not drawn from the live Supersite trial.

Life Cycle Stage	Baseline Carbon Emissions (HRA) ($kgCO_2e$)	Bio HRA Carbon Emissions ($kgCO_2e$)	Difference (%) (Increase/ Reduction)
A1 – A3	17,799.73	16,868.88	5.23%
A4	163.98	169.59	3.42%
A5	1,326.71	1,036.74	21.86%

Table 5: Lifecycle Stage Comparison to BAU

Carbon Benefits and Considerations (Matrix)

Table 6 presents the findings of the carbon benefits and considerations matrix for Bio HRA application as a surfacing material. **All scoring is bold and underlined.**

Technical data used during benchmarking and the carbon benefits and considerations matrix were supplied by the manufacturer and are not derived from the Supersite live trial in North Lanarkshire. While reliance on supplier-provided information may introduce uncertainty in confidence levels, the information and data represents the best available evidence at the time of the appraisal. Data quality has been considered when selecting supplier information and, where possible, supplier values were chosen from manufacturers' standard test reports, specifications and product datasheets that reference recognised test methods and certification.

BENEFIT/LOAD UNDER REVIEW	CONSIDERATIONS	SCORING SYSTEM	JUSTIFICATION
Costs	Transport, operational, material procurement	1 - Significant additional costs **<u>2 - Costs approximate baseline</u>** 3 - Costs significantly lower than baseline	Material cost is estimated to be above the baseline due to the biogenic binder. However, this initial cost has potential to be offset over the extended lifetime of the asset due to its reduced maintenance potential.
Maintenance	Design life, maintenance burden, on-time for plant	1 – Significantly more maintenance/lower longevity **<u>2- Approximately same maintenance/similar longevity</u>** 3 – Significantly less maintenance/higher longevity	The biogenic binder does not impact any of the characteristics of conventional HRA, ensuring strong texture retention and deformation resistance. These characteristics indicate the requirement for less maintenance and a long service life.
Scalability	Manufacturing facilities	1 - Lab testing only 2 - In process of commercialisation w. small scale manufacture **<u>3 - Already has market presence with developed supply chain</u>**	Bio HRA mixes are widely available from Tarmac, with high market presence and established manufacturing routes. The appetite for bio-blends is growing and can be produced at existing asphalt plants with minimal capital change.
Compliance with specifications	Requirements for standards departures	1 - Requires significant departure(s) from standard and has not been used before by end client **<u>2 - Requires some departure from standard, but has been used before by end client</u>** 3 - Does not require any departure from standard.	The biogenic mix aligns with existing HRA specifications, but the bio component may require documented binder documentation and likely client acceptance testing (DSR, BBR, ageing tests).
Environmental	Nature-based solution	1 - Would have significant net disbenefit for environmental factors (noise, AQ, biodiversity, landscape etc) **<u>2 - Would have negligible net benefit/disbenefit or no overall change</u>**	Bio-binder reduces fossil carbon intensity, but net environmental benefit depends on feedstock sourcing and the supply chain. However, Bio HRA can incorporate high RAP mixtures.

BENEFIT/LOAD UNDER REVIEW	CONSIDERATIONS	SCORING SYSTEM	JUSTIFICATION
		regarding environmental factors 3 - Would have significant net benefit/disbenefit for environmental factors.	
	Road noise	1 - Would have significant net disbenefit **2 - Would have negligible net benefit/disbenefit or no overall change regarding** 3 - Would have a significant net benefit	There are no expected changes in operational noise levels however, the product has potential to reduce maintenance requirements and therefore reduce noise from personnel and plant on site.
	Climate resilience/future proofing	1 - Would have significant net disbenefit **2 - Would have negligible net benefit/disbenefit or no overall change regarding** 3 - Would have a significant net benefit	The mix maintains HRA durability and resilience to thermal cracking and rutting. However, long-term ageing behaviour of bio-modified binders under extreme temperatures and UV requires continued monitoring.
Risk and safety	H&S impacts, safety testing data	1 - Would present increased risk or safety versus BAU option 2 - Would present no overall risk increase or safety impact versus BAU option **3 - Would present lower risk or safety impact versus BAU option.**	The bio-mix does not impact on the HRA health and safety profile. However, the bio binder has potential to be used in warm mix asphalt which would require lower installation temperatures, reducing worker heat exposure risk.
Technology Readiness Level	Is it commercially available, is there enough R&D?	1 - Not yet commercially available 2 - Commercially available from worldwide suppliers 3 - Commercially available from European suppliers **4 - Commercially available from UK suppliers** 5 - Commercially available from local suppliers	Commercially available from large supplier in the UK though availability is quarry plant specific and may not be viable locally deployment to all local authorities.
Constructability	How easy is it to handle on site, install, recover, curing time, specialist equipment/training, storage?	1 - Specialist contractors, time on site and/or equipment required **2 - No considerations required above and beyond baseline solution**	Construction is in line with standard HRA laying with no special plant modifications required.

BENEFIT/LOAD UNDER REVIEW	CONSIDERATIONS	SCORING SYSTEM	JUSTIFICATION
		3 - Significant benefits to on-site activity / ease of installation	
Supply Chain	Material availability	1 - Novel materials used with limited supply **2 - Materials are available with some supply restrictions** 3 - Materials are readily available	Aggregates, plant capacity and RAP streams are generally available; However, bio-binder supply is dependent on regional concentration and feedstock processing capacity.
Circular Economy	Recycled content	1 - Virgin materials are used with little or no recycled content **2 - Materials contain a level of recycled content** 3 - Materials are predominantly recycled and/or use novel sources of recycled content that would otherwise be discarded as waste	The bio-mixture used in North Lanarkshire included significant recycled content (26% RAP). However, the source of the biogenic binder has not been specified, ideally feedstocks will be residues however, the source of biomass is often not given.
	Ease of recycling	1 - Minimal recycling of material possible upon removal **2 - Limited recycling is possible and/or significant reprocessing required** 3 - Reuse/recycling is easy and convenient	The HRA mixture containing RAP is reclaimable and reusable in asphalt processes with standard reheating and rejuvenation. However, mixed binders (bio and aged binder) may require controlled processing parameters and rejuvenator dosing,

Table 6: Carbon benefits and considerations matrix

Long-Term Performance Analysis

The carbon analysis within this report does not contain lifespan analysis. This will be finalised dependent upon the publishing of longevity test results in partnership with the University of Nottingham.

These tests will focus on the following:

- Durability and Aging Resistance,
- Skid Resistance and Surface Integrity,
- Lifecycle Carbon Savings,
- Traffic and Environmental Stress Testing,
- Optimal Reapplication Intervals.

Conclusion & Recommendations

Conclusions

The Bio HRA live trial demonstrated positive results for sustainable road surfacing when compared to conventional HRA on the same site and depth, with the trial recording 9.06 $kgCO_2e/m^2$ versus 9.19 $kgCO_2e/m^2$ for the baseline, a 1% reduction across A1-A5 lifecycle stages (raw materials, distribution transport and manufacturing) per square meter. This minimal reduction can be accounted to differences in transport emissions. When the two trial sections are compared directly a 5.23% reduction in A1-A3 stage emissions and a 21.86% reduction in A5 stage emissions is evident. This reduction is not as significant as expected due to the high volume of RAP in the conventional HRA baseline.

Bio HRA also holds potential to offer further carbon savings when compared with HRA not containing any Reclaimed Asphalt Pavement (RAP). RAP usage varies depending on Local Authority specifications and design. To allow for a more conservative comparison Bio HRA has been modelled against HRA containing no RAP. This modelling demonstrated a potential to equate for 13% carbon savings across material extraction to construction emissions stages.

These reductions are predominantly driven by lower A1-A3 embodied emissions from the presence of biogenic binder and the inclusion of 26% RAP in the mix. Higher A4 emissions remained however, this is attributable to Bio HRA being produced at a more distant asphalt plant than the standard HRA. This demonstrates that the most significant carbon opportunities lie in material selection and production processes rather than installation logistics.

A key aspect of Bio HRA is that it does not affect standard HRA production, laying and compaction procedures, with no specialist plant or unusual installation requirements. This indicates that Bio HRA has potential for integration into existing delivery practices without major changes to site workflow, training or equipment, supporting more straightforward trial scaling where material supply permits. However, regional availability of bio-binder feedstock and plant processing capacity may constrain immediate widespread deployment and should be factored into procurement decisions.

However, the confidence in the supplier supplied data must also be considered. The emission factor for Bio HRA from Tarmac was calculated in accordance with PAS 2050 and the Asphalt Pavement Embodied Carbon Tool asPECT. While the supplier has been transparent, the absence of an independent EPD for the specific Bio HRA mix limits overall confidence levels of the carbon appraisal. To increase this confidence level independent verification or EPD is required for the emission factor shared.

Recommendations

It is advised that Tarmac should obtain a third-party verified EPD for the Bio HRA binder additive to replace supplier only emission factors and enable auditable comparisons. Alternatively, in the meantime, they should secure independent verification of the Bio HRA emission factor or have their internal carbon tool independently verified to be in accordance with standards previously identified as well as EN 15804+A2.

It is recommended that robust long-term monitoring (over 5+ years) be implemented at treated sites to comprehensively evaluate performance and verify lifecycle carbon savings. This further long-term monitoring will allow for more expansive carbon modelling to assess end-of-life scenarios to provide a more comprehensive understanding of whole life carbon emissions.