
concretene™
Innovate UK project:
Railway Construction Innovation
(Global Centre of Rail Excellence)
Ref: 10098655
Final report – August 2025
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Competition: Global Centre of Rail Excellence: railway construction innovation

Project: Graphene enhanced concrete sleeper for lower embodied carbon

Innovate UK project Ref: 10098655

Final report by Alex McDermott, Project Manager

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Overview

The purpose of this project was to partner with an international concrete producer to develop a reduced carbon railway sleeper and demonstrate in-service performance on a live railway.

Project funding was provided as part of a £7.5m collaboration between Innovate UK, the Department for Business, Energy and Industrial Strategy (BEIS) and the Global Centre of Rail Excellence (GCRE) to deliver and demonstrate innovation in Railway Construction.

The Global Centre of Rail Excellence is a vast purpose-built site – located in the Dulais Valley, South Wales – for world-class research, testing and certification of rolling stock, infrastructure and innovative new rail technologies from across Europe. Currently under construction, GCRE aims to provide opportunities for emerging technologies, helping de-risk innovation, pioneer a Net Zero railway.

Cobmore Holdings were successfully awarded both phases in the competition:

Stage	Description	Dates
Phase 1	Feasibility study: Awarded to 24 successful organisations	May 23 – Jun 23
Phase 2	Development & demonstration: Awarded to 15 of the 24 phase 1 organisations to develop and demonstrate their innovations live at GCRE, becoming a permanent feature on the railway	Jan 24 – Mar 25
	Industry demonstration showcase	Mar 25

The aim of this project was to develop and produce railway sleepers modified with Concretene with lower embodied carbon. Existing sleepers are manufactured principally using an Ordinary Portland Cement (OPC) binder, which on average is responsible for 86% of the embodied carbon in concrete [ICE Low Carbon Roadmap].

Concretene creates a stronger concrete, which in turn allows the proportion of cement to be reduced, thereby reducing carbon whilst maintaining curing characteristics, a vital metric for a precast factory with high-capacity outputs and limited storage space.

Previous low-carbon sleeper mixes trialled by Cemex showed promise, however the long-term durability standards were not met. Concretene has demonstrated the ability to counter these deficiencies in previous testing and therefore expected to compliment Cemex's previous work.

With an annual production of 600,000 sleepers (12,000 tonnes CO_2), forecast to rise to 1m units by 2030, this project presented a significant opportunity for a step-change reduction in carbon on Network Rail's (NR) infrastructure. Independently to this funding competition, NR updated their concrete sleeper standard to encourage innovative low-carbon alternatives and invited Concretene onto the Steering Group, which will encourage new lower-carbon technologies, focusing on a performance specification rather than prescribing concrete ingredients.

Concretene sleepers will assist NR in achieving its 2029 carbon commitments to reduce scope one and two greenhouse gas emission by 46% and scope three emissions by 28%.

With GCRE's capability to support innovation by acting as a testbed for cutting-edge green technologies, this project had the unusual feature of a live railway environment, designed to

provide confidence to the traditionally risk-averse rail industry, particularly supporting future technical assurance from asset owner and track maintainer Network Rail.

Consulting Engineer Arup joined the project to provide independent technical overview and assurance, offering guidance to ensure that design and performance criteria were met, important for future accreditation beyond the scope of this project.

As an independent test house, the Building Research Establishment (BRE) was subcontracted to undertake a suite of durability testing to confirm compliance with standards and compare against the non-Concretene-modified concrete mix. This testing will be ongoing for one year beyond project end, completion due March 2026.

Project context

Concretene was developed to address the need for improving concrete by reducing embodied carbon, improving curing times and long-term durability. In May-2021 (Innovate-UK project-number: 99366), Concretene laid the first commercial-scale graphene enhanced concrete slab, with the successful deployment as a world-first demonstration of a 220T ground-bearing floor-slab with no joints/reinforcements (saving 14t of CO_2 by a 30% reduction in cement).

However, sleeper concretes are specialist mix designs with additional performance additives and further formulation development was required to confirm and optimise performance and compatibility. The concrete mix design used by partner Cemex incorporates a proportion of limestone, designated CEM II A-L. These types of concrete are becoming more common as part of the industry's carbon reduction journey, offering around 10% reduction when compared to CEM I concretes. It was therefore important that Concretene demonstrated compatibility with these increasingly popular concretes.

This project was an ideal fit because:

- Funding fit with Concretene's overall core development plan.
- Created a formal development agreement with Cemex, one of the world's largest concrete producers.
- Use of precast concrete, allowing a high degree of control in factory conditions.
- Provided a rare live railway environment for a novel technology testing.
- Opportunity for the technology in remain indefinitely in live track, acting as a living laboratory.
- Ongoing showcase to the European rail industry, particularly Network Rail, owner and maintainer of 50m railway sleepers.

Objectives

The project objectives were:

1. Primary: Demonstrate that Concretene technology reduces embodied carbon in sleepers whilst maintaining strength, serviceability, durability and quality through laboratory tests and GCRE site trials. Target 10% carbon reduction.
2. Primary: Maintain the performance requirements prescribed in standards EN13230:2 Railway Applications - Track - Concrete Sleepers and Bearers - Part 2 and Network Rail NR/L2/TRK/030 (60N/mm2 compressive, 6N/mm2 flexural strengths).
3. Secondary: Reduce initial curing times, improving manufacturing efficiency and production costs.

Sleeper manufacturer Cemex's current mix design was used to demonstrate compatibility and non-disruption with their existing operations.

Project partners

- Cobmore Holdings, SME, owner of Concretene technology.
- Cemex Rail, one of two UK suppliers of precast concrete sleepers. Concretene has an existing development relationship with Cemex as supplier of concrete to previous Concretene pours in Manchester.
- Arup, a world leading engineering consultancy and equity partner of Concretene.
- Building Research Establishment (BRE), an internationally respected third-party test house.

Project structure

The project was split into distinct work packages, each with allocated resources:

WP1: Project-Management (Owner: Cobmore)

WP2: WP2: Develop Performance & Test Criteria (Cobmore)

WP3: Formulation Development (Cobmore)

WP4: Statistical Concrete Laboratory Trials (Cobmore)

WP5: Cemex factory batching production and testing (Cemex)

WP6: Concretene site trials at GCRE (Cobmore & Cemex)

WP7: Ongoing performance monitoring (Cobmore & Cemex)

WP8: Communication, dissemination and exploitation (Cobmore)

As the Project Manager, Alex McDermott was responsible for day-to-day management of the project and programme across formulation and concrete testing laboratories in Manchester. He was the key interface with Cemex and coordinated the factory trials.

Project progress (Phase 2)

Q1 (1 Jan 24 – 31 Mar 24)

Q1 commenced with the teams mobilised from Concretene and Cemex.

The team met the GCRE construction team to understand the construction programme in more detail, where it was confirmed that the permanent way installation would commence December 2024, aligned to Concretene's programme. Concretene sleepers would be installed in the first sidings being constructed, as the loop doesn't commence until 2026. Once the design was completed, GCRE would send the permanent way drawings to Concretene to mark up the

preferred position for the sleepers install and GCRE's installation contractor would then facilitate this. It was noted that this was subject to change, depending upon site progress.

Following the work undertaken with Cemex during Phase 1 and working with technical partner Arup, a series of technical meetings were held, providing an update on the current 'state of the art' mix designs used in the production of sleepers, which evolved from the mix design assessed during phase 1. The effect of this variation would be investigated as part of the forthcoming development work, specifically in WP3 Formulation Development, and WP4 Concrete Laboratory Trials.

A technical meeting with Cemex confirmed the key parameters and controls used in the manufacturing of sleepers in their Rochester factory, examples including defining a cement reduction target, understanding the current mix design, method and control of the curing process. Following this, the formal procedures were provided, to be followed and replicated in Concretene's labs during the extensive testing programme.

The method of curing uses heat to achieve very early strength development, allowing release of the prestressed tendon loads and therefore de-moulding. It is important that the testing in Concretene's labs replicate this in WP4. Concretene do not have this specialist equipment, however it could be sourced from our partner The University of Manchester's Graphene Engineering Innovation Centre (GEIC). We used this equipment as part of our testing regime through a subcontract arrangement.

Cemex confirmed their current mix design is based upon a CEM IIA-L i.e. a limestone cement. Concretene had not been tested with this type of cementitious material before and therefore this was the focus of the formulation development work that commenced in February. Similarly, two admixtures needed to be assessed.

The materials laboratory carried out testing during Q2, with concrete materials due to arrive from Cemex in early April. A dedicated area within the lab was prepared for this project, which ensured the Cemex sourced the materials remain segregated from the other general concrete constituent materials.

The testing requirements were reviewed with Cemex and confirmed with the Building Research Establishment (BRE), with the contract order having been placed.

Q2 (1 April – 30 June 24)

Development work in the Manchester laboratories continued throughout phase 2.

The same concrete constituent materials used to produce sleepers in Cemex's Rochester factory were used in our lab. Due to a delay in receiving these materials, there was a six-week delay to the start of the main concrete trials. However, formulation development work continued during this period and concrete testing was ongoing with similar concrete materials.

The isothermal calorimeter was set up, which was used to indicate successful formulation parameters most likely to give best performance results, within a short timeframe of 1-3 days. This would accelerate the Q3 research, reducing the reliance on having to wait for concrete samples to cure before testing and analysis. This, together with the oven curing process, would enable quicker development throughout Q3, using the 'fail fast, learn fast' principle. Therefore,

the end date of WP4 remained as previous, despite the impact of the six-week materials delivery delay.

The factory-produced sleepers are heat cured to a Cemex-developed procedure during the first 18 hours after casting. A drying oven was purchased to reproduce these curing conditions.

During this period, we employed a cement scientist, Dr Yasmim Mendonça, building upon the teams' experience and capability. Yasmim worked with Cemex on mix design to maximise the benefits of Concretene. The intention was to utilise Cemex's mix design exactly, however, small changes would be required to achieve the optimal benefits of Concretene.

The testing schedule and programme was agreed with the Building Research Establishment. Originally forecast to commence in June, this was pushed back to commence in July and the programme showing this over a 3-month period, which was staggered to suit the BRE's resources. This change to the programme was not critical.

The programme was updated, with the overall end date unchanged.

[Appendix 2.1 - Technical Report Q2]

Q3 (1 July - 30 September 24)

Development work in the Manchester laboratories continued throughout Q3, with progress made in formulation development. In mid-August however, Cemex informed us of two significant and permanent changes made to their mix design:

1. Company-wide business decision to change to own-branded admixtures, changing the mix-design chemistry.

2. Desire for greater conformity to specifications.

Together, these necessitated a simplification of their sleeper mix design for further development of Concretene. The old mix design will not be used again and therefore there was no benefit in continuing to develop Concretene for this mix design.

Although much of the work done to date remained relevant and valid, a repeat programme of development work was required. We assessed the impact of this to require an additional three months to repeat part of WP4, specifically activities 4.5 to 4.8.

The repeat development work presented an opportunity to test the sensitivity of Concretene against mix design changes, which will help mitigate future development risk. The additional costs were 100% funded by Concretene.

Although there remained a risk that further mix design changes may occur in future, Cemex assured us that these changes were rare and none further were planned.

This changed was accepted by Innovate UK, with the new end date being 31 March 2025.

To mitigate the delays as far as practicable, four tonnes of the new specification aggregates were received during w/c 23rd September. This same batch of materials would be used for the remainder of the development work to December.

The isothermal calorimeter was used to undertake initial baseline formulation work. This has been very beneficial to the programme, allowing the team to test a wide range of formulation variations, results gained within 3 days that predict the 28-day strength. This has allowed us to minimising time analysing formulations that were unlikely to offer benefits.

Our cement scientist Yasmim led the technical development, working closely with our formulation scientists. The learning gained over this quarter would be applied to the new materials and mix design to optimise the repeat development, minimising programme impact as far as practicable.

The Building Research Establishment durability testing programme was pushed back to commence in December.

[Appendix 2.2 - Technical Report Q3 (Concretene)]

Q4 (1 October - 30 December 24)

Concretene development work continued throughout Q4 in our labs with development proving to be more technically challenging than envisaged. When Cemex changed their mix design and admixture in August, our desktop review predicted that the Concretene development work completed at that point could be directly transferred to the new mix design, with only minor revalidation or reformulation required.

Testing during this quarter however demonstrated considerable further development being required, which is particularly challenging as the mix design is dissimilar to most other concretes, having a very low water content and a reliance on Cemex's bespoke new admixture.

The Concretene formulation initially developed prior to August did not demonstrate statistically significant performance uplifts in the new mix design. However, more recent formulation iterations showed improvement and progress was made.

Therefore, further formulation development work and iterative testing was necessary during Q4, and would continue into Q5.

A significant number of additional formulation variants were tested to find the formulation that offers:

1. The largest uplift in strength, with
2. Consistent and reliable performance

With only 11 weeks left until the sleepers were programmed to be deployed and in use at GCRE for Industry Day (20 March), this left only 8 weeks to finalise formulation development, undertake validation tests at Cemex's production facility, produce and test prototype sleepers, adjust the formulation if necessary, produce and deliver 60 sleepers to GCRE.

Durability work with the BRE was rescheduled to commence w/c 17rd February, two weeks after we were due to mobilise at Cemex's Rochester production plant.

Q5 (1 January - 30 March 25)

This was the final period of the project which concluded with the successful demonstration of strength and durability performance improvement and the deployment of Concretene sleepers in track at the GCRE demonstration facility in South Wales.

Formulation finalisation:

During January, formulation development work continued in the Manchester labs, with several formulations tested and evaluated in Cemex's concrete mix design.

Cemex factory testing:

The best performing of these formulations were then taken forward for testing at Cemex's Rochester sleeper production factory throughout February, where Concretene spent the entire month. The formulations were initially tested at lab scale, with Cemex undertaking all production works including mix design, materials preparations, mixing, casting, curing and testing. This was an important step to provide confidence to Cemex that the results obtained were real and repeatable. A summary of the lab results achieved:

	Control	Concretene 1	Concretene 2	Concretene 3	Concretene 4
Date Cast	11/02/2025	11/02/2025	11/02/2025	11/02/2025	11/02/2025
Test Type	Cubes	Cubes	Cubes	Cubes	Cubes
Slump mm	30	30	50	Collapse	collapse
Max Temp °C	35	35	35	35	35
17hr strength N/mm2					
Cube 1					
Cube 2					
Cube 3					
Avg					
% strength uplift	-	**5.8%**	**8.3%**	**6.8%**	**6.5%**

Sleeper testing:

Following these successful trials, Concretene was deployed in prototype sleepers, all of which passed the 24hour static flexural point load ("transfer load") tests:

	Control	Concretene 1	Concretene 2
Date Cast	12/02/2025	12/02/2025	12/02/2025
Test Type	Sleeper	Sleeper	Sleeper
24hr static bend test kN			
Minimum permissible	230	230	230
Sleeper 1	Pass	Pass	Pass
Sleeper 2	Pass	Pass	Pass

Sleeper 3	Pass	Pass	Pass
Sleeper 4	Pass	Pass	Pass
Pass/fail	**Pass**	**Pass**	**Pass**

With the compressive strength enhancements and static load tests completed, the next step was to reduce embodied carbon. Cemex produced three new mix designs that were trialled, initially without the use of Concretene to ensure that the required rheology could be achieved. This concluded that, with the concrete constituent materials available to Cemex on plant, the cement content could be reduced by around 10%. This mix design was used to produce the sleepers and sampling sent to Building Research Establishment for durability testing.

A total of 76 Generation 1 sleepers were produced, 60 of which have been deployed at GCRE. The remaining sleepers remain at Cemex, where we are actively in dialogue with Network Rail to identify a low-risk deployment location on the rail network.

Carbon reduction:
With the above reduction in cement content, and cement accounting for an average of 85% of the CO2 in concrete (precise figures not currently established by Cemex, percentage worked out from ICE Low Carbon Concrete Routemap 2022 & Mineral Products Association Fact Sheet 18), Concretene has successfully lowered the Cemex's standard sleeper embodied carbon by 7.0%.

Durability:
Durability testing at BRE is being undertaken to the requirements of the British Standard and Network Rail sleeper design standards, with testing ongoing to the following schedule:

BRE testing schedule:	
ASR expansion	Due to finish May 2026 (Interim levels of expansion will be available during the 12 month period of the test)
Natural carbonation	Due to finish Feb 2026 (Measurements will also be made after 3 and 6 months)

Interim results have been received as follows:

Property	**Reference mix**	**Concretene mix**	**Performance improvement**
Mean Taber wear index	[redacted]		**+9.5%**
Mean water penetration (mm)	0	0	**Performance maintained**

Mean chloride migration coefficient ($x10^{-12}$ m^2/s)	[redacted]	**+5%**
Mean total shrinkage at 27 days (Microstrain)		**+22%**
Freeze/thaw (kg/m) [draft results]		**Both classified Very Good**
Petrographic [draft results]	*BRE commentary:* *Both appear to be very good concrete, with comparable appearance and features.* *Both concretes show what appear to be self-healed shrinkage cracks at higher magnifications and abundant un-hydrated cement clinker grains.* *Neither of these are considered detrimental.*	

The results have demonstrated performance uplift of the Concretene mixes in comparison to the control mixes. Water penetration is the same as the control at 0mm penetration which is also a positive result.

GCRE deployment:
Concretene sleepers were transported to GCRE and installed in a siding. This demonstrated that the sleepers can be handled, installed and used like any other concrete sleeper without disruption or any special provisions.

Communication & dissemination:
Concretene has significantly increased communication and dissemination during this final period, generally through social media. Two specific events were targeted:

Concrete Show 26-27th February 2025:
Concretene exhibited alongside The Graphene Council and were seminar speakers at the event.

Innovate UK Showcase 19th February 2025:
Technology showcase event to demonstrate the work done on the formulation and practical application of the technology in railway sleepers.

GCRE industry Demonstration Day 20 March 2025:
220 guests from rail industry, government and press invited to showcase of 12 rail innovations. Video content produced by Concretene was shared on social media by Innovate UK, Department for Business & Trade and GCRE

Conclusion

This project has demonstrated Concretene technology in the production and deployment of Generation 1 low-carbon sleepers on a live railway. The development work at Cemex's factory was undertaken by Cemex's own resources, showcasing the non-disruptive application of Concretene into existing systems, processes and hardware.

The sleepers produced in this project included a cement reduction of around 10% . This mix was used to produce the sleepers and samples sent to Building Research Establishment for durability testing, the initial results from which have been positive, testing ongoing until March 2026.

With this reduction in cement content, and cement accounting for an average of 85% of the CO_2 in concrete, Concretene has successfully lowered Cemex's standard sleeper embodied carbon by 7.0%. Although slightly down on the 10% initial target, this is significant achievement, considering the external disruptions encountered through the project. [Note that precise CO_2 figures are not currently established by Cemex, the percentage reduction being worked out from ICE Low Carbon Concrete Routemap 2022 & Mineral Products Association Fact Sheet 18].

GCRE Demonstration:
Concretene sleepers were transported to GCRE and installed in the railway. This demonstrated that the sleepers can be handled, installed and used like any other concrete sleeper without disruption or any special provisions.

The industry day held on 20th March was a significant success. More than 220 industry personnel attended, including several influential personnel including Network Rail's Technical Authority and engineering representatives of Transpennine Route Update. A summary of key discussion points:

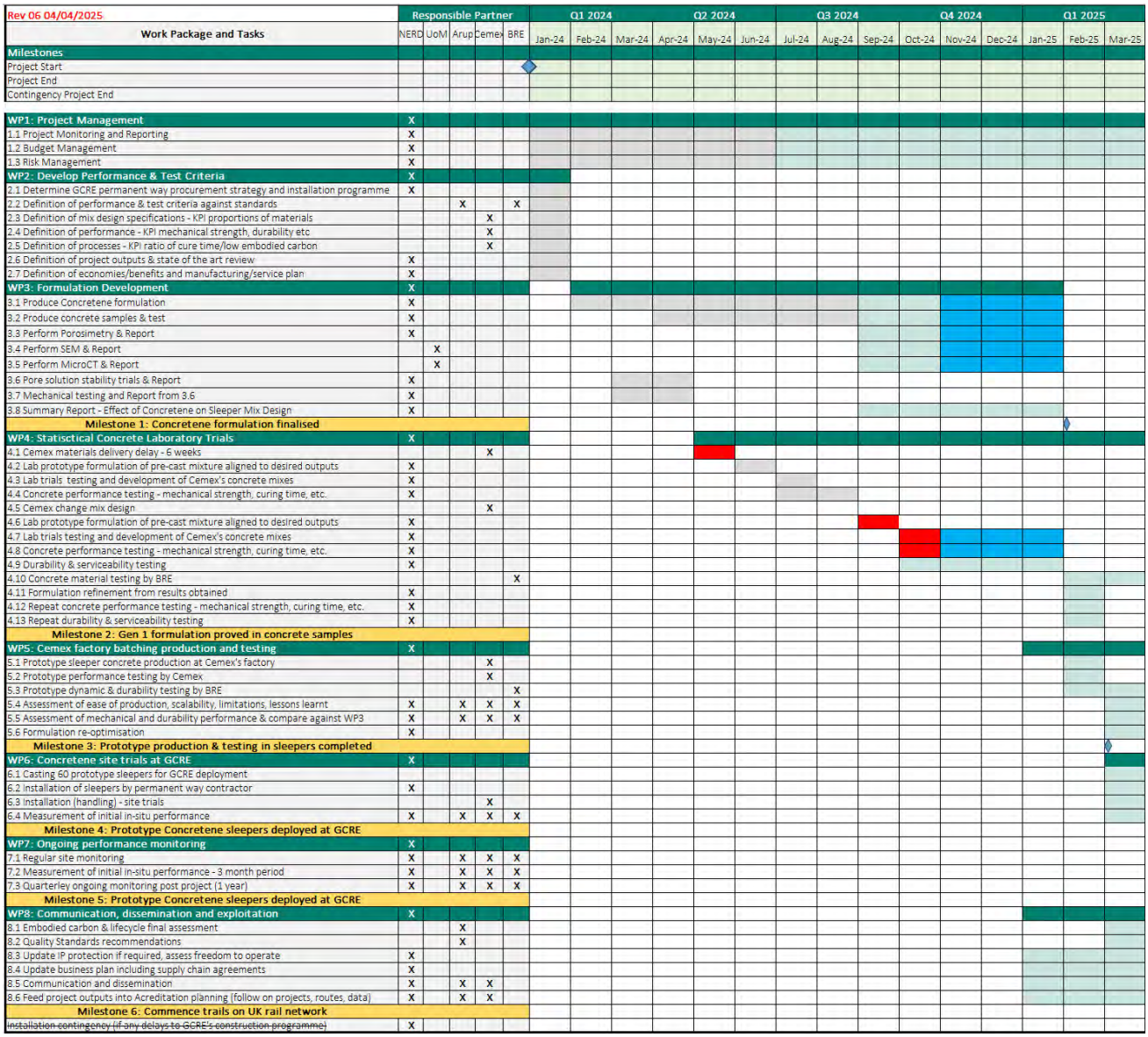
1. Network Rail's technical authority confirmed their intention to deploy the remaining Generation 1 sleepers on the network, in a managed risk environment, suggesting changing out every 4/5th sleeper with the Concretene version, to assess performance over time.

2. Track contractor and Concretene sleeper installer KGJ Price identified a suitable location in a quarry (location currently unknown) where they are trialling other innovative sleepers. This environment is ideal, as it is a low-speed line but subject to heavy goods axle loads. Network Rail confirmed support for this location.

Network Rail will convene a meeting with all parties later in 2025 to make arrangements to take this forward.

Next steps:
Cemex are particularly enthusiastic to build on the success by producing a Generation 2 very low carbon new mix design. This will require a change of constituent materials, as lowering the cement to this value removes a significant proportion of the fines and therefore another low-carbon replacement material must be used to replace this. Concurrently, Concretene development work will continue in parallel and when Cemex's new mix design is completed, the next phase of testing will be scheduled, resulting in Generation 2 Concretene sleepers. Cemex considers Concretene as a technology to help them work towards achieving 'very-low carbon' concrete.

Appendix 1: Programme



Rev 06 04/04/2025	Responsible Partner					Q1 2024			Q2 2024			Q3 2024			Q4 2024			Q1 2025		
Work Package and Tasks	NERD	UoM	Arup	Cemex	BRE	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25
Milestones																				
Project Start																				
Project End																				
Contingency Project End																				
WP1: Project Management	X																			
1.1 Project Monitoring and Reporting	X																			
1.2 Budget Management	X																			
1.3 Risk Management	X																			
WP2: Develop Performance & Test Criteria	X																			
2.1 Determine GCRE permanent way procurement strategy and installation programme	X																			
2.2 Definition of performance & test criteria against standards			X		X															
2.3 Definition of mix design specifications - KPI proportions of materials				X																
2.4 Definition of performance - KPI mechanical strength, durability etc				X																
2.5 Definition of processes - KPI ratio of cure time/low embodied carbon				X																
2.6 Definition of project outputs & state of the art review	X																			
2.7 Definition of economies/benefits and manufacturing/service plan	X																			
WP3: Formulation Development	X																			
3.1 Produce Concretene formulation	X																			
3.2 Produce concrete samples & test	X																			
3.3 Perform Porosimetry & Report	X																			
3.4 Perform SEM & Report		X																		
3.5 Perform MicroCT & Report		X																		
3.6 Pore solution stability trials & Report	X																			
3.7 Mechanical testing and Report from 3.6	X																			
3.8 Summary Report - Effect of Concretene on Sleeper Mix Design	X																			
Milestone 1: Concretene formulation finalised																				
WP4: Statisctical Concrete Laboratory Trials	X																			
4.1 Cemex materials delivery delay - 6 weeks				X																
4.2 Lab prototype formulation of pre-cast mixture aligned to desired outputs	X																			
4.3 Lab trials testing and development of Cemex's concrete mixes	X																			
4.4 Concrete performance testing - mechanical strength, curing time, etc.	X																			
4.5 Cemex change mix design				X																
4.6 Lab prototype formulation of pre-cast mixture aligned to desired outputs	X																			
4.7 Lab trials testing and development of Cemex's concrete mixes	X																			
4.8 Concrete performance testing - mechanical strength, curing time, etc.	X																			
4.9 Durability & serviceability testing	X																			
4.10 Concrete material testing by BRE					X															
4.11 Formulation refinement from results obtained	X																			
4.12 Repeat concrete performance testing - mechanical strength, curing time, etc.	X																			
4.13 Repeat durability & serviceability testing	X																			
Milestone 2: Gen 1 formulation proved in concrete samples																				
WP5: Cemex factory batching production and testing	X																			
5.1 Prototype sleeper concrete production at Cemex's factory				X																
5.2 Prototype performance testing by Cemex				X																
5.3 Prototype dynamic & durability testing by BRE					X															
5.4 Assessment of ease of production, scalability, limitations, lessons learnt	X		X	X	X															
5.5 Assessment of mechanical and durability performance & compare against WP3	X		X	X	X															
5.6 Formulation re-optimisation	X																			
Milestone 3: Prototype production & testing in sleepers completed																				
WP6: Concretene site trials at GCRE	X																			
6.1 Casting 60 prototype sleepers for GCRE deployment																				
6.2 Installation of sleepers by permanent way contractor	X																			
6.3 Installation (handling) - site trials				X																
6.4 Measurement of initial in-situ performance	X		X	X	X															
Milestone 4: Prototype Concretene sleepers deployed at GCRE																				
WP7: Ongoing performance monitoring	X																			
7.1 Regular site monitoring	X		X	X	X															
7.2 Measurement of initial in-situ performance - 3 month period	X		X	X	X															
7.3 Quarterley ongoing monitoring post project (1 year)	X		X	X	X															
Milestone 5: Prototype Concretene sleepers deployed at GCRE																				
WP8: Communication, dissemination and exploitation	X																			
8.1 Embodied carbon & lifecycle final assessment			X																	
8.2 Quality Standards recommendations			X																	
8.3 Update IP protection if required, assess freedom to operate	X																			
8.4 Update business plan including supply chain agreements	X																			
8.5 Communication and dissemination	X		X	X																
8.6 Feed project outputs into Acreditation planning (follow on projects, routes, data)	X		X	X																
Milestone 6: Commence trails on UK rail network																				
~~Installation contingency (if any delays to GCRE's construction programme)~~	X																			

Appendix 2.1 - Technical Report Q2 (Concretene)

Our people

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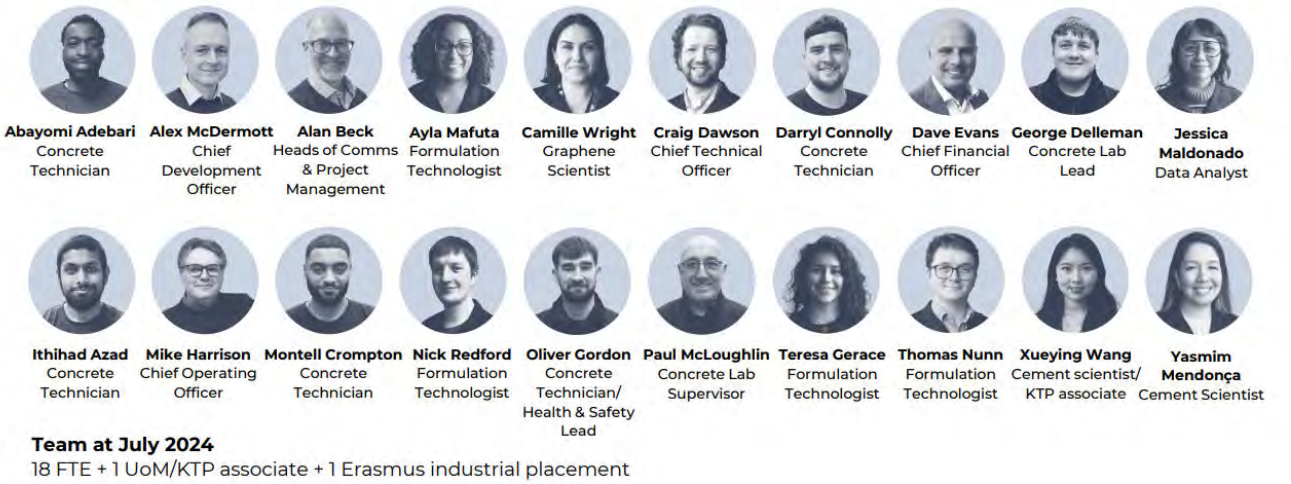

Abayomi Adebari Concrete Technician
Alex McDermott Chief Development Officer
Alan Beck Heads of Comms & Project Management
Ayla Mafuta Formulation Technologist
Camille Wright Graphene Scientist
Craig Dawson Chief Technical Officer
Darryl Connolly Concrete Technician
Dave Evans Chief Financial Officer
George Delleman Concrete Lab Lead
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Ithihad Azad Concrete Technician
Mike Harrison Chief Operating Officer
Montell Crompton Concrete Technician
Nick Redford Formulation Technologist
Oliver Gordon Concrete Technician/ Health & Safety Lead
Paul McLoughlin Concrete Lab Supervisor
Teresa Gerace Formulation Technologist
Thomas Nunn Formulation Technologist
Xueying Wang Cement scientist/ KTP associate
Yasmim Mendonça Cement Scientist

Team at July 2024
18 FTE + 1 UoM/KTP associate + 1 Erasmus industrial placement

Gen 2 – increased capacity and automation

1. Hire of cement scientist and data analyst to optimise materials testing processes and analysis
2. Switch from metal to plastic cube moulds enables >2x testing throughput.
3. Purchase of isothermal calorimetry work and additional testing equipment
4. Storage conditions for samples optimised with automated pH and temperature control

Oct 23: 150 samples tested → **Jun 24**: 424 samples tested

Gen 2 – collaboration and verification

CEMEX

- Committed to providing cement and aggregates free-of-charge ongoing
- Supplier of concrete for Gen 1 demonstrator projects
- Providing technical support for mix design and access to testing facilities

SAINT-GOBAIN

- Developing agreement for a bespoke admixture for Concretene
- Positive assessment of Concretene lab facilities and processes
- Supporting with future laboratory accreditation (ISO)

ARUP

- Cement experts Fragkoulis Kanavaris and Magdalena Janota (above) advising on commercial mix design (S3) and project outputs
- Support towards accreditation and commercial adoption

Appendix 2.2 - Technical Report Q3 (Concretene)

GCRE – Summary

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- Due to issues with a change in Concrete mix-design programme is delayed by ~3months.
- Materials from Cemex received w/c 23rd September
- Isothermal Calorimetry will be used to determine best performance of Concretene Formulations in CEM-II/L (Currently ongoing)
- Bespoke Concretene variants will be produced as required based on existing CEM-I performance and calorimetry results (Ongoing)
- Best performing Concretene formulations will be down-selected for testing in concrete(s) based on;
  - Highest Cumulative Heat of Hydration – Indicative of higher strength
  - Highest Peak Heat of hydration – Indicative of positive microstructural changes (durability)
  - Earliest Setting time(s)
- Plan in place to have results by Christmas in:
  - CEMII/L Isothermal Calorimetry
  - Current Cemex concrete mix design (385kg CEM-II-L/m3)
  - Redesigned – Lower carbon Cemex concrete mix design (e.g. 300kg CEM-II-L/m3 (TBC)) with performance comparison to current.

Isothermal Calorimetry

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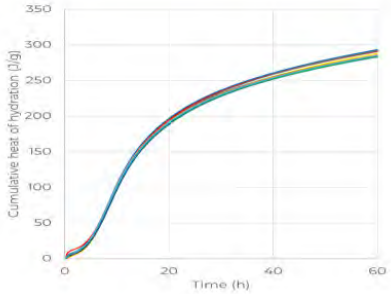
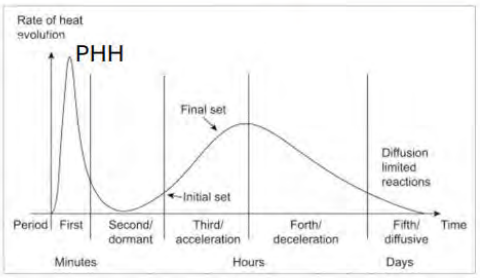
(a)



(b)



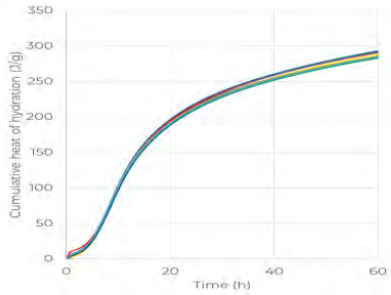
Isothermal calorimetry measures the chemical reactivity of cement reactions as energy produced.

It is a common method used to study cement hydration. It can be used to quantify the early reactivity, the onset of the main reaction indicative strength improvements can be predicted via an increase in cumulative heat of hydration at time$_x$ (fig (a)). Indications of (beneficial) microstructure can also be predicted by a higher peak heat of hydration (PHH fig (b)).

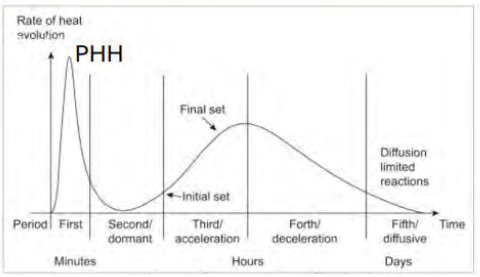
Isothermal Calorimetry

concretene

(a)



(b)

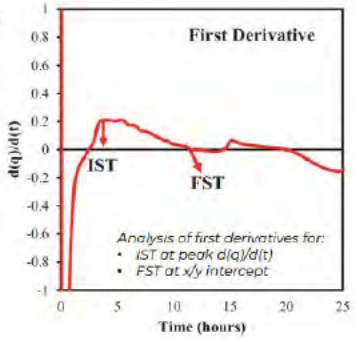


Isothermal calorimetry – Expectations = Improved CEMII/L activity

Higher indicative strength measured by increased CHH at 24h and 60h (highest J/g)
A positive change in microstructure (durability) measured by PHH (highest W/g)
Earlier final setting time

Isothermal Calorimetry

(a)



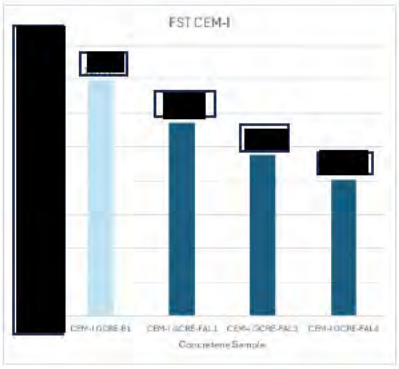
By calculating the first derivative peaks it is also possible to predict the initial (IST) and final (FST) setting time of the cement.

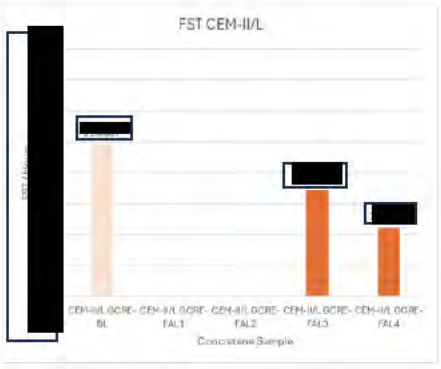
In this project we will be prioritising formulations with:

- Higher PHH (J/g)
- Highest CHH at 24h
- Highest CHH at 60h
- Earliest IST
- Earliest FST

Best performing formulations will then be tested in appropriate concrete mix design

Final Setting Time (FST)

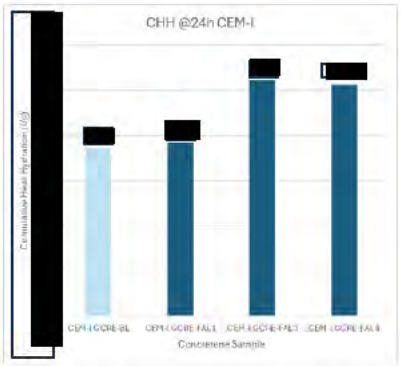


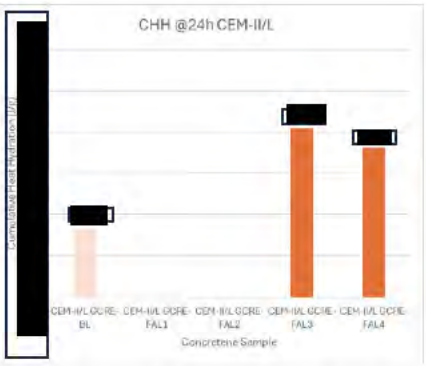


(Early Results)

- 1st derivative calculations have been applied to give indicative FST
- CEMII/L has quicker final set than CEM-I as tested by Isothermal calorimeter
- CEM-II/L has similar trend to CEM-I in terms of final setting time where an increased loading of Concretene formulation results in a reduction in set-time indicating potential sleeper throughput benefits
- Further testing will be conducted to measure the limitations of this effect.

Indicative Strength

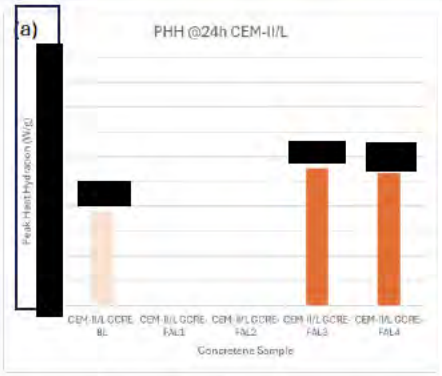


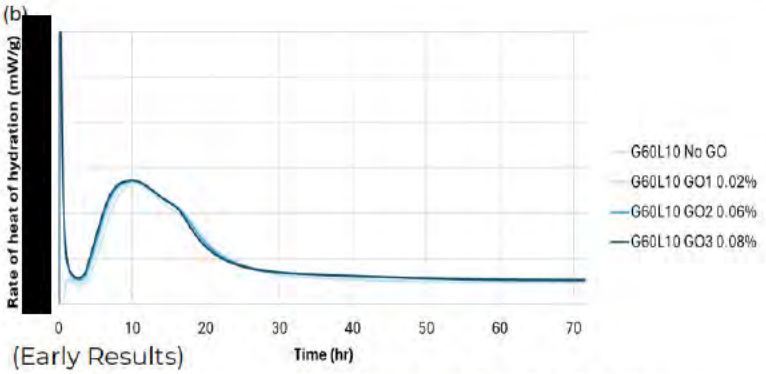


(Early Results)

- Cumulative heat of hydration figures have been used as an indicator that improvements in the activity and therefore indicative strength should be expected when formulations REF:FAL3 and REF:FAL4 are used. These formulations should be considered for further testing
- CEMII/L has lower indicative strength (J/g)than CEM-I after 24h – in line with expectations.
- Addition of Concretene REF:FA could lead to a recovery in cement strength as indicated by cumulative heat hydration where CEM-II/L-REF:FAL3 has a comparable level to CEMI-BL (206 J/g vs. 202 J/g respectively)

Indicative Durability

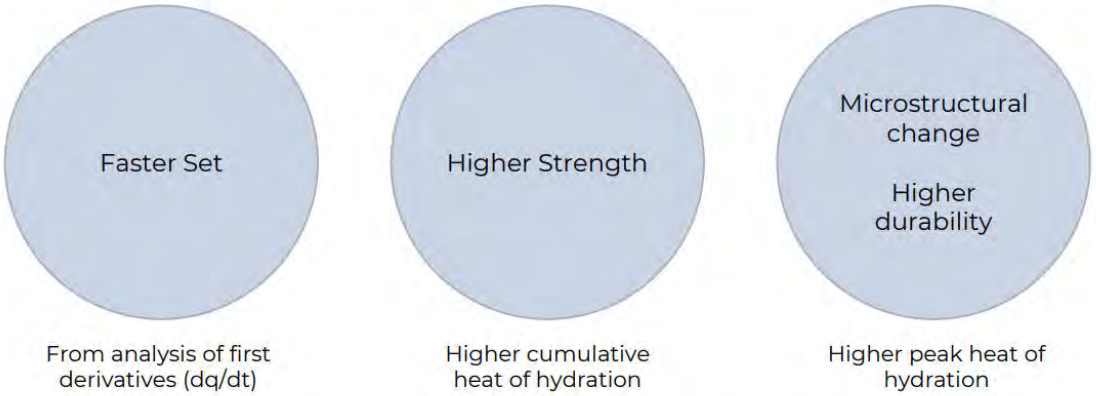




(Early Results)

- A change in the PHH can be used to indicate a change in the early age microstructure. A higher PHH is indicative of the formation of beneficial hydration products within a specific cement type.
- CEMII/L has lower PHH (J/g)than CEM-I after 24h – in line with expectations (???).
- Addition of Concretene REF:FAL3 and FAL4 have higher PHH than the baseline (BL) indicating a beneficial change to the microstructure of this cement composite over the baseline.
- Concretene formulation has induced earlier and quicker limestone reaction, starting ~15hours (fig b). The effects this phenomena have on strength of CEMII/L cements requires further investigation.

Results summary – To date



From analysis of first derivatives (dq/dt)

Higher cumulative heat of hydration

Higher peak heat of hydration

Whilst IsoCal can be used as a predictive tool for the performance of Concretene additives

- No models currently exist that directly correlate uplifts seen with graphene modification between cement and concrete
- The method does not take into account the engineering constraints of cement vs concrete (e.g. slump and compaction)

Appendix 2.3 - Technical Report Q4 (Concretene)

concretene

1.0

Summary

Company name: Cobmore Holdings Ltd
Company number: 13835452
VAT registration no.: 402273440

www.concretene.co.uk

Registered Office:
1 Swan Street
Wilmslow
SK9 1HF

Highlights

- Baseline performance gives confidence to see uplifts with reasonable level of confidence
- Performance uplifts between 6-10% observed in 'Verona' formulations in Cemex concrete (Concretene ref: T10)
- Stagegate process used to down select two formulae for further testing in Cemex Field trials
- Compressive testing and water absorption testing at Concretene Ltd to be completed by 26/02/25
- Cemex testing to start w/c:03/02 and continue over four week period
- BRE samples supplied from Cemex field trials (UKAS accredited laboratory).

Formulation

Formulation

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- Recent site-pour with specific 'Verona' formulation yielded >20% strength uplift in comparison to baseline CEMIII concrete.
- Good shelf stability (>1 month)
- Relatively low carbon footprint
- Relatively low cost of Graphene Nano-platelet (at scale)
- Alternative formulation tested (Brasilia)
- Iterative approach to modify this formulation to work with CEMIIA/LL cement and concrete.
- Scale-up from 1L to 15L batch of final formulation(s)

concretene

2.2

Concrete – GCRE – T10

Summary of activity

CASTING

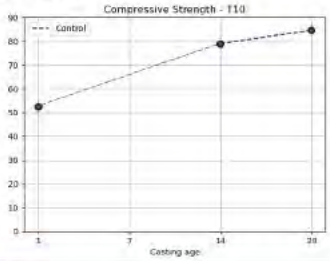
- 1 Day = 210 compressive cubes – 100x100mm
- 14Day = 62 compressive cubes – 100x100mm
- 28Day = 148 compressive cubes – 100x100mm

TESTING

- 1 Day = 190 compressive cubes
- 14Day = 12 compressive cubes (Low number for statistical confidence)
- 28Day = 80 compressive cubes

Materials Lab – Baseline Assessment

Baseline T10 - GCRE



T10 Baseline			
Type	**1D/MPa (StD)**	**14D/MPa (StD)**	**28D/MPa (StD)**
T10	(5.0%)	(0.7%)	(1.7%)

Comments

- Acceptable deviation (<4.5%)
  - 1 Day = **5.0%**
  - 14 Day = **0.7%**
  - 28 Day = **1.7%**

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2.3

T10/Concretene

concretene

Materials Lab – Compressive Strength Summary

Approach

Use same batch size as control baseline

Use same batch size as control baseline

Pre-condition batched raw materials (temperature 18-22C)

Use same mixer as control baseline

Perform dosing sweep from [redacted] (calorimetry)

Measure and record slump

Cast 100x100mm cubes and compact using vibration table

Measure and record compressive strength

Test each formulation in triplicate

Compare to daily control cube

Compare to statistical baseline

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2.3.1

GCRE – T10/Brasilia

Materials Lab – Compressive Strength Summary

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GCRE – T10/Brasilia – Summary

1 Day Strength

- Little evidence of uplift at 1 day versus daily controls
- CRT503 and CRT506 evidence of >5% uplift at loading

14 Day Strength

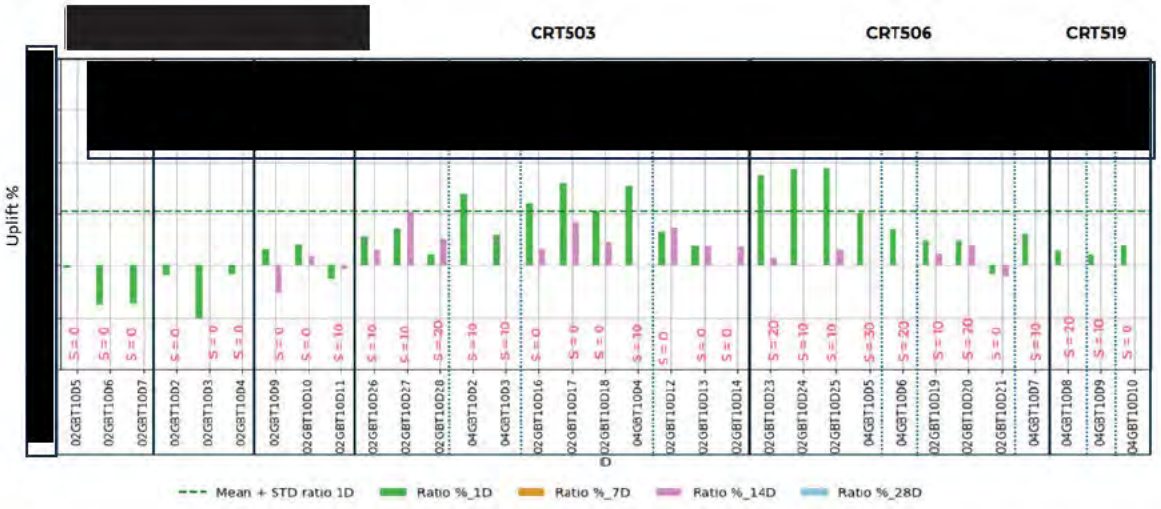
- **~4%** Uplifts observed of in Formulation CRT503. Confidence low (small data-set for baseline)

Conclusion

- Consider CRT503 and CRT506 for further iterative testing through stage-gate at loadings between [redacted]

Materials Lab – Compressive Strength Summary

Brasilia – T10 – Results – Ratio Base-line



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2.3.2

GCRE - T10/Verona

Materials Lab – Compressive Strength Summary

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GCRE – T10/Brasilia – Summary

1 Day Strength

- Evidence of uplift at 1 day versus daily controls for CRT507 and CRT509
- Evidence of uplift at 1 day versus statistical baseline for CRT507 and CRT509

14 Day Strength

- No results at present

Conclusion

- Consider CRT507 and CRT509 for further iterative testing through stage-gate at loadings between 0.003-0.02%.

Materials Lab – Casting Summary

concretene

Verona – T10 – Week 04 - Results 1D

Concretene Production GE1										
Mixing Method	ID	CRT REF	CRT (GNP:GO)	%G BWoC	SP1 (grams in SM)	SP2 (SP:GO)	% DC	% MC	% BL	Formulation - Name
	CBT10D11									
	GBT10D12	507	[redacted]							Verona
	GBT10D13	507								Verona
	GBT10D14	507								Verona
	GBT10D15	509								Verona
	GBT10D16	509								Verona
	GBT10D17	509								Verona
	GBT10D18	520								Verona
	GBT10D19	520								Verona
	GBT10D20	520								Verona

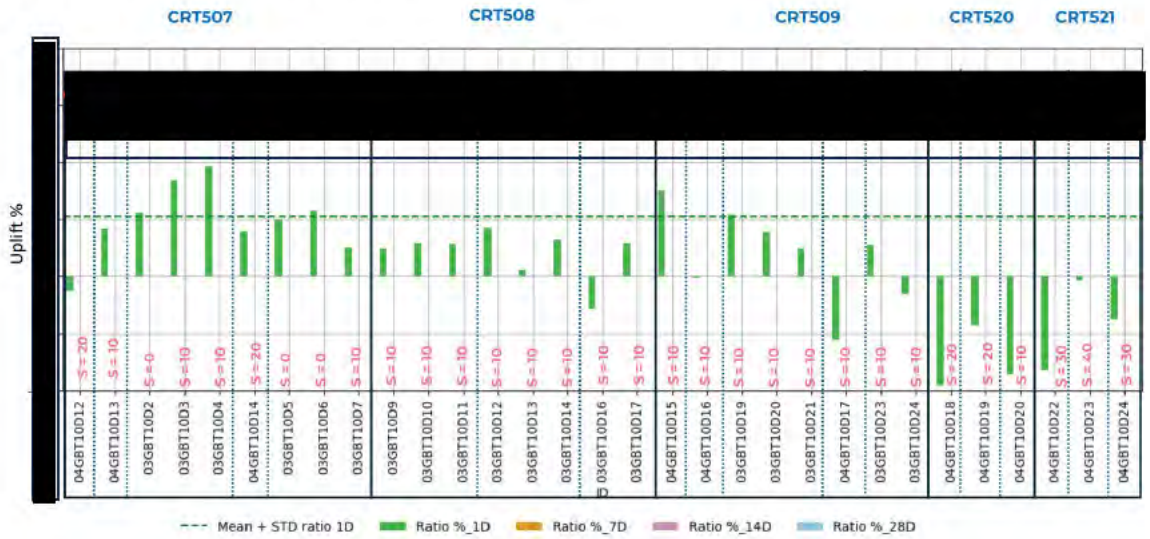
Materials Lab – Casting Summary

Verona – T10 – Week 04 - Results 1D

Concretene Production GE1									
Mixing Method	ID	CRT REF	CRT (GNP:GO)	%G BWoC (grams in SM)	SP1	SP2 (SP:GO)	% DC	% MC	% BL	Formulation - Name
	CBT10D21									
	GBT10D22	521	[redacted]							Verona
	GBT10D23	521								Verona
	GBT10D24	521								Verona
	GBT10D25	522								Verona
	GBT10D26	522								Verona
	GBT10D27	522								Verona
	GBT10D28	523								Verona
	GBT10D29	523								Verona
	GBT10D30	523								Verona

Materials Lab – Compressive Strength Summary

Verona – T10 – Results – Uplift% versus Base-line



GCRE Sleeper Trial

concretene

Stagegate process

Iteration 1

- Brasilia – Isothermal Calorimetry data = fast set, higher heat hydration (higher strength) in CEMIIA/LL (12%)
- Verona – Promising results in other trial (+15-20% compressive strength in CEMIII concrete)

Stage-gate

- 1 Day = >5% versus daily baseline considered, >5% versus statitstical control considered
- Iteration 2 = Optimise loading Build statistical dataset (expectations)

GCRE Sleeper Trial

concretene

Stagegate process

Stage-gate

- Brasilia
  - Two formulations for consideration (CRT503, CRT506)
  - Low confidence in 1 day uplift due to higher performing daily controls.
  - Low confidence in 14 day uplift due to small data-set for control
  - Higher cost Raw Materials
  - Park forward for further iteration – optimised loading
  - Do not take forward for pilot-scale production
  - Do not take forward for testing at Cemex

Stagegate process

Stage-gate

- Verona
  - Two formulations for consideration (CRT507, CRT509)
  - Good confidence in 1 day uplift due to higher performing versus daily controls and statistical baseline.
  - Risk - 14 & 28 day testing not yet perfomed
  - Lower cost Raw Materials
  - Take forward for further iteration – optimised loading
  - Take forward for pilot-scale production
  - Take forward for testing at Cemex

Further testing

Further Testing

- Verona
  - 2 x 15L batches CRT507 for testing and sending to Cemex (w/c 03/02)
  - 2 x 15L batches CRT509 for testing and sending to Cemex (w/c 03/02
  - Testing at [redacted] BWoC in triplicate to set expectations for field-trials.
  - 1 Day tests – All completed 31/01/25
  - 14 day tests – All completed 13/02/25
  - 28 day tests – All completed 26/02/25 (Strength and Water Absorption)
  - Field trials at Cemex – Rochester - commencing 03/02/2025.
  - 60 sleepers produced by 28/02/2025
  - BRE test samples produced as part of field-trials

Appendix 3.0: Results summary

Test samples produced by Cemex in their Rochester production factory:

	Control	Concretene 1	Concretene 2	Concretene 3	Concretene 4
Date Cast	11/02/2025	11/02/2025	11/02/2025	11/02/2025	11/02/2025
Test Type	Cubes	Cubes	Cubes	Cubes	Cubes
Slump mm	30	30	50	Collapse	collapse
Max Temp °C	35	35	35	35	35
17hr strength N/mm2					
Cube 1	[redacted]				
Cube 2					
Cube 3					
Avg					
% strength uplift	-	**5.8%**	**8.3%**	**6.8%**	**6.5%**

Sleeper samples produced by Cemex in the Rochester production factory:

	Control	Concretene 1	Concretene 2
Date Cast	12/02/2025	12/02/2025	12/02/2025
Test Type	Sleeper	Sleeper	Sleeper
24hr static bend test kN			
Minimum permissible	230	230	230
Sleeper 1	Pass	Pass	Pass
Sleeper 2	Pass	Pass	Pass
Sleeper 3	Pass	Pass	Pass
Sleeper 4	Pass	Pass	Pass
Pass/fail	**Pass**	**Pass**	**Pass**

Test samples produced by Cemex in the Rochester production and tested by BRE@

Property	**Reference mix**	**Concretene mix**	**Performance improvement**
Mean Taber wear index	[redacted]		**+9.5%**
Mean water penetration (mm)			**Performance maintained**
Mean chloride migration coefficient ($x10^{-12}$ m^2/s)			**+5%**
Mean total shrinkage at 27 days (Microstrain)			**+22%**
Freeze/thaw (kg/m) [draft results]			**Both classified Very Good**
Petrographic [draft results]	*BRE commentary:* *Both appear to be very good concrete, with comparable appearance and features.* *Both concretes show what appear to be self-healed shrinkage cracks at higher magnifications and abundant un-hydrated cement clinker grains.* *Neither of these are considered detrimental.*		

Note that tests are ongoing for one year beyond the project end date and will be updated in March 2026.

Appendix 4: Risk register

10098655 Concretene Sleeper Risk Register					
Assessment Stage:	Q4 end	**Assessment Date:**	09/01/2025	**Version:**	P05
Author:	Alex McDermott	**Date of next review**	Q5 end	**Designation:**	Project

Activity or Risk	Pre Risk Rating			Safety Controls	Residual Risk Rating			Status
	IL	IS	IR		RL	RS	RR	
Technical (Risk owner: Dr Craig Dawson)								
New formulations instability	3	4	12	Screening of stabilising additives to prevent agglomeration/separation, reversion to previous formulations with demonstrated stability instability encountered.	1	4	4	UN
Failure of formulation to work in sleeper mix designs due to incompatibility with limestone cements and/or admixtures	3	4	12	Significant progress made with formulation development. Testing has demonstrated compatibility, the remaining development work is now to refine the formulation for optimum results	1	4	4	UP
Durability tests show structural service life less than 60 years	3	4	12	Micro and macro imaging of Concretene formulation development already undertaken has demonstrated that the fundamental chemistry of concrete is not altered. Observed reduced microcracking and less porosity indicates a longer service life is achievable. Phase 2 to include durability testing by BRE and Cemex to determine this.	1	4	4	UN
Failure to achieve increased strength target in cement/embodied carbon.	2	4	8	The formulation is being optimised throughout the Phase 2 study to maximise consistent and reliable strength uplift. If targets cannot be met, develop for a reduced but reliable target and/or pivot e.g. look at early strength gains as a benefit for precast applications.	1	4	4	UP
Failure to achieve Network Rail Accreditation, resulting in design engineers being unable to specify its use	2	5	10	GCRE established to enable industry confidence in new technologies, team includes Cemex as sleeper manufacturer, BRE as independent test house and Arup as technical partners. Strength of the team to remove any barriers potentially preventing Concretene sleepers being specified, provided they meet the technical performance requirements. Network Rail have provided a Letter of Support and we are in active dialogue, which aligns with this funding opportunity.	1	5	5	UN
Safety & Environmental (Risk owner: Alex McDermott)								
Occupational health risk from handling nano-materials	2	4	8	PPE to be utilised for all personnel handling graphene outside the secure container. Graphene mixed into liquid form in controlled laboratory environment (in extraction hoods). Team will update risk-assessments in line with emerging studies, which have to date not shown any specific concerns over graphene use when control measures are implemented. Commercialisation production volumes will be produced in specialist materials chemicals plants, dry powdered graphene will never be required on construction or rail sites and therefore no risk of dust exposure.	1	4	4	UN
Recyclability of GEC at end of structure life not fully determined	3	3	9	Initial destructive lab-scale testing has demonstrated that the material can be handled in the same way as standard concrete, further work will be needed to study this, beyond the end of this project.	1	3	3	UN

Release of nano-particles into the environment possible environmental accumulation / damage.	2	2	4	Graphene quantities required are very low (<0.1wt%), good bio-compatibility observed in tests, materials transferred and handled by chemicals companies using industry standards and good practice. For the trials, Concretene will be transport directly to Cemex Rochester and provide a data sheet and usage instructions. Deployment of the material will be supervised of the formulation into sleepers at Cemex's facilities. Aqueous graphene solutions avoid dust creation. Once mixed into concrete and cured, graphene becomes an integral component in concrete and cannot be separated back into nano-dust particles. Therefore, sleepers can be handled, maintained and recycled as per ordinary sleepers	1	2	2	UN
Managerial								
Delays to concrete materials delivery affecting programme	3	3	9	The effect of this delay has been mitigated by several factors as far as practicable (plastic molds, the use of an isothermal calorimeter, employment of a Cement Scientist), with an extension of time granted from December 24 to March 25.	1	3	3	UN
Extensive programme delay due to Cemex mix design change	5	3	15	Calorimeter work to mitigate delays as far as practicable, learning from previous work remains valid and will further mitigate delay, PCR submitted and accepted for an EoT to end of March 25.	5	1	5	UN
Commercial & IP								
Failure to source graphene raw material for >£100/kg, making the costs unviable for the rail industry	3	3	9	Working with our equity partner Black Swan Graphene, who are already at ~£100/kg and with scale up, forecast this to fall to £10-15/kg. Our market research has demonstrated this to be acceptable to industry. Longer term, working towards cost parity with existing admixtures.	1	3	3	UP
Additional cost due to delayed programme	5	1	5	All additional costs to be covered by Concretene.	5	1	5	UN
IP sits outside of the current worldwide patent and breaches existing IP	2	4	8	The existing patent was specifically written to provide flexibility for formulation development for different applications. We expect that any refinement works required for compatibility with sleeper concretes to sit within the existing patent, which has worldwide protection. Any new IP will be protected as part of this project.	1	4	4	UN
Immature supply chain for large scale deployment of GEC in sleepers, reducing growth potential	2	4	8	NERD has an existing contract with concrete supplier Cemex which is willing to deploy GEC commercially. Our graphene addition process requires no additional training, hardware or software and therefore is non-disruptive to commercial batching plants. We are working closely with graphene suppliers to a reach a viable graphene price. Black Swan are an equity partner, working closely with NERD to develop joint scale up plans and target manufacturing cost and volumes to meet Concretene's scale up assessment.	1	4	4	UN
Emergence of competing products, limiting the competitive advantage	2	4	8	We believe we are the only company in the world to have successfully deployed large scale engineered graphene enhanced concretes out of the lab into real world demonstration projects. The completion of testing and accreditation activities with GCRE and Network Rail, together with the support of Cemex and GEIC on a consultancy basis, creates a strong technical group.	1	4	4	UN

Risk	The likelihood of the harm being realised	Rating	Key to risk rating:
Hazard	Something with the potential to cause harm	1-6	= Low
IL	Initial likelihood/probability	8 - 12	= Significant / Medium
IS	Initial severity	15-25	= Unacceptable / HIGH
RL	Residual likelihood/probability	IR	Initial risk rating
RS	Residual severity	RR	Residual risk rating
			Status: UN = unchanged, UP = updated risk (red text), N = new risk (blue text), R = resolved risk (strikethrough text)

Appendix 5: Finance summary

Project costs to date

	Total eligible costs	Eligible costs claimed to date	Percentage of eligible costs claimed to date
COBMORE HOLDINGS LTD (Lead)	£486,337.00	£485,837.92	99.90%
Totals	£486,337.00	£485,837.92	99.90%

Partner finance details

	Total eligible costs	Funding level	Total grant approved	Remaining grant	Total grant paid in advance	Claim cap	Claim retention
COBMORE HOLDINGS LTD (Lead)	£486,337.00	70.00%	£340,086.64	£349.36	£0.00	90.00%	£0.00

Appendix 6: Exploitation plan

Innovate UK	
	Project Monitoring Form
	Project Exploitation Plan

COMPETITION PRIORTY

Graphene enhanced concrete sleeper
Innovate UK Project No: 10098655

COMMERCIAL RESTRICTED

Original Date: 27th March 24
Last review: 7th April 25
Revision: 04

Responsible Author
Alex McDermott

Project Leader
Alex McDermott

Circulation: All Project Partners
Project Monitoring Officer

Company name: Cobmore Holdings Ltd
Company number: 13835452
VAT registration no.: 402273440

Registered Office:
1 Swan Street
Wilmslow
SK9 1HF

www.concretene.co.uk

This plan is a living document and will be updated during the project. The aim of the plan is to confirm the business case for the project and describe the partner activities towards exploitation of the results of the project so that 1) changes in the commercial environment can be monitored and accounted for, 2) adequate resources are committed to exploitation and 3) so that exploitation can be monitored by the stakeholders.

Business Case

Partners' capability to develop and exploit the technology

Summarise the Technical Approach to be taken
We have developed a Concretene formulation specifically for Cemex's existing precast concrete sleeper concrete mix design. As a developing technology, graphene enhanced concretes (GECs) are currently unavailable commercially or at scale. Although several manufacturers have GEC's in development, Concretene is closest to market and has been demonstrated at commercial scale in ready mixed concrete projects. Prior to this project, Concretene had only been tested in CEM I (Ordinary Portland Cement) concretes. Cemex's concrete mix contains a different cement that includes a blend of OPC and crushed limestone, known as CEM II A-L. It also contains a Cemex branded superplasticiser additive. This project has developed a specific Concretene formulation for this application and mix design.

Summarise the innovative aspects of the project, are they still innovative?
Current concrete sleeper designs use a high-performance concrete, with strengths achieved by using a high cement content of 360kg/m3 of concrete and additives. With cement accounting for ~85% of CO2 within concrete, this means the current material has a high embodied carbon. Although there are other existing technologies that focus on reducing the cement by replacement with partial cement replacement technology, such as GGBS and fly ash, these materials are by-products of other heavy carbon industries such as steel making, the production of which is in terminal decline due to furnace upgrades. Furthermore, there are distinct disadvantages associated with these materials, including much slower curing times, which is undesirable for precast sleeper applications produced in high-output factories. This is the principle reason why Cemex don't use these materials in their sleepers. Concretene offers the opportunity to achieve the high and early strengths required using the latest limestone cement technologies, without requiring the use of these cement replacement materials, reducing embodied carbon and maintaining the rapid cure characteristics of high cement concretes. As Concretene makes the concrete stronger, it enables the cement content to be reduced to achieve the same strength. Therefore, Concretene remains an innovative way of reducing embodied carbon.

Explain the roles of each of the consortium members highlighting the necessary skills and experience

Company name: Cobmore Holdings Ltd
Company number: 13835452
VAT registration no.: 402273440

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The project built on previous projects which have resulted in successful large-scale commercial demonstration of ground-bearing GEC slabs for general ready mixed concrete applications using CEM I with no additives.

Concretene has worked with Network Rail as the technical authority and Cemex as the sleeper manufacturer. Development work at Cemex's production facility will be funded by Cemex, in return for being the first to licence Concretene technology in sleeper applications. Concretene purchasing the sleepers from Cemex and paid other costs including transportation to GCRE.

Network Rail are not an official partner but have issued a Letter of Support and have engaged with Concretene for the development of their new sleeper standard 'NR/L2/TRK/030 Concrete Sleepers and Bearers'. They monitored progress through the project, attended the GCRE industry day, and following this project will seek to trail Concretene sleepers on their network.

Cemex are one of the largest precast sleeper manufacturers in the UK and an existing strategic partner of Cemex with the testing, development and deployment of Concretene products, having deployed several hundred tonnes of Concretene enhanced concrete slabs to date.

Results will be exploited by Concretene, under a licence agreement with Cemex, who will sell directly to Network-Rail and other rail sleeper purchasers.

The Building Research Establishment (BRE) is a respected independent test house, with decades of experience working with sleepers. They have a long relationship developing new sleeper technology with Cemex. They have been contracted to undertake several durability tests, all aligned to the technical requirements in the design standards.

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Business Plan & Opportunity

Summary of Expected Deliverables From Project
How are you going to grow your business and increase your productivity into the long term as a result of the project? The purpose of this project was to develop a Concretene formulation that improves the performance of Cemex's existing concrete sleepers, at a price point that is acceptable to their ultimate client, Network Rail. We will enter into a commercial agreement with Cemex for the purchase of Concretene formulation at volume. An exclusivity period of 1 year will be agreed with Cemex, following which Concretene will seek to penetrate the remainder of the UK concrete sleeper market, and internationally thereafter. Any exclusivity period will apply to UK only. Therefore, opportunities will be sought to sell Concretene in Europe, outside of the exclusivity agreement. All IP generated during this project sits within our patent pending.

Commercial Opportunity for Each Deliverable

For each product, process or service envisaged, identify:
1. The Market Niche for each Outcome Graphene enhanced concrete sleepers are a niche application to reduce embodied carbon in all concrete sleepers. The efficacy of the technology for different cements and admixtures will vary, but have been specifically determined for Cemex's mix design on this project. It is believed that Concretene can successfully be used with other sleeper concretes with minimal further development, as the mix designs are similar because the performance requirements and environmental exposure are similar in different countries and geographical locations.
2. The means by which IPR will be protected Two patent applications have been submitted and trademark secured. This IP covers the work done on this project. A freedom to operate has been undertaken as part of this study, with the results currently under consideration and next steps being planned.

3. Quantify the commercial returns expected, together with the timescale. **UK:** There are only two concrete sleeper suppliers in the UK; our partner Cemex and Trackwork Moll. Concretene will propose and agree offtake agreements with both suppliers but are more advanced with Cemex due to the testing already undertaken. The Concretene will be manufactured in the Manchester pilot production facility and provided directly to Cemex/suppliers. Following this period, agreements will be sought from other geographical areas with manufacturers in country. **Europe:** Trackwork Moll is part owned by Leonhard Moll Betonwerke of Munich, Germany, who also supply concrete railway sleepers across Europe. We will leverage our UK agreement for initial supply across Europe. Concretene will initially be produced in the UK and supplied across Europe. We will engage

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with other principal EU sleeper manufacturers including:

- Sateba
- Tracktec
- TSF-A
- Kirchdorfer
- Voestalpine

For other worldwide key markets, Concretene will be licenced for manufacture in country of use, using the existing construction chemical businesses. Demand generation will be through the largest concrete sleeper manufacturers in these key locations:

India:

Concretene manufacturer TBC.

- GPT Group
- Malu Group
- Gita Group
- Deya Engineering
- Shri Kesharia Concrete Products

USA:

Concretene manufacturer TBC.

- Vossloh (previously Rocla)
- Voestalpine

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4. Market opportunity:

The following approach will be adopted for commercialisation of Concretene in key markets.

Worldwide concrete sleeper demand (per year, forecasted in 2019):

Country	Concrete sleeper demand per year TAM	SAM	Target market
Key Markets:			
UK	600,000	600,000	540,000
USA	1,000,000	500,000	250,000
India	4,640,000	2,320,000	500,000
EU & Scandinavia:			
Germany	1,400,000	700,000	350,000
France	800,000	400,000	200,000
Italy	2,000,000	1,000,000	500,000
Spain	1,200,000	600,000	300,000
Czech. Rep.	250,000	125,000	62,500
Switzerland	150,000	75,000	37,500
Romania	12,000	6,000	0
Belgium	400,000	200,000	100,000
Austria	200,000	100,000	50,000
Netherlands	400,000	200,000	100,000
Greece	30,000	15,000	0
Sweden	400,000	200,000	100,000
Norway	60,000	30,000	0
Denmark	150,000	75,000	37,500
Rest of world:			
Brazil	500,000	250,000	0
South Africa	305,000	152,500	0
Japan	400,000	200,000	0
Chile	200,000	100,000	0
Tiawan	120,000	60,000	0
Argentina	60,000	30,000	0
Russia	3,500,000	0	0
China	3,000,000	0	0
Total	**21,777,000**	**7,938,500**	**3,127,500**

Demand volumes sourced from: An Examination on Performance of Railway Sleepers, Suresh Kumar A, Muthukannan M. International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-8 Issue-4S2, December 2019

UK sleepers:

Network Rail will soon update their concrete sleeper standard to encourage innovative low carbon alternatives and have provided Concretene with the draft version for information purposes. This has helped determine the durability testing regime, currently being undertaken with the BRE.

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There are 600,000pa concrete sleepers currently produced in the UK each year for domestic use, with our Target Market equating to 90% of this volume.

Concretene will be initially deployed in 90% of Cemex's sleepers of 300,000 units per year in year 1 (270,000 units), followed by 90% of all UK concrete sleepers (540,000 units) from year 2 onwards, following the end of the exclusivity agreement. Network Rails forecast this volume to remain steady throughout the initial part of the next Control Period, up to 2030.

Worldwide deployment:

We will focus on the following key international geographies from year 3 onwards, partnering with sleeper producers in these key geographies The target market will be achieved over a 3 year period, securing 33% each year:

Year 3 onwards			
Country/Region	**Concrete sleeper TAM (per year)**	**SAM**	**Target market**
Europe (inc. Scandinavia)	7,452,000	3,726,000	1,837,500
India	4,640,000	2,320,000	500,000
USA	1,000,000	500,000	250,000

Revenue model: License agreement - £1 per sleeper

(£ 000)	**2026**	**2027**	**2028**	**2029**	**2,030**
Licencing revenue	270	540	1,800	2,500	3,000

5. The existing or emerging competitive offerings

There are several 'green concretes' which use cement replacement materials such as GGBS, the by-product of the coal fired power stations. However, this industry is in terminal decline and these materials offer significant drawbacks for precast applications, not least of which much slower initial curing times, which drive slower factory production and therefore more expensive sleepers that quickly become commercially unviable.

To remain competitive, sleepers (and other precast concretes) need to achieve high early curing strengths (50N/mm2 compressive strength after 17 hours), allowing them to be stripped from the moulds and moved out of the factory to allow new sleepers to be cast. This currently relies heavily on CEM I cements and admixtures to achieve this curing profile and is the reason why GGBS is not used for sleeper applications.

The recent adoption by Cemex of CEM II A-L limestone cements represents a step forward in reducing embodied carbon as a middle ground, however the resulting carbon reduction is marginal (~<5%), as the cement is similar to CEM I, thus being a small step change rather than a revolution for carbon reduction in sleepers.

There are other emerging technologies, including calcined clays and geopolymers, but these are currently at low TRL and only likely to be adopted at scale later this decade at best.

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We therefore believe that Concretene can offer a genuine step change carbon reduction opportunity in the short to medium term.

The potential impact

Summary of wider benefits from the Project for those outside the consortium

Economic impacts:

Parity of costs with existing sleeper technology when production is at scale, whilst delivering better environmental credentials.

Customer benefits:

Sleeper embodied carbon savings, contributing towards reducing track infrastructure carbon and Network Rail's net zero target. Potential durability enhancements, subject to testing confirmation that is currently ongoing and will be assessed when the results are confirmed.

Benefits to the supply chain/wider industry:

Quicker curing times leading to reduced production costs and greater commercial advantage. The technology developed for sleeper applications can apply to the whole precast concrete market, increased graphene demand, leading to production scale-up and cost reduction, with benefits to other UK sectors (e.g. general precast industry). Technology licensing will propagate economic benefit throughout global supply chains.

Productivity:

Potential reduction in initial curing duration will facilitate increased factory production volumes without increasing plant, equipment and labour resources or costs.

Government priorities:

Supporting a knowledge-based economy by pioneering the use of graphene enhanced technologies, where the UK is considered a global leader.

Concretene will be the first mass use of nano material technology in construction and is therefore creating a new sector within construction, paving the way for the use of other nano material technology.

Environmental:

As an Early Adopter Client, Network-Rail's sleepers contain 10,000T of CO_2. Network-Rail will be able to mitigate 2,400T CO_2e/year, rising to 3,960 CO_2e/year with increased sleeper production (NR 10 year plan). Wider potential of reduced carbon footprint of construction across the UK, in-line with the carbon reduction strategy.

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Regional impacts:

Establishment of a new UK graphene enhanced material manufacturing base and strong export generating business in the North-West..

Social:

Creation of new jobs at Concretene with further multipliers across the UK of ~32 jobs over 5-years following the project. These will mainly be skilled jobs in a high-value industry across manufacturers and contractors.

Health and Safety improvements are expected on construction sites due to reduced complexity of construction site operations, resulting in safer working environments.

Arup will lead the route to specificity of Concretene by designers in other applications.

Negative societal/economical/environmental impacts:

Graphene has low-toxicity, mitigating any potential negative environmental impact. However it remains a new cutting edge material, with more to learn about its long term effects. Concretene are working with the UoM to understand and evaluate.

Dissemination activities during & after the project

We will continue to target trade, local and national press across themes of rail and construction, technology, environment (Concretene has already gained favourable coverage in The Times, BBC news, New Civil Engineer, Construction Enquirer and more).

We will use Concretene's social media and website, alongside the channels of our strategic partners, to provide regular updates on project progress.

Following up with key UK partners following the GCRE industry day will be critical to seeking deployment on the UK's rail network, with a follow up meeting scheduled for mid April 2025.

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Appendix 7: Demonstration day overview

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