HS2

Accelerating the UK Adoption of Calcined Clay for Concrete

Bridge Owners Forum, 5th November 2024

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PA mtc Manufacturing Technology Centre expedition

UK construction is facing a 'perfect storm' of challenges

A 'perfect storm' of Net Zero, Resource Scarcity and Cost challenge on the horizon:

- Concrete is responsible for 8% of global emissions[1]
- 48% increase in demand for cement expected by 2050[1]
- Net deficit of slag production and decline in other common supplementary cementing materials due to the phasing out of steel and coal industries[2]
- Rising production costs of up to 20% due to energy demand[2]
- DfT has an extensive construction portfolio, using 20% of all concrete purchased in the UK annually[3]

As a result, costs and emissions could spiral further

To mitigate risks & achieve Net Zero by 2050 action needs to be taken now to scale alternative options

1. Heriot-Watt University's Centre of Excellence in Smart Construction Research Bulletin April 2023
2. Low Carbon Concrete Routemap, ice.org.uk, 2022
3. Mike Pittman, TRIB.

Current landscape

What is calcined clay?

- Proven low carbon material – made by heating clay to 600-800°C, then ground to cement fineness
- ~80% lower carbon than cement
- Adoption at scale will help hit 2030/35 targets and save money
- ICE/GCB Concrete Routemap identifies it as the only practicable scalable low carbon ingredient in short-med term
- Other countries e.g. France already using at scale - we are being left behind

Current situation?

- Market deadlock
- No UK processing facility at present
- No UK test facility
- Familiarity remains low and forms a barrier to adoption
- UK steel foundries are closing meaning we import the vast majority of GGBS - prices are rising and suppliers simply pass cost rises onto clients.
- We will not hit carbon reduction targets without calcined clay *

**Ref: LCCG/ ConcreteZero Gap Analysis Part 1 (pending publication)*

Calcined Clay is a mature, cost efficient and sustainable solution

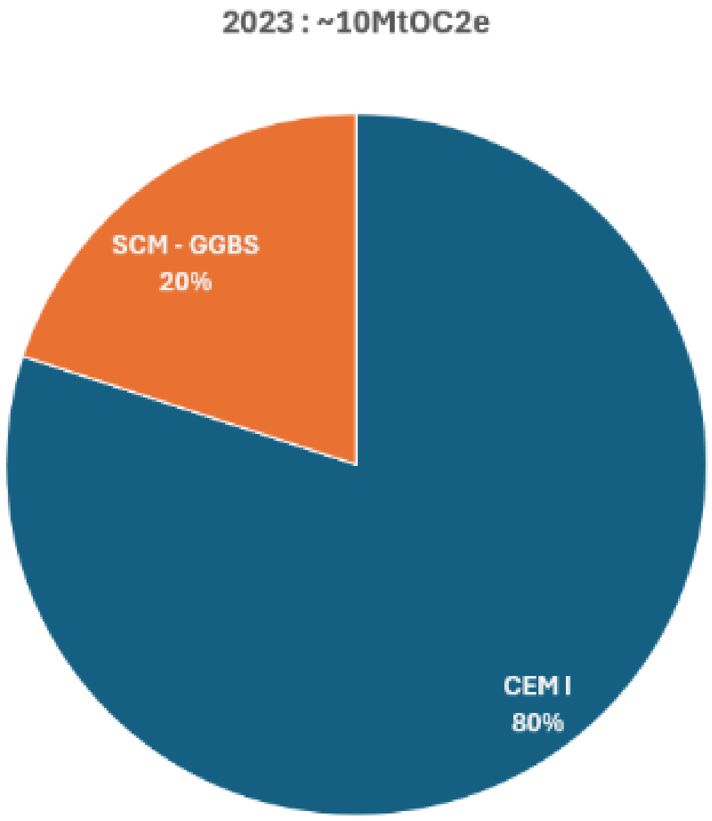
COST	The cost of currently available "green" concrete is increasing due to material and production costs	40% cheaper production for Calcined Clay compared to Portland cement production.[1]
CARBON	Availability of low carbon supplementary materials is shrinking and is open to geopolitical risk.	39% reduction in production GHG emissions 24% reduction of lifecycle energy use compared to Portland cement production.[1]
CIRCULARITY	Cement production relies on by-products from polluting gas and oil production processes and supply is at risk.	Utilising waste and local clay through calcination reduces waste and transportation costs and provides a more local and circular model.

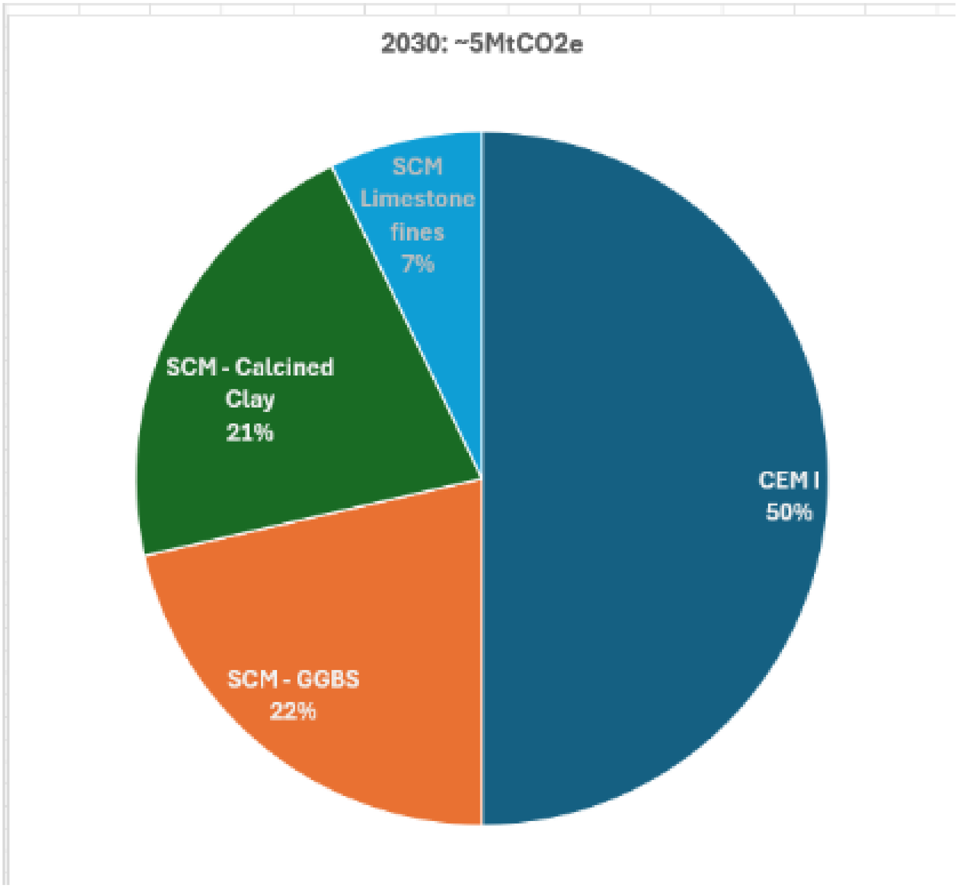
Additionally:

- Reduces the need for clinker by up to 50%.
- High quality material can be made from naturally abundant UK clays e.g. London clay, which is a waste material in many large infrastructure projects.
- It is not a novel material and conforms to current standards.

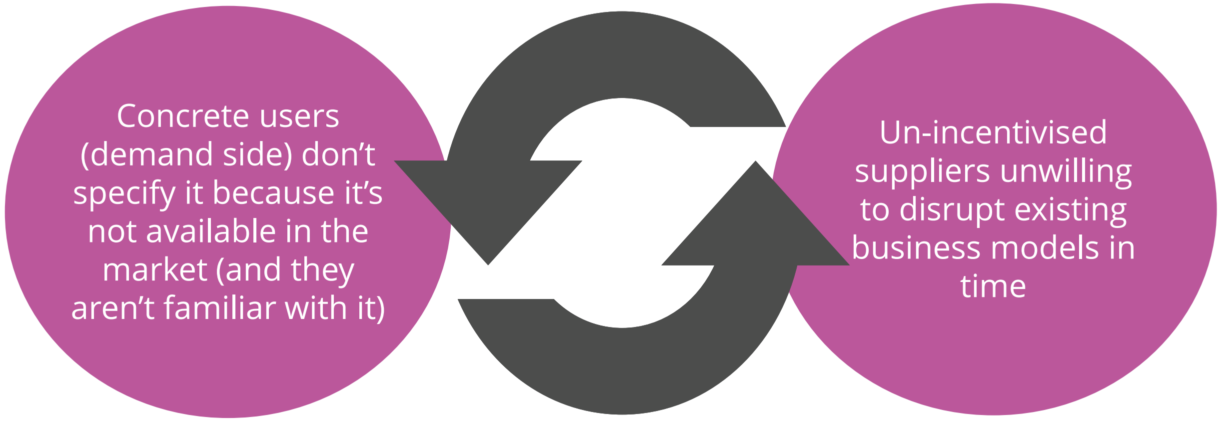
1. Transformation of London clay into construction resources: Supplementary cementitious material and lightweight aggregate, HS2 Learning Legacy, 2020.

Calcined Clay is part of the solution and the opportunity to reduce UK carbon targets





The UK is stuck in a cycle which needs to be broken to scale benefits & support 2030 decarbonisation targets



The traditional supply chain is unlikely to take the lead in breaking this cycle, as it has plans to invest in Calcined Clay in the next **7-15 years**.
It is waiting for CCUS but this cannot be considered a certainty.
Delay could miss the opportunity to **support 2030/35 decarbonisation targets.**

> "Our view is that by the end of the next decade, 80% of the clinker in Europe will be decarbonized [relying on Carbon Capture Utilisation and Storage]
>
> *- Major Cement producer*

The Barriers to Change

Calcined clay has not been implemented to date in the UK due to a complex system of interconnected barriers.

	MORE PREVALENT ON SUPPLY SIDE		*MORE PREVALENT ON DEMAND SIDE*	
	There are some assumed technical & economic challenges related to the adoption of Calcined Clay.	**The supply side does not see the benefit or imperative to adopt Calcined Clay.**	**There is a lack of awareness and confidence amongst key demand-side decision makers.**	**The demand side is being held back by cultural and organisational barriers typical of the industry.**
KEY CONTRIBUTING BARRIERS	Workability challenges due to water & admixture demands Modifications required to produce Calcined Clay (CAPEX) High costs of producing Calcined Clay (OPEX) Uncertainty on the availability, location and quantity of high quality clay deposits	Uncertainty of demand, meaning the investment isn't justified No route map that explicitly considers or prioritises the use of Calcined Clay Focus on short-term profit over other factors Concerns about the carbon impact of Calcined Clay Carbon credit allocation favoring regular cement production Lack of standardisation for measuring carbon footprints of SCMs	Uncertainty on standards / regulations for using Calcined Clay in concrete Uncertainty on the benefits of Calcined Clay Uncertainty on the use cases of Calcined Clay Concerns about the impact of Calcined Clay on cement / concrete performance Lack of industry collaboration & knowledge sharing Limited capacity to explore Calcined Clay	Resistance to use concrete of a different colour Lack of control over procurement activities Resistance to innovation due to low margins, risk appetite & optimised processes
SO WHAT?	There is a need to dispel myths around techno-economic barriers and show it can be done at a commercial scale.	There is a need to demonstrate the benefits of Calcined Clay, give clear demand signals and shift the policy landscape.	There is a need to drive industry awareness, knowledge and confidence on Calcined Clay.	There is a need to incentivise organisations to embrace the change required to adopt Calcined Clay.

KEY: Informational | Techno-economic | Environmental | Cultural | Organisational | Regulatory

Calcined Clay is an attractive and technically proven low carbon solution, and stakeholders are eager to adopt it

Phase 1 commissioned by HS2 has:

- Brought together a task and finish consortium to drive change
- Engaged and informed the wider market
- Shown the UK technical feasibility
- Created a benefit case to validate and progress the use of Calcined Clay

HS2 will continue to spearhead the next phases of development.

Calcined Clay is gathering momentum

Our market engagement has revealed great interest in Calcined Clay from both demand and supply-side organisations.

Benefit case is clear

- Long-term cost savings
- Savings of ~6.2 million tonnes of embodied carbon by 2030
- HS2 excavated waste is a good source material providing circularity
- Calcined clay facilities create green jobs in the UK

Calcined Clay is technically proven

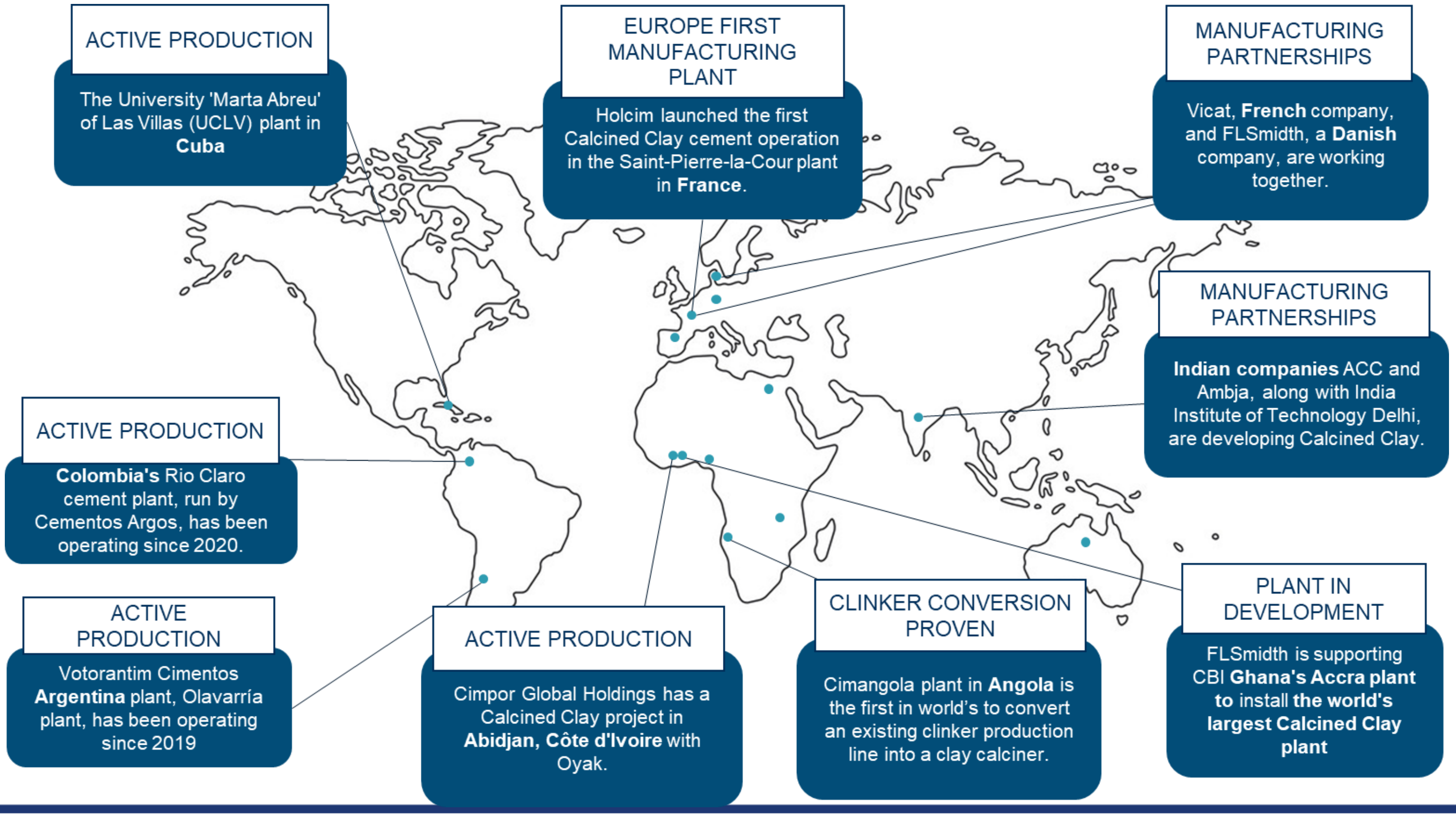
Calcined Clay meets all technical performance requirements in standard BS8500 & BS8615 and can be used in >95% of concrete. Clays of sufficient quality are readily available within the UK.

Calcined Clay is THE Fast Scale-Up Opportunity

Calcined Clay – UK benefit case

Calcined Clay is attracting global interest

UK efforts in Calcined Clay have been focussed on research, other countries have focused on manufacturing development.
There is now an opportunity for the UK to commercialise research and deliver benefits.

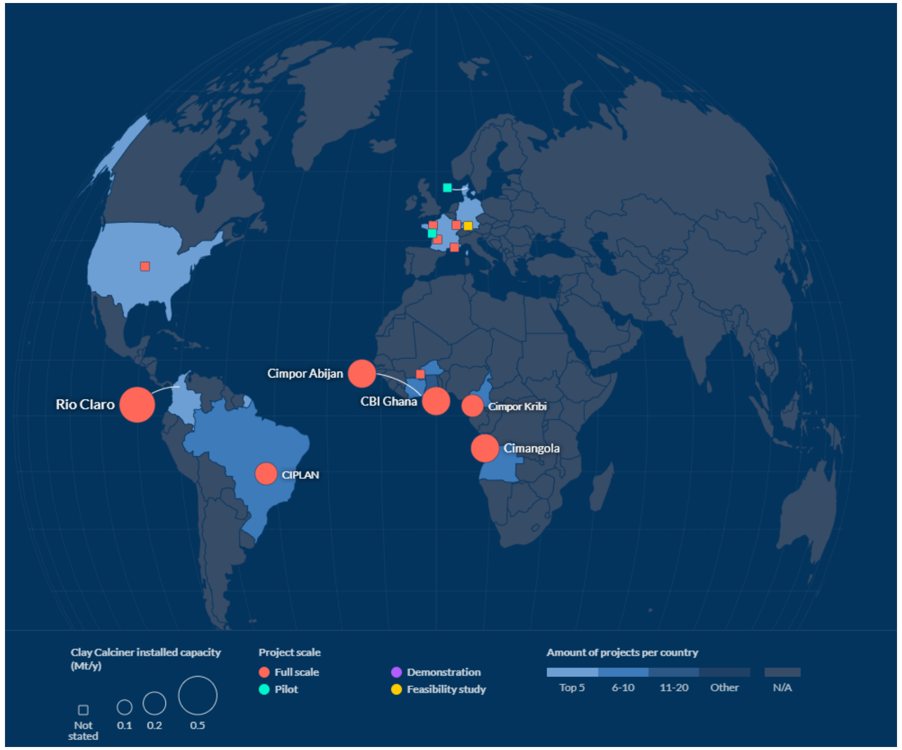


Calcined clays: making a global impact, International Cement Review CemNet.com, 2022.

Global Calcined Clay Supply

There is already a developing global market and supply chain for calcined clay cement, providing lessons learned for the UK and providing resilience to UK schemes

Current worldwide capacity of Calcined Clay cement has been mapped by LeadIT [1]. Further information also provided in our previous session.



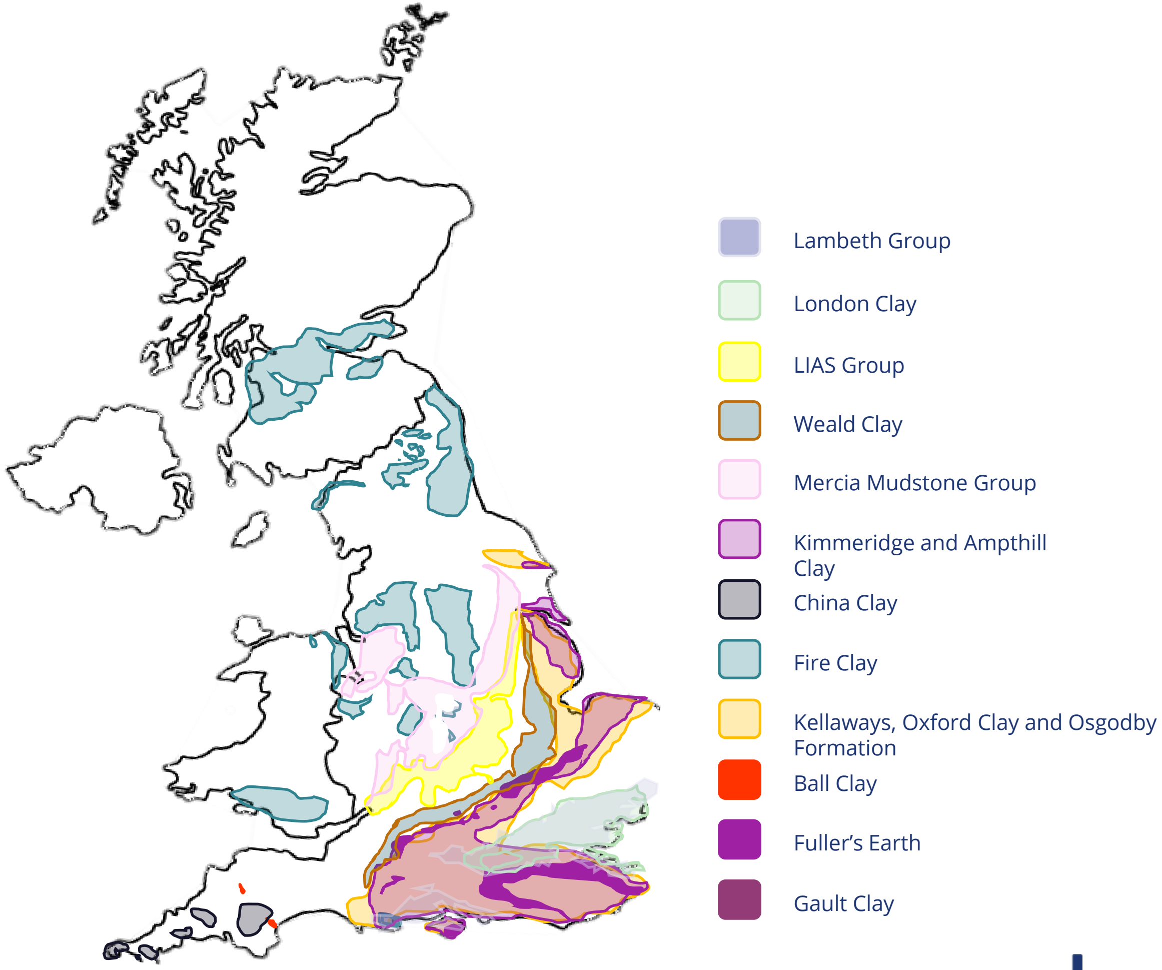
Company	Location	Technology	Capacity (Mt pa)		Investment (m USD)
			Calcined Clay	Cement	
Hoffmann Green Cement	**France**	**Flash calciner Existing production line**	**-**	**0.05**	**11.38**
Rio Claro	Colombia	Rotary kiln New production line	0.45	2.3	**78**
Xeuilley	France	-	-	1	**-**
Holcim (La Malle)	**France**	**Existing production line**	**0.2**	**2**	**6.58**
FLSmidth	Denmark	Electric calciner	-	-	6.62
CBI Ghana	Ghana	-	0.405	0.55	80
Cimangola	Angola	-	0.3	1	**-**
Holcim (Saint Pierre-la-Cour)	**France**	**Rotary kiln Existing production line**	**0.12**	**-**	**42.7**
Heidelberg Materials	France	-	0.8	-	**70.5**
Vicat Group (Ciplan)	Brazil	Rotary kiln	0.2	-	**-**
Cimpor (Abijan)	Ivory Coast	Rotary kiln	0.3	0.8	**-**
Cimpor (Kribi)	Cameroon	Flash calciner	0.2	0.8	**-**
Ash Grove Cement	**USA**	**Rotary kiln Existing production line**	**0.365**	**-**	**-**
CIMAF	Burkia Faso	-	-	-	**34.18**
Votorantim Cimentos	Brazil	Rotary kiln	0.292	0.7	**64.5**

[1] - Green Cement Technology Tracker [Internet]. Leadership Group for Industry Transition. Available from: https://www.industrytransition.org/green-cement-technology-tracker/

Raw Material Availability

Clays of sufficient quality are readily available within the UK, geographically most clays are concentrated in the south of the UK .

	Classification	Kaolin Content	Smectite Content	Illite Content	Reserves
London Clay	Low-grade kaolinitic clay	Up to 36%	Minor	Minor	-
Gault Clay	High-grade smectic clay	Minor	Majority	Minor	-
China Clay	High-grade kaolinitic clay	75-94%	-	-	Commercially sensitive
Fire Clay	High grade kaolinitic clay	Majority	-	Minor	3.5 Mt
Ball Clay	Kalonitic clay	Majority	-	-	454Mt (2011)
Oxford Clay	Mixed clay	Up to 12.5%	Majority		-
Kimmeridge Clay	Low-grade mixed clay	Up to 20%	Majority		-
Ampthill Clay	Medium grade smectic/illitic clay	Up to 18.5%	Majority		-
Fuller's Earth	High-grade smectic clay	-	80-85%	-	9.3Mt
Mercia Mudstone Group	Illitic clay	-	-	Majority	-
LIAS Group	Illitic/Smectic clay	19%	Minority	Up to 43%	-
Weald Clay	Medium-grade mixed clay	31%	10%	53%	-
Lambeth Group	Medium-grade mixed clay	Major	Minor	Major	-



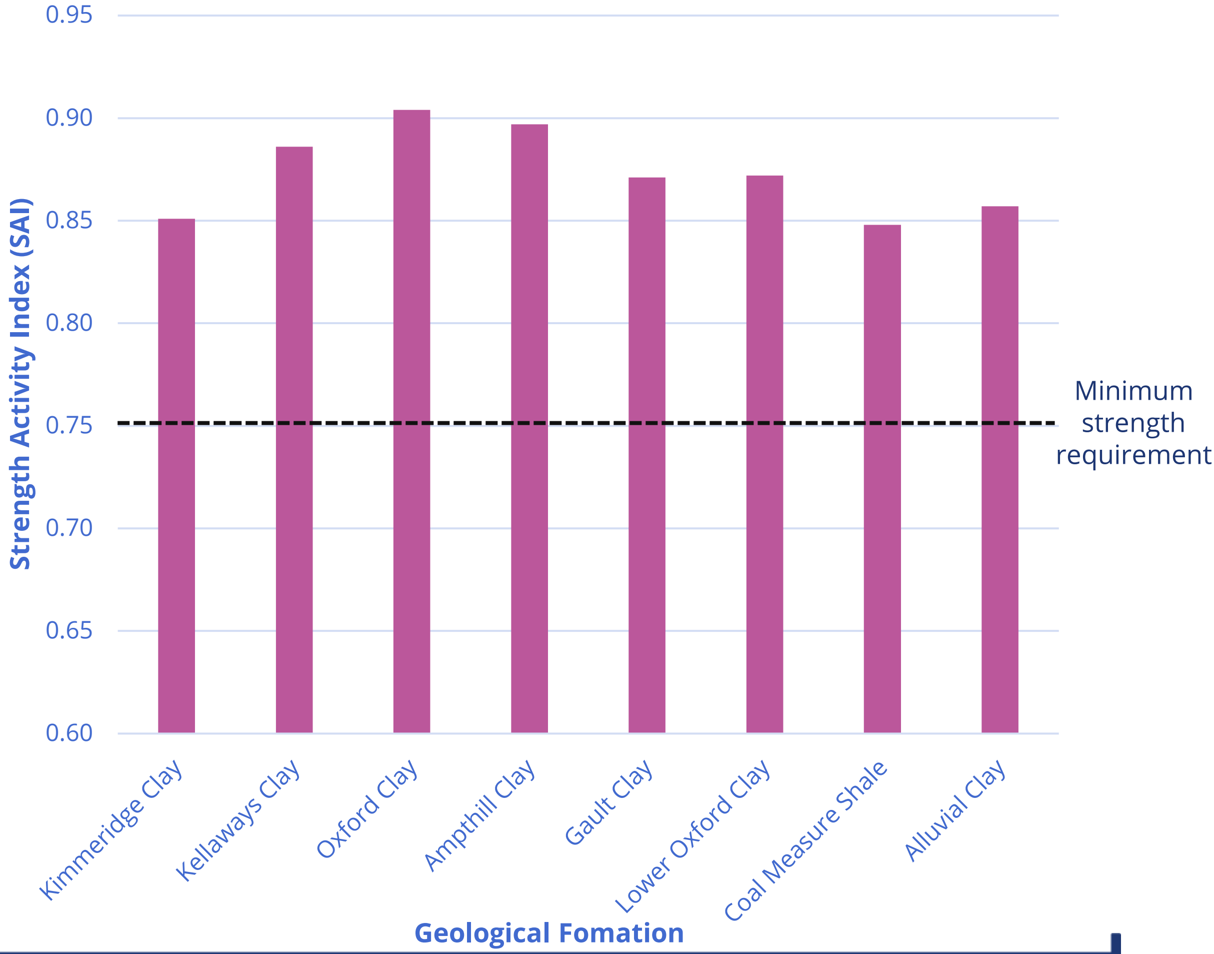
[3] - British Geological Survey. Swelling and shrinking soils. British Geological Survey. 2023. Available from: https://www.bgs.ac.uk
[4] - Natural Environment Research Council (NERC). www.ukri.org. Available from: https://www.ukri.org/councils/nerc
[5] – BGS. Mineral Planning Factsheets. Available from: https://www.bgs.ac.uk/mineralsuk/planning/mineral-planning-factsheets/

Raw Material Performance

Further evidence from a growing body of research demonstrates that most clays in the UK could be used irrespective of classification

		Mineralogy (wt%)				
Geological Formation	**SAI**	**Kaolinite**	**Smectite**	**Illite**	**I/S***	**Quartz**
Kimmeridge Clay	0.851	5.8	0	0	45	22.4
Kellaways Clay	0.886	15.8	0	0	36.5	24.9
Oxford Clay	0.904	12.5	0	0	45.1	20.3
Ampthill Clay	0.897	18.4	0	0	31.3	20
Gault Clay	0.871	8.9	30.5	11.7	0	20.3
Lower Oxford Clay	0.872	6	22.2	5.7	0	40.1
Coal Measure Shale	0.848	19	0	28.4	0	43.6
Alluvial Clay	0.857	3.7	0	19.9	0	32.8

***Interstratified smectite/illite**



SAI of mortar samples produced from calcined clay cement using 'low-grade' clays sourced from the UK [7]

[8] - Ayati B, Newport D, Wong H, Cheeseman C. Low-carbon cements: Potential for low-grade calcined clays to form supplementary cementitious materials. Cleaner Materials. 2022 Sep;5:100099.

What are the key performance features of Calcined Clay Concrete?

	PERFORMS EVEN BETTER	PERFORMS THE SAME	POTENTIAL CHALLENGES
Workability	• Workability retention • Compatibility with air entertainers and retarders • Compatibility with accelerators (excl chloride) • Only PCE eater reducing admixture compatible		• Meets requirements, does require higher water or admixture demand; pick 'right' superplasticiser
Pouring aptitude & stability	• Good cohesion – a high potential for stable high flow mixes • No bleeding and settlement • No static and dynamic segregation • Stability at a higher admixture or water dosage	• Pump-ability • Extrusion • Vibration	
Finishing	• Good finish-ability • Absence of black stains	• Absence of bubbles • Ease of de-moulding	• Meets requirements, there is some colour inconsistency where different clays will give different shades of brown. Production process can be adjusted to control colour
Strength Development	• Some evidence to suggest synergy with limestone filler resulting in better strength	• Low heat of hydration • Setting time • Initial strength • Sensibility to retarders • Plastic shrinkage and cracking	
Hardened Concrete		• Final strength • Drying shrinkage and cracking • Abrasive resistance	• Meets requirements, research is underway on mechanical properties (e.g. creep, elastic modulus) - expected to be the same as fly-ash
Durability			• Meets current code requirements, further research is underway on carbonation and resistance to aggressive ground, expected to be similar to fly-ash

Calcined Clay has 120+ years of recorded use

1902 & 1919 Egypt

Aswan & Sennar Dam

Used in Dam

1933 USA

Golden Gate Bridge

Used in Golden Gate Bridge Anchorage Blocks

1948 India

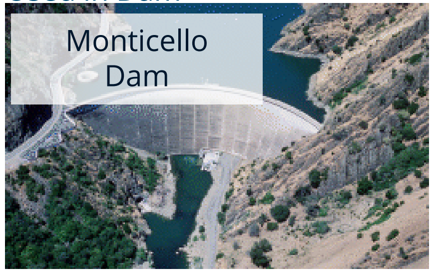
Bhakra Dam

Used in Dam

1951 & 1953 USA

Davis and Monticello Dam

Used in Dam



1962 – 2000 Brazil

Used in 4 different Dam projects

2014 India

Used in reinforced concrete in

2020 Denmark

Lolland

Used in road and rail bridge

2021 France

La Malle

Used in walls and slabs

2025: Société du Grand Paris (new Paris subway)

Do British Standards allow the use of Calcined Clay?

Calcined Clay meets all technical performance requirements in the most recent British standard (BS8500) and can be specified and used now.

CALCINED CLAY MEETS UK PERFORMANCE REQUIREMENTS

Calcined Clay meets performance requirements and, in some cases, **provides additional performance benefits**

CALCINED CLAY IS WIDELY APPLICABLE

Calcined Clay can be used to meet **most** concrete applications.

SUBSTITUTION WITH CALCINED CLAY IS ALLOWED IN STANDARDS

The standard (BS EN 197-1) allows for **up to 55%** substitution of CEM I with Calcined Clay
Ternary blends possible

...plus there is already a code for its production: BS 8615:2019

Not only is it technically possible to utilise Calcined Clay, it has the potential to provide significant additional benefits

-40%

CARBON

Up to 40% reduction in embodied carbon as a result of using Calcined Clay

-30%

COST

Up to 30% reduction in production costs as a result of using Calcined Clay

CIRCULARITY

An improved circular economic model as a result of using Calcined Clay

RESILIENCE

Improved supply chain resilience + resource security when using Calcined Clay

What does BS8500 say about SCMs in concrete?

BS8500 specifies the permissible types and proportions of supplementary cementitious materials (SCMs), including Calcined Clay, that can be used in concrete mixes.

1

There are many different types of cement which are each designated a type category. This defines the proportion and type of additions allowed.

Common cements	Type	Proportion of additions	Allowable additions
Portland cement	CEM I	6-20	A1
Portland slag cement	CEM II	A or B	S
Portland silica fume cement		A or B	D
Portland pozzolana cement		A or B	P or Q
Portland flyash cement		A or B	V or W
Portland limestone cement		A or B	L (or LL)
Portland composite cement		A or B or C	M
Blastfurnace cement	CEM III	A or B or C	S
Pozzolanic cement	CEM IV	A or B	P or Q or V
Composite cement (EN 197-1)	CEM V	A or B	S with P or Q or V
Composite cement (EN 197-5)	CEM VI	-	M

Figure 1. Cement designations

2

These designations are then utilised to define the % replacement level of Calcined Clay allowed. They are now also assigned a performance category.

Cement Designation	Combination	Replacement Level (%)	Combined Performance Category
CEM II/A-Q	CIIA-Q	6-20	A1
CEM II/B-Q (+SR)	CIIB-Q (+SR)	21-35	A2, D2
CEM II/A-M (Q-L)	CIIA-QL	36-50	B1, C1
CEM II/A-M (L-Q)	CIIA-LQ	12-20	B1, C1
CEM II/B-M (Q-L)	CIIB-QL	21-35	B1, C1
CEM II/B-M (L-Q)	CIIB-LQ	21-35	B1, C1
CEM II/C-M (Q-L)	CIIC-QL	36-50	-
CEM II/C-M (Q-L)	CIIC-LQ	36-50	-
CEM IV/B (Q)	CIVB-Q	36-55	E4

Figure 2. SCM Replacement Levels in Cement Blends (Q= Calcined Clay, L = Limestone (to BS8500-1 Table A.6)

What does BS8500 say about Calcined Clay?

Calcined Clay included in pink - highlighted permissible types and proportions of SCMs .

1

There are lots of different types of cement which are each designated a type category. This defines the proportion and type of additions allowed..

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Portland flyash cement		A or B	V or W
Portland limestone cement		A or B	L (or LL)
Portland composite cement		A or B or C	M
Blastfurnace cement	CEM III	A or B or C	S
Pozzolanic cement	CEM IV	A or B	**P or Q or V**
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CEM II/A-Q	**CIIA-Q**	**6-20**	**A1**
CEM II/B-Q (+SR)	**CIIB-Q (+SR)**	**21-35**	**A2, D2**
CEM II/A-M (Q-L)	**CIIA-QL**	**36-50**	**B1, C1**
CEM II/A-M (L-Q)	**CIIA-LQ**	**12-20**	**B1, C1**
CEM II/B-M (Q-L)	**CIIB-QL**	**21-35**	**B1, C1**
CEM II/B-M (L-Q)	**CIIB-LQ**	**21-35**	**B1, C1**
CEM II/C-M (Q-L)	**CIIC-QL**	**36-50**	**-**
CEM II/C-M (Q-L)	**CIIC-LQ**	**36-50**	**-**
CEM IV/B (Q)	**CIVB-Q**	**36-55**	**E4**

Figure 2. SCM Replacement Levels in Cement Blends (Q= Calcined Clay, L = Limestone (to BS8500-1 Table A.6)

Service Life Examples

Chlorides other than from marine

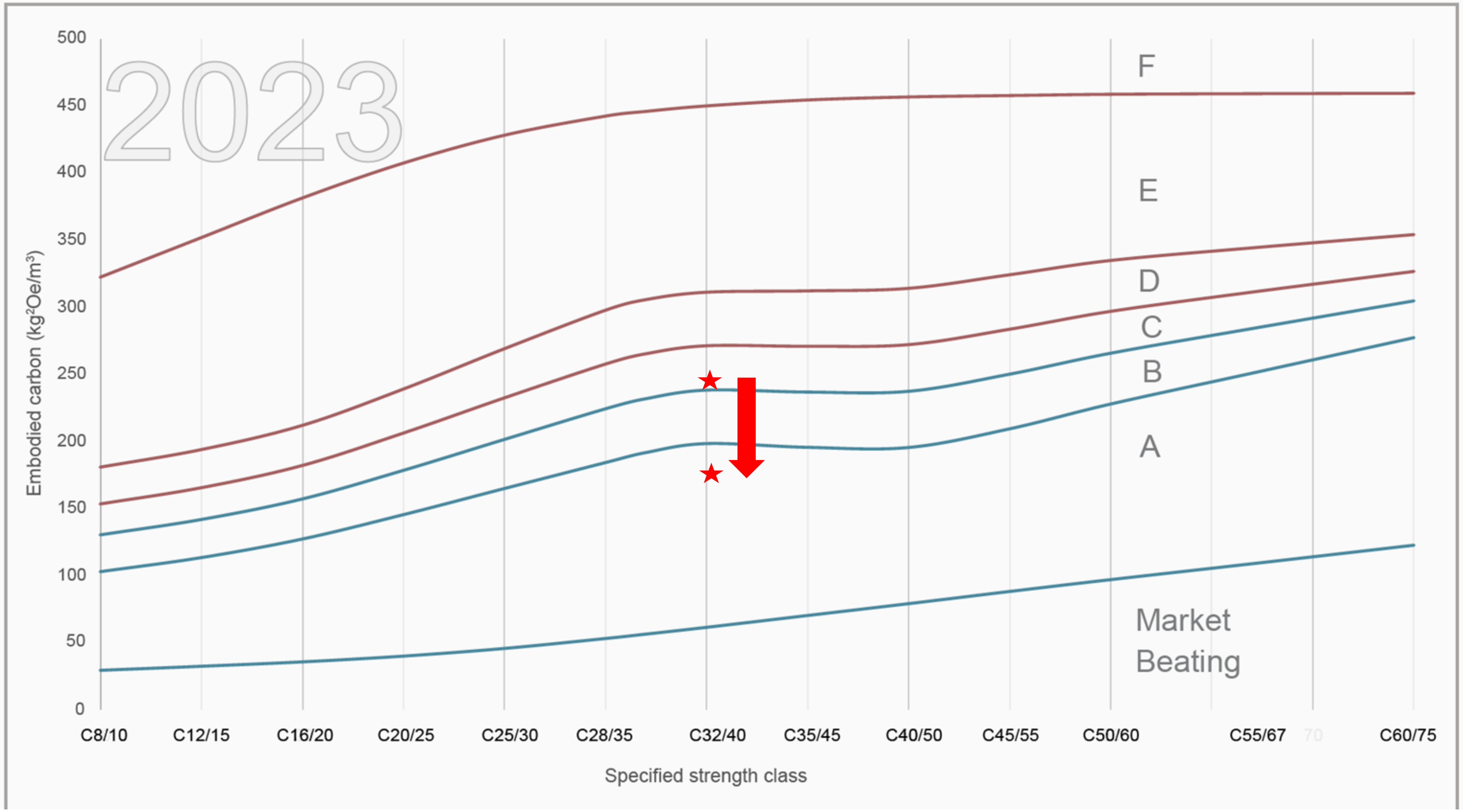
	Exposure condition				Minimum strength class, minimum binder content, maximum water/cement ratio								
Typical example	Primary	Secondary	Calcined Clay (Q) Designation and replacement level	Performance category	50 years				100 years				
					Typical nominal cover to reinforcement				Typical nominal cover to reinforcement				
					30 + Δc	40 + Δc	50 + Δc	60 + Δc	30 + Δc	40 + Δc	50 + Δc	60 + Δc	Notes
Elements subject to airborne chlorides protected from rainfall	XD1	XC3/4, XF1	Q (6-55%)	Any	C28/35, 320, 0.55	C28/35, 300, 0.60	C28/35, 300, 0.60	C28/35, 300, 0.60	C28/35, 380, 0.40	C28/35, 340, 0.50	C28/35, 300, 0.60	C28/35, 300, 0.60	Limiting proportions adequate for any associated carbonation induced corrosion (XC). Minimum strength classes given for freeze-thaw resistance
Elements subject to water saturation with de-icing agent and freezing	XD3	XF4	CIIA-Q (6-20%)	A1, B1, C1		C40/50, 380, 0.35	C40/50, 360, 0.45	C40/50, 360, 0.45				C40/50, 380, 0.40	
			CIIB-Q (21-35%)	A2, D2		C40/50, 380, 0.40	C40/50, 320, 0.55	C40/50, 320, 0.55			C40/50, 380, 0.40	C40/50, 340, 0.50	
			CIVB-Q (36-55%)	E4		C40/50, 380, 0.40	C40/50, 320, 0.55	C40/50, 320, 0.55			C40/50, 360, 0.45	C40/50, 320, 0.55	

Carbon intensity of concrete with calcined clay

Potential to move large majority of UK concrete from average of 'C', into current A-band

*(indicative preliminary calculations, using information from stakeholder engagement. Final figures dependent upon logistics, geography and production plant).

Figure 1: LCCG Market Benchmark for embodied carbon, normal weight concrete, LCA stages A1 to A3
(Ready-mixed: cradle to batching plant gate, Precast: cradle to mould)



Summary - Next Steps

The HS2-led Task and Finish Group finalised a position paper outlining next steps

A series of interventions were identified which would work to break the current market deadlock:

- **Development of demonstrator projects** using imported calcined clay amongst key clients such as HS2, National Highways and Environment Agency to build familiarity with the material
- Develop a set of **Advance Market Commitments** to demonstrate the clear demand signal
- **Build the business case** and work to procure a **pilot testing kiln**, which would build confidence and knowledge of the different UK clays
- **Enabling and Adoption Drive**, including identification of a site for the first full production kiln

Calcined Clay: Benefits and Adoption for UK Concrete

per

V2 September 2024

WHO WE'VE ENGAGED

… Undertaking these steps over the next 6-12 months could lead to an operational kiln by 2027 and scaled to 4Mt p.a. by c.2030

Proposed work packages

Work Package 1– *Planning, delivering, learning lessons from demonstrator projects*

Initially, using imported calcined clay for speed and to help 'prove the market'

HS2 has started engagement and **allocated up to 100k** to support own supply chain. Additional demonstrator projects (EA York flood defense scheme and NH, NG and AW also exploring)

Work Package 2 – *HS2 / Innovate UK/ SBRI 'scientific programme' and demonstrator at SCS JV (Already live)*

HS2 and SCS JV have already secured c.**£400k investment** from Innovate UK to establish a robust body of scientific test data (inc. durability) for abundant London clays excavated during construction.

Work Package 3 – *Plans and business case for a pilot kiln*

National Facility for Low Carbon Clay

DfT/TRIB sponsored, delivered by HS2/Expedition/PA

Unlocks £1-1.5 million Innovate UK capital equipment budget.

Helps to build confidence and familiarity with calcined clay, incentivising the supply chain.

Work Package 4 – *Advanced Market Commitments*

Utilising the Innovate UK AMC framework and toolkit to develop a set of offtake agreements and letters of intent, from clients and key contractors/concrete buyers

This derisks and gives clear demand signal that innovators can use to raise green finance for operational kiln (i.e. leverage £30-50m of external funding)

Work Package 5A – *Change and adoption campaign*

Continuation of Task and Finish Group, demand and supply side readiness programme, including identifying site for first Calcined Clay kiln.

Phased in during demonstrators / required to help investment for WP 5B

Work Package 5B – *Feasibility study for full-scale plant + circular clay supply chain; pan transport sector*

- Assess the feasibility and practicality of establishing an end-to-end circular supply chain, by harnessing unique size/position of transport construction pipeline

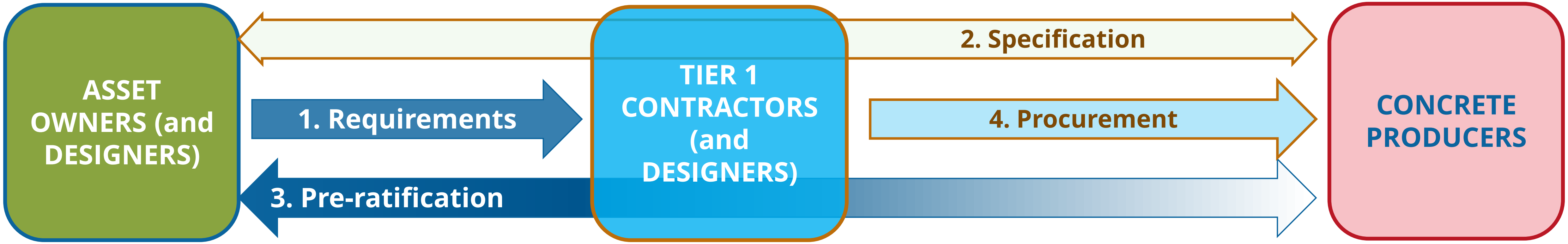
AMC indicative model

1

STEP 1. Intent. Asset Owners, Designers and Tier 1 con (collective)
ALL : *"We show our strong support for the use of innovative low-carbon concretes through a series of corporate commitments"*

2

STEP 2. Specification. Tier 1 contractors
Tier 1s: *"On each project, we commit to exploring how we can use innovative low-carbon concrete"*



3

STEP 3. Pre-Ratification. Asset Owners (with Designers)
AOs: *"On each project, we will pre-ratify the use of innovative low carbon concretes that meet technical and commercial requirements"*

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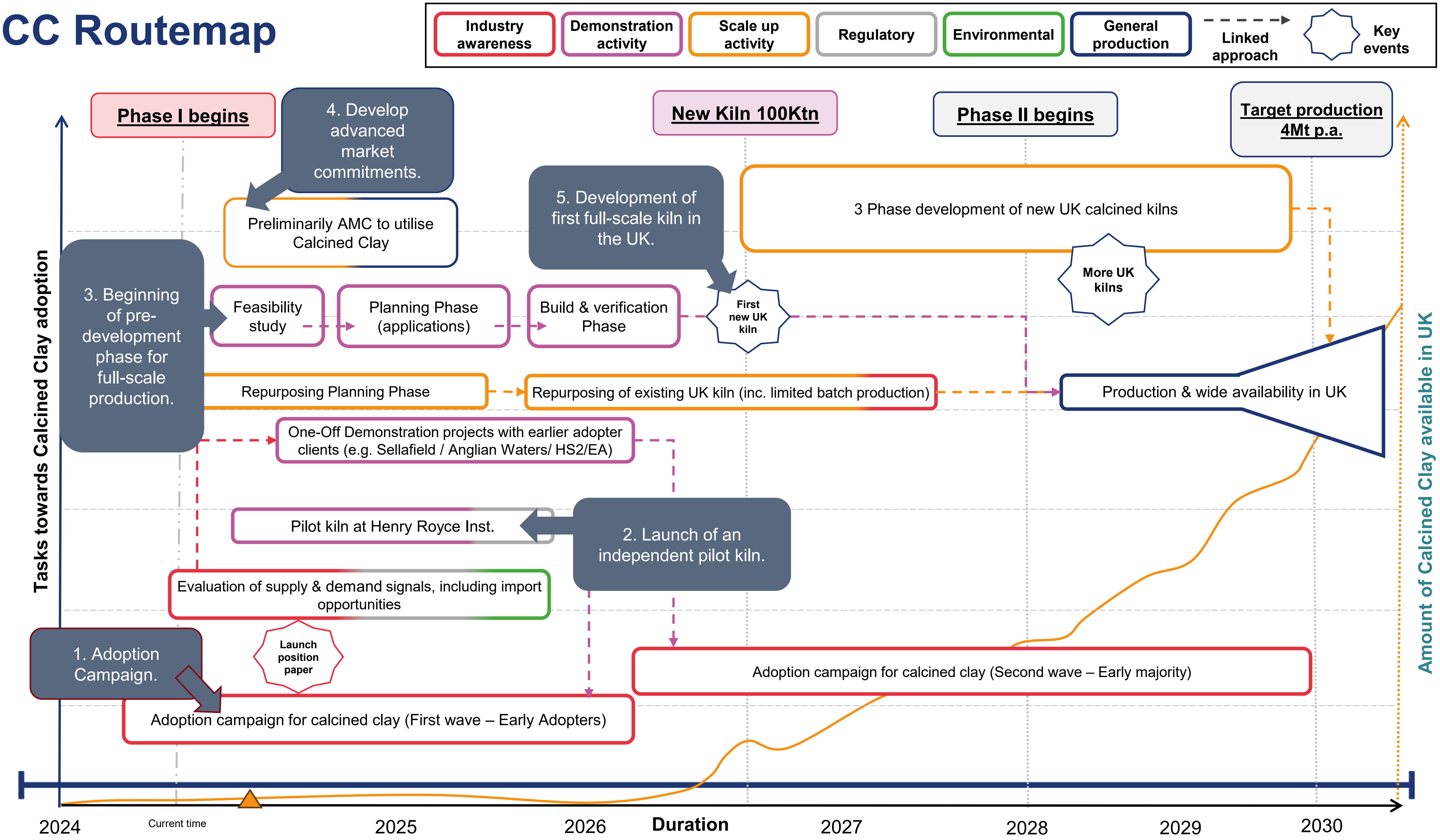
STEP 4. Procurement. Tier 1 contractors
Tier 1s: *"We commit to purchasing innovative low carbon concrete(s) over an agreed period"*

CC Routemap



Industry awareness
Demonstration activity
Scale up activity
Regulatory
Environmental
General production
Linked approach
Key events
Phase I begins
4. Develop advanced market commitments.
New Kiln 100Ktn
Phase II begins
Target production 4Mt p.a.
Preliminarily AMC to utilise Calcined Clay
5. Development of first full-scale kiln in the UK.
3 Phase development of new UK calcined kilns
More UK kilns
3. Beginning of pre-development phase for full-scale production.
Feasibility study
Planning Phase (applications)
Build & verification Phase
First new UK kiln
Repurposing Planning Phase
Repurposing of existing UK kiln (inc. limited batch production)
Production & wide availability in UK
One-Off Demonstration projects with earlier adopter clients (e.g. Sellafield / Anglian Waters/ HS2/EA)
Pilot kiln at Henry Royce Inst.
2. Launch of an independent pilot kiln.
Evaluation of supply & demand signals, including import opportunities
1. Adoption Campaign.
Launch position paper
Adoption campaign for calcined clay (Second wave – Early majority)
Adoption campaign for calcined clay (First wave – Early Adopters)
Tasks towards Calcined Clay adoption
Amount of Calcined Clay available in UK
2024
Current time
2025
2026
Duration
2027
2028
2029
2030

Thank You

Questions?

Standards

Additional Information to be shared with design teams / wider stakeholders

One of the key parameters to consider is the certain conditions that the concrete will be exposed to and compression strengths needed

Exposure

X0 – Concrete in very dry or no significant exposure to the environment

XC – Condition relating to carbonation of concrete (ingress of CO2) and associated reinforcement corrosion

XD – Condition relation to chloride ingress other than from seawater (e.g. de-icing salts) and associated reinforcement corrosion

XS - Condition relation to chloride ingress from seawater and associated reinforcement corrosion

XF – Condition relating to concrete exposed to freeze-thaw cycles

XA – Condition relating to concrete exposed to chemical attack (not used in the UK for aggressive ground conditions)

Compressive Strength
Example: C 32 / 40

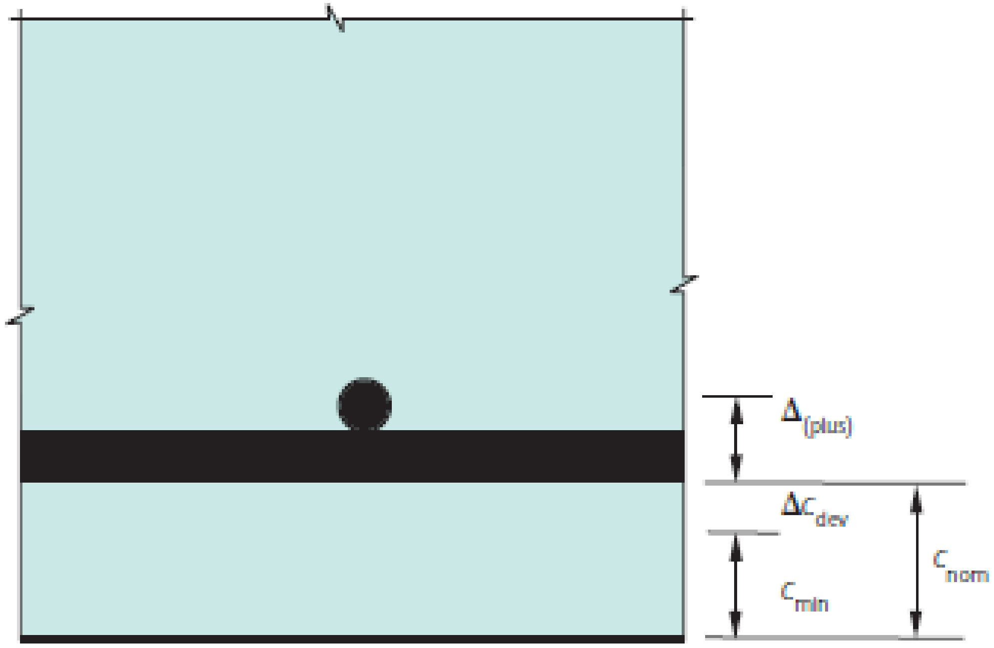
C – normal weight concrete (LC for lightweight concrete)
32 – cylinder strength
40 – cube strength

Strength compliance at a specified age (normally 28 days) but may be / should be extend to later ages where applicable.

Calcined Clay can be utilised under all exposure conditions with the exception of XA

Cover to reinforcement

- Durability to BS 8500 assumes minimum cover to reinforcement is achieved. (C_{min})
- Allowance is made for deviations in the cover due to construction tolerances (ΔC_{dev} -typically 5-15mm)
- Nominal cover ((C_{nom}) = $C_{min} + \Delta C_{dev}$) is used to determine the depth of reinforcement cover for structural design and construction.
- Permitted deviation away from the surface of the concrete (maximum cover, $\Delta_{(plus)}$) should also be specified



Notes

c_{min} = Minimum cover

Δc_{dev} = Allowance made in design for deviation (towards face of concrete)

c_{nom} = $c_{min} + \Delta c_{dev}$ = nominal cover

$\Delta_{(plus)}$ = Permitted deviation (away from face of concrete) –

Service Life Examples

Tables in BS 8500 give recommended limiting values for durability of concrete containing carbon reinforcing steel or prestressed elements with an intended working life of 50 or 100 years.

Examples

- Carbonation
- De-icing salts
- Marine conditions

Service Life Examples

Carbonation exposure

	Exposure condition				Minimum strength class, minimum binder content, maximum water/cement ratio								
Typical example	Primary	Secondary	Calcined Clay (Q) Designation and replacement level	Performance category	50 years				100 years				
					Typical nominal cover to reinforcement				Typical nominal cover to reinforcement				
					30 + Δc	40 + Δc	50 + Δc	60 + Δc	30 + Δc	40 + Δc	50 + Δc	60 + Δc	Notes
Internal or permanently wet elements	XC1		Q (6-55%)	Any	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	C20/25	Carbonation resistance now based on strength class alone
Buried concrete in DC-1 ground	XC2	DC-1	Q (6-55%)	Any	C25/30	C25/30	C25/30	C25/30	C25/30	C25/30	C25/30	C25/30	
Vertical surface exposed to rain and freezing	XC/3/4	XF1	Q (6-55%)	Any	C40/50	C35/45	C30/37	C28/35	C45/55	C40/50	C35/45	C32/40	

Service Life Examples

Chlorides from marine exposure

	Exposure condition					Minimum strength class, minimum binder content, maximum water/cement ratio									
Typical example	Primary	Secondary	Calcined Clay (Q) Designation and replacement level	Performance category	50 years					100 years					
					Typical nominal cover to reinforcement					Typical nominal cover to reinforcement					
					30 + Δc	40 + Δc	50 + Δc	60 + Δc		30 + Δc	40 + Δc	50 + Δc	60 + Δc		Notes
Exposed horizontal surfaces near coast	XS1	XF3	CIIA-Q (6-20%)	A1, B1, C1			C40/50, 380, 0.40	C40/50, 340, 0.50							Limiting proportions adequate for any associated carbonation induced corrosion (XC). Minimum strength classes given for freeze-thaw resistance
			CIIB-Q (21-35%)	A2, D2	C40/50, 380, 0.35	C40/50, 340, 0.50	C40/50, 320, 0.55	C40/50, 320, 0.55			C40/50, 380, 0.35	C40/50, 360, 0.45	C40/50, 320, 0.55		
			CIVB-Q (36-55%)	E4	C40/50, 380, 0.40	C40/50, 320, 0.55	C40/50, 320, 0.55	C40/50, 320, 0.55			C40/50, 380, 0.40	C40/50, 340, 0.50	C40/50, 320, 0.55		
Elements permanently submerged below mid-tide level	XS2		CIIA-Q (6-20%)	A1, B1, C1				0.35, 380							
			CIIB-Q (21-35%)	A2, D2		380, 0.40	340, 0.50	320, 0.55				380, 0.35	360, 0.45		
			CIVB-Q (36-55%)	E4		360, 0.45	320, 0.55	320, 0.55				380, 0.40	340, 0.50		
Elements in tidal/ splash and spray zones	XS3		CIIA-Q (6-20%)	A1, B1, C1											
			CIIB-Q (21-35%)	A2, D2			380, 0.35	360, 0.45							
			CIVB-Q (36-55%)	E4			360, 0.45	320, 0.55					380, 0.35		