

Decarbonising the UK Concrete Industry: Closing the emissions gap

Phase 1 scoping study

October 2024



Contents

1.0 Executive summary	06
2.0 The baseline projection	10
3.0 Typical allocation of embodied carbon of concrete	12
4.0 “CCU” or “CCS” ... but not “CCUS”	14
5.0 Carbon reducers and carbon eliminators	16
6.0 Readiness and timelines for scaling	20
7.0 Making money by reducing carbon	22
7.1 The cost and monetary value of carbon	22
7.2 The cost of emerging carbon reducers and potential carbon eliminators	24
7.3 Encouraging adoption of carbon reducers and carbon eliminators	24
7.4 The financial case for implementing carbon reducers and carbon eliminators	24
8.0 Potential pathways to closing the gap	27
9.0 Conclusions and next steps	34
Notes and references	38
Appendix	40



Abbreviations used in the text

AACM	Alkali activated cementitious material
BAU	Business as usual
CBAM	Carbon Border Adjustment Mechanism
CC	Carbon capture
CCS	Carbon capture and storage
CCU	Carbon capture and use
CCUS	Carbon capture and use or storage
DESNZ	Department for Energy Security and Net Zero (a part of the UK government)
ERMCO	European Ready Mix Concrete Organisation
ETS	Emissions trading scheme
GDP	Gross domestic product
GGBS	Ground granulated blast-furnace slag
GHG	Greenhouse gas
HMG	His Majesty's Government (The UK government)
IEA	International Energy Agency
LCA	Life cycle analysis
LCCG	Low Carbon Concrete Group
MAC	Mechanically activated clay
MPA	Mineral Products Association
ONS	Office for National Statistics
SCM	Supplementary cementitious material
TRL	Technology readiness level

Caution

This report summarises the results of the phase 1 “scoping study”. The scoping study has not been peer-reviewed.

Further work is required in phase 2 of the study to test the underlying assumptions, assess additional methods of carbon reduction and elimination and to develop the models and analyses.

Until completion of the additional work, the projected rate at which the carbon gap may be reduced and closed, and the associated financial benefits or costs are initial findings likely to be revised.

Readers should recognise the probability of revisions during phase 2 and take care to make appropriate use of the initial findings.

Phase 2 is targeting a late 2024 start date with initial reporting for comment in late summer 2025 and a final report at the end of 2025.



Executive summary

This analysis defines the carbon gap as the difference between projected carbon emissions from concrete production in the UK and a Paris-aligned pathway to net zero.

This scoping study provides an initial assessment of the effect of combining different measures to close the carbon gap. These measures include *current* best practices that can and must be urgently scaled today, coupled with *future* technological advances which will need concerted and coordinated further development across the sector to deploy at scale. In all likelihood, both current and future practices will be needed to meet necessary emissions reductions in concrete production and use.

This analysis includes financial considerations alongside technical ones and, while significant uncertainty remains, including around the nature of future carbon trading regimes, there do appear to be viable methods of closing the carbon gap by the early to mid-2030s, herein referred to as 'Goldilocks pathways'.

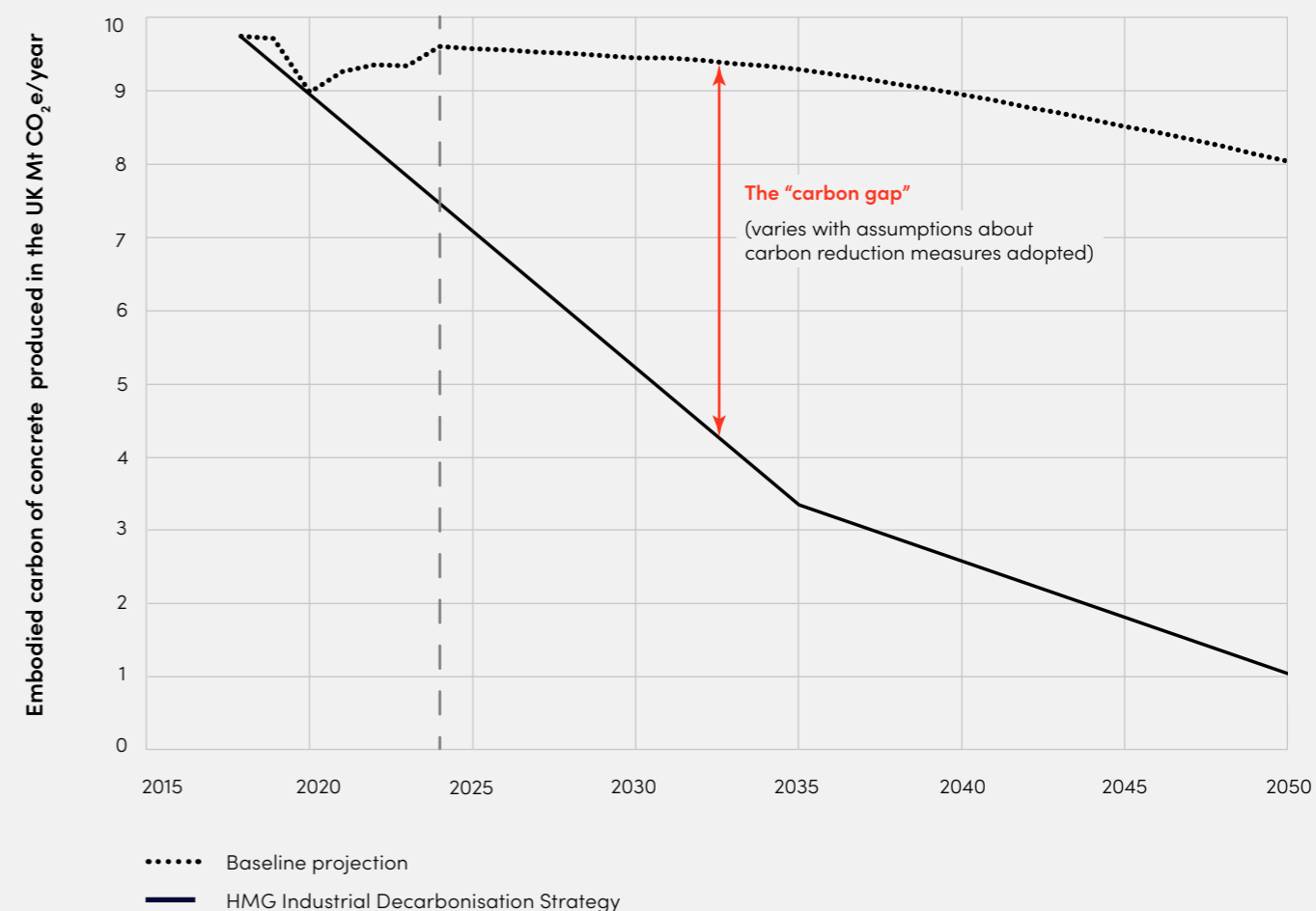
The best practice examples already in use today and that can be scaled further straight away include measures such as using concrete more efficiently, reducing clinker content (through using concrete of the lowest suitable strength class

and increasing use of Supplementary Cementitious Materials (SCMs)) and continuing to reduce the embodied carbon of clinker. If their use is maximised within limits set by current standards and operational norms, these methods can reduce the carbon gap, but not close it.

To fully close the carbon gap measures which reduce the embodied carbon of the cementitious materials are also needed. The report identifies four priority areas for development to achieve medium- and long-term carbon reductions. They are:

1. Development of near zero carbon Portland cement. This includes:
 - Reclamation of cement from demolition arisings, and
 - Carbon capture and use (CCU) on emissions from factories producing Portland cement. In this approach the captured carbon has the potential to provide additional revenue streams to improve financial returns.
2. Development of near zero carbon supplementary cementitious materials to replace some of the clinker in concrete.
3. Development of clinker-free concretes.
4. Carbon capture and storage (CCS) to deliver near zero carbon Portland cement.

Figure 1: The carbon gap.



Closing the carbon gap using primarily concretes that include Portland cement requires CCU and / or CCS to be technically and financially viable. This analysis indicates that approaches 1 to 3 mentioned above, if they can be successfully developed and scaled, are expected to be financially preferable. For CCS, the cost of capturing, transporting and storing carbon dioxide adds cost to the production of concrete.

While clinker-free concretes may provide carbon emissions reductions at a lower cost, their introduction will need to be planned to manage the risk inherent in materials with a limited track record. As such it is important to adopt a phased introduction into uses of progressively greater consequence.

This analysis also considered the barriers faced in accelerating the supply and demand of low carbon concrete. Addressing these barriers, such as the competitiveness of clinker replacements in a regime where clinker production receives a free allocation of carbon credits, the development of codes and standards for innovative concrete products, and the redevelopment of existing infrastructure, is critical and needs to be accelerated.

Similar findings are likely to apply to markets beyond the UK, while recognising that strategies for closing the carbon gap need to be assessed on a global basis.



The key takeaways from this report are:

- 1. Immediate action** - all potential concrete decarbonisation levers need to be progressed and scaled rapidly, now, so we can start to close the carbon gap,
- 2. Urgently raise ambition** - already established solutions on the market will likely not be enough to fully eliminate emissions associated with concrete, and thus;
- 3. Close the gap** - advance combinations of technologies that have the potential to eliminate all emissions.

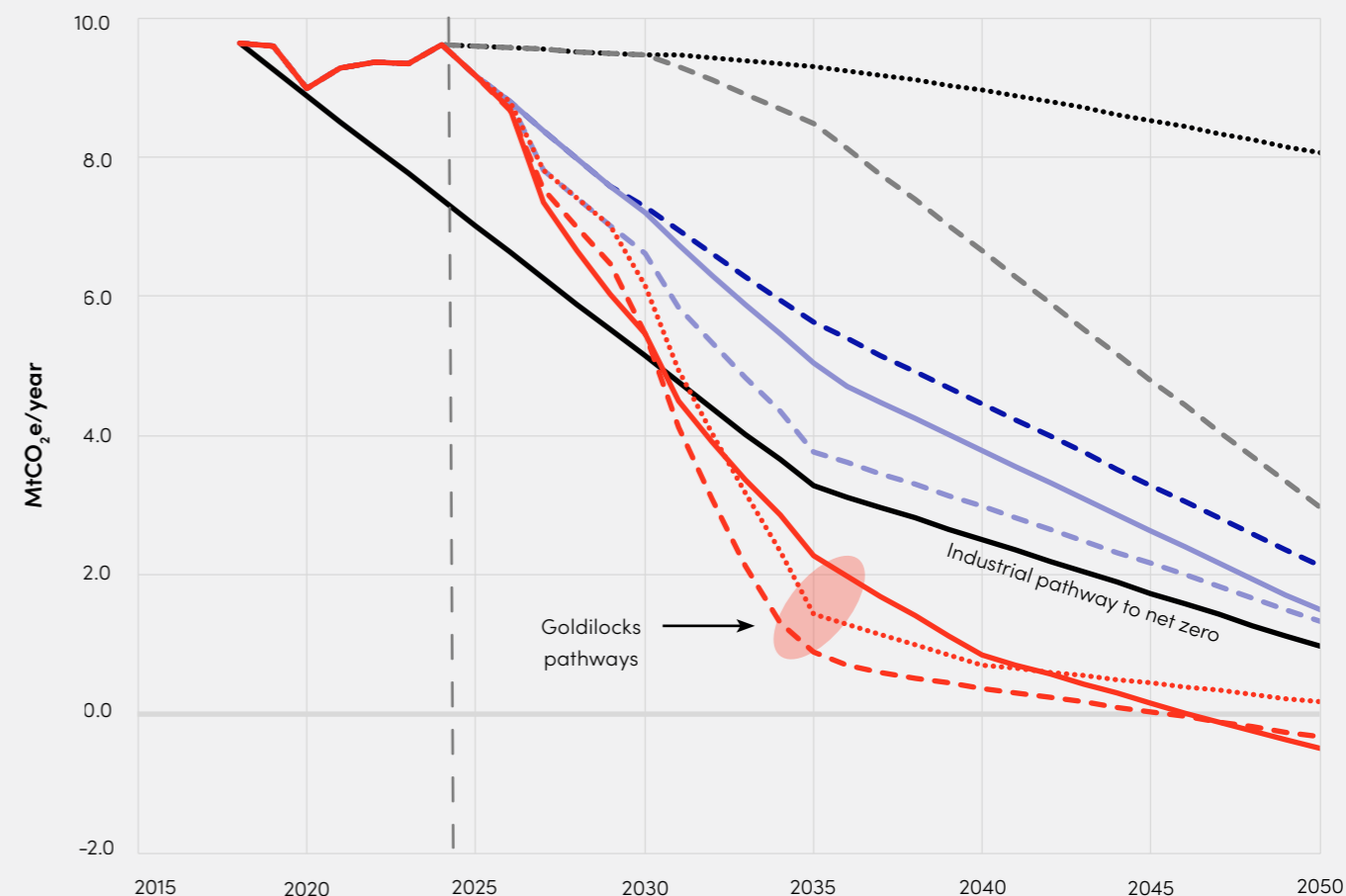
About this report:

This scoping study has been conducted by the Low Carbon Concrete Group (LCCG) and is published and part-funded by ConcreteZero. Participants and funding are being gathered for a second phase which will test and develop the work completed in this scoping study.

The Industrial Decarbonisation Strategy (1) defined by the UK government is used as a representative Paris-aligned pathway.

The study focuses on the embodied carbon of concrete (Life Cycle Analysis stages A1 to A3).

UK concrete sector emissions (LCA stages A1 to A3), potential pathways to 2050.



The Low Carbon Concrete Group, October 2024

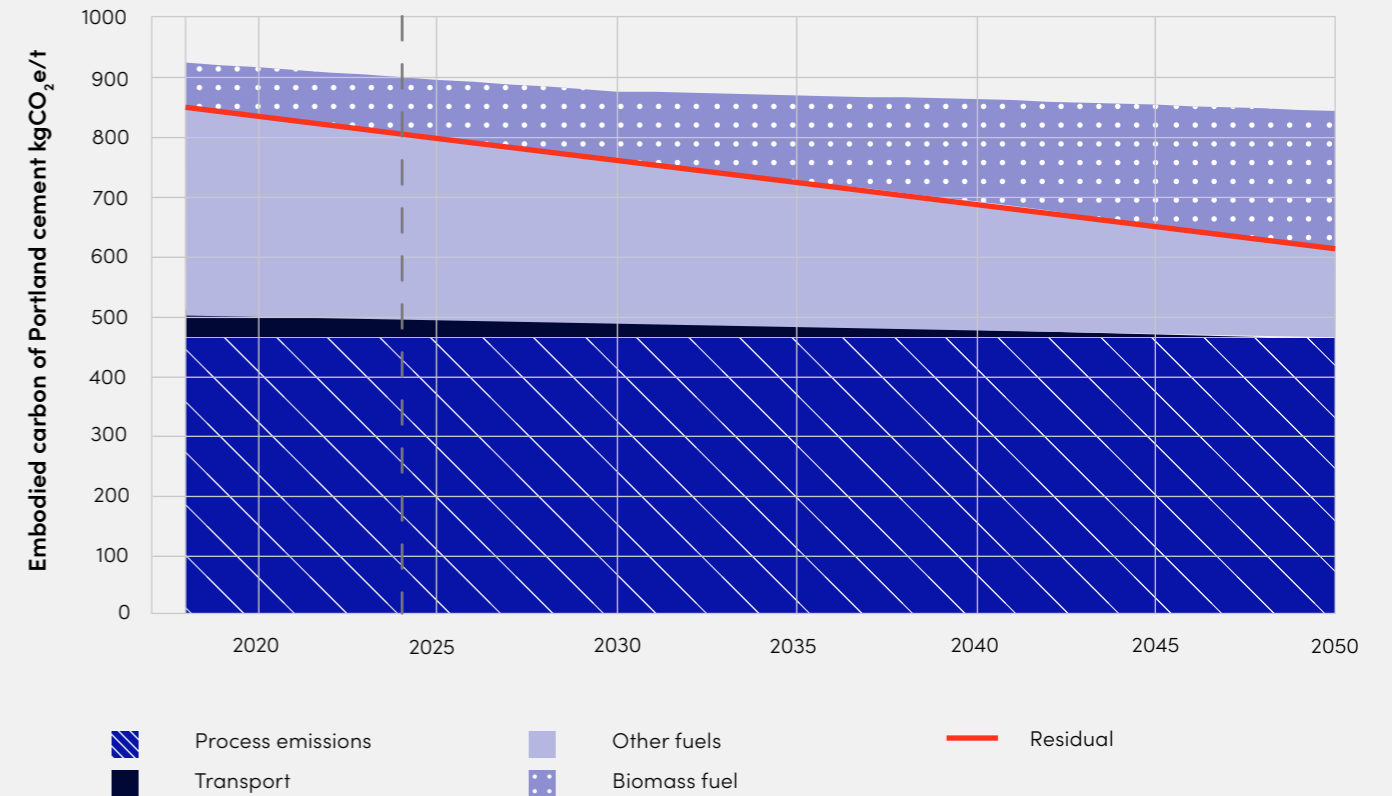
- HMG pathway to net zero
- Baseline projection
- - - + CCS
- - - + Max current code SCMs
- + MAC SCM
- - - + Reclaimed Portland cement
- + CCU
- + Clay AACM (no CCU)
- - - + CCU and AACMs

While closing the carbon gap does appear to be possible, it will require concerted and coordinated action across the sector. This requires a step change from action to date.

2.0



Figure 2: Projected embodied carbon of Portland cement.



The baseline projection

The baseline projection is based on the reduction in the embodied carbon of Portland cement as presented in the MPA publication UK Concrete Industry Sustainable Construction Strategy Framework (2) and the MPA Roadmap published in 2020 (3). The proportion of Portland cement replacement using SCMs is assumed to remain constant at 20%. This represents the average use of SCMs in

concrete produced in the UK (7). The baseline projection assumes no reduction in emissions due to carbon capture and use (CCU) or carbon capture and storage (CCS). Reductions in embodied carbon are principally due to projected switching to biomass fuel; current UK guidance is that any biomass portion of fuels is classified as carbon neutral¹.

The volume of new concrete produced is projected to increase in tandem with GDP growth. However, the rate of growth of concrete production is expected to be lower than that of GDP.

This scoping study assumes that concrete production increases at half the rate of GDP growth.

The baseline projection is shown in **Figure 1**, while the projected embodied carbon of Portland cement is shown in **Figure 2**.

Historical GDP since 2018 is taken from the ONS website (4).

Projected GDP growth is in accordance with forecasted Global Trade Outlook figures published by the UK government in 2023 (5).

Historical UK concrete production since 2018 is based on the European Ready Mix Concrete Organisation (ERMCO) annual statistics reports (6).

¹ Phase 2 of this study may remove future increases in the use of biomass from the baseline. This will allow biomass to be included as one of the carbon reduction measures assessed.

3.0

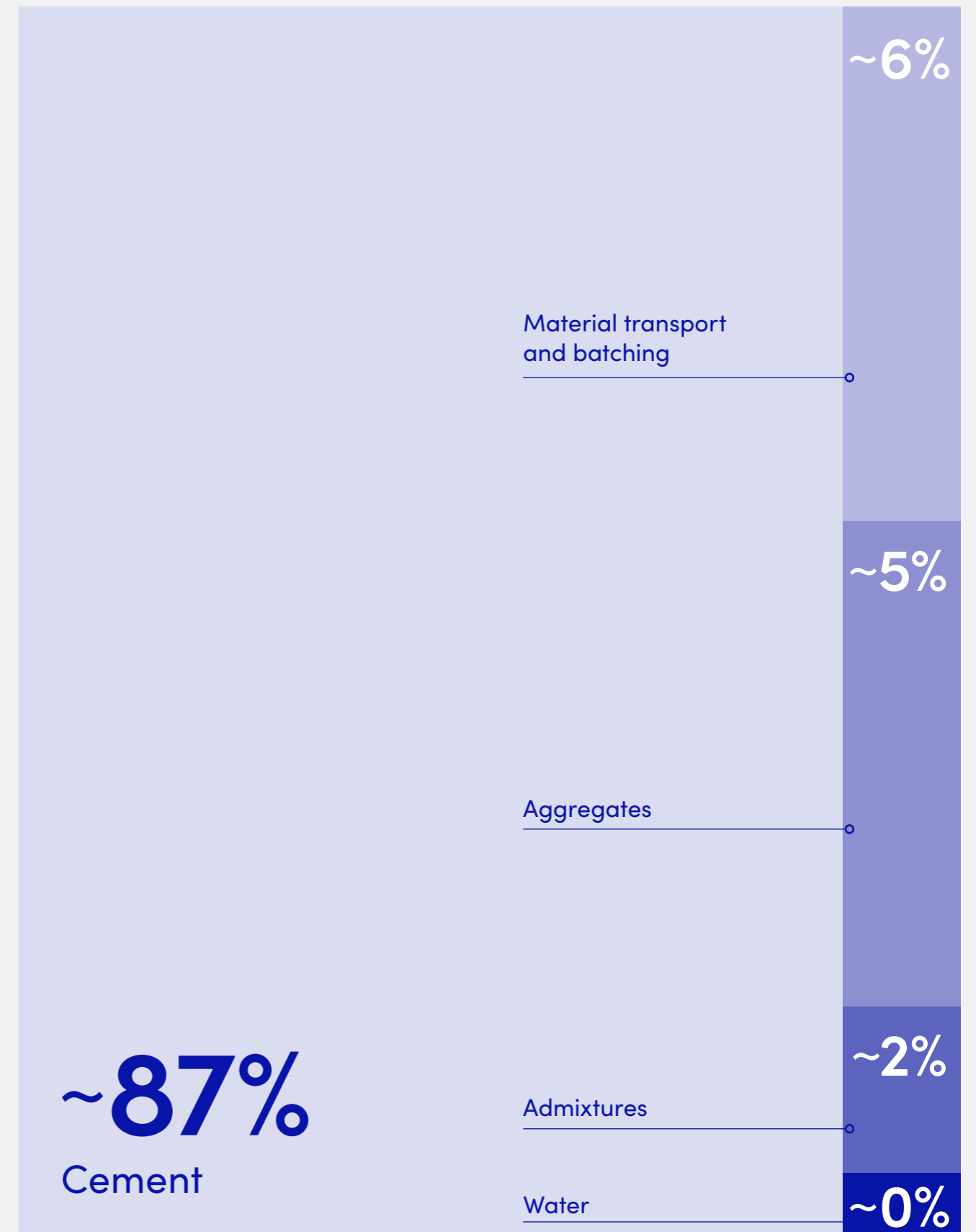
Typical allocation of embodied carbon of concrete

A large majority of the embodied carbon of concrete is attributable to the cement content. This is largely due to the release of carbon dioxide when limestone is broken down during the production of clinker to make Portland cement.

Reducing carbon emissions arising from Portland cement production is a core element of reducing the embodied carbon of concrete.



Figure 3: Extract from the LCCG Low Carbon Concrete Routemap (8).



“CCU” or “CCS” ... but not “CCUS”

This study distinguishes between:

CCU Carbon Capture and Use

Instead of being released into the atmosphere, the carbon is captured and repurposed to create economically valuable material.

CCU may enable factories producing clinker for Portland cement to create economic value from the CO₂ currently discharged into the atmosphere. This may improve profitability.

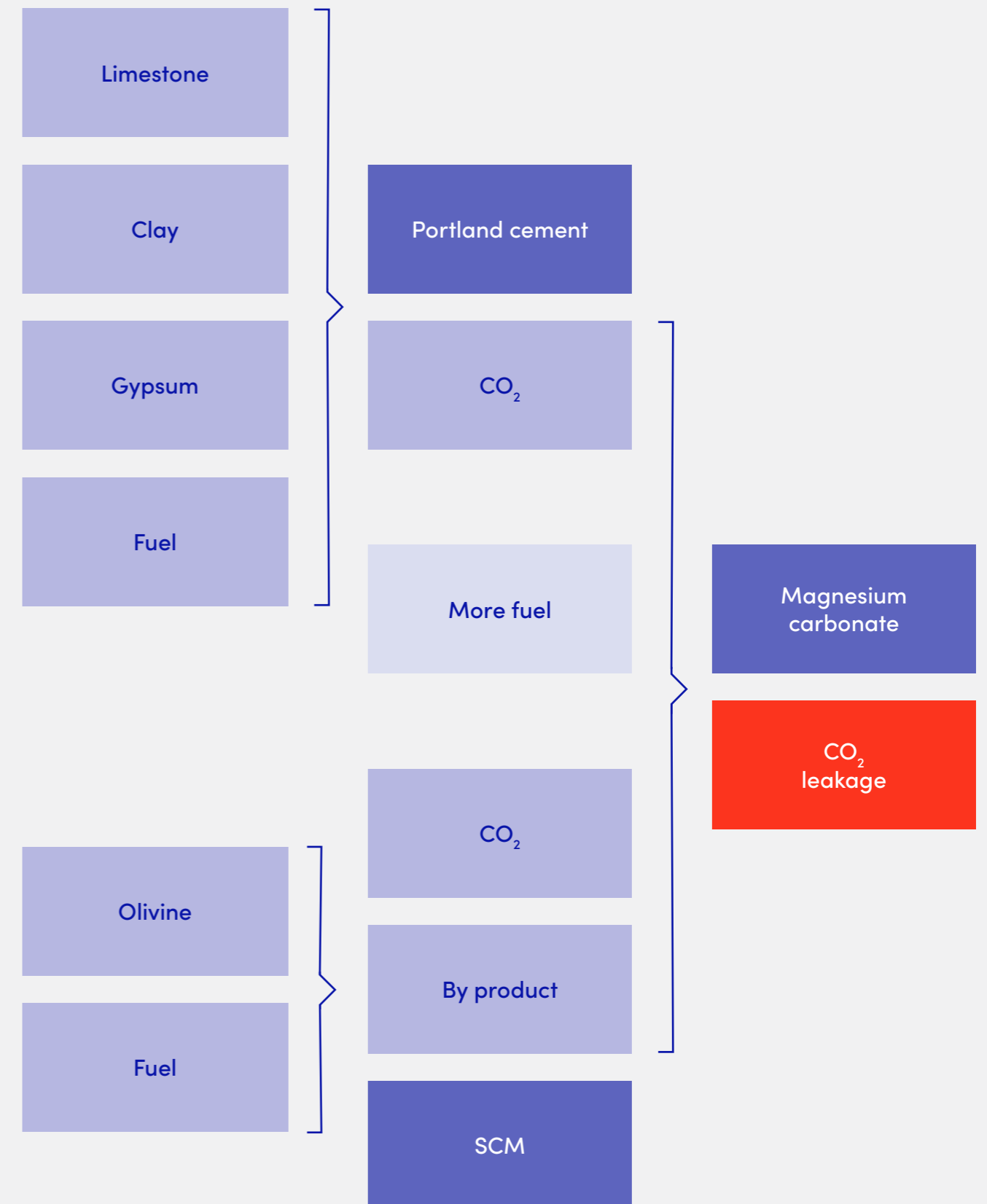
CCS Carbon Capture and Storage

The captured carbon is stored in a manner that adds no financial value.

CCS will add cost to factories producing clinker for Portland cement. This will reduce profitability.

This study does not use the abbreviation CCUS.

Figure 4: An example of CCU to create additional financial value to factories producing Portland cement (image based on the processing proposed by Seratech).



Carbon reducers and carbon eliminators

Some carbon reduction measures can only reduce carbon emissions.

Carbon reducers are critical to delivering short-term reductions in emissions.

However, carbon reducers cannot by themselves deliver net zero.

Other carbon reduction measures have the potential to eliminate carbon emissions.

Carbon eliminators are key to closing the carbon gap.

Table 1 identifies the principal approaches to reducing and eliminating embodied carbon.

Currently, industry effort is principally focussed on approaches 2, 3 and 7. Approaches 4 and 6 in particular may warrant additional attention.

There are many existing and emerging carbon reducers.

There are several emerging potential carbon eliminators.

Due to limited resources in the scoping study it was only possible to model a limited number of representative carbon reducers and potential carbon eliminators.

The carbon reducers and potential carbon eliminators modelled in this study are summarised in Appendix A. The associated embodied carbon for cementitious materials is summarised in Figure 5.

Figure 5 suggests that cementitious materials now considered low carbon such as GGBS and calcined clay may in 5 to 10 years be viewed as higher carbon materials.

Table 1: Principal approaches to reducing and eliminating embodied carbon.

Avoid the potential to generate GHG emissions

1 Use concrete more efficiently to reduce the volume of concrete required to deliver the required utility	Reducer
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Minimise the residual GHG emissions to be managed

2 Use less clinker ^a in concrete	Reducer
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3 Reduce the embodied carbon of the clinker	Reducer
---	---------

4 Zero clinker concrete	Potential eliminator
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5 Reduce the embodied carbon of the non-cementitious constituents	Reducer
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6 CCU to create material with financial value	Potential eliminator
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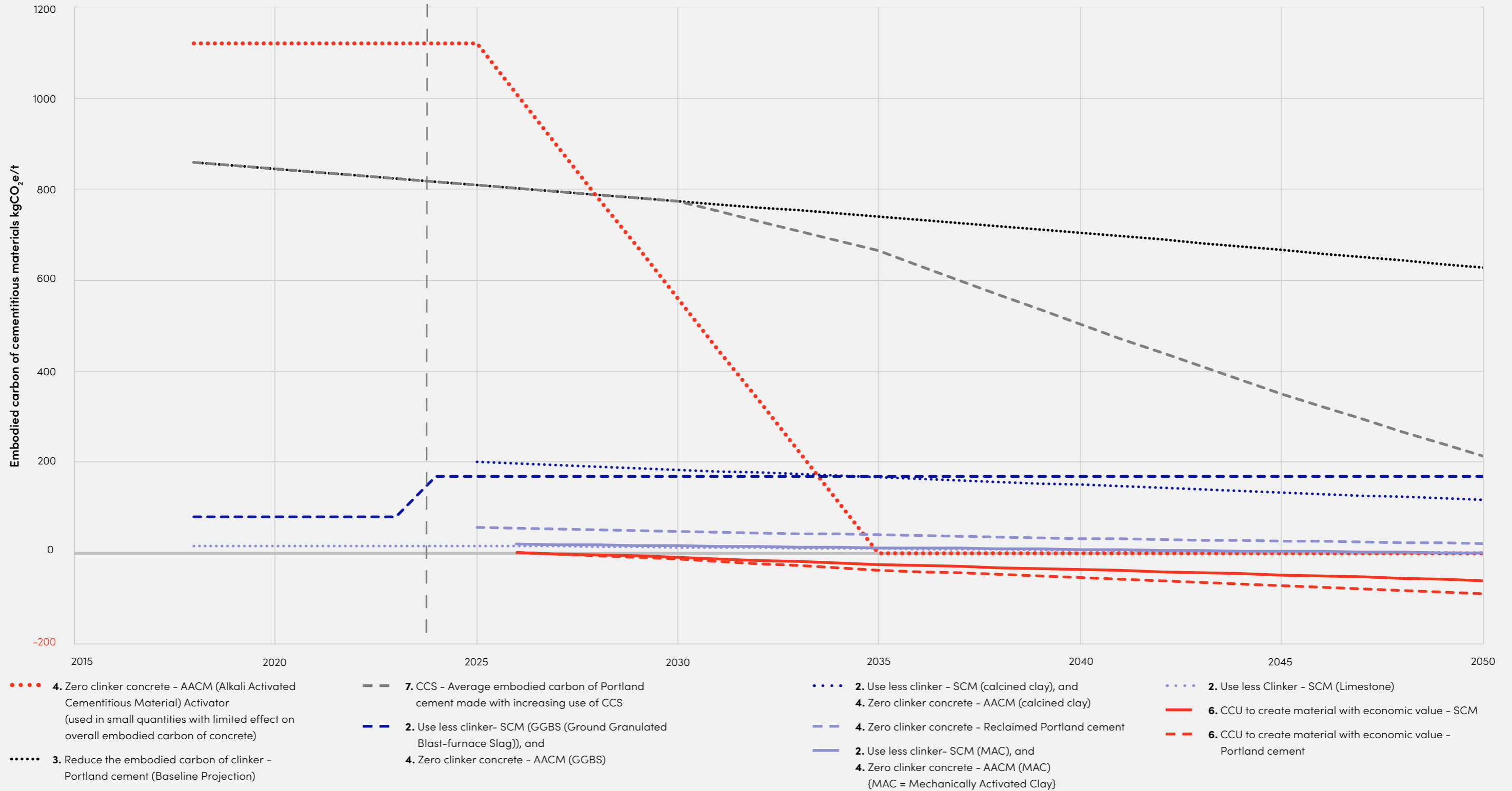
Manage the residual GHG emissions

7 CCS	Potential eliminator
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Notes to table 1

a) Clinker is the principal ingredient of Portland cement. It is made by heating limestone and clay. During the heating process, the limestone breaks down to release carbon dioxide. This is the principal contributor to the embodied carbon of Portland cement.

Figure 5: Projected embodied carbon of cementitious materials.



Notes to Figure 5

The values of embodied carbon are based on the MPA Roadmap (Portland cement), industry guidance, discussions with suppliers and product developers, and modelling completed as part of this scoping study. The numbers in the key relate to the carbon reduction or elimination approaches identified in Table 1. The key also identifies the

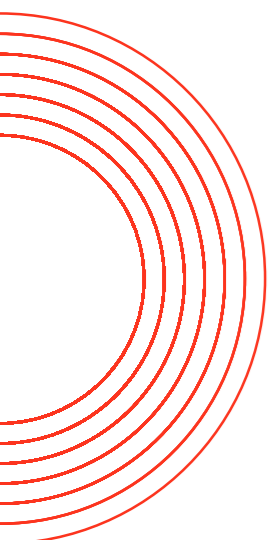
cementitious material for which the curve shows the projected embodied carbon. Where the embodied carbon projection is based on discussion with a single supplier or product developer, the relevant organisation is also identified. The numerical modelling for Figure 5 assumes that, for all the materials, the balance between biomass and other fuels used for

thermal energy is the same as in the MPA Roadmap projection. In accordance with current UK guidance, any biomass portion of fuels is classified as carbon neutral. Carbon dioxide generated during the manufacturing process, which

is captured and permanently sequestered using CCU or CCS does not contribute to the embodied carbon of the cement. CCU or CCS which sequester CO₂ from biomass remove carbon dioxide from the atmosphere. This reduces the calculated embodied carbon and may result in cement with negative embodied carbon.

6.0

Readiness and timelines for scaling



Some of the carbon reducers are at a technology readiness level (TRL) which has already enabled utilisation to the maximum current potential. For example, use of GGBS as an SCM is at TRL 9; nearly all GGBS produced globally appears to be fully utilised, principally as an SCM to replace Portland cement (9).

Some further carbon reducers are in principle sufficiently developed to be used at scale. However, these reducers may deliver insufficient financial advantage to encourage adoption. In many usages significant reductions in concrete volume used could deliver the intended utility, however, there is often lower cost or higher value in constructing a form which uses more concrete. For example:

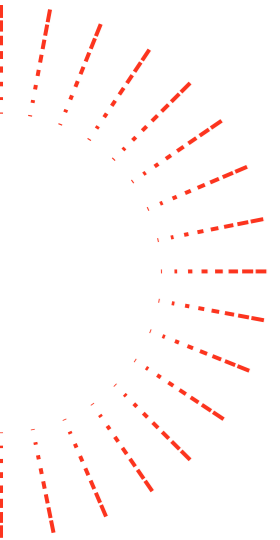
- It is usually more economical to construct solid concrete slabs rather than using more complicated formwork to create voids which can substantially reduce the volume of concrete used.
- Reduced spans between walls and columns can substantially reduce the volume of concrete required in building structures. However, a financial balance must be reached between the value of the larger open spaces and the cost of the additional material that is required to form structures that span further.

Other carbon reducers and all of the potential carbon eliminators are at earlier TRLs. Although many show potential to deliver substantial reductions in carbon emissions, further development is required to demonstrate performance, establish pilot plants, and scale production.

In this scoping study the TRL and programme for scaling are in part informed by the views of the individuals and organisations developing the carbon reducers and potential carbon eliminators discussed. This requires further investigation and assessment in the next study phase.

TRLs are not the only barriers to adoption at scale. Other barriers include cost, availability of industry guidance, in-house standards, access to finance and insurance, availability of precedents, and client and supply chain expectations.





Making money by reducing carbon

Carbon reducers and carbon eliminators are unlikely to be adopted at scale across the concrete sector unless they deliver larger or at least similar levels of profit as other options.

Existing production facilities are unlikely to be decommissioned or modified to reduce or eliminate carbon emissions, unless such changes result in increased profits.

7.1 The cost and monetary value of carbon

There is a wide variation in the expected costs of

- Releasing CO₂ to the atmosphere

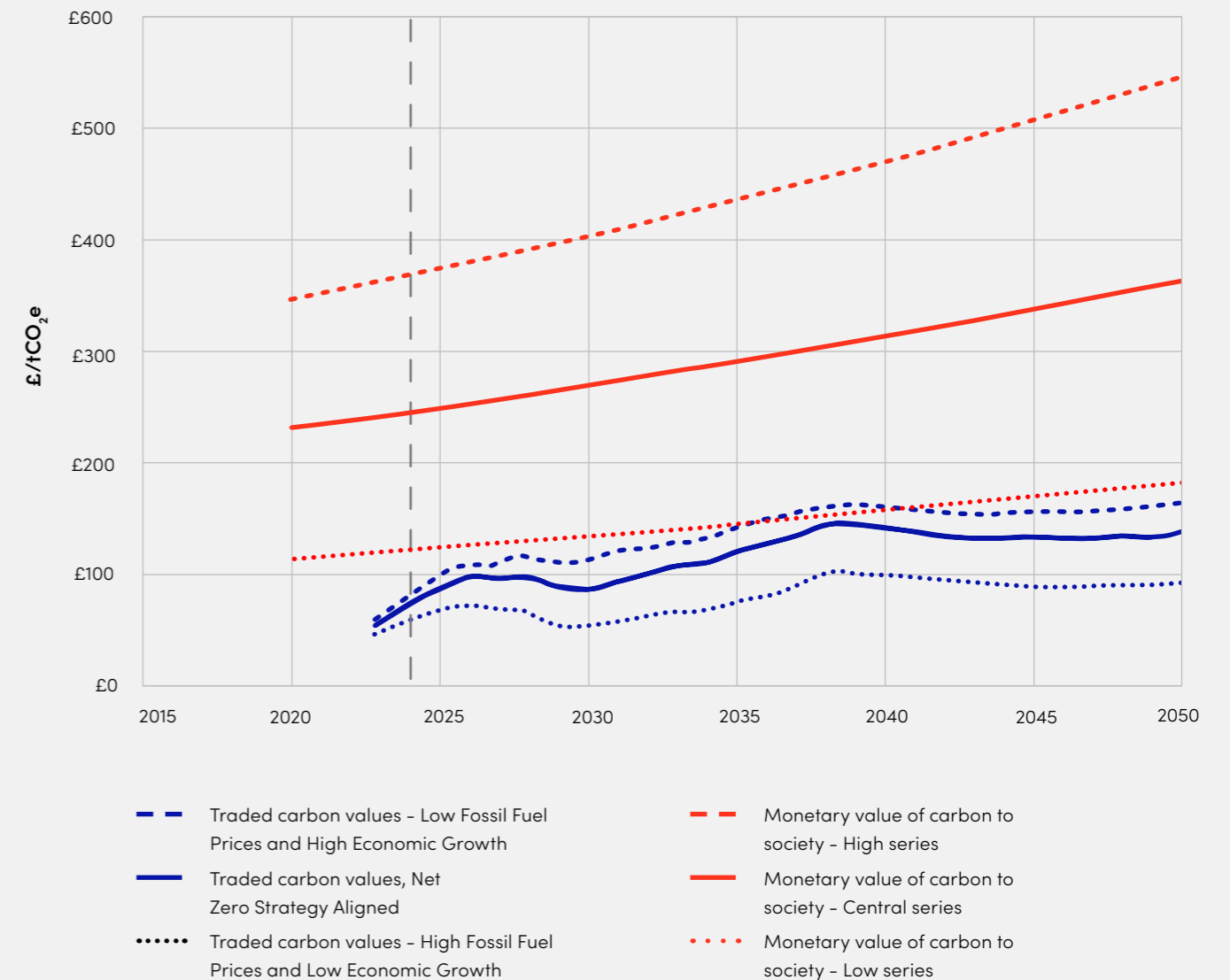
- Capturing CO₂
- Transporting and then permanently storing CO₂.

There is also a wide variation in the expected monetary value to society of releasing CO₂ into the atmosphere.

DESNZ provides clear guidance on

- The carbon values consistent with the UK's national and international climate commitments (to be used for policy appraisal) (13).
- The traded cost of carbon i.e. the cost of purchasing allowances within the UK Emissions Trading Scheme (14).

Figure 6: DESNZ guidance on the traded cost and value to be used for policy appraisal.

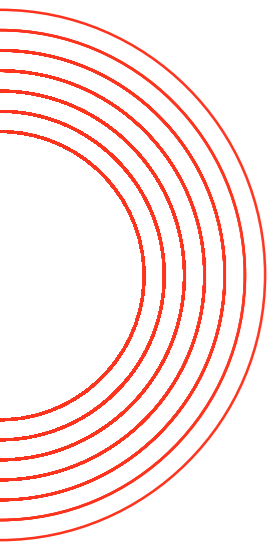


The projected traded carbon values are substantially below the target consistent carbon values as shown in **Figure 6**. This suggests that the UK ETS in isolation will not drive the carbon reductions that are required to meet the UK's national and international commitments.

Free allocation of carbon credits under the UK Emissions Trading Scheme (ETS) is currently based on clinker production (15). This free allocation is calculated

using a benchmark value derived from the embodied carbon of the top 10% most efficient clinker production. Broadly speaking, if producer output increases, the number of free allowances received also increases. It appears likely that this approach will continue at least until 2030 (16). Free allocation after 2030 has not yet been determined.

Producers of clinker-free cements must buy carbon credits within the ETS for all GHG



emissions. As a result, there is currently a financial disincentive to adopt certain carbon reduction technologies.

If a Carbon Border Adjustment Mechanism (CBAM) is implemented the free allocation of carbon credits may be reduced or eliminated. In this scenario, there would be a stronger incentive to reduce the emissions associated with cement production. It may also allow policymakers to increase the traded price of carbon more rapidly than is suggested by the current DESNZ guidance. This would create a stronger financial case for the adoption of methods of carbon reduction and elimination.

In this scoping study:

- The monetary value to society of carbon emissions is based on the DESNZ Central Series.
- The cost for financial comparison of pathways is based on the DESNZ Net Zero Strategy Aligned carbon prices. In addition, it is assumed that there is a free allocation to clinker as summarised in Appendix A. The financial cost is the same regardless of whether the carbon is released to the atmosphere or captured and stored (CCS).

7.2 The cost of emerging carbon reducers and potential carbon eliminators

The products which are currently being developed are those which, it appears, will deliver cement and concrete at a lower financial cost than business as usual within the economic context described above.

Additional carbon reducers and eliminators are likely to be financially viable and be brought to market if the economic cost of carbon were increased to align with the target consistent carbon price.

7.3 Encouraging adoption of carbon reducers and carbon eliminators

To enable confidence in financial projections for the development and scaling of methods of carbon reduction and elimination:

- Authoritative guidance is required on the cost and availability of CCS.
- Clarity is required on the medium- and long-term free allocation of carbon credits under the ETS.

Implementing a regime in which the traded cost of carbon rises to align with the target consistent carbon price would provide an unambiguous financial incentive to reduce carbon emissions in line with the UK's national and international commitments.

All the above require action at government level.

7.4 The financial case for implementing carbon reducers and carbon eliminators

Table 2 summarises the economic case for the various carbon reducers and potential carbon eliminators. Table 2 has been prepared in the context of the carbon pricing arrangements described above.

Table 2: The financial case for adoption of carbon reducers and carbon eliminators.

Measure	Reducer / Eliminator	Current arrangements	Financial case for adoption
			If carbon costs rise to match policy appraisal values and free allowances are increasingly withdrawn
Avoid the potential to generate GHG emissions			
1 Use concrete more efficiently to reduce volume needed to deliver required utility	Reducer	Weak	Strong (until lower carbon concrete becomes available)
Minimise the residual GHG emissions to be managed			
2 Use less clinker in concrete	Reducer	Weak	Strong
3 Reduce the embodied carbon of the clinker	Reducer	Moderate	Strong
4 Zero clinker concrete	Potential eliminator	Disincentive	Strong
5 Reduce the embodied carbon of the non-cementitious constituents	Reducer	Weak	Moderate
6 CCU to create material with economic value	Potential eliminator	Potentially Strong	Strong (subject to the cost of CC and the price of products)
Manage the residual GHG emissions			
7 CCS	Potential eliminator	Weak without government subsidy	Moderate (subject to the cost of CCS)

8.0

Potential pathways to closing the gap

This section summarises potential pathways which the UK concrete sector could follow. The pathways are a development of those presented in Section 8 of the Low Carbon Concrete Routemap. The development of the pathways has been conducted by the LCCG as part of this scoping study and with reference to the Institution of Structural Engineers Concrete technology tracker (18).

To generate the pathways, the carbon reduction and elimination measures summarised in [Table 1](#) were implemented sequentially and cumulatively, broadly in line with the assessed technology readiness levels (TRLs). [Table 7](#) in [Appendix B](#) summarises the measures included in each pathway.

Figure 7: Pathways for the embodied carbon of concrete.

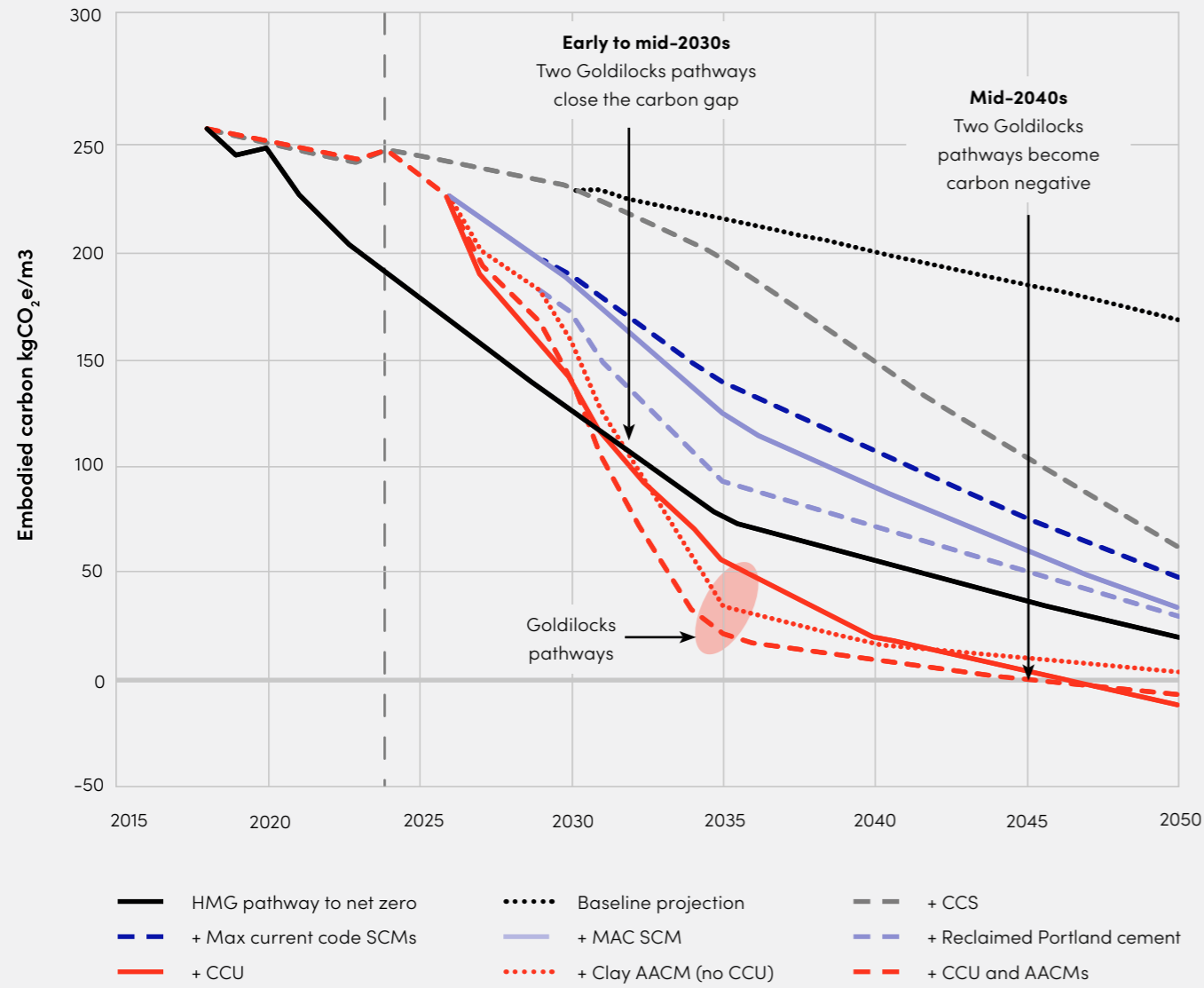
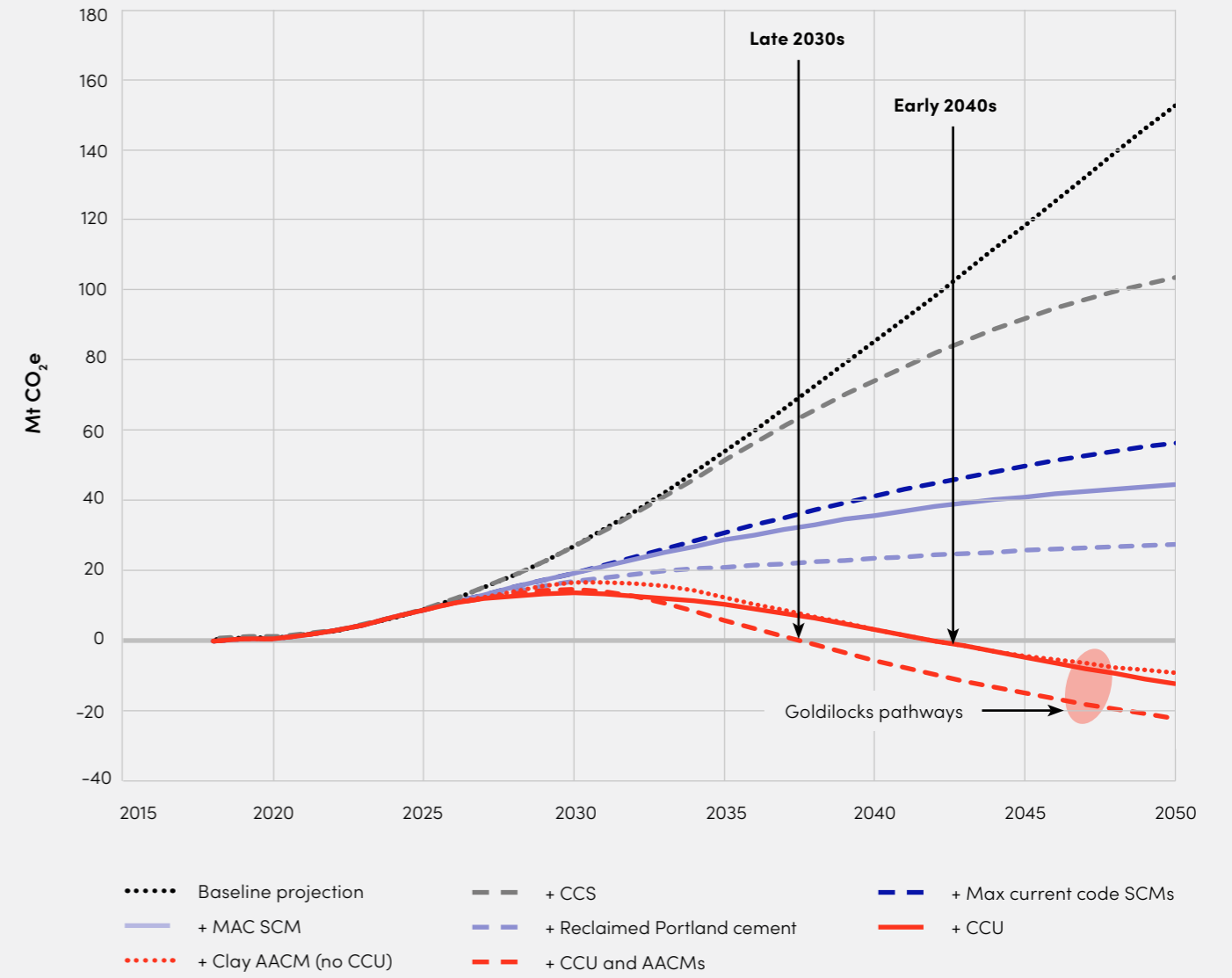


Figure 8: The cumulative carbon gap.



Goldilocks pathways

Figure 7 shows that three of the pathways close the carbon gap by the early to mid-2030s.

Figure 8 shows that these three pathways also close the cumulative carbon gap by the mid-2040s.

In this scoping study these three pathways are called the Goldilocks pathways.

The Goldilocks pathways make use of the carbon eliminators as summarised in Table 3. There are many approaches to CCU and several approaches to using reclaimed cement. In the Goldilocks pathways, Cambridge Electric Cement and Seratech concrete are used to represent the use of reclaimed Portland cement and CCU respectively.

Assumptions

The pathways indicate potential. Modelling of the pathways includes assumptions. The assumptions need to be tested to determine the extent to which the potential can be delivered.

Table 4 summarises the principal assumptions that require further investigation. The pathways will be updated as the investigations identify

additional information. Investigation of the assumptions will also inform future work that is required to enable implementation of the carbon reducers and eliminators.

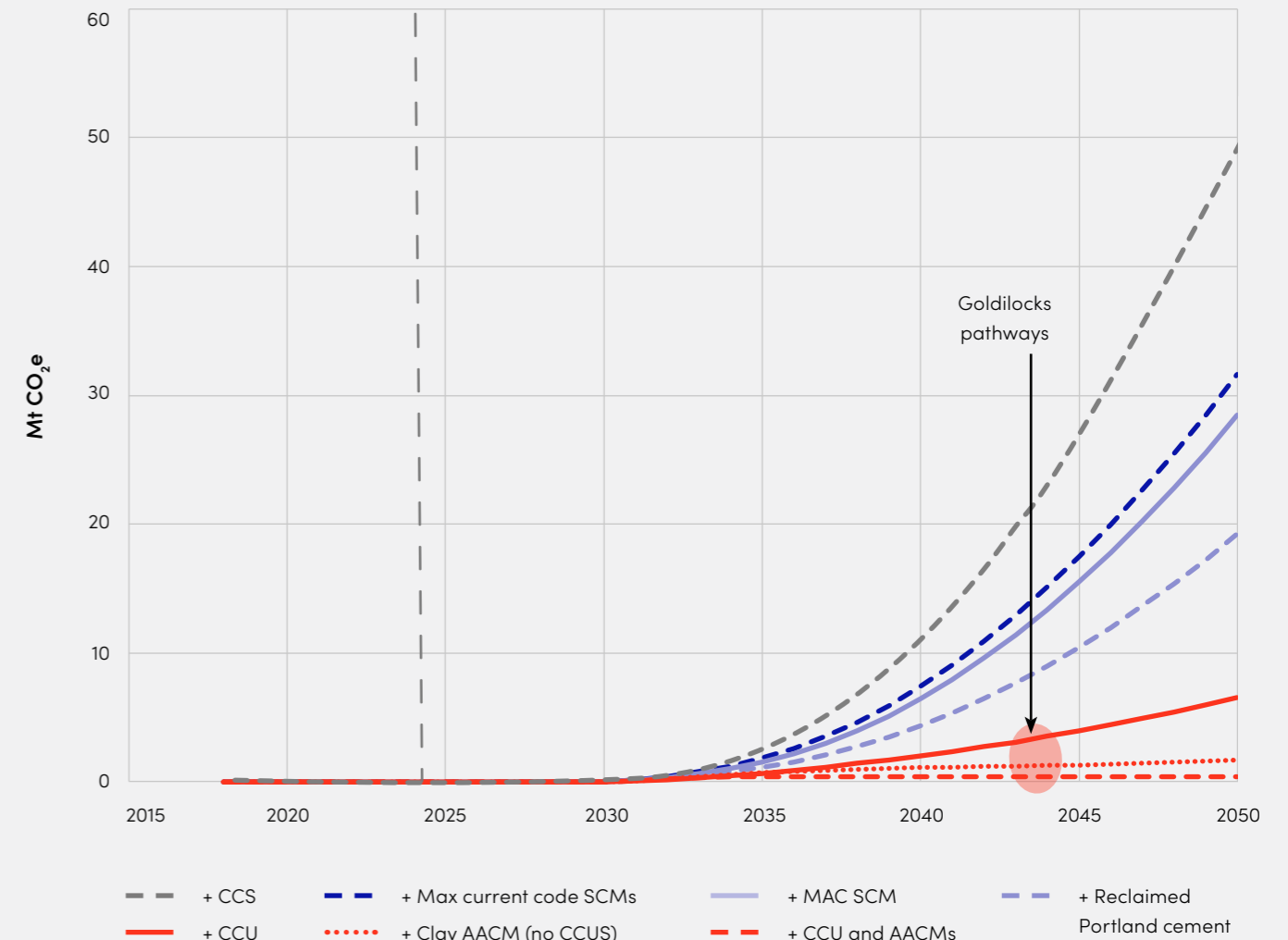
Table 3: Carbon eliminators used in the Goldilocks pathways.

Pathway	Carbon eliminators used	Notes on code compliance
+ CCU	Reclaimed Portland cement CCU CCS	Concretes and constituents that are close to compliance with existing UK concrete codes. Limited development of the codes required.
+ Clay AACM (no CCU)	Reclaimed Portland cement AACMs based on Clay CCS	Concretes and constituents will require substantial development of the UK codes before adoption at scale.
+ CCU and AACMs	Reclaimed Portland cement CCU AACMs based on clay and the products of CCU CCS	

Notes on Table 3:

The Goldilocks pathways use limited CCS on the flue gases from kilns for calcining clay and residual Portland cement factories which do not use CCU.

Figure 9: Cumulative use of CCS.



Use of CCS

Figure 9 summarises the cumulative use of CCS for each pathway.

Pathways which make less use of CCS are less reliant on successful scaling of CCS. These pathways also leave more successfully developed CCS capacity available for use by other industries.

The IEA, among others, suggest that there will be over-demand for the CCS capacity that is being developed: "CCUS deployment

has been behind expectations in the past but momentum has grown substantially in recent years, with over 500 projects in various stages of development across the CCUS value chain. Nevertheless, even at such level, CCUS deployment would remain well below what is required in the net zero Scenario." (16)

Therefore, pathways which make less use of CCS may assist the wider drive for society to meet net zero.

Financial cost and social value

Figure 10 indicates that, as well as reducing GHG emissions, all of the pathways explored in this scoping study are expected to deliver financial benefits relative to the baseline projection. This is true regardless of whether we use the traded cost of carbon or the target consistent carbon price. The Goldilocks pathways are projected to have the largest financial benefit. These financial projections need to be tested once the cost

of CCU, CCS, and zero clinker concrete have been further researched.

Since the Goldilocks pathways deliver the largest reductions in emissions, they are projected to yield the greatest monetary benefits to society. This is summarised in Figure 11.

Figure 10: Cumulative financial benefit relative to baseline projection.

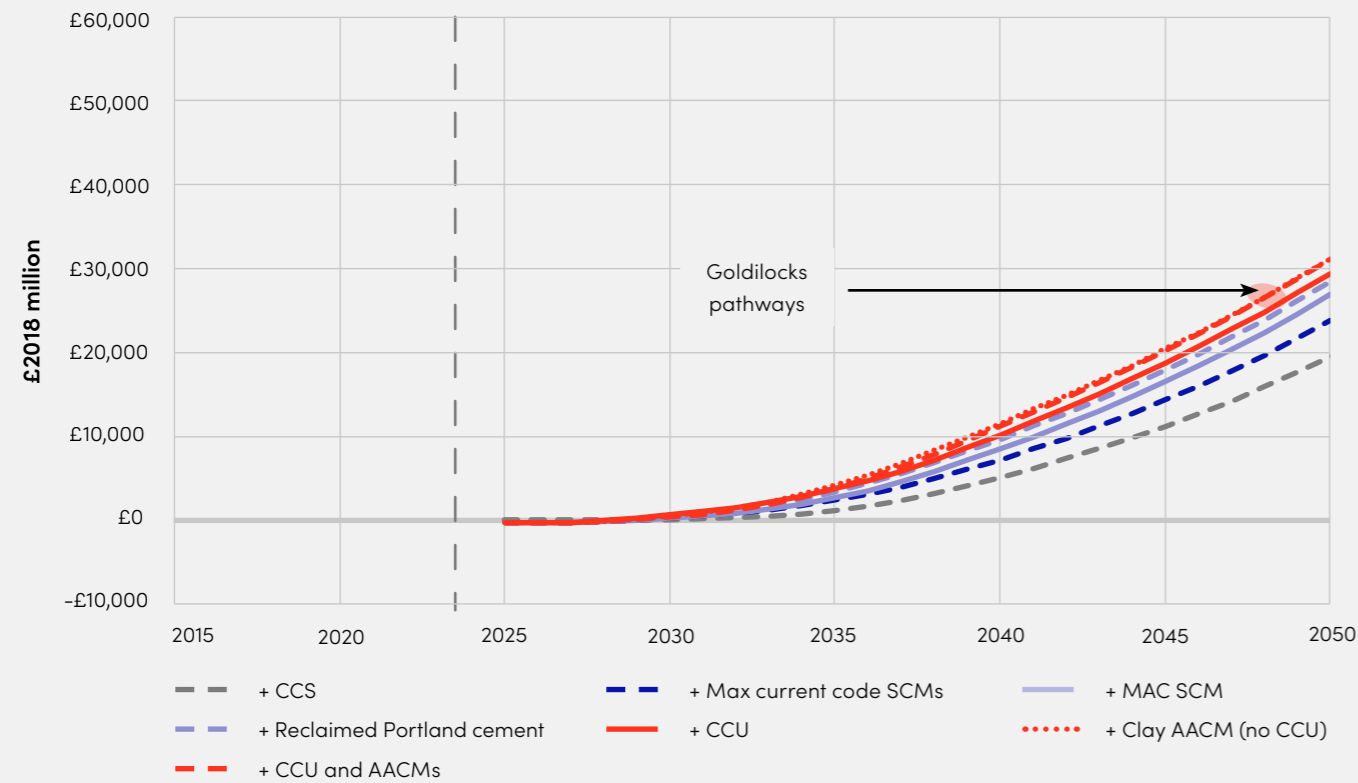


Figure 11: Cumulative beneficial monetary value to society relative to baseline projection.

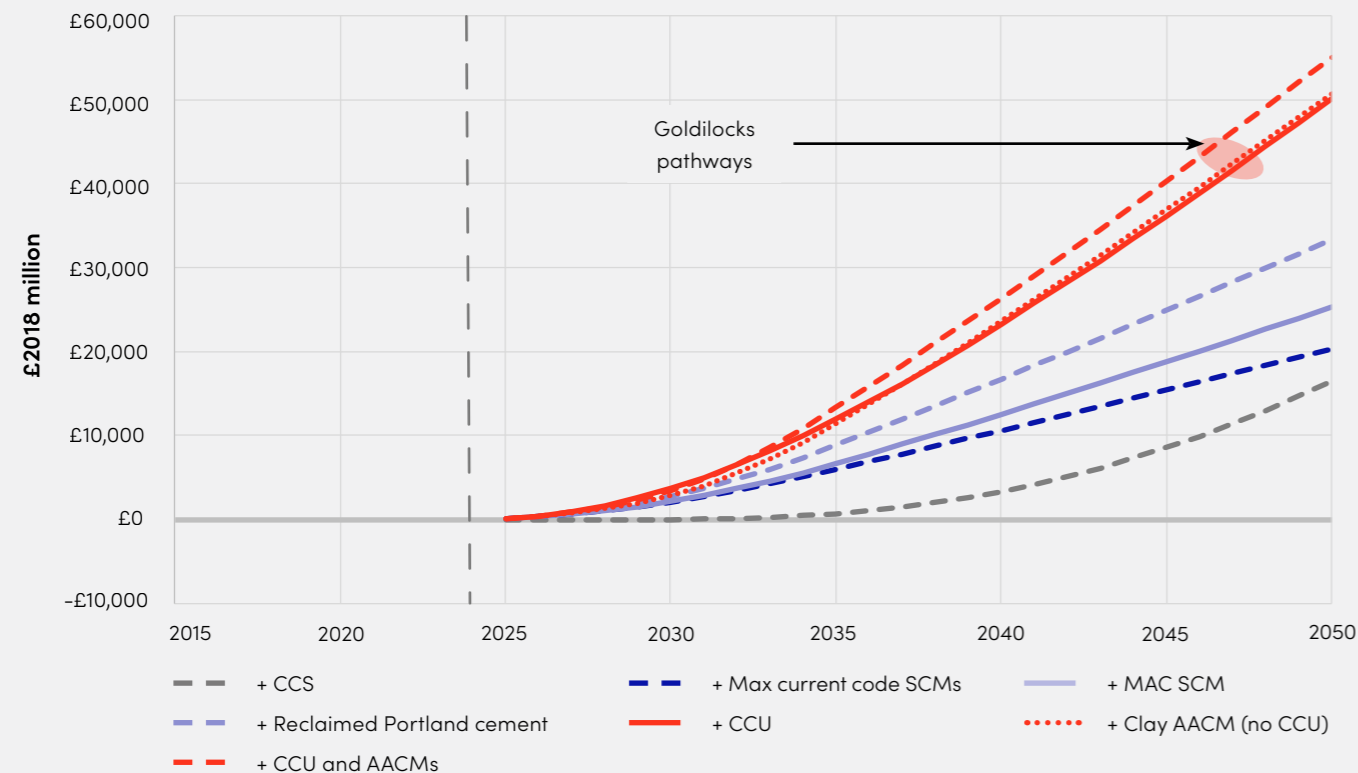


Table 4: Principal pathway assumptions requiring further investigation.

Method of carbon reduction or elimination	Principal assumptions requiring further investigation
Avoid the potential to generate GHG emissions	
1 Use concrete more efficiently to reduce volume needed to deliver required utility	Financially realistic projections for medium- and long-term improvements in efficiency.
Minimise the residual GHG emissions to be managed	
2 Use less clinker in concrete	Programme for scaling of UK calcined clay production. Technical viability and programme for development and scaling of UK mechanically activated clay production. Extent to which clinker use will be reduced by improved mix design, aggregate grading etc.
3 Reduce the embodied carbon of the clinker	The availability of sustainable biomass. Whether production of Portland cement is the best use of sustainable biomass, which is a constrained resource.
4 Zero clinker concrete	Suitability of clay available in the UK for use as an AACM. Suitability of the products of CCU for use as an AACM instead of as an SCM. Extent of development of current guidance, and time required.
5 Reduce the embodied carbon of non-cementitious constituents.	The rate at which carbon will be reduced.
6 CCU to create material with economic value	Technical viability of scaling, including possible integration into existing cement factories. Availability, price, and embodied carbon of raw materials. Successful use of by-products to create material with financial value. Carbon leakage through the capture process.
Manage the residual GHG emissions	
7 CCS	The cost and capacity available to the concrete sector. Carbon leakage through the capture process.

Conclusions and next steps

It appears to be technically and financially viable for the UK concrete sector to move onto the HMG Industrial Pathway to net zero by the early to mid-2030s. This report has outlined the importance of such “Goldilocks pathways”.

Using concrete based on Portland cement, with only limited requirement for development of the current codes may achieve this. It appears that all parts of the concrete supply chain should be able to make money doing this.

Use at scale of concretes which do not include Portland cement could also provide a viable path to net zero. This will require the swift development of codes and standards for these products, as well as the redevelopment of existing infrastructure.

By activating such pathways and closing the gap by the early to mid-2030s, we can also eliminate the cumulative carbon gap before 2050. This is a pivotal opportunity for the sector, both in the UK and globally.

To deliver any of the pathways that *fully* close the gap, will require development and scaling of carbon eliminator technologies.

CCS necessarily carries a financial cost. In contrast, other carbon elimination technologies such as CCU and clinker-free concrete have the potential to avoid this financial penalty. CCU for instance has the potential to generate additional revenue streams by providing additional material of financial value, thereby improving financial returns.

Carbon elimination technologies needed to close the carbon gap are likely to include a combination of some or all of the following:

- Reclaimed Portland cement
- CCU in the production of Portland cement
- SCMs with near zero embodied carbon
- Concretes which do not include Portland cement
- CCS

A concerted effort across the entire supply chain as well as clear signalling from government and clients will be required to close the carbon gap.

The current arrangement of carbon credits and carbon pricing provide little financial incentive to develop lower carbon alternatives. By allocating free carbon credits to clinker but not

to clinker alternatives, the system disincentivises development of certain lower carbon options.

Measures which reduce the free allocation of carbon credits for clinker production, or which raise the traded price of carbon would increase the financial incentive to develop lower carbon technologies to reduce GHG emissions arising from the use of cement and concrete.

Figure 12 summarises priority actions for the UK concrete sector to close the carbon gap.

A second phase of this study is required to develop this action plan. The second phase should include:

- Testing and developing of the assumptions and analyses included in this scoping study.
- Assessment of a wider range of carbon reduction and, particularly, carbon elimination technologies than could be included in the scoping study.
- Identification of core technologies which should be tested and, if suitable, developed.
- A comprehensive action plan detailing required actions, deadlines for completion, responsible parties, and potential funding arrangements.



Figure 12: UK concrete: priority actions to close the carbon gap.

Short-term and ongoing carbon reduction

Maximise use of the carbon reducers

1. Use concrete more efficiently

2. Reduce clinker content

- Use concrete of the lowest suitable strength class.
- Increase use of SCMs through:
 - Maximising the use of limestone.
 - Developing mechano-chemical activation of clay.
 - Reducing the embodied carbon of calcined clay.
 - Ensuring adequate funding for the assessment of fly ash from stockpiles
 - Continuously assessing optimal GGBS use to minimise global rather than project-specific emissions.

3. Continue to reduce the embodied carbon of clinker



Act NOW for medium and long term carbon reduction

Focus on potential eliminators

Priority 1: Near zero carbon Portland cement

- Develop and scale use of reclaimed Portland cement technology.
- Develop and scale CCU technologies which add value and deliver very low embodied carbon Portland cement.
 - Support guidance for the uses of the resulting volumes of material containing the sequestered carbon.

Priority 2: Near zero carbon SCMs (beyond 20% limestone)

- Develop and scale technologies such as lower carbon activated clay.
- Get the code guidance ready in advance or in parallel.

Priority 3: Clinker-free concrete

- Assess available clays for use in AACM concrete.
- Develop options for the use of other AACMs, such as using material arising from the Seratech process.
- Prepare code guidance in advance of, or in parallel with, product development.
 - Code development must be proactive. Safe, but permissive. e.g. Flex 350.
 - Educate designers and industry to use the codes safely and proactively.

Priority 4: CCS

- Develop and scale any economical CCS options. If not needed by the concrete sector another sector will use the capacity.

Supported by the ongoing maximisation of the use of carbon reducers

Notes and references

Industry engagement

This scoping study has been discussed with the MPA. However, the MPA has not had sight of the completed report before publication. The MPA has provided the following statement:

"This scoping study has been discussed with the Mineral Products Association (MPA), the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and industrial sand industries in the UK. MPA consider it necessary for the study on closing the gap between GHG emissions and client pathways to net zero to properly consider the sector's active programme to decarbonise, as set out in the industry-recognised MPA UK Concrete and Cement Industry Roadmap to Beyond Net Zero. In depth engagement is required to ensure active projects are appropriately accounted for. The MPA does not agree with fundamental aspects of the scoping study. In particular:

- The MPA consider that CCS will have a larger role to play in decarbonising concrete in the UK than is assumed in the scoping study. Two major projects are being actively developed.
- Technologies proposed in the study are yet to be proven – for example, the Cambridge Electric Cement technology is an early-stage concept, with to date, no evidence of useable material equivalent to Portland cement being produced.
- The MPA remain to be convinced that clinker-free concrete and CO₂ sequestration in concrete will play as large a part in the decarbonisation of concrete in the UK as is assumed by some of the pathways described in this scoping study, and

- The MPA consider that alternative cement and concrete-specific pathways (one example being the SBTi pathway for cement) would be more appropriate for assessing GHG emissions arising from the production of cement and concrete in the UK than the Industrial decarbonisation pathway published by HM Government which covers all industrial sectors."

Study personnel

The scoping study was conducted by Bruce Martin for the LCCG. Bruce is an Associate Director at Expedition Engineering. The views and opinions expressed in this document are his and may not reflect those of other members of the LCCG.

Information and comment have been provided by:

- **Paul Astle** – Decarbonisation Lead, Ramboll
- **Professor Susan A. Bernal** – Chair in Structural Materials, University of Leeds and EPSRC Early Career Research Fellow
- **Dave Cotton** – Technical Director, Atkins Realis
- **Michal Drewniok** – Lecturer in Civil Engineering, University of Leeds
- **Hisham Hafez** – Research Fellow, University of Leeds
- **Aurelia Hibbert** – Senior Energy and Decarbonisation Consultant, Mott MacDonald
- **Dr Mike de Silva** – Principal Consultant, Sweet Spot Sustainability Consulting
- **John Ward** – Managing Director, Pengwern Associates and Visiting Senior Fellow at the Grantham Research Institute on Climate Change and the Environment
- **Dr Pete Winslow** – Director, Expedition Engineering



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Appendix A

Principal assumptions included in the scoping study

Table 5: Carbon reducers modelled in the scoping study.

Carbon reducers	Key assumptions
Use concrete more efficiently to reduce the volume of concrete required to deliver the required utility	
In some uses, the theoretical reduction in volume of concrete required to deliver the same utility is over 40%. However, there does not appear to be an economic case to achieve this.	The scoping study models a linear reduction in the volume of concrete required for constant utility from 0% in 2024 to 6% in 2030 with no further reduction thereafter.
Use less clinker (kg/m3) in concrete	
Specification of lower strength concrete + reduction in requirements for early strength gain.	The scoping study assumes small, near negligible, reductions will be delivered using this approach.
In theory, reductions in total cement content of 25% to 30% are often possible (ref: review of data underlying the LCCG Market Benchmark, 2023 Update). In practice, on average, a smaller reduction will be achieved.	
Optimise aggregate grading to reduce total cement content	The scoping study assumes small, near negligible, reductions will be delivered using this approach.
It is reported that optimisation of aggregate grading would reduce total cement content by around 15%.	
SCM – GGBS	This phase of the study assumes that GGBS is available in the UK at 20% of total cement use until 2024 Reduces linearly to 10% of total cement use in 2035 and remains at 10% of total cement use after that. (9) The embodied carbon of GGBS is taken as: • 80 kgCO ₂ e/t until 2024 (11) • 168 kgCO ₂ e/t after 2024 (12)
SCM – Factory blended limestone (15% to 20%)	The scoping study assumes that limestone is available for use as an SCM at 0% of total cement content in 2023 increasing linearly to 15% in 2030 after which the percentage will remain constant.

Carbon reducers	Key assumptions
SCM – Clay activated by calcination	This study assumes that calcined clay will become commercially available in the UK in 2025 and that, if required, the supply has the potential to grow to 50% of total UK cement use by 2035 and 100% by 2040. The cost of manufacturing calcined clay is taken to be 2/3 of the cost of manufacturing Portland cement. The traded cost of carbon calcination emissions is added to the manufacturing cost. It is assumed that on market entry calcined clay will be priced at cost parity with Portland cement, but that this will reduce linearly until 2030 when the cost will be in accordance with the paragraph above. The embodied carbon of calcined clay is taken to be 200 kgCO ₂ e/t in 2024. Kiln thermal emissions are projected to decrease at the same rate as MPA projections for the manufacture of Portland cement.
SCM – Clay activated by mechanico-chemical process	It is reported that mechano-chemical activation (MCA) may be more effective than calcination for activation of most clays sourced in the UK. While the total energy required is expected to be higher, mechano-chemical activation is powered by electricity from the grid and will therefore have a lower embodied carbon than current generation calcined clay. This study assumes that mechano-chemically activated clay will become commercially available in the UK in 2028 and that if required, the supply has the potential to grow to 50% of total UK cement use by 2035 and 100% by 2040. The cost of manufacturing mechano-chemically activated clay is taken to be 20% higher than the cost of manufacturing calcined clay. It is assumed that on market entry activated clay will be priced at cost parity with Portland cement, but that this will reduce linearly until 2035 when the cost will be in accordance with the paragraph above. The embodied carbon of mechano-chemically activated clay is taken to be 20 kgCO ₂ e/t in 2024 reducing linearly to zero in 2050 as the supply chain decarbonises.
Reduce the embodied carbon (kgCO₂e/t) of the clinker	
Included in the baseline projection, based on the estimates included in the MPA Roadmap.	In this approach the cost of concrete is assumed to remain constant (2018 prices), except for variations due to the traded cost of carbon.
Reduce the embodied carbon of the non-cementitious constituents	This is taken to include transport and batching plant emissions. The embodied carbon of the non-cementitious constituents is assumed to reduce linearly from 2018 to 2050. In this study the cost of the non-cementitious constituents is assumed to remain constant (2018 prices). The cost of the residual embodied is calculated as described above.

Appendix A (continued)

Principal assumptions included in the scoping study

Table 6: Potential carbon eliminators modelled in the scoping study.

Potential carbon eliminator	Key assumptions
Zero clinker concrete	
Reclaimed cement – Cambridge Electric Cement	About to undergo industrial scale trials. Scalable, although limited in the UK by the scale of steel production and by the quantity of demolition arisings. Production starts in late 2020s increasing to 2.6 Mt of Portland cement per year by 2035 after which production remains constant. Embodied carbon of Portland cement produced: 57 kgCO ₂ e/t in late 2020s reducing to 21 kgCO ₂ e/t in 2050.
AACM concrete based on clay activated by calcination	This study assumes that calcined clay will become commercially available in the UK in 2025 and that, if required, the supply has the potential to grow to 50% of total UK cement use by 2035 and 100% by 2040. The cost of manufacturing calcined clay is taken to be 2/3 of the cost of manufacturing Portland cement. The traded cost of carbon calcination emissions is added to the manufacturing cost. It is assumed that on market entry calcined clay will be priced at cost parity with Portland cement, but that this will reduce linearly until 2030 when the cost will be in accordance with the paragraph above. The embodied carbon of calcined clay is taken to be 200 kgCO ₂ e/t in 2024. Kiln thermal emissions are projected to decrease at the same rate as MPA projections for the manufacture of Portland cement.
AACM concrete based on clay activated using the mechanico-chemical process	It is reported that mechano-chemical activation (MCA) may be more effective than calcination for activation of most clay sourced in the UK. While the total energy required is expected to be higher, mechano-chemical activation is powered by electricity from the grid and will therefore have a lower embodied carbon than current generation calcined clay. This study assumes that mechano-chemically activated clay will become commercially available in the UK in 2028 and that, if required, the supply has the potential to grow to 50% of total UK cement use by 2035 and 100% by 2040. The cost of manufacturing mechano-chemically activated clay is taken to be 20% higher than the cost of manufacturing calcined clay. It is assumed that on market entry activated clay will be priced at cost parity with Portland cement, but that this will reduce linearly until 2035 when the cost will be in accordance with the paragraph above. The embodied carbon of mechano-chemically activated clay is taken to be 20 kgCO ₂ e/t in 2024 reducing linearly to zero in 2050 as the supply chain decarbonises.

Potential carbon eliminator	Key assumptions
CCU to create material with economic value	
Developer projects magnesium carbonate	Codes – Needs a semantic update of the codes to achieve SCM code compliance. Also needs comprehensive test regime to demonstrate performance (can use Flex 350 for AACM). Scalability – Olivine is globally abundant, including in parts of the UK. However, new mines will be required. TRL – Moving from lab to industrial trials. Timeline – Target 25% market share by 2035. Embodied carbon of products: <ul style="list-style-type: none"> Portland cement ≈ 0 kgCO₂e/t in late 2020s reducing to -90 kgCO₂e/t in 2050 SCM ≈ 0 kgCO₂e/t in late 2020s reducing to -60 kgCO₂e/t in 2050 Magnesium Carbonate ≈ 0 kgCO₂e/t in late 2020s reducing to -60 kgCO₂e/t in 2050 Cost: Developer projects viable profitability if marketed below the market price of Portland cement and SCM produced by the current supply chain. Developer projects magnesium carbonate will have significant economic value up to about 25% penetration of the Portland cement market, after that lower value uses as road base etc.
Seratech silica produced using flue gases from a biomass power station and used as an SCM or AACM.	Codes – Needs a semantic update of the codes to achieve SCM code compliance. Also needs comprehensive test regime to demonstrate performance (Can use Flex 350 for AACM). Scalability – Olivine is globally abundant, including in parts of the UK. However, new mines will be required. TRL – Moving from lab to industrial trials. Timeline – Target 25% market share by 2035 Embodied carbon of products: <ul style="list-style-type: none"> Electricity ≈ -150 kgCO₂e/MWh SCM ≈ -160 kgCO₂e/t Magnesium Carbonate ≈ -160 kgCO₂e/t Make AACM from olivine. Sequester CO ₂ to create magnesium carbonate by-product.
CCS	Assume CCS has notional 70% efficiency in 2024, increasing linearly to 90% in 2050. Assume no contribution from CCS until 2030, with 10% of residual cement production emissions captured and stored by 2035 and 50% (lower bound) to 90% (upper bound) captured and stored in 2050. Carbon pricing: For assessing the overall monetary value to society of carbon emissions the study uses the Central Series provided in “Valuation of greenhouse gas emissions: for policy appraisal and evaluation” (13). For assessing the economic viability of alternatives to clinker the study uses the Net Zero Strategy Aligned values provided in “Traded carbon values used for modelling purposes” (14). In addition, it is assumed that there is a free allocation to clinker of: 690 kgCO ₂ e/t clinker in the period 2021 to 2025 (15). 630 kgCO ₂ e/t in the period 2026 to 2030 (15). It is assumed that there will be no free allocation after 2030.

Appendix B

Carbon reducers and carbon eliminators included in each pathway

Table 7: Carbon reducers and carbon eliminators included in each pathway.

		Baseline projection	+ CCS	+ max current code SCMs	+ MAC SCM	+ reclaimed Portland cement	The Goldilocks pathways		
							+ CCU	+ Clay AACM (no CCU)	+ CCU and AACMs
1	Use concrete more efficiently to reduce the volume of concrete required to deliver the required utility		✓	✓	✓	✓	✓	✓	✓
2.1	Use less clinker in concrete	Specify lower strength concrete + Reduce requirements for early strength gain	✗	✗	✓	✓	✓	✓	✓
2.2		Optimise aggregate grading to reduce total cement content	✗	✗	✓	✓	✓	✓	✓
2.3		SCM – GGBS	✓	✓	✓	✓	✓	✓	✓
2.4		SCM – Factory-blended limestone	✗	✗	✓	✓	✓	✓	✓
2.5		SCM – Clay activated by calcination	✓	✓	✓	✓	✓	✓	✓
2.6		SCM – Mechanically activated clay (MAC)	✗	✗	✗	✓	✓	✓	✓
3	Reduce the embodied carbon of the clinker (traditional production of Portland cement)		✓	✓	✓	✓	✓	✓	✓
4.1	Zero clinker concrete	Reclaimed Portland cement	✗	✗	✗	✗	✓	✓	✓
4.2		AACM concrete using clay activated by calcination	✗	✗	✗	✗	✗	✓	✓
4.3		AACM concrete using mechanically activated clay (MAC)	✗	✗	✗	✗	✗	✓	✓
5	Reduce the embodied carbon of the non-cementitious constituents		✓	✓	✓	✓	✓	✓	✓
6.1	CCU to create material with economic value	SCM produced as part of a process which includes CCU on flue gases of a traditional cement factory	✗	✗	✗	✗	✓	✗	✓
6.2		AACM produced as part of a process which includes CCU on flue gases of a traditional cement factory	✗	✗	✗	✗	✗	✗	✓
7	CCS on flue gases of cement factory and / or kiln for clay calcination		✗	✓	✓	✓	✓	✓	✓

Appendix C

Representative processes for reclaimed Portland cement and CCU

Reclaimed Portland cement: The Cambridge Electric Cement process for reclaimed Portland cement

Description

Reclaim cement paste from demolition arisings

Heat to 1400 °C to reactivate the cement paste, after grinding etc. This can then be re-used as Portland cement

- Can heat: In an existing clinker kiln (but limited to 10 to 15%), in a steel furnace, or independently.
- Synergies work well heating in an EAF steel furnace.
- The vast majority of the furnace thermal energy can be provided electrically from the decarbonised grid.
- But some lime must be added as flux for the furnace.
- The process emissions from forming the lime constrain the potential to eliminate embodied carbon.

Projected to deliver a profit if Portland cement arising is sold at cost parity with Portland cement from traditional cement factories.

Current Technology Readiness Level

TRL 4 (About to undergo industrial scale trials - TRL 5)

Scalability

Significant, although limited in the UK by the scale of steel production and by the quantity of demolition arisings

Key actions that will accelerate adoption

Engagement by code committees and completion of testing regime

Early take up in concrete which does not need to be demonstrated to be code compliant.

For example

- Cinder blocks.
- Incorporation into projects of sufficient scale to accommodate the cost of testing to demonstrate performance.

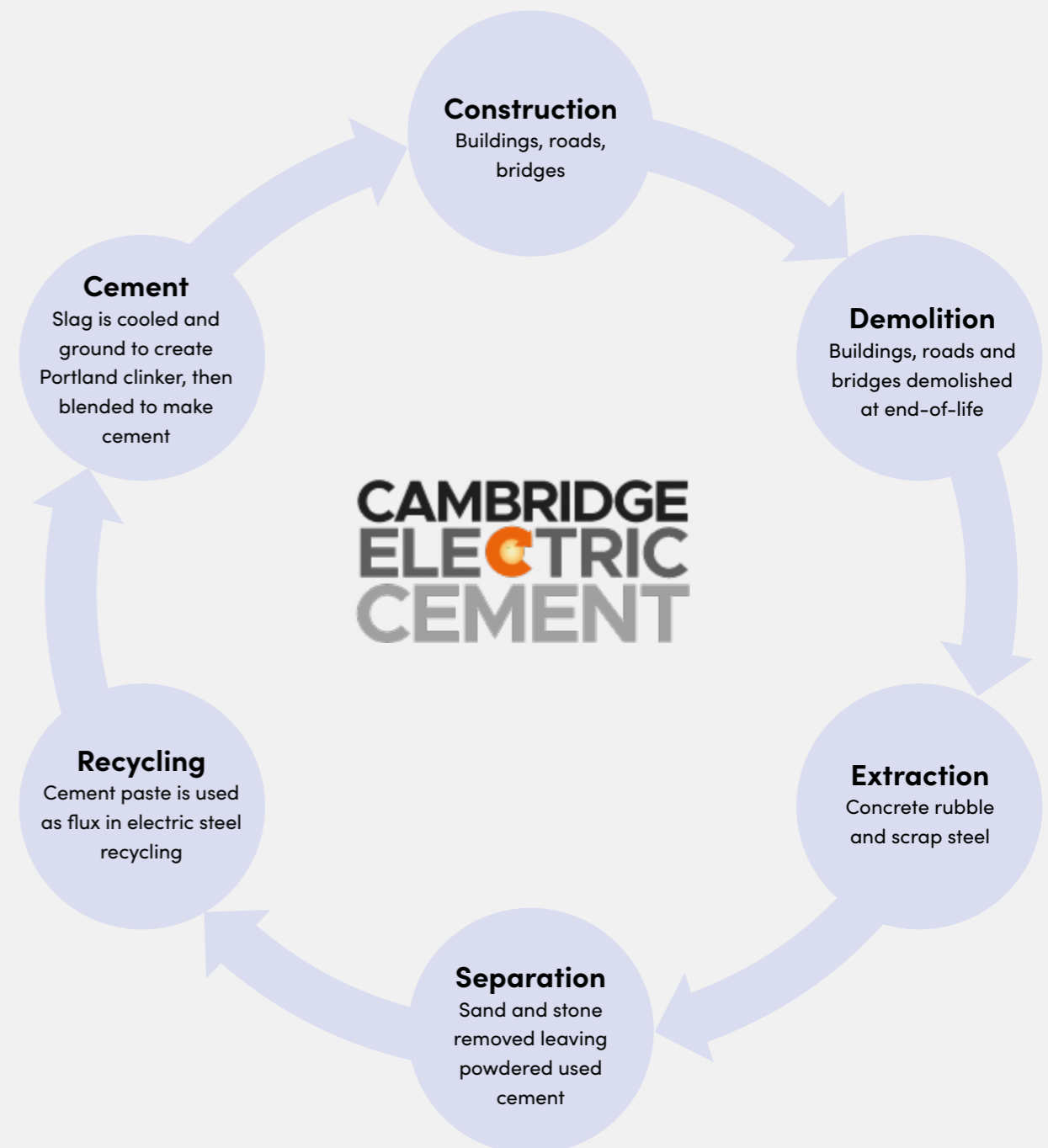
Principal barriers to be addressed

Portland cement produced includes some inert material (e.g. sand)

- Needs a semantic update of the codes to achieve code compliance.
- Also needs comprehensive test regime to demonstrate performance.

Inertia to incorporate into EAF facility, although good progress is being made

Introducing Cambridge Electric Cement, no emissions, no landfill



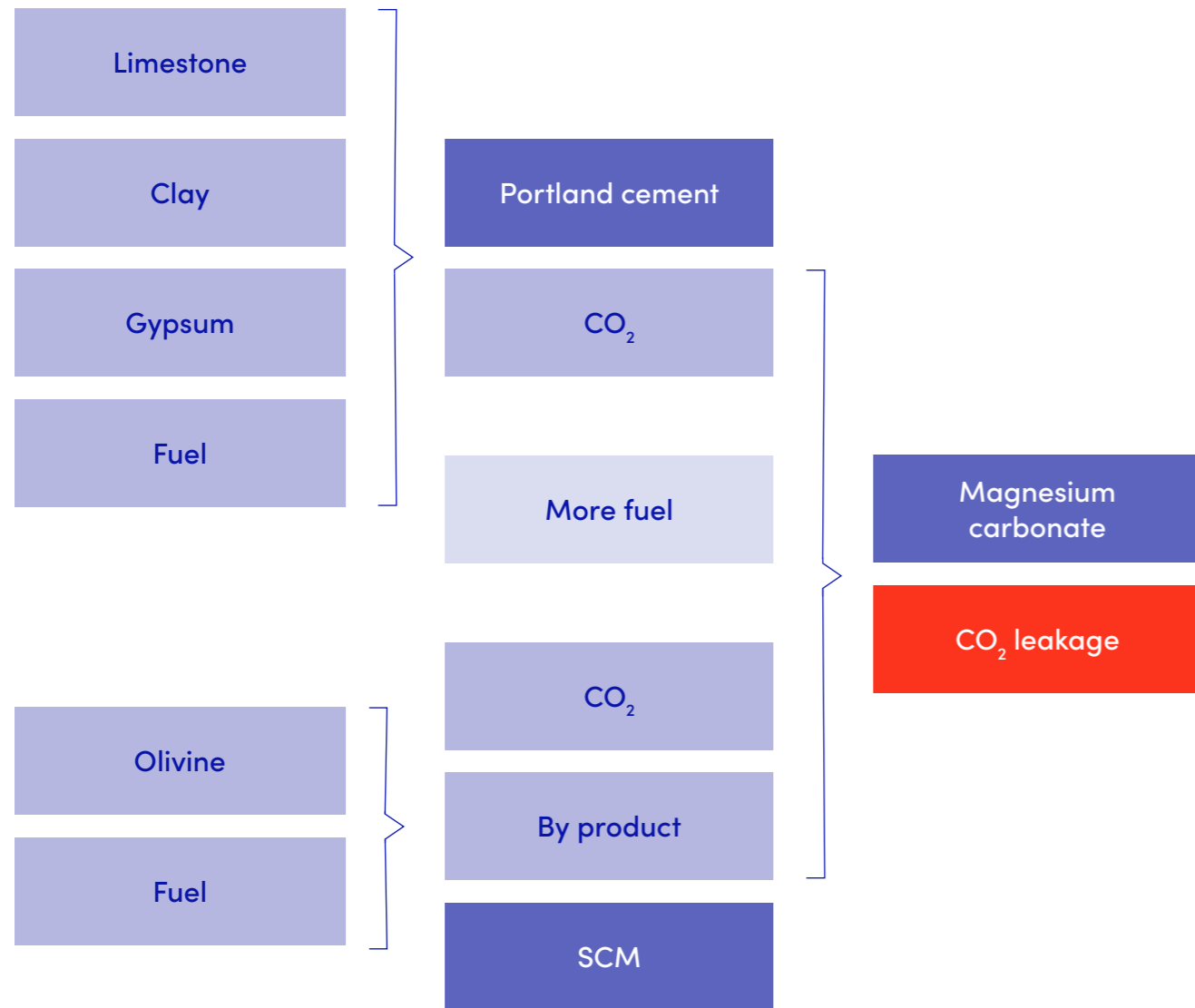
Source: cambridgeelectriccement.com/the-product/

Appendix C (continued)

Representative processes for reclaimed Portland cement and CCU

CCU: The Seratech process with CCU on the flue gases of a traditional cement factory

Process



Codes

Needs a semantic update of the codes to achieve SCM code compliance. Also needs comprehensive test regime to demonstrate performance. Can use Flex 350 for AACM.

Scalability

Olivine is globally abundant, including in parts of the UK.

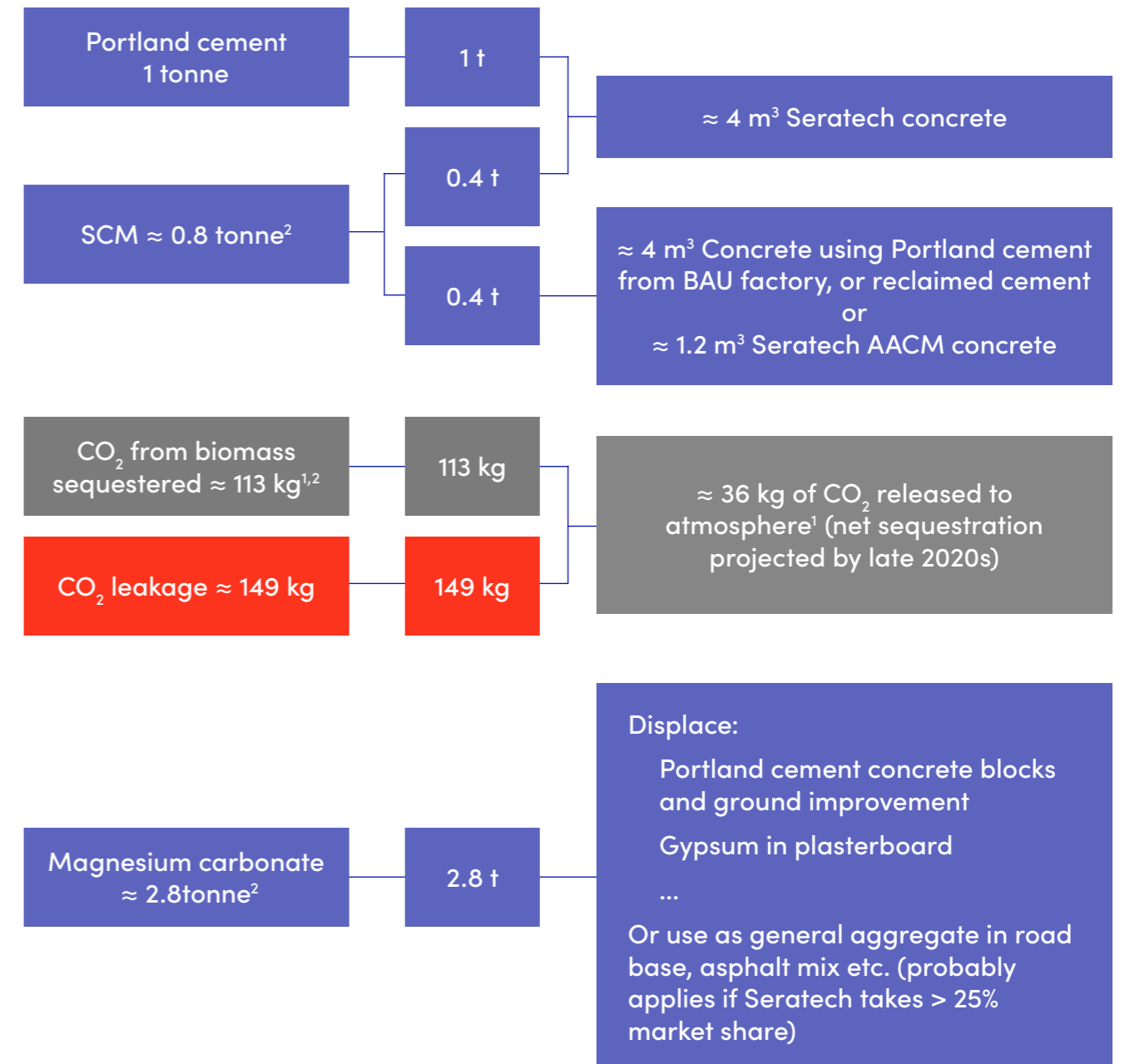
TRL

Moving from lab to industrial trials.

Timeline

Target 25% market share by 2035.

Use of factory outputs



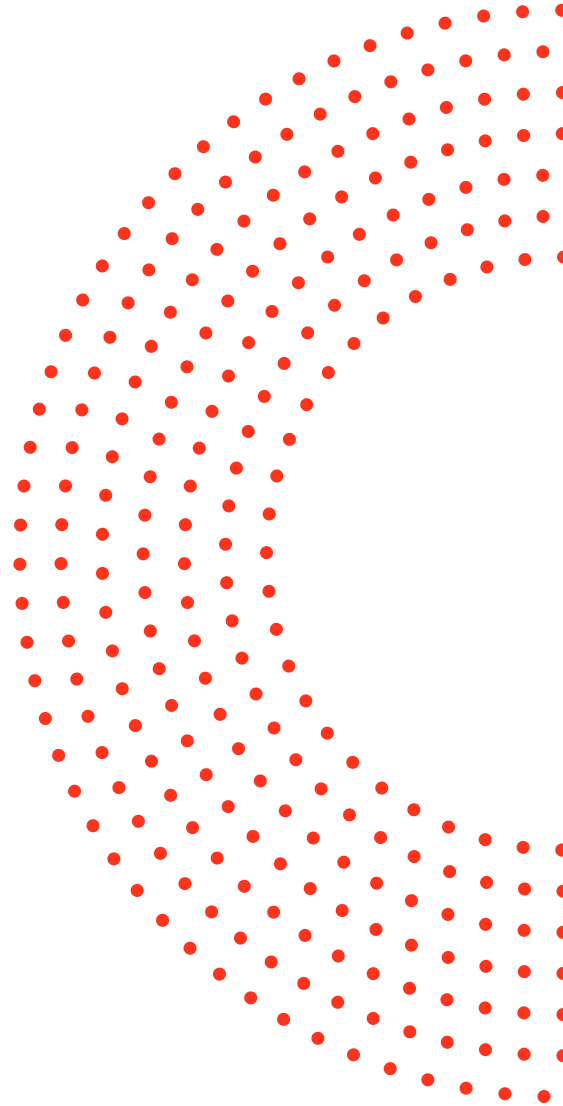
Notes:

1. Based on cement kiln biomass proportion in 2023.
2. Quantities vary with efficiency of the kiln.

For more information, please reach out to:

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The Climate Change Organisation (The Climate Group) with Company Registration Number: 4964424 and Charity Registration Number: 1102909
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