This report has been prepared for the Department of Energy and Climate Change and the Department of Business, Innovation and Skills

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Cement Appendices

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INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CEMENT

APPENDIX A - METHODOLOGY

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The overall methodology used in this project to develop a decarbonisation roadmap for the cement sector consists of four stages:

(1) Evidence gathering and processing based on literature, interviews and workshops
(2) Modelling of draft pathways, including scenario testing and sensitivity analysis;
(3) Testing and developing final pathways
(4) Creating a sector Vision for 2050 with main conclusions and recommendation of Next Steps

This methodology is illustrated in Figure 1 and summarised in the report. A detailed description is given in this Appendix.

An important aspect of the methodology has been Stakeholder Engagement to ensure that all implicated parties have been invited to participate and contribute. We have worked closely with the Minerals Product Association (MPA) to identify and invite the right people from the sector. In addition we have worked with the Department of Energy and Climate Change (DECC) and the Department for Business Innovation and Skills (BIS) to identify appropriate academic and other stakeholders, such as financial industry personnel, to participate and contribute.

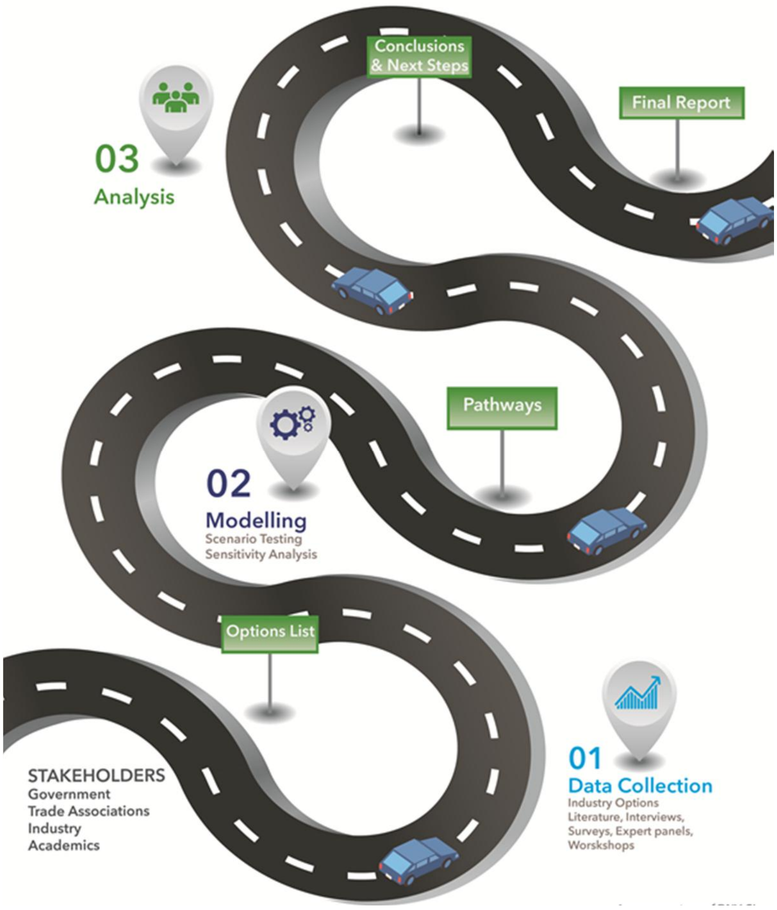

Figure 1 Roadmap Methodology

1. Evidence gathering

Evidence gathering focused on technical and social and business evidence, and aimed to acquire information about:

- Decarbonisation options (i.e. technologies)
- Enablers and barriers to decarbonisation and energy efficiency
- Background to the sector
- Current state and future changes within the sector
- Business environment and markets
- Potential next steps

This evidence was required either to answer the principal questions directly, or to inform the development of pathways and the sector Vision for 2050. The evidence was developed from the literature review, interviews and information gathering workshops. By using these different sources of information, the evidence gathered could be triangulated to improve the overall research. Themes that were identified during the literature review could subsequently be used as a focus or a starting point during the interviews and workshops. The data from the literature could be subjected to sensitivity testing by comparing it with information from the interviews and the workshops. In a similar way, information gaps during the interviews and workshops could be populated using literature data.

The different sources of evidence were used to develop a consolidated list of enablers and barriers for decarbonisation, and a register of technical options for the cement sector. This information was subsequently used to inform the development of a set of pathways to illustrate the decarbonisation potential of cement industry in the UK.

The evidence gathering process was supported by high levels of engagement with a wide range of stakeholders, including industry members, trade association representatives, academics and members of DECC and BIS.

The evidence gathering exercise was subject to inherent limitations based upon the scale of activities and sample sizes that could be conducted within the time and resources available. The literature review was not intended to be exhaustive and aimed to capture key documentation that applied to the UK. The four companies interviewed represented all of the carbon emissions produced in the UK Portland cement sector (emission from the UK production of Aluminate cements is out of scope of this project) and captured UK decision makers and technical specialists in the cement sector. These interviews were conducted to provide greater depth and insight to the issues faced by companies. However, because many of the companies in the UK are globally owned, it was difficult to involve senior staff at a global corporate level. This also applied to workshop attendees.

The identification of relevant information and data was approached from a global and UK viewpoint. The global outlook examined dominating technologies and process types, global production and CO_2 emissions (in the EU27) and the global outlook to 2050, including the implications for cement producers and consumers, and production and demand uncertainties. The UK outlook examined the sector structure, recent history and context including consumption, demand patterns and emissions, the business environment, organisational and decision-making structures and the impacts of UK policy and regulation. The major UK cement producers and their key sites, dominant technologies and processes were also reviewed.

Long term and shorter term implementation options were considered. options examined were classified into eleven categories in order to group similar technology options: energy efficiency, waste heat recovery (including its use for electricity generation), cementitious substitution, fuel switching, incremental efficiency improvements, carbon capture, alternative cements, alternative kiln designs, advanced grinding technology, recycling and oxygen enrichment.

2. Literature Review

A literature review was undertaken on the cement sector. Its aim was to help to identify options, enablers and barriers for implementing decarbonisation throughout the sector. It seeks to answer the Principal Questions, determine the enablers and barriers for implementing decarbonisation and identify what are the necessary conditions for companies to invest and consider carbon management as a strategic issue to determine appropriate technical options for the sector.

The literature review covered over 39 documents. This was not a thorough literature review or Rapid Evidence Assessment (REA) but a desktop research exercise deemed sufficient by the project team[1] in its breadth and depth to capture the evidence required for the purpose of this project. Based on the table of contents and a quick assessment (10 to 30 minutes per document), criteria were defined to identify which documents were to be used for the detailed analysis and information gathering (see **Error! Reference source not found.** of **Error! Reference source not found.**). Where literature was deemed significant and of good quality, it was read and results were gathered on the principal questions.

The review has drawn on a range of literature (published after 2005, with minor exceptions), that examines energy efficiency and decarbonisation of the sector and also wider reviews, studies and reports deemed relevant to energy-intensive industries overall. sector-based and academic literature was also added. The documents are listed in Section 6 of the main report.

The literature review was conducted in the following phases:

- Broad literature review and information/data collection
- Detailed literature analysis on technical points of note
- Identification of decarbonisation options and associated enablers/barriers
- Information on adoption rate, applicability, improvement potential, ease of implementation, capex, Return on Investment (ROI) and the saving potential for all options where available;
- Construction of decarbonisation options list for short- (2015-2020), medium- (2020-2030) and long-term (2030-2050)
- Provision of information on strengths, weaknesses, opportunities, threats, enablers and barriers. This information was used in the information gathering workshop as a starting point for discussion. It provided evidence to support the development of a consolidated list of enablers and barriers for decarbonisation and, subsequently, to inform the list of the possible technological options and pathways that would lead to decarbonisation

[1] DECC, BIS and the consultants of PB and DNV GL.

	Details
Main focus (all in the cement sector)	Energy efficiency improvements CO_2 and decarbonisation Fuel switching
Secondary focus	Enablers, barriers, policy Carbon capture utilisation and storage (CCUS)
Excluded	Carbon offsetting Non-CO_2 emissions Technologies not applicable to the UK cement manufacturing sector Product switching (from cement to other materials)

Table 1: Scope of review

The most relevant documents for the technical and the social and business review included:

- Cement Sustainability Initiative, Development of state of the Art-Techniques in cement Manufacturing: Trying to Look Ahead (CSI/ECRA-Technology Papers), 2009.
- MPA, cement GHG Reduction Strategy, 2013.
- MPA, The UK cement Industry aims to reduce greenhouse gases by 81% by 2050, 2013.
- The European cement Association, The role of CEMENT in the 2050 Low Carbon Economy, 2013.
- Global CCS Institute, Deployment of CCS in the cement Industry, 2013.
- Ricardo AEA, Decarbonisation of heat in industry: A review of the research evidence – Report for DECC, 2013.
- International Energy Agency & World Business Council for Sustainable Development, cement Technology Roadmap 2009.
- MPA, Novel cements: low energy, low carbon cements.
- Cembureau, cements for a low-carbon Europe, 2013.
- World Business Council for Sustainable Development, the cement Sustainability Initiative – Climate Actions, 2008.
- House of Commons, Written evidence submitted by the Mineral Products Association (HOT07).
- The Boston Consulting Group, Assessment of the Impact of the 2013-2020 ETS Proposal on the European cement Industry, 2008.
- The Boston Consulting Group, The cement sector: A Strategic Contributor to Europe's Future, post-2011.
- DECC, The Future of Heating, 2013
- CIVITAS, Are our decarbonisation targets self-defeating?, 2012
- Centre for Low Carbon Futures, Technology Innovation for Energy Intensive Industry in the United Kingdom. 2011.
- IEAGHG, Deployment of CCS in the cement Industry, 2013.

3. Criteria for including literature

As described earlier, the literature review followed a quick assessment process. General criteria used for including/excluding literature are shown in Table 2.

	Considerations	Final criteria
Literature value	Preference was given to official and peer-reviewed publications, like academic papers or governmental publications. Industrial information by MPA and industry consortiums from Europe were also taken as a reference points (grey literature). The grey literature was used as input to the workshops.	Preference was given to official publications. Various industrial information reports were provided by MPA.
Time period to be covered	Given the fact that the European Energy Directive (end 2012) is a recent factor in the energy-related political landscape, preference was given to information which was (very) recently published. Some valuable, but older, information was included, as technology penetration is conducted at different speeds throughout the cement sector	No constraint was set on the date of the publication, but older information was given a lower quality rating, due to it not reflecting the current landscape.
Geographical area	Preference was given to the UK industry, with a broader look to Europe, as the technology competition in this area is the most prominent.	No geographical exclusion criteria were used, but information on the UK cement sector was given a higher quality rating, due to its higher relevance.
sector specifics	Given the specific nature of the UK cement sector, some technologies could be discarded, as there are no plants using them.	Technologies not relevant or potentially applicable to UK cement sector, were excluded
Language	As the majority of information is in English, no special attention was given to publications in other languages.	The search was limited to papers in English, but where easily obtainable qualitative information was found in other languages, this was included[2].

Table 2: High level selection criteria

The reports used for this literature review, provided by MPA and found during the internet search included academic reports, international bodies studies, magazine articles and private sector studies. The quality, relevance and objectivity of each document was analysed by reading the abstract (where present), followed by a skim-read of the document.

Each document was given a score on different aspects of relevance:

- Category: is the content of the document focusing on technology, enablers/barriers or policy-related aspects
- Affiliation: what is the source of the document: academia, governance or is it sector-based
- Financial-technical evaluation criteria present (YES/NO)
- Overall quality of the document (+/++/+++)
- Relevance for the UK cement sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on enablers and barriers: (0/+/++/+++)
- Information on policy/legislation: (0/+/++/+++)

[2] Some valuable references are in German.

- Document relevant for developing scenarios: (0/+/++/+++)

Based on all these aspects, the document was given a relevance classification: “high”, “medium high”, “medium low” or “low”.

The approach to selecting and categorising literature is depicted in Table 3.

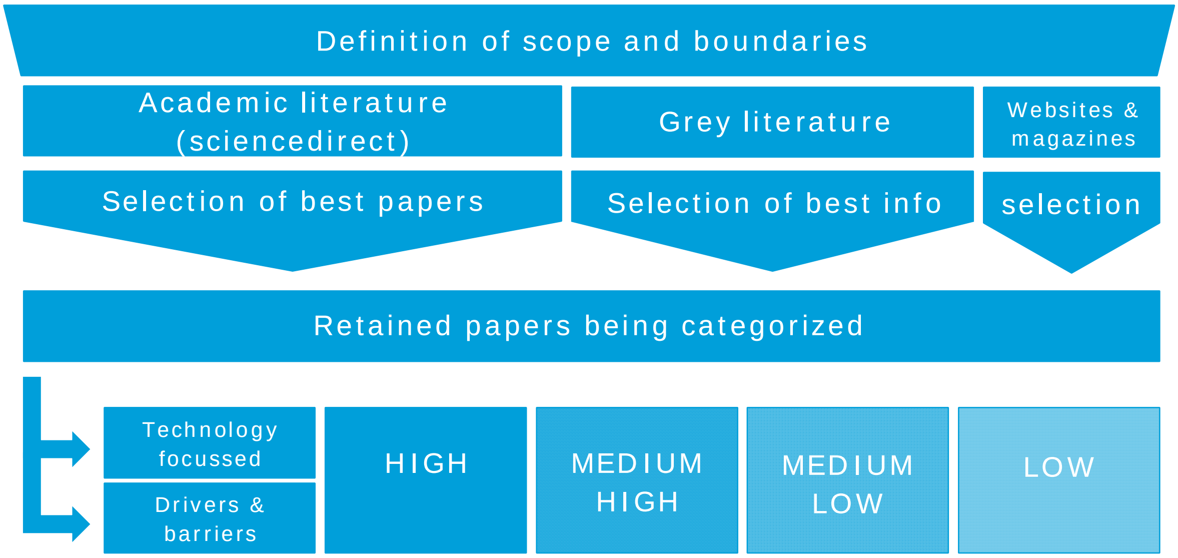

Table 3: Diagram of the selecting and categorising process

All documents categorised as “high” and “medium high” were read in detail, assessed and then included in the literature review process. The documents categorised as “medium low” and “low” were read and assessed in part and only included if a significant reason for inclusion was found.

Energy saving measures (if present) were listed from each document included in the review process and this list was used to construct a decarbonisation options list for short (2015-2020), medium (2020-2030) and long-term (2030-2050) timelines.

NOTE: Additional and specific information/data was added to the overall review process from e.g. stakeholder input datasheets and as a result of following citation trails, expert knowledge and further targeted searches and recommendations.

Method of analysing literature

The following method was used to go through the selected literature:

1. Reading and noting of the abstract (or summary) followed by review of the document in detail to extract any relevant information on sector description/outlook and information/data on energy savings and decarbonisation measures.
2. Relevant information (if appropriate) was extracted from other sources (or referred to) and document citation trails (if appropriate) were checked for further relevant information/data.
3. Incorporation of the documents into the literature review and collating of the most relevant information/data on energy saving and decarbonisation measures.
4. Energy savings, where possible, were preferably extracted as a percentage, or as a specific energy saving per relevant unit.

5. For financial savings, the amounts were kept in their original currency and reference year.

4. Technical Literature Review

Identifying literature

The primary aim of the literature review has been to gather evidence on technical potential and options (under different timelines) in order to inform on the opportunities and challenges associated with the decarbonisation of energy use and improved energy efficiency for the cement sector in the UK.

In parallel to the review process, a number of key academics were identified to participate and provide perspectives on current research and to provide additional input and feedback. This was to ensure that the appropriate literature and research had been identified, screened and included.

Research questions

The evidence review addressed the following research questions:

TECHNICAL POTENTIAL: What existing research is there on the technical potential for improving the energy efficiency and lowering the carbon footprint of the cement Industry to 2050? What generic and specific technical measures exist and what is their potential?

TECHNOLOGY COSTS: What research is available on the costs of these technical measures, and what does it tell us?

DRIVERS/ENABLERS: What does research tell us about the drivers/enablers for organisations in the cement sector to decarbonise their energy use? What are the perceived benefits for industrial organisations to decarbonise their heat use?

BARRIERS: What does research tell us about the barriers for organisations limiting effective decarbonisation of their energy use?

PRINCIPAL QUESTIONS: Check for other links to issues raised by Principal Questions.

SWOT analysis: Check for any information using terms strengths, weaknesses, threats and opportunities.

Information provided by DECC and TAs

One document was put forward by DECC, with relevance to the literature search:

1. Ricardo AEA, Decarbonisation of heat in industry: A review of the research evidence, *UK Department of Energy and Climate Change,* 27 August 2013.

The Mineral Products Association (MPA) promotes cement across all sectors and government ensuring that both the industry and its products remain competitive, innovative and are not unnecessarily or disproportionally hindered by new regulation, standards or legislative changes. They act as the industry's focal point, playing the principal role in communication between their members and government, the European Union and other external interest groups and trade bodies. MPA offer advice, analysis and information to all parties. They actively stimulate innovation, R&D and further development of the industry. MPA has produced a greenhouse gas reduction strategy for the UK cement industry; this document projects CO_2 emissions forward to 2050 under two scenarios, identifying key technologies and actions necessary to achieve these decarbonisations. The MPA strategy provided input to this study, along with a comparator against which the study outputs could be gauged.

Information found by the consortium during technical literature review

A number of additional documents were identified during the course of the literature review. These documents were identified through Internet search engines and through the cement sector team.

A complete reference list is available in Section 6 of the main report.

5. Social and Business Literature Review

In addition to the work and process described in the technical literature review, the social and business literature review key points and additions are:

- We reviewed over 25 documents to create a broad overview of the sector SWOT and identification of enablers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment;
- Literature reviewed: included documents from Trade associations, companies, DECC and BIS. Specific search terms were used which were agreed with DECC to identify the key enablers and barriers;
- We used a systematic and structured approach to the literature review. The criteria for assessing the relevance of the literature were defined to determine whether they address the key principal questions. The literature identified was analysed using a quick assessment process to identify the most relevant information on SWOT, enablers and barriers to decarbonisation; and
- Based a brief assessment we presented the results in a table as below. The analysis resulted in identification of documents to be used for detailed analysis and information gathering. Where literature was deemed significant and of good quality (three stars or above), the literature was read and reviewed and results were gathered on the principal question areas.

	Year	Relevance	Quality	Characteristics	SWOT, Enablers and Barriers	Uncertainties future trends	options	pathways
Title 1		+++	++	0	++++	++	0	++++
...		++	+++	++	0	+++	+	+
...		+	++	+	0	++++	++	0
Title 10		++	++++	+++	++	+++	+++	++

Table 4: Literature review assessment process (0= very low, ++++ very high)

The outcome of the literature review was a comprehensive list of strengths, weaknesses, opportunities, threats, enablers and barriers which were used in the Information Gathering Workshop as a starting point for discussion and voted on to check which ones were most material.

6. Interviews

The information gathering stage of the project also involved a series of interviews. These aimed to obtain further details on the cement industry and to gain a deeper understanding of the Principal Questions, including how companies make investment decisions, how advanced technologies are financed, the companies' strategic priorities and where climate change sits within this.

There are only four operational Portland cement manufacturing companies in the UK at present. As such it was proposed that all four be interviewed along with the MPA. We identified the proposed interviewees in liaison with the MPA, the four companies themselves, DECC and BIS, meeting the criteria defined in the methodology. All of the companies agreed to be interviewed. The interviews were held with:

- Mineral Products Association
- CEMEX
- Lafarge Tarmac

- Hanson
- Hope Construction Materials

The manufacturing companies interviewed together represent 100% of the sector emissions from Portland cement manufactured in the UK although it should be noted that the UK also receives imports of cement; some of the importers do not have any UK manufacturing capability.

Comments collated via the MPA, the workshop and subsequent email correspondence was also used as part of the evidence gathering process to supplement the interviews.

Interviewees were interviewed using the "Interview Protocol" template, developed in liaison with DECC and BIS. The Interview Protocol was used to ensure consistency across interviews, to ensure that the interviews could be used to fill gaps in the literature review, identify key success stories of decarbonisation, and extract the key social and business barriers of moving to low-carbon technologies. The "Interview Protocol" can be found further in this Section. It was agreed that no quotes will be directly attributed to those interviewed, with the exception of the MPA.

Assumptions

1. Results from the desk research social and business and technology review are available and partially well covered. Well covered parts were not addressed during the interview. Available results:
    a. option register overview
    b. sector and Subsector characteristics
    c. sector SWOT analysis
    d. Main trends and enablers
    e. Some on hurdles and barriers for change and/or energy or decarbonisation
2. Preparation of interviews included analysis of website and annual report for business strategy and any energy and emission reduction strategy information. This reduced the need to get some extra clarification on business strategy.
3. The technical team reviewed any gaps in data or information (e.g. specifically related to that company data) that were appropriate to obtain during the interview process);
4. We understood interviewee's role prior to conducting the interview and we checked this during the interview if needed.
5. Energy and decarbonisation strategy not available/clear for most organisations;. All interviews were conducted by very experienced interviewers, with their own proficient way to deal with issues around openness, issues of consent, encouraging openness, and follow-up.

Interview Template

We identified the proposed interviewees in liaison with MPA, DECC and BIS in order to give a good coverage of the sector.

Interview Protocol

Preparation

1. Interviewee identification

Interviewees are identified in liaison with the Department of Energy and Climate Change (DECC) and the Department for Business, Skills and Innovation in order to achieve good coverage of each sector. The steps taken to identify relevant candidates are:

- Identify the number of subsectors using SIC codes listed in the ITT or another appropriate subsector division;
- Where possible subsectors were grouped based on similarities in products or production techniques to reduce the number of subsectors; and
- Identify which subsectors and/or organisations were most significant using the following criteria:
    - Size (e.g. by revenue and/or emissions)
    - Innovation level of companies
    - Whether headquartered in UK
    - Level of supply chain integration
- Select candidates best positioned to represent the views of the breadth of subsectors

2. Interview Preparation

The focus of each interview is to be informed by research of the key issues and challenges, successes and opportunities faced by each sector and an understanding of the specific knowledge held by the interviewee. The research incorporates:

- Social business literature review
- The findings of the technical review and decarbonisation options identified
- Review of company websites, annual reports and other materials relating business and emissions reduction strategies
- Assessment of the role of the interviewee and extensiveness of their knowledge
- Review of website, ONS data, IBIS data and annual reports information related to business and energy and emissions reduction strategies.
- Development of the options register

Interview Format

1. Introductions

Interviewer sets out the project context and interview agenda.

2. Goals

Interviewer introduces the goals of the project as follows:

1. To determine the current state, ambitions/plans, successes and problems/challenges of each of the interviewee's organisation and/or sector with regard to energy use, energy reduction and carbon reduction:

    a. Identify and analyse examples of the implementation of energy and carbon reduction projects to deliver insight in the problems and barriers at a company level

    b. Develop an understanding of the decision-making processes

    c. Develop an understanding of the relationship between energy/carbon strategy and business strategy.

2. To develop insight into the energy and carbon reduction options available to the organisations/sector and their potential:

    a. As currently deployed by organisations

    b. As an option to be deployed in the future

3. Understanding of the main drivers and barriers for change in general and with regard to energy and carbon reduction in the sector
4. To develop insight into the specific characteristics (strengths, weaknesses, opportunities and threats) of subsectors (where required).

3. Existing and future strategy for energy and carbon reduction

Interviewer to engage the interviewee on the focus of their organisations energy and carbon strategy using the following questions:

1. What is your organisations strategy for energy and carbon reduction? (If the strategy is clear, summarise and ask for confirmation). Cover the following sub-questions:
   - **a** What are the main elements of the strategy?
   - **b** How far in advance are you planning the company's energy efficiency strategy?
   - **c** In your opinion, what are the enablers and/or challenges for the strategy?
     - **i)** Please specify why:
       1. Constrained finance for funding for investments internally or externally
       2. Etc…
2. Do you consider your organisation as a leader (innovator/early adopter) or as a follower (early, late majority) on energy and carbon reduction? Cover the following sub-questions:
   - **a.** Can you give one or more example(s) of actions undertaken by members of your organisation that fit with the stated market position?
   - **b.** Do you expect the organisation's position with regard to energy and carbon reduction to change?
   - **c.** Please state why your organisation is/ is not a leader.
3. What energy and carbon projects have you implemented the last five years and why? What energy and carbon projects have you not implemented the last five years and why?

   Guidance for interviewer: use the prepared options register (prepared by technical lead and sector team) to identify energy and carbon reduction options. For parts of the list that are not covered, challenge the interviewee to identify options that could be valuable. With front runners place emphasise on more innovative options.
4. How important is energy and carbon reduction for your organisation? Please address how the carbon and energy strategy fits into wider business strategy and the extent to which it is embedded.

4. Stories (interviewees not self-identified as leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project that went well and another that did not.

5. Stories: Questions for leaders (only for self-identified leaders)

Interviewer to lead discussion of a story or example related to an energy or carbon reduction project using the questions below:

1. What energy and carbon reduction options have been implemented, why, when and where?

2. Can you tell the story of a project from the initial idea generation until now? Ensure this covers how ideas were generated (i.e. the step before any appraisal of options takes place):

    a. What was the timeline, sequence of events?

    b. Cover: idea generation, feasibility study (technological, financial, and organisation), decision making, board presentation, and implementation

    c. What was your process for making a case for an investment and who was involved? Consider: key factors during decision making, required payback, main perceived/actual risks, influence of alternative options for investment, financial and non-financial factors.

    d. What were the critical moments (breakthroughs, barriers)?

3. What was the original position of the main stakeholders to the energy carbon project? Did their attitudes towards the subject change? How?

4. Why do you consider this story as a success or an area for improvement?

5. What are the main conclusions you can draw from this story - positive and negative?

    a. Lessons for future action?

    b. Main drivers and barriers for energy and carbon reduction in your company?

    c. Lessons for the way of organising energy and carbon reduction options within you company?

    d. Conclusions regarding potential reduction targets on short-, medium- and long-term?

    e. How well did the carbon reduction option work in practice, in relation to the anticipated performance?

6. Can any reports/presentations on this innovation be supplied?

6. Business Environment: value chain and capacity for innovation

Interviewer to ask the following questions:

1. What do you consider to be the main drivers for energy and carbon reduction in the sector?

    a. What are main characteristics of the main parts of the production process? Following the structure of the options register:

        i. Ask specific questions on any elements not covered in the desk research

        ii. Ask specific questions on the characteristics of the subsector (input, process, output, energy use, value chain, competitive forces)

    b. What do you perceive as the strengths and weaknesses of your value chain?

    c. What have been the main changes in the value chain over last 10 years?

    d. What innovations do you expect to see in the value chain in the coming 10/20/30 years?

    e. What are possible game changers for the value chain/ sector?

2. Main innovators/early adopters in the sector:

a. Who influences action (whom or what are they listening to? Why?):

i. Organisations and people within organisations (role/function)?

ii. Within or outside the sector (other sectors, academics, non-government organisations, politicians etc.)?

3. Questions on the dimensions of innovations[3] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[4]). After filling the list, ask for clarifications and examples that underpin answers in the following areas:

a. Technical: networks with other companies, academics, knowledge of competitive and emerging technologies, participation in R&D, pilots, experiments

b. Human Capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement

c. Organisation: horizontal communication lines, clear goals/responsibilities, customer focus

d. Management: clear performance criteria for projects, structural follow up of main improvement projects in management meeting, clear status information on projects

4. (optional) Please set out a characteristic story of a (successful) sector and subsector that implemented a change/innovation related to energy or carbon reduction. This question should be asked if consortia/sector teams feel a need to get a better overview of success stories. The question is relevant because in most business environments managers are influenced most by their peers.

7. Drivers and barriers for sector change

Interviewer to lead a summary discussion of the main drivers and barriers for sector change (general and or specific for energy and carbon reduction) using the following questions:

1. What do you consider the main drivers for change in the sector?

a. Please state specific drivers in the following fields: social, policy, technical regulatory factors

b. Interviewer to review the pre-prepared list of main driver and check seek further detail from the interviewee

2. What do you consider the main barriers for change in the sector?

a. Please state specific barriers in the following fields: social, policy, technical regulatory factors

b. Interviewer to review the pre-prepared list of main barriers and seek further detail from the interviewee

Function of Interview Template and Protocol:

The Interview Template was designed to collect, build upon and collaborate specific answers to Principal Questions which are not covered by results of desk research. The general timeline of one interview is illustrated below:

[3] Questions are asked to get a better (and broad overview of space/possibilities for change (not only including investments but also the change that potential of option will materialise.

[4] This way of working is chosen to be able to just cover the field quickly and get a quick first idea what they consider the important aspects so we can spend as much time as possible on this. We normally don't use the survey results to collect quantitative answers to these.

Intro	5-10 minutes
Current state and plans energy and decarbonisation	20-30 minutes
Stories of energy/decarbonisation	30-45 minutes
Business environment and innovation power	15-20 minutes
Enablers and barriers for sector change (to test workshop questionnaire)	If time left

Table 5: General interview timeline

7. Information Gathering Workshop

The information gathering stage of the project also involved Workshop 1, the 'Information Gathering Workshop'.

We worked with MPA, DECC and BIS to identify the most relevant attendees for the workshop. The research work already undertaken as part of the literature review and interviews were used to inform the content of the workshop.

The workshop was divided into two key activities. The first activity focused on reviewing all potential technological options for decarbonisation and identifying adoption rate, applicability, improvement potential, ease of implementation, CAPEX, ROI, saving potential and timeline for the different options. This was done through two breakout sessions, one focused on collecting more data and the other focused on the timeline under different scenarios. The second activity involved splitting participants into five groups to discuss and vote on the enablers and barriers. Participants were also asked if they had any other enablers and barriers to be included. The aim of this section of the workshop was to prioritise the enablers and barriers and begin to consider how to overcome them (so that this could feed into later work on the options register, pathways and Next Steps).

We recognise that the voting process was based on initial reactions and that everyone voting may not have the expertise required on specific technical solutions to decarbonisation. In order to counter this limitation, MPA provided a validation of the options data after the first workshop.

The outcome of the Information Gathering Workshop (and all information gathering stages of the project) was a consolidated list of enablers and barriers, and a more complete list of possible technological options with a suitable timeline for their implementation.

8. Pathways

A pathway is a combination of different decarbonisation options, deployed under the assumed constraints of each scenario that would achieve a decarbonisation level that falls into one of the following decarbonisation bands:

- 20-40% CO_2 Reduction;
- 40-60% CO_2 Reduction; and
- 60-80% CO_2 Reduction.

In addition, two purely technology-driven pathways were developed: a Business as Usual (BAU) pathway and a Max Tech (Max Tech) pathway. The BAU pathway consisted of the continued roll-out of technologies that are presently being deployed across the sector. The Max Tech pathways - Max Tech 1 and Max Tech 2 - included a technology or technology combination that would achieve the maximum CO_2 reduction possible within the sector, given constraints of deployment rates and interaction. Two Max Tech pathways were developed because two potential avenues for reaching the maximum decarbonisation of the sector exist and it is presently not possible to determine which would be more likely. The pathways have not been optimised to achieve a certain decarbonisation level.

9. Pathways Development and Analysis

Overview

Pathways were developed in an iterative manual process in order to facilitate the exploration of uncertain relationships that would be difficult to express analytically. This process started with the data collected in the evidence gathering phase. This data was then challenged and enriched through discussions with the sector team and in the first workshop.

Logic reasoning (largely driven by option interaction and scenario constraints), sector knowledge and technical expertise were applied when selecting options for the different pathways under each scenario. For example, incremental options with lower costs and higher levels of technical readiness were selected for the lower decarbonisation bands, whereas more technically and financially challenging options were selected for the higher decarbonisation bands in order to reach the desired levels of decarbonisation. These pathways were challenged by the sector team, modelled and assessed under the three scenarios and finally challenged by the Stakeholders participating in the second workshop. This feedback was then taken into account and final pathways were developed. All quantitative data and references were detailed in the options register and relevant worksheets of the model.

It is important to keep in mind that the pathways results are the outcome of a model. As with all models, the accuracy of the results is based on the quality of the input data. There are uncertainties associated with the input data and the output should therefore be seen as indicative and used to support the Vision and Next Steps, not necessarily to drive it. Also the model was a simplification of reality, and there are likely to be other conditions which are not modelled.

The analysis only produced results (pathways) which were iterative inputs of the model operator, without any optimisation.

Process

1. The gathered evidence (from literature review, sector team discussions, stakeholder feedback and judgement) was consolidated into a condensed list of options.
2. Timing and readiness of options was developed by the sector team and during the first workshop, based on evidence from literature, sector knowledge and technical expertise.
3. BAU and Max Tech options were chosen and rolled out to the maximum level and rate allowable under the current trends scenario.
4. Options were added to the BAU pathway or reduced or taken out of the Max Tech pathway until each intermediary pathway band was reached.
5. Technical constraints and interactions across the list of options were taken into account when selecting options and roll-out.
6. The roll-out was adjusted to account for the output of the social and business research as well as current investment cycles.
7. Pathways were modelled under the current trends scenario, accounting for changes in production and the carbon emissions of the electricity grid.
8. The results were reviewed and modifications made to the deployment, applicability and reduction potential for any options that appeared to be giving an unexpected or unusual result.

9. Further changes to option choices were made as required through iterations of points 4-8.
10. Revised pathways under current trends were produced for presentation at the second workshop.
11. Feedback on pathways was used to make any further necessary adjustments to the pathways under current trends.
12. The final pathways developed under current trends were used as a basis for the development of pathways under challenging world and collaborative growth scenarios.
13. Deployment of each option under challenging world and collaborative growth was adjusted according to the constraints of each scenario, including the removal of options that would not be likely under challenging world and the deployment of additional options that would become feasible under collaborative growth.
14. Roll-out for each option was adjusted within the technical and scenario constraints in order to reach each pathway band where possible. Note that not all pathway bands are possible under some scenarios.

The options are listed in Appendix C.

Deployment of options

For each pathway, options were selected and deployed over time according to their readiness level, timing constraints, and those most likely to allow the pathway band to be achieved. This process occurred iteratively, involving the sector team, Trade Association and other Stakeholders (who contributed via the second workshop). The sector Lead provided an expert view on whether the options identified in each pathway produced a feasible pathway.

As described within the pathways section of the report, the technologies included within each banded pathway under each scenario may differ in order to meet the pathway band under each scenario.

The selection and deployment of options accounted for evidence from the social and business research, for example which options could be deployed without any changes to policy and where the roll-out of options may be slowed or curtailed by identified barriers or accelerated by enablers.

Option Interaction

There were a number of possible ways in which options could interact with each other. These interaction types, and how they were dealt with in the development of pathways, are described below:

- **One option excludes another:** This is taken into account by the user in the roll-out inputs in the option Selector by ensuring that no exclusive options are rolled out to a conflicting level in the same time period. For example, 'fuel switching to biomass' and 'fuel switching to natural gas' are options that are mutually exclusive. It can therefore be seen that as 'fuel switching to biomass' deploys to 75%, 'fuel switching to natural gas' reduces to 25% accordingly.
- **One option depends upon another being adopted:** This is taken into account by the user in the roll-out section of the option Selector by ensuring that if any option requires a precursor that this precursor is rolled out to the appropriate level.
- **Options are independent and act in parallel:** The "Minimum Interaction" pathway curve assumes that all options are independent and their effect on energy or emissions are therefore incremental.
- **Options improve a common energy or emission stream and act in series:** The "maximum interaction" pathway curve assumes that the saving from each option reduces the remaining energy or emissions for downstream options to act upon.

Due to the choice of top down modelling methodology, the distinction between type 3 and type 4 interactions was not possible on an option-by-option basis. The pathways curves therefore included a “maximum interaction” and a “minimum interaction” curve. The actual pathway curve would lie between these two extremes.

Evidence not used in Pathways Modelling

Specific energy use of processes was considered constant in the modelling, whereas they are actually dependent on the load factor (production level) of the equipment. Increasing the production level of existing equipment often increases efficiency (in terms of kWh/tonne cement or Mt CO_2/tonne cement), which should be taken into account when calculating emissions. However, a full bottom-up model would be needed, which was beyond the scope of this work.

The options were modelled with a fixed CO_2 and fuel saving as input values. As technologies mature, it is likely that these values would increase. This was not taken into account in the model, as the uncertainty of the extent of that development is high.

The adoption rates and applicability rates were used to inform deployment, but without a full bottom-up model implemented on a site-by-site basis, it was difficult to link these parameters directly to investment cycles.

10. Pathways Modelling

Scenarios

Modelling pathways starts with the development of scenarios. A scenario is a specific set of conditions external to the sector that would directly or indirectly affect the ability of the sector to decarbonise. An example of a condition in a scenario was the emissions factor of the electricity grid. Where appropriate, conditions were described qualitatively through annual trends. The scenarios analysis also included qualitative descriptions of exogenous drivers which were difficult to quantify, or for which analytical relationships to quantitative factors were indefinable.

For each pathway, the following three scenarios were tested: current trends, challenging world and collaborative growth. Scenario parameters are shown in Table 6 below. These scenarios are based on literature review, interviews and stakeholder input at workshops and sector meetings.

Current Trends

The current trends scenario projected moderate UK and global growth with UK producers maintaining current production levels but where increase in demand is met by increase in imports. Alongside this, international policies on climate change were assumed to develop, gradually but effectively driving down emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 100 g/kWh by 2030.

Cement production was assumed to stay constant during the entire period from 2015 to 2050 at a nominal level of 10 Mt/yr.

Challenging World

The challenging world scenario was characterised by lower global growth rates than those currently being experienced. Climate change was assumed to have a lower profile than at present, so that there would be less effective action to reduce emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 200 g/kWh by 2030.

Cement production was assumed to decline by 0.5% annually during the entire period from 2015 to 2050 due to reduced demand from the construction sector coupled with more intense competition from imports.

Collaborative Growth

The collaborative growth scenario was represented by higher levels of global growth than those currently being experienced and concerted action to reduce carbon emissions.

New low-carbon generation technologies were assumed to progressively decarbonise the electricity grid to 50 g/kWh by 2030.

Cement production was assumed to increase by 0.5 due to increased demand from the construction sector.

	Challenging world (cement production to decline by 0.5% annually)	Current trends (No increase in cement production)	collaborative growth (cement production increased by 0.5% annually)
International consensus	National self-interest	Modest	Consistent, coordinated efforts
International economic context	More limited growth, some unstable markets, weakening of international trade in commodities	Slow growth in EU, stronger in world, relatively stable markets	Stronger growth in EU, stable markets, strong international trade.
Resource availability and prices	Strong competition, High Volatility High price trends.	Competitive pressure on resources. Some volatile prices Central price trends.	Competitive pressure on resources. Some Volatile prices Central price trends.
International agreements on climate change	No new agreements. Compliance with some agreements delayed	Slow progress on new agreements on emission reductions, all existing agreements adhered to.	Stronger worldwide agreements on emission reductions, consistent targets for all countries
General Technical Innovation	Slow innovation and limited application	Modest innovation, incidental breakthroughs	Concerted efforts lead to broad range of early breakthroughs on Nano, bio, green and ICT technologies.
Attitude of end consumers to sustainability and energy efficiency	Consumer interest in green products only if price competitive. Limited interest in energy efficiency.	Limited consumer demand for green products, efficiency efforts limited to economically viable improvements	Consumer willing to pay extra for sustainable, low carbon products. Strong efforts to energy efficiency even where not cost effective.
Collaboration between sectors and organisations	Minimal joint effort, opportunistic, defensive	Only incidental, opportunistic, short term cooperation	Well supported shared and symbiotic relationships
Demographics (world outlook)	Declining slowly in the west Higher growth elsewhere	Declining slowly in the west Modest growth elsewhere	Stable in the west Slowing growth elsewhere

	Challenging world (cement production to decline by 0.5% annually)	Current trends (No increase in cement production)	collaborative growth (cement production increased by 0.5% annually)
World energy demand and supply outlook	Significant growth in demand with strong competition for resources. High dependence on imported fossil fuels	Balanced but demand growth dependent on supplies of fossil fuels from new fields.	Growing demands balanced by strong growth in supply of renewable energy, slowly declining importance of fossil fuels.
UK Economic outlook	Weaker OBR growth assumption.	Current OBR growth assumption (0%)	High OBR growth assumptions
Carbon intensity of electricity	Weakest trend of electricity carbon intensity reduction 200g/kWh at 2030	Stronger trend of electricity carbon intensity reduction 100g/kWh at 2030	Rapid decline in electricity carbon intensity 50g/kWh at 2030
Price of electricity	Could be higher or lower than existing ones	Central prices	Likely to be higher
Fossil Fuel	Higher and volatile fuel prices UEP high	UEP central	UEP central
Carbon Prices	UEP low carbon price	UEP central carbon price	UEP high carbon prices
CCS availability	Technology develops slowly, only becoming established by 2040	Technology does not become established until 2030	Technology becomes proven and economic by 2020
Low carbon process technology	New technology viability delayed by 10 years	New technology economically viable as expected	New technology viability achieved early

Table 6: Summary of scenario context and specific assumptions applicable to the scenarios

11. Options

Classification and Readiness of Options

The options were divided into two groups reflecting their techno-commercial readiness.

- Short term options
- Long term options

Short term options are characterised by being available for implementation either immediately or from 2020 onwards and typically offer smaller incremental CO_2 savings. They include generic energy efficiency options including electricity generation from waste heat as well as the use of alternative raw materials or increased use of biomass fuels.

Long term options, in contrast, are currently at early stages of development and so are unlikely to be implemented prior to around 2030. They include breakthrough technologies such as carbon capture and advanced kiln technologies.

Options Processing

The options register shown in Appendix C was developed jointly by the technical and social and business research teams. This was achieved by obtaining the list of potential options from interviews, literature, asking participants at the information gathering workshop which options they would consider to be viable, and through receiving detailed information packs from members of MPA. The technical team drafted the first list of options. However, each option had strengths, weaknesses, enablers, and barriers which needed to be taken into account to develop and refine the options register to feed into the model.

A comprehensive list of enablers and barriers identified from the literature review was refined and triangulated with the information gathering workshop and interviews. To find the most relevant enablers and barriers for incorporating into the options register and pathways, enablers and barriers that were not supported by the information gathering workshop and interviews were removed from the list.

The impact of social and business research was captured in the options register, under the individual technologies (where possible) and in the subsequent pathways selected.

We have used the decision tree below to determine whether the social and business findings should impact upon the options and pathways. The pathways represent a selection of options, and this determines when and to what extent the options become active.

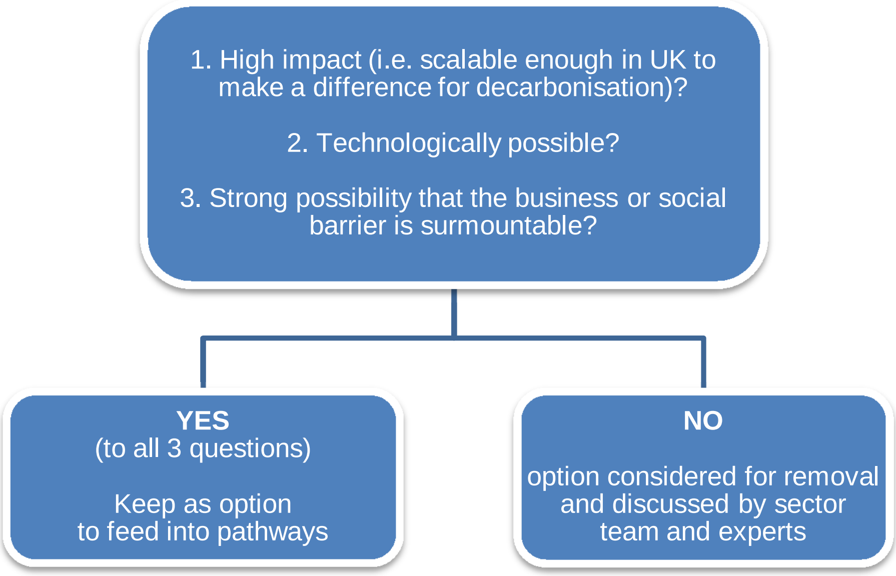

Figure 2 Social and Business pathways Impact Tree

12. Next Steps

The output of the pathway development and social and business research included identification of barriers to and enablers for:

- Implementation of the pathways; and
- Decarbonisation and energy efficiency in the cement sector more generally.

To draw conclusions, the analysis of barriers and enablers is taken further by describing a list of possible next steps to be implemented by a combination of industry, government and other organisations. These actions can take the form of strategic conclusions which are high-level and/or longer term, or more specific, discrete activities which can lead to tangible benefits.

The development of conclusions and next steps has considered the following:

- Actions from other cement decarbonisation projects
- Necessary changes in future markets, product features, business environment to enable the different pathways
- The outputs of workshops held as part of this project covering decarbonisation pathways and next steps
- Actions that help maximise the success of a pathway under a range of scenarios
- options within the pathways that are necessary for success, e.g. if a particular technology option is necessary for the success of a number of pathways, or an option has a very high decarbonisation potential, actions to implement this option are included
- Policy and regulations that could contribute to the removal of barriers and/or enhancement of enablers

The possible next steps can be divided into three main groups: strategy, opportunity and analysis, and tools and resources, as illustrated in Table 7.

Market and strategy	Opportunity and analysis	Tools and resources as enablers
Leadership, strategy, structure, organisation, communication, promotion, PR	Innovation, research and development	Policy and regulation
International competition and markets	On site deployment of technology	Finance
Company decision making and strategy	Energy supply and infrastructure	People management and skills
	Value chain opportunities	

Table 7: Next steps

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CEMENT

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

The info-graphic below highlights the top strengths, weaknesses, opportunities and threats in relation to decarbonising the cement sector in the UK.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
UK cement Industry is well established and has steadily improved its energy efficiency and environmental performance	cement making is a capital-intensive industry	cement is an attractive option for green buildings	Competition from international competitors
Vertical-integrated manufacturing facilities	UK industries are particularly vulnerable to offshoring of production	Sector has a strong pipeline of smaller innovation projects waiting to be implemented	High price of energy
cement/concrete reabsorbs a highly significant amount of CO_2 during its life and end-of-life	Sector is historically weak at obtaining funding for innovation from government	Collaboration to develop demonstration projects	Uneven playing field/ carbon leakage
cement Industry is well placed to make good use of alternative fuels and waste by-products	Technology lock-in	If additional alternative financing mechanisms were available more advanced technologies with longer paybacks (5-8 years) would be implemented	Regulatory uncertainty
	Energy intensive		Lack of alternative financing available threatens the ability of cement sector to deploy technologies with longer payback times

Table 8: SWOT analysis for cement sector

2. Market Structure

sector	Industry Definition	Market share of major companies (2012)	Key external drivers
Portland cement	There are only four companies that produce Portland cement in the UK. Portland cement is the world's most commonly used type of cement and is used to make concrete and mortar as well as other building materials. It is produced by heating materials such as limestone in a kiln to form what is called clinker, grinding the clinker, and adding small amounts of other materials.	1. CEMEX 21% 2. Hanson 19% 3. Larfarge 37% 4. Tarmac 10% NB: In 2013 Lafarge SA and Anglo American formed a joint venture Lafarge Tarmac. As a result, part of the business was sold to form a new UK competitor – Hope Construction Materials – but up to date market data is not currently available. NB: As of 2012 approximately 12% of UK cement was imported by independent importers.	• Demand from construction of built environment and infrastructure projects

sector	Revenue (£M)	Profit (£M)	Wages (£M)	Annual Growth	Production Volume (Mt)	Exports (£M)	Imports / Demand (%)	Revenue / employee (£"000)	Wages / Revenue (%)	Employees Total	Employees / establishment	Average wage (£"000)	Share of the economy (%)	Number of companies
Portland cement	431 (2012)	Unknown	70 (2012)	3% (2012 – 13)	8.6 (2013)	Unknown	12 (2012)	166.8	16.2	2583 (2014)	646	27,100	0.01	4

3. Assessing Enablers and Barriers

The first stage in our analysis was to assess the strength of the evidence for the identification of the enablers and barriers. This was based on the source and strength of evidence and whether the findings were validated via more than one information source. If the strength of the evidence was deemed high or medium high, then for the social and business research the enabler and/or barrier was included and information was used to support the answer to the principal question '*What are the main business enablers and barriers to decarbonisation?'*. If the strength of the evidence was deemed high or medium high for the technical options, the uncertainties in the modelling were reduced. The evidence was given a relevance classification of: "high", "medium high", "medium low" or "low". The classifications are defined in Table 9 below.

It should be noted that the nature of the interview and workshop discussion process means that these represent the opinions and perceptions of the interviewees and workshop participants which could not always be backed up with evidence from other information sources.

The evidence was analysed and interpreted using a variety of evidence analytical techniques such as SWOT analysis, system analysis and root cause analysis/causal mapping where possible.

Classification	Definition
High	High relevance for the UK cement sector Good financial-economic decarbonisation data Recent information (after 2000[5]) Provides a good example/story of decarbonisation Validated across all evidence gathering methods
Medium high	Relevance for the UK cement sector Financial-economic data not always complete or clear-cut and only generic decarbonisation data Provides a good example/story of decarbonisation Validated by more than one evidence gathering method
Medium low	Information that is too general or too specific Relevant grey literature Old information but still relevant Only mentioned via one evidence gathering method
Low	Background information No or low applicability for the UK cement sector Grey literature of limited value Old information Lack of relevance and/or only mentioned once

Table 9 Evidence Classification Definition

A **SWOT analysis** is a different lens to examine the enablers and barriers and reinforce conclusions and linkages between evidence sources. It identifies how internal strengths mitigate external threats and can be used to create new opportunities, and how new opportunities can help overcome weaknesses. By clustering the various possibilities, we identified key stories from the SWOT analysis which enabled us to describe the business and market story in which companies operate. In order to understand the inter-linkages between the SWOT analysis for the sector and the key enablers and barriers we identified from the literature review, interviews, and workshop, we analysed the root causes of the enablers and barriers and linked it back to the market environment and internal decision making. The top SWOT outcomes were identified from the literature review, reinforced in the interviews and voted on by workshop participants as the most important. These were shown above in **Error! Reference source not found.** of this Appendix B.

[5] Two publications older than 2000 were included in the high quality documents

System analysis can be used to help decision makers identify a better course of actions and make better decisions. It is a process of studying a procedure or business in order to identify goals and purposes, and to create systems and procedures that will achieve those goals most efficiently. It uses an experimental approach to understand the behaviour of an economy, market or other complex phenomenon.

Root cause analysis is a method of problem solving that tries to identify the root causes of a problem. A root cause is a cause that - once removed from the problem - prevents the final undesirable event from recurring. **Causal mapping** is a visual representation, showing causalities or influences as links between different nodes. These maps can be used to aid strategic planning and thinking.

4. Detailed analysis of enablers and barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Workshops	Analysis
1	**Financial/ Technology**	**Technological & financial feasibility**- if technology is proven and financially viable (typically less than 3 year payback) it is more likely to be deployed.	**1 Literature source:** Boston Consulting Group 2011 found that: "the cement sector is not obtaining reasonable returns, as average return on capital over the last four years has been between 3 – 5 percent below the cost of capital. This lack of returns has been, in part, due to exogenous factors and imposed liabilities. In order to meet environmental legislation in Europe, operations face major investments and operating costs. In addition, capital requirements are one to two times higher compared	**4 Interviews** Interviewee: "We've looked at putting in solar farm and financing was ok, but the connection cost was £13m. So we've looked at all these alternatives, but currently the best option is to keep increasing alternative fuels use and optimisation of equipment." Interviewee: "We have a range of projects, but they have to hit specific hurdle rates to receive capital. More incremental decarbonisation opportunities are delivered as part of daily operation of plants." Interviewee: "Our typical payback period is up to 3 years	**(4)** Workshop participants indicated that it was difficult to determine when something is proven and viable. Participants discussed that often it is enough for one plant to have demonstrated the technology prior to it being implemented. Another workshop table indicated that being the first mover is the least preferred option, and indicated it is best to be the first follower. However, participants indicated that any innovation that was determined to	Across the information sources it was clear that technologies that have been successfully trailed previously and with payback periods under 3 years would more likely be implemented over others. However, interviews also indicated that if third parties invested in the upfront costs of a technology with a longer payback the investment would likely go through. Under the current economic climate, acceptable payback periods range from 2-5 years within the industry with the average limit being 3 years. Some more strategic projects that could be utilised elsewhere or that have other benefits apart from reducing energy/carbon are given consideration with payback periods up to and occasionally beyond 5 years, but no further than a maximum of 7 years. Following rather than being a first mover with a new technology is the preferred option as this lessens the risk of investment.

			to other regions (with the exception of the US) and the cost of electricity is also higher due to CO2 costs and feed-in tariffs."	although we do sometimes allow 5-7 years if it's a strategic project" Interviewee: "We seek 1 year payback periods if possible, no more than 2 years max."	have an acceptable payback period (typically up to 3 years, but less for some companies) would be invested in assuming capital is available. During the workshop companies were not permitted to discuss their suitable payback periods due to competition regulations.	
2	**Innovation**	**Pipeline of technological innovations to reduce energy/carbon** – ideas waiting for investment	---	**4 Interviews** Interviewee: "We tend to have a long term wish list of projects to be implemented, but will depend on future market. Interviewee: "No huge projects that are in pipeline though – the big drive is to increase alt fuel use (e.g. 65% at one plant at the moment). Highest we've managed has been 85%."	**(2)** Workshop participants indicated that there are only limited technical solutions that are ready to be implemented and are not yet implemented already. Remaining innovations are hugely expensive (e.g. CCS) and/or	Interviewees expressed confidence that there are robust innovation pipelines for next five years, but that these were predominantly incremental improvements rather than any step change technologies. It should be noted that 'smaller' projects still require multi-million pound investment. New innovations in pipeline are carefully assessed against criteria such as ROI and carbon savings. However, any investment has to compete for Capex with other non-energy related investments at plants and ideas that offer the best return

				Interviewee: “We try to have 5 years capital programme for all plants. Make sure pipeline is still on track or not – but difficult financial times. Without any big projects we’ve tried to continue a long term plan of smaller energy improvements. Some projects payback period would be about 7-8 years in current economic climate – try to keep these in pipeline if financial situation changes so we can put these forward.” Interviewee: “We do have many projects we are always putting forward – healthy pipeline of projects over next 5 years including some big ones. We’ll have to see if they become viable financially” Interviewee: “Quite in touch with	will provide an unacceptable return in terms of cost or carbon savings.	are more likely to be selected. Workshop participants noted some larger projects (inc. CCS) that could be considered, but these are not considered financially affordable for UK companies, are not yet developed technically or they do not offer a significant carbon saving compared with their cost.

				international scene on what is happening as well as with supply chain – great network and get approached by entrepreneurs, etc. on new ideas to implement" Interviewee: "Each project is weighed against each other to determine which offers best value and returns. If selected then it'll go into a detailed costing and feasibility study (at that point we're investing a bit of money to get this study done). Have a team of engineers working on projects they'll work on each year. If a project gets through the study it goes to Exec to be signed off if above a certain threshold. Quarterly decisions, although it can be pushed through by special exec. decision."		

				Interviewee: "Payback periods are typically 3 years max. The longest payback we've asked for recently is a 4 year payback. 5+ years doesn't make much business sense. We've got plenty of smaller projects in pipeline within the acceptable payback periods."		
3	**Management & organisation**	**Commitment by top management to an environmental policy/ climate change strategy-** enables top management to sign off on low carbon technologies as they align with the company's strategies and policies.	---	**5 Interviews** Interviewee: "Main concern at the moment is to reduce emissions. Partly in response to EU pressures (EU ETS), partly to Climate Change Agreement (UK), Carbon Reduction Commitment (UK), but also partly due to internal commitment to reduce emissions" Interviewee: "Plus point is that top level commitment to improving energy/climate	**(4)** Workshop participants indicated that top management leadership is a necessary condition to reducing carbon. They also noted that they felt govt. should better recognise the leadership shown by UK cement companies on reducing carbon. Some participants called for the govt.	All companies in the UK expressed the view that their senior management are engaged with climate change and consider it an important issue for their company and sector. The UK cement industry considers itself to be a world leader on tackling climate change for their sector and feel they have demonstrated long-term leadership from an early stage. Top level commitment has enabled UK companies to make many significant carbon-reducing investments to date, but it was noted by interviewees that decision-making always has to be balanced with cost implications. In recent years the need to reduce energy use costs has been

	performance is there, but it does have to be affordable” Interviewee: “You need to be aware these are really global companies who compete strongly on environmental issues. The companies cannot sit still and they have no choice, but to have sustainability strategies” Interviewee: “We accept the scientific evidence on climate change and that business and society have to find ways of addressing it” Interviewee: “It would be nice to feel that we have a moral obligation on climate change, but it’s no good if it puts us out of business. So we will always try and do what we can within constraints of business and the fact	to avoid any additional climate change policy sticks and to recognise the industry’s early leadership and decarbonisation achievements to date.	as important as decarbonisation concerns although EU and UK climate change regulations are also having an increasing impact on operating costs. Interviewees commented that sustainability and climate change in general has become a key strategic issue and a market differentiator for major cement companies and this is also driving carbon-reduction investments.

	that shareholders have given us money and entrusted it to us. We have to survive as a business and our first priority has to be the shareholders, then our staff, then further stakeholders inc. the environment" Interviewee: "Trying to balance. Some of our initiatives are driven by the want and the need to increase decarbonisation rather than financial calculations"		

4	**Market & Economy**	**A stable and profitable business environment would encourage further capital investment and innovation in UK.**	**2 Literature sources:** MPA 2009 state that: "Growth in the construction sector will provide a platform for investment in new products. Without construction sector growth UK assets will continue to decline and will place the UK vulnerable to imports when demand returns" Boston Consulting Group 2008 found that: "Based on the expected cost of production in the EU assuming the carbon price of CO2 versus the cost of producing in non-ETS countries, clinker and cement production in the EU is not competitive without free allowances allocation. As a	**3 Interviews** Interviewee: "The big issue for investment is money. 35% reduction in market makes things difficult" Interviewee: "A stable and buoyant cement market would be the biggest enabler! Because we are capital intensive we only make the profit on the last few thousand tonnes per year so if we have higher consumption we'll have the excess capital to invest in more improvements" Interviewee: "Long term market stability is a big problem" Interviewee: "cement consumption in the UK per capita is the lowest in Europe. So we're not spending enough on construction or we're using different materials."	**(4)** Workshop participants indicated that a stable business environment is very important. They indicated that there are currently too many market distortions, interferences and vested interests that undermine profitability and could lead to offshoring of production and carbon leakage. One example that was noted was the Carbon Price Floor which they called to be scrapped. Participants noted that the EU demands that the sector meets carbon challenge, but are not appreciating that these extra costs make companies	All companies expressed the view that the key enabler to driving more investment in the UK was a stronger market for cement. Some companies said that the on-going downturn in the cement market since 2007 is preventing them from making many long term investment decisions in the UK. Demand is currently around 35% less than it was in 2007 and this has led to significant consolidation in the sector over the last few years. Interviewees recognised that govt alone could not re-energise the market, but noted that govt stimulation of increased house building would be very beneficial as would delivering a large scale national infrastructure plan.

			result, the “wise businessman” will prefer to relocate production to more competitive countries, this leading to production offshoring. At CO2 prices above €35/t (expected for the 2013-2020 period3) the current proposal of the Directive will lead to the complete offshoring of the cement industry. At CO2 price of €25/t4, more than 80% of EU clinker production will be at risk of offshoring by 2020: 100% of the Italian, Greek, Polish and UK production, almost 100% of Spanish, ~75% of German and 65% of the French, ~70% of the production of the smaller EU producers”	Interviewee: “There is a need for long term growth to enable more investment. We need delivery of government infrastructure pipeline (not just promises).”	uncompetitive.	

5	**Legislation**	**A stable, consistent and predictable regulatory environment would enable better long term planning and investment**	**2 literature sources:** Boston Consulting Group found that (to reduce carbon and remain competitive cement companies require): "− A consistent and predictable legal framework which allows for long-term investment planning and integrates economic, environmental and social considerations within a coordinated and consistent industrial policy at European level − Climate change and energy legislation that is characterised by a legal framework where parameters are fixed long-term, and continued security of supply is	**6 Interviews** Interviewee: "Government induced policy risk is one of the most significant obstacles to investment - More certainty on regulations and costs is very important for the industry so the companies can make long term investment decisions" Interviewee: "We need long term policy certainty" Interviewee: "A big barrier is regulatory risk and uncertainty – at both UK and EU level (especially at EU level) and the degree of interference into emissions markets is a big problem. Phase 3 was only a few months old before the whole debate on backloading began and now we're working on Phase 4. Our timetables are	**(4)** Workshop participants said that the sector requires very long term planning and therefore a more predictable regulatory environment would assist investment decision-making. The sector is already looking at 2020-2050 view and participants feel that govt policy does not currently meet the sector's need to ensure regulatory certainty that far into the future. Participants expressed the view that govt. still operates on a more short-term basis that hampers the ability of the cement companies to plan effectively beyond 2020.	A consistent finding across all information sources is that policy certainty is extremely important to the UK cement industry. Interviewees and workshop participants were of the view that constantly changing UK and EU regulations on energy and carbon are having a negative impact on their ability to forecast, plan and invest appropriately as policy uncertainties are leading directly to commercial uncertainties. Consequently the EU - and UK in particular - are seen as investment risks by global cement companies and this in compounded by the flat growth currently seen in the market. This is making internal competition for capital more difficult for UK cement companies who are competing with plants in countries around the world. Policy certainty to 2030 and beyond is something all companies in the sector would like to see as the industry has very long investment cycles.

guaranteed with competitive energy prices, in a unified European market; − Stronger coordination of national social policies and incorporation of social and economic feasibility considerations in one industrial policy for Europe in order to allow companies to proceed with long-term and structural investment decisions. − The high level of regulatory uncertainty in Europe discourages companies from making the investments required in order to improve the efficiency of cement plants and the lack of an appropriate legal framework deters	much longer than these phases so constant interference results in much more cost for us to address." Interviewee: "The cross sectorial reduction factor – A cap across sectors. We didn't see this coming and it was done at a time when already well into phase. We'd already sold cement and couldn't go back and ask for extra money for those emissions! When you work in global company it totally undermines your position." Interviewee: "The carbon price needs to be forecast to be considered in project feasibility studies. The price doubled in price over last year. Actually in line with DECC's prediction, but they're not always right. Price volatility

	companies from adopting structural adjustments” Centre for Low Carbon Futures 2011 found that: “Long term clarity is seen as vital to underpin high cost, long term technology investment.”	often related to EU policy. There’s backloading issue to try and push carbon price up to 15euro price per tonne which people want. What we need is certainty. Lots of EU ETS discussions right now to 2020, but we need to certainty to 2030-2050 if possible. By 2020 there’ll need to be a global agreement. For example, they changed allowances after most recent phase of EU ETS began.” Interviewee: “The power sector seems to be able to scaremonger and get decisions made in their favour. Govt intervention tends to destabilise us rather than help and creates inadvertent disruptions in the market. It’s very hard for us as business people that we can		

				ever trust that a govt policy will remain in place – need long term regulatory certainty to enable better long term business decisions." Interviewee: "We would like legislative certainty. Will bring more financial certainty." Interviewee: "We want a stable, long term policy environment which does not undermine the competitiveness of UK manufacturing."		
6	**Legislation**	**Level playing field - Reform of UK climate change / energy regulations, taxes and incentives -** Reform required to allow UK-based cement producers to be more cost competitive	**3 literature sources:** Boston Consulting Group 2008 found that: "Compared to the EU as a whole, UK clinker production is exposed to a higher risk of offshoring for three main reasons: a less competitive production cost, **a higher expected**	**5 interviews** Interviewee: "Talking generally a lot of the issues are driven by regulation (climate change agreement, decarbonisation commitment, EU ETS) – a huge part of decision making is driven by regulation. Then the other huge part of it is driven by business needs and operational efficiency.	**(4)** RO: Participants noted the Renewables Obligation has led to cement companies competing with each other and other sectors for scare biomass-containing fuels. FiT CfD: An equivalent of FiT	Across all information sources it was found that the UK cement sector has disproportionate costs placed upon it compared with EU and global competitors due to unilateral climate change policies in place in the UK. All companies expressed a desire for a more level playing field to improve their competitiveness against international producers and competing sectors in the UK that attract more Government support. Some companies wish existing policies such as Carbon Price Floor

			carbon price and the geographic configuration of the country itself." And (in separate BCG report) that: "An even playfield in compliance with regulatory requirements to guarantee that all competing players are subject to the same impositions across the (European) region" CIVITAS 2012 found that: "UK regulations only add to already considerable costs created by EU legislation. As a consequence, government policy is likely to be environmentally and economically self-defeating by encouraging mobile companies to relocate to less carbon-constrained	The one that overrides everything is maintaining competitiveness – we look at these big strategic decisions based on complying with regulation and maintaining competitiveness." Interviewee: "We need better support for our industry – we need it to be cheaper to invest than to be taxed. If the flip over is so expensive then ultimately it'll drive us out of business in the UK. Too many sticks, not enough carrots." Interviewee: "We should have a level field play. Very hard to get permits for example. Could offer streamlined procedures." Interviewee: "We need competitiveness for the cement industry. Need support for indirect	CfD's is needed to compensate the cement sector more. CPF: Participants called for the Carbon Price Floor to be scrapped. RHI: Participants also called for access to the Renewable Heat Incentive to avoid biomass diversion away from the sector and reform to the RHI. They also suggested reform to the 'closed loop' policies which favour recycling rather than burning of wastes such as tyres which, when applied in the cement sector, involves the recycling of the metal and mineral content; participants considered that	to be scrapped altogether and others to be altered to exclude/exempt the cement industry as appropriate or to limit the cost burden placed upon them. UK cement companies said that the entire UK clinker production sector industry is currently at risk of off-shoring as imports from some countries are already competitive on price. The likely substantial increases in electricity prices over the next few years are expected to exacerbate the situation further.

			developing economies. This problem is known as 'carbon leakage' and paradoxically results from the ambition of the government's decarbonisation strategy."	impacts." Interviewee: "We are committed to WBCSD CSI guidance and commitments, but there is little motivation in some countries to participate. We're some way off have a global GHG agreement." Interviewee: "There are many differences with UK. The Carbon Price Floor was introduced unilaterally as a tax. Affects UK, but not EU. Waste regulations are also threatening to take away streams of waste we can use for making cement; this could mean reverting back to fossil fuels."	the recycling aspect of coprocessing is not recognised. can lead to unintended negative consequences in terms of decarbonisations. Moreover, incinerators that burn the same type of waste are excluded from the EU ETS and therefore their CO_2 emissions are not accounted for, at least in the same way that the same CO_2 would be accounted in the cement industry	
7	**Market & economy**	**Better recognition of whole-life impacts of cement/concrete as a building material –** i.e. regulatory promotion of	**2 Literature sources:** CEMBUREA 2009 found that: "Some national design codes and standards place undue emphasis on minimising	**5 Interviews** Interviewee: "There is a drive to reduce carbon which is not just based on compliance costs – it's also to do with overall company sustainability strategy	**(3)** Workshop participants indicated that there is too much focus on the carbon generated in producing cement (and	All information sources indicated that cement (concrete) has useful qualities that are not currently fully recognised. In particular the thermal mass properties of concrete as a building material and the re-carbonisation of a significant proportion of carbon during the lifetime and recycling of concrete –

	thermal properties of concrete in buildings to reduce building energy use during lifetime.	embodied impacts and energy use of products, whilst little or no attention is paid to the whole-life performance of buildings. The benefits of heavyweight materials used in construction works should be recognised in existing and future legislation, such as the Energy Performance of Buildings Directive (EPBD). In addition, national compliance tools for assessing both energy consumption and sustainable performance of buildings need to be amended to take due account of thermal mass and climate change." And that: "Concrete can	including enhancing our product attractiveness to clients – Getting more and more requests for it from govt and other clients. UK definitely has much higher demand for low-carbon building materials – this is a driver from the govt who want to lead on climate change." Interviewee: "We explain carbon profile of product to our customers if they want to understand impacts. In future the industry could include full life cycle benefits (of concrete) and sell benefits to clients" Interviewee: "We also need to look more at the impact in buildings and where we improve their carbon performance over lifetime" Interviewee: "cement is essential for carbon	concrete) and very little recognition of the thermal properties of concrete which can lead to highly significant energy use reductions by buildings that are suitably designed with such properties in mind. Participants expressed a desire for govt to look at the whole life cycle of cement in terms of use in concrete buildings as well as recycling and the natural recarbonisation that takes place when concrete is broken down. Participants said that suitable encouragement of the use of concrete in new buildings through govt policy and standards could potentially be a	this re-carbonisation can be up to 30% of the total carbon emitted to produce the cement. Interviewees stated that they would like to see more government recognition of such properties and appropriate measures to encourage use of concrete to lower emissions from buildings through their lifetime. It was proposed that this could be achieved by modifying or implementing appropriate building standards and certifications in the UK.

	achieve significant energy efficiency when used in construction. Concrete can buffer a large proportion of heat gains in buildings. The high thermal mass of concrete decreases heating fuel consumption by 2-15% compared to equivalent lightweight constructions; this has been proven in research across the range of climates found in Europe” And that: “During the life of a concrete structure (such as a building or a road) the hydrated cement contained within the concrete reacts with the CO2 in the air. This process is called concrete carbonation. As	savings down the line in terms of its use, not just manufacture.” Interviewee: “you can say that client demands are a significant driver on the cement companies. Although it is still not the majority of clients that demand such high data and certification standards for the cement, the clear trend is we’re heading more and more in this direction” Interviewee: “Govt is the biggest buyer, so if it wants to increase sustainability in the supply chain it easily can. Could use certifications and update building standards. It’s all in standards and certifications.” Interviewee: “Full life cost of housing / embodied carbon –	very large enabler to reducing UK carbon overall (from wasted building energy) and improving UK demand for cement which would lead to greater ability to make further investments in UK cement plants.	

	part of the CO2 emitted during the cement production is reabsorbed by the cement through carbonation, this reaction is also referred to as cement recarbonation. The carbonation effect is enhanced when concrete is crushed and recycled." Nordic Innovation Centre 2005 found that: "The calculations show that up to 30% of the total CO2 emission from cement production, or up to 57% of the CO2 emission from the so-called calcination process in cement manufacturing, is re-absorbed when the cement is utilized in concrete	not well acknowledged or supported. Timber frame is favoured when building sector is doing better as it is now as it is quicker to use and capacity is easier to ramp up for a builder. But a concrete house lasts twice as long as a timber frame house and the thermal mass and efficiency are much better and there is the reabsorption of carbon into concrete and recyclability. Depending on who you speak to concrete is better; timber people will say timber is better. If govt were looking at more incentives in cement/concrete that would be useful." Interviewee: "We are committed to sustainable built environment and disappointed to see govt drop the sustainable homes	

			construction in the Nordic countries."	code. 10% of carbon in home comes from building materials, 90% from energy consumption during lifetime. We're concerned that if we build less sustainable homes now we'll be locked into them for 100+ years. Better regulation has a big role to play."		
8	**Technology**	**Funding for the development and successful deployment of CCS (or Carbon Capture and Use) would enable the sector to significantly reduce sector emissions**	**3 Literature sources:** DECC 2013 found that: "Industrial CCS could be a key technology for the decarbonisation of industry sector, potentially allowing energy intensive industries to continue using fossil fuels while significantly reducing emissions. ESME modelling suggests that a significant component of long-term industrial	**6 Interviews** Interviewee: "We have seen quite a few DECC commissioned reports on viability of CCS in industry, but haven't seen similar level of commitment to actually funding CCS plants" Interviewee: "We can't decarbonise as without CCS as 60% is process emissions – so when targets are set for reductions fundamentally the scale of the challenge is bigger as we have to try and eradicate the other 40% somehow."	**(4)** Workshop participants indicated that CCS will be required to meet long term decarbonisation targets as process emissions make up such a significant proportion of cement's emissions profile. Participants questioned when such R&D will be funded in the UK and by whom. They indicated that they would be very interested in CCS	A clear finding from the information sources was that CCS will be required if cement plants are to reach the target of an 80% reduction in carbon by 2050. This is because the calcination process in heating limestone is an unavoidable source of the sector's carbon emissions. The only way to eliminate the emissions from calcination is to use CCS or to create completely new types of cement, but the latter approach has its own barriers obstructing it (See Barrier 3) All companies in the UK said that they could not afford the capital or be willing to take the risk on scaling-up research or piloting such an uncertain and expensive technology without government and/or cross-sector support. Even if CCS does become technically viable in future

			abatement potential lies in CCS technology. Industries which emit carbon from their manufacturing process itself (for example CO2 emitted as a consequence of chemical reactions [e.g. cement]) are likely to need to implement CCS to decarbonise. Industries which are most likely to be suitable for CCS are iron and steel, cement, oil refining and chemicals. 29 Industrial facilities which are located close to other industries or power stations and storage sites are more likely to be able to implement CCS if they can share transport and storage infrastructure. cement: Post-	Interviewee: "Our question to the govt would be can you support our industry for the next ten years to get new tech such as CCS invested in? Green grants etc. to keep us competitive and help with stakeholders in local planning issues. Planning is a major issue for us and the building trade as well. We've been observing CCS developments however if we built a plant within next 10 years then it'll still be too soon for CCS. So this uncertainty over new tech and whether our plant will be obsolete straight away is a barrier to making a new one. You'd never recover the delta." Interviewee: "CCS will have to be implemented to significantly reduce much of our sector	if they had the funds to invest in it, but it is not commercially viable and particularly for first movers.	there are significant concerns over capital and running costs as current estimates are that a new plant with CCS installed would cost approximately double the cost of a plant without CCS and this could make cement produced at CCS-equipped plants fundamentally uncompetitive with traditional plants. However, enthusiasm for researching and ultimately deploying CCS was found from the majority of workshop participants. Most interviewees considered it unlikely that any CCS could be deployed prior to 2025. Some interviewees consider Carbon Capture and Use to be of more promise as CCS would require extensive transportation of carbon across the UK to storage sites. The point that without CCS, decarbonisation efforts could only really focus on the 40% non-process emissions shows that CCS is essential for deep decarbonisation.

			combustion capture technology using amines is considered most suitable for current cement production methods although research into Oxyfuel methods is also under way.” EIAGHG 2013 found that: “CCS will be required if cement manufacturers are to meet overall decarbonisation targets as efficiency savings have limitations. Most cement companies feel CCS is relevant to them, but only a third are willing to contribute to a pilot project due to high costs” CEMBUREA found that: “Carbon capture and storage is currently being researched by the cement	emissions.” Interviewee: “A key enabler to decarbonisation is more R&D into decarbonisation opportunities such as carbon capture and use in the cement sector.” Interviewee: “UK cement industry is not big enough to fund CCS research. Enabler would be support for pilot studies such as those in Europe. Don’t want UK to fall behind in carbon capture. We want more research grants available and a proper strategy to make it costs effective for sector.”		

			industry. Although not proven on an industrial scale, research on carbon capture (post combustion and oxyfuel technologies) is being undertaken by the European cement Research Academy (ECRA) to identify the possibilities it has to offer."			

9	**Management & organisation**	**Agreed and achievable, sector-wide targets and carbon-reduction roadmaps** assist sector in reducing emissions in coordinated manner	**1 Literature source:** MPA 2009 found that: "Considerable early action by the UK Portland cement industry has decoupled economic growth from environmental impact and the industry has reduced absolute CO2 emissions by 55 per cent between 1990 and 2011 (27 per cent reduction per tonne of output), outstripping the UK economy as a whole. MPA cement launched its first Carbon Strategy in 2005. The short term period of action in the original strategy ended in 2010. Since then there has been a considerable effort by policy makers,	**3 Interviews** Interviewee: "The cement sector maybe the only sector to have fully road mapped not just the manufacture of our product, but also how the product then plays a significant role in the value chain of carbon emissions in concrete and buildings, etc." Interviewee: "cement industry is very forward thinking on sustainability and have road mapped well ahead of other sectors, but are constrained by costs and market/policy uncertainties" Interviewee: "As an industry we have our roadmap. Innovation is crucial. All the competition are looking at lower energy cement, but there are a lot of challenges and it will take time to spread this around."	**(3)** Workshop participants noted that carbon-reduction roadmaps and targets are already in place (MPA roadmap). All are published and available, but perhaps govt. is less aware because officials change regularly. Participants indicated that they felt the market place is well aware of cement sector roadmaps as the cement companies are very effective at communicating these to construction sector.	The UK cement sector already has emissions-reduction roadmaps in place that have been created by the MPA in collaboration with UK companies. The MPA's roadmap presents two scenarios that they think are achievable. The first scenario does not include CCS and forecasts a maximum emissions reduction of 62% by 2050 (compared with 1990 levels). The second forecasts a possible reduction of 81% if CCS is successfully deployed. Many participants noted that they felt government were simply not particularly aware this road mapping work had already been completed and agreed to by the sector companies.

			NGO's and industry groups to map the necessary reductions in emissions to address the scientific imperative to minimize anthropogenic induced climate change. There has also been considerable research into low carbon pathways and carbon foot printing."			
10	**Innovation**	**Government funding and/or investment support for decarbonisation R&D activities and Capex costs.**	**4 Literature source:** Boston Consulting Group state that: "The right regulatory incentives to drive growth (includes) − Focus European R&D&I funds on targeted key priorities, such as energy and resource efficiency, and align national and EU funding programmes;	**3 Interviews** Interviewee: "Financing of projects is the key – if long payback there may be some need for some sort of external support such as GIB. Interest rates need to be more favourable to invest in many projects." Interviewee: "Low carbon cements are being developed by some of the companies globally,	**(3)** Workshop participants said that UK cement companies are continually investing in operational improvements using their own funding. However, they noted that additional availability of capital would be helpful depending	It was found d from all information sources that as the cement sector is very competitive on price and the UK market is still experiencing sluggish growth, there is less capital available to invest in the UK and/or investing the capital in the UK is more risky and less attractive than investing it in other countries. The cost of borrowing for cement companies in the UK is often prohibitively high when compared with the potential ROI or the payback times many innovations would entail. There has been some hope that the Green Investment Bank would

			− Reform state aid legislation in order to allow public seed money for bringing existing technologies to market and bridge the gap for investment where return on investment is currently too low across the industry." MPA 2009 state that: "The European industry is undertaking practical research and collaborating with equipment suppliers to find the best capture methods for cement but if the UK wants to be a leader then UK Government financial support is necessary for the UK cement industry. Without this support the UK cement industry will miss	but the research is not happening in the UK itself" Interviewee: "There is some R&D going on in the sector at universities such as Sheffield, Birmingham and Imperial. However, UK R&D tends towards cement types and formulas rather than plant and equipment related research which tends to be done abroad. Some of the new cement/concrete formulas are based on lower carbon outcomes" Interviewee: "With some funding for R&D, academic bodies tend to be much better than the cement companies at claiming this funding. However the funding would be very useful for the industry, but it all happens so quickly with so little visibility that the companies	on the level and type of funding.	provide an avenue for capital for longer term projects, but the interest rates are also not suitable to be commercially viable. Some other form of government-led investment support could prove useful to the industry. However, all the companies interviewed said that while generating capital or gaining approval for it is difficult they are still investing in many incremental efficiency improvements every year as part of BAU.

			its most ambitious scenario of an 81 per cent emission reduction by 2050." Centre for Low Carbon Futures 2011 found that: "Some industry respondents commented on the difficulty of accessing government support to promote industry R&D (in UK)." EIAGHG 2013 found that: "Most cement companies feel CCS is relevant to them, but only a third are willing to contribute to a pilot project due to high costs"	miss the opportunity to take some of this money. This money for R&D might be much better spent by the operators rather than academic and research bodies." Interviewee: "A couple of companies have spoken with GIB, but the rates are mainly market rates so not particularly cheap way to borrow" Interviewee: **"**Waste heat recovery is something we've wanted to do for a long time, but even with high electricity costs we can't get payback down under 6-7 years so we can't get that one to go ahead. Would need some kind of external incentive such as a grant from the govt. Electricity supply is pretty problematic so this would be a good candidate to add additional energy		

				supply. Doesn't appear to be anything out there from government to support this. Could possibly work out agreements with equipment suppliers and payback through electricity but not sure it'll work."		
11	**Innovation**	**Projects with additional side benefits in addition to decarbonisation**	**---**	**1 Interview:** Interviewee: "There are some projects that if they are just based on energy then they are hard to justify, but some of them we can point to ways they improve the quality of the product or enhance throughput – i.e. looking at wider context to further justify the cost"	**(2)** Workshop participants indicated that projects that had additional benefits – beyond energy and carbon savings – would get more management buy-in, but most ideas have already been implemented.	While workshop participants recognised this as an enabler, they expressed the view that this is simply BAU for them and that they are constantly seeking to maximise co-benefits from various projects that they invest in.

Barriers

#	Category	Barriers	Literature review	Interviews	Workshops	Analysis
1	**Financial**	**Requirement for short payback periods and/or high rates of return on energy efficiency projects**	**1 Literature source:** Boston Consulting Group 2011 found that: "the cement sector is not obtaining reasonable returns, as average return on capital over the last four years has been between 3 – 5 percent below the cost of capital. This lack of returns has been, in part, due to exogenous factors and imposed liabilities. In order to meet environmental legislation in Europe, operations face major investments and operating costs. In addition, capital requirements are one to two times higher compared to other regions (with the exception of the US) and the cost of electricity is also higher due to CO2 costs and feed-in tariffs"	**4 Interviews** Interviewee: "The project engineers will work up cost of a project – that determines the cost of capital – the benefits in terms of fuel, cost, carbon period laid out against cost. If payback period is not acceptable then it will be rejected unless it's a strategic project which can be shared around company. If a project is just plant based then payback period needs to be within 1-5 years. If strategic then there is more room for negotiation." Interviewee: "We've rejected several ideas for upgrades – some of which would have cost millions of pounds – as the payback period and ROI were poor compared with other plant investments and we couldn't justify the costs" Interviewee: "If a project had a return of a year then it would be instantly signed off" Interviewee: "Payback periods are another industry barrier. Companies need to be able to pay back investments in 2-3 years rather than the 10+ years the government often wants companies to invest. A couple	**(3)** Workshop participants indicated that energy is not treated differently to other areas of business when considering ROI and making investment decisions. Therefore capex funds are often tied up in other areas that offer a better return. An acceptable payback was more important than capital costs and companies are willing to fund expensive projects if the payback period is acceptable. Some participants indicated that most of the 'low hanging fruit' energy efficiency projects have already been implemented and some of the possible future innovations are expensive and do not offer an acceptable return on investment either in energy/cost savings or reducing carbon. It was also noted that because UK cement companies are carbon/energy efficiency leaders this means that global cement companies could	In this energy intensive industry nearly all of the easy energy efficiency and decarbonisation measures have been adopted. This means that the remaining opportunities tend to be harder and with more challenging investment profiles. Payback periods for advanced technologies were seen as the most important barrier across the information sources. Some projects are deemed to be prohibitively expensive without offering significant energy and carbon savings. It should also be noted that for the cement sector the average return on capital over the last four years has been between 3 – 5% below the cost of capital; this is an important aspect regarding availability of capital. Many of the options discussed in the interviews and workshop such as waste heat recovery had paybacks of over 7 years

				of companies have spoken with GIB, but the rates are mainly market rates so not particularly cheap way to borrow” Interviewee: “Unfortunately we don’t have a mandate to just invest in things we want to – it’s got to make economic sense” Interviewee: “The return of capital would need to be more that the cost of capital. Typically need to be able to generate capital.”	achieve better carbon/energy reductions and returns on investment by investing in plants in other countries instead of the UK.	or were not suitable for sites. The interviews revealed that decision making criteria usually included payback of 3 years or less or in some instances even 1 year or less. The maximum payback reported was 5 years for standard projects, but most insisted on 3 years as a typical maximum for projects to be green lit. However, some companies indicated that they sometimes got the go ahead for projects with high payback periods (5-7 years) if they were deemed to be strategic i.e. the project had potential to be subsequently rolled out at other plants and/or had additional benefits beyond energy and carbon savings. Workshop participants highlighted that there may be an opportunity for cross sector sharing to finance large demonstration projects to overcome payback or to utilise third

						party financing.
2	**Financial**	**Lack of access to and competition for capital –** internal competition for funds from cement plants outside UK.	---	**6 Interviews** Interviewee: "There is capex competition with plants elsewhere around the world – projects and plants compete on cost savings, carbon savings and market opportunities." Interviewee: "Internal competition for capex is big barrier" Interviewee: "There is also a lot of internal benchmarking within companies by different plants in different countries. They are competing with each other for investment. The recession has affected many companies in sector, not just in UK. Financial investment has declined across the world so internal competition for capital investment is very strong." Interviewee: "Return on investment is critical (and the assessment includes carbon price)" Interviewee: "We are competing for capital within an international business. This is a barrier for us." Interviewee: "As part of global company competing for capex the cases can be difficult to make –	**(4)** Workshop participants indicated that competition for capital can be separated out from lack of capital in some cases. Plants in other countries often offer a better return on investment (partly because of lower carbon prices elsewhere). Global agreements are needed on carbon prices, but this is difficult to resolve. For the time being companies must assume such agreements will not be made in short term future. Some participants indicated in the UK there is a need for someone/body to bridge the gap between cement companies that want additional capital for energy efficiency and funding organisations that could provide such capital.	Multi-national companies highlighted that it is difficult to obtain funds for UK energy efficiency projects, when there may be more profitable investments more closely aligned to the core business in other plant locations outside the UK. Interviews highlighted that R&D funding has become more limited in size and number, or R&D funding available is not earmarked for process efficiency innovations. The workshop and interviews indicated that in some instances there is no capital available, and in others, the capital is limited due to governance structure of the company or expenditure limited to a percentage of turnover. The cost justification of energy efficiency projects over other projects was seen as an additional internal decision making

				regulatory regime, high and increasing electricity costs, EU ETS, CPF, etc."		barrier.
3	**Market**	**Risk aversion – companies are wary of being locked in to the 'wrong' investment choices** (in part due to high technology costs, long investment cycles and concerns over product quality impact)	**1 Literature source:** DECC 2013 notes that cement sector suffers from risk-averse thinking - wary of risks to product quality or being locked in to 'wrong' investment choice.	**3 Interviews** Interviewee: " Risk aversion – due to poor economic conditions we've had ideas we could do work on, but concern over payback period and technical hiccups/delays related to quality of supply, etc. has put industry off quicker investments" Interviewee: "Unfortunately to date new formulas have often had quality issues compared to traditional Portland cement. Durability is very important and it could take decades of testing for these products to prove their longevity of strength compared to Portland cement. When you build skyscrapers and infrastructure you are spending billions of dollars and you need to know it will last!" Interviewee: "We've got a robust change procedure, but have to be careful with any projects that could interfere with product quality and production levels." Interviewee: "A barrier is that we need to ensure product quality and technical performance whilst using multiple fuel types."	**(4)** Workshop participants indicated that there are potentially serious consequential financial and reputational risks involved relating to product quality. The long life time of cement means that it must be durable for many decades and this also means that testing new materials and formulations takes a long time. To overcome this barrier would require investment in new materials that can demonstrate the process and safety. The conservatism of structural engineers was also noted as a barrier.	Product quality is a particularly important concern for the cement sector as concrete structures are expected to maintain their strength and structural integrity for a long period of time. It was also found that construction specifies such as architects and engineers are typically risk-averse due to safety and financial concerns. Therefore finding radical new replacements for traditional cement formulations such as Portland cement is problematic. Any new cement products need to be thoroughly tested and this is especially the case for any new concept that significantly deviates from traditional materials. Therefore any promising new 'low-carbon' cements would require many years of durability testing before they would be approved by

						certification bodies or considered by customers. While work is on-going to lower the carbon emitted from production of Portland cement, these are often incremental changes to the formulas used and not the step change required to eliminate significant carbon from the process of creating cement by using completely novel materials. To date, new concepts such as Novacem cement have not been deemed successful or are unsuitable for the UK.
4	**Legislation**	**Increasing competition for of diversion of alternative fuels and biomasses.** Specifically, the Renewable Heat Incentive increases	**2 Literature sources:** DECC 2013 found: "Refuse derived fuels (RDF) can be derived from processing household, commercial and industrial wastes. Nearly 40% of the UK cement industry's thermal energy demand is supplied using RDF. RDF has approximately 50% biogenic energy content, therefore 50% of the energy from RDF is considered to be renewable. The cement industry also burns tyres as a fuel, part of which is natural rubber which is considered to	**7 Interviews** Interviewee: "RHI is a problem – 10 years ago we were the only company who bought some alternative fuels and now we can't afford them compared to other companies. It was previously almost zero cost and now similar price to coal. If you look at small scale biomass then RHI takes it all away from us as we can't get the incentive, Interviewee: "Security of supply is a worry – we need to know we can get a long term supply when investing in new alt fuel equipment. One key	**(4)** Workshop participants indicated that the sector has been a pioneer in the use of biomass alternative fuels and have demonstrated their viability as a fuel source as well as breaking down permit barriers with the Environment Agency in recent years. It was noted that the RHI is applied to other users, but not the cement sector. However, no specific reason has been given for this decision and many participants felt that their	A consistent finding from all information sources was that the Renewable Heat Incentive and other renewable policies are hampering the cement industry's ability to source biomass-containing alternative fuels and these are being diverted elsewhere. The RHI rewards certain sectors and households for burning biomass, but the cement sector does not currently qualify for the incentive and therefore

		biomass costs for cement sector as it is not eligible.	be renewable." MPA 2009 states: "Government policies currently inhibit the maximized use of Alternative Waste Derived Fuel in cement manufacture which results in a continued reliance upon fossil fuels. Other policies allow Alternative Waste Derived Fuel to be incinerated without a charge being placed on the resulting GHG emissions which means there is uneven treatment of the combustion of the same fuels in different applications • Current Government policies to enhance the use of renewable heat are poorly focused and incentivise the use of biomass for some activities but not others, potentially creating a shift in biomass use from one sector to another without an overall environmental benefit. The current Renewable Heat Incentive creates an incentive to move biomass use from cement kilns to other potentially less efficient uses. This is an unwelcome intervention in the market by a poorly designed policy.	question we now get asked when we do alt fuel capex is "Do you have a contract in place to get this material for the long term?" Need to remove distortions out of the market such as RHI – it is not recognising that it can be burned anywhere, why should one person get advantage?" Interviewee: "Have been pushing govt to allow cement sector to have energy incentives such as RHI. Govt is offering the incentives to other industries, but not cement sector. So the cement sector will be priced out of purchasing fuels such as biomass fuels. At the moment we're not allowed access to the RHI because we are a direct firing industry. Basically any sector that uses boilers is offered this incentive by using biomass boilers where steam can be measured, but there is no difference to it being burned for direct fire in terms of emissions impacts" Interviewee: "The RHI is not currently fair on our sector. Other sectors attract the incentive whereas we do not because we were already doing it. Power sector can get the incentive just by being late to party and they are high profile." Interviewee: "The RHI needs to be	use of alternative fuels was less carbon-intensive than other sectors and households that are eligible for the RHI. Participants expressed the desire for more stability and certainty on RHI and for it to be reformed to allow cement companies to become eligible. i.e. DECC to recognise direct-firing in the RHI.	they can no longer match the price some other users are willing to pay for some biomass fuels. The industry argues that as pioneers in the use of alternative fuels this is frustrating, but more importantly that there is no net carbon benefit to burning biomass in their sector or in another sector. Several interviewees argued that there were two reasons that the cement sector may in fact hold an advantage over other users of biomass and therefore the industry deserves to qualify for the RHI: 1. Some other users of biomass are quite small and geographically diverse - this is particularly true of households. The cement industry argues that their more centralised use of biomass is more energy and CO_2 efficient. 2. The cement sector is able to make use of the

			• In 2011 almost 17% of fuel was from biomass fuel and biomass fractions. It is assumed that 40 per cent of fuel use will comprise of biomass by 2050. This is an ambitious assumption for the same reasons as outlined above for AWDF but is also likely to be principally influenced by the pressure on the power generators and others to fuel switch.”	reformed to offer us same incentive as we're doing same thing as other sectors, just not being rewarded” Interviewee: “RHI is having a significant impact on biomass availability” Interviewee: “We'd like policies which support use of biomass in cement.”		ashes created from burning alternative fuels by incorporating them into their cement product without creating waste. There were no information sources that presented any justifications as to why the cement sector does not qualify for RHI while other sectors do.
5	**Organisation**	**Shortage of qualified engineers and specialist skills and knowledge**	**1 Literature source:** DECC 2013 notes that cement sector suffers from a Shortage of qualified staff (esp. heat engineers) and aging of workforce.	**3 Interviews** Interviewee: “We have concerns about UK skills available.” Interviewee: “We struggle to attract top graduate talent compared with more glamorous sectors such as tech. There are concerns about a knowledge gap occurring when more people retire from sector.” Interviewee: “We need specialised technical resources/skills. cement plant operators are highly skilled. If a kiln is down for a day this can cost £100k. More complex tech needs greater skill. The reduction in manufacturing in UK makes it difficult to find graduates wanting to come into sector. Smaller pool to recruit from. How can govt help? We	**(3)** Workshop participants indicated that it is difficult to attract top talent to the cement sector. They also noted that it takes time to suitably train individuals.	The evidence sources for this barrier were slightly mixed in terms of the importance placed upon this barrier. Two interviewees and the literature reviewed indicated a shortage in skilled workers, but the workshop findings were not quite so strong. Some participants argued that they did currently have sufficiently skilled workers, but that the longer term outlook was not so promising as the sector has a less attractive image than other sectors which makes graduate

				need an environment where heavy industry can flourish and make youngsters want to study and join sector. cement perception is not positive, but reality is its very clean and technical work. Visitors are always surprised by the level of skill required to make cement! We need to promote positive side of industry." Interviewee: "sector is rurally-based. We generally attract local youth/students with well-paid apprenticeship. When we go look for specialists such as environmental experts it can take a long time to attract the right person though."		recruitment more difficult. Some participants noted that they felt the government needs to do more attract young people into heavy industries including cement.
6	**Legislation**	**Un-level GLOBAL playing field** with overseas competition due to differences in climate change and energy policies. (Two distinct levels – Global playing field & EU	**3 literature sources:** Boston Consulting Group 2008 found that: "Based on the expected cost of production in the EU assuming the carbon price of CO2 versus the cost of producing in non-ETS countries, clinker and cement production in the EU is not competitive without free allowances allocation. As a result, the "wise businessman" will prefer to relocate production to more competitive countries, this leading to production offshoring. At CO2 prices	**4 interviews** Interviewee: "The carbon price floor is fundamental because it's charged to electricity providers and they pass that on to the customers. As cement is electricity intensive this means higher costs compared to others in EU and elsewhere. It's the cumulative impact of energy and carbon prices that it making us uncompetitive (in the UK)" Interviewee: "We would like revisions to Annex 2 of Emissions trading directive to include cement sector and that – with Phase 4 of ETS – once it's fixed, then no interference whatsoever and then	**(4)** Participants indicated the lack of a level playing field is leading to more investment being made outside the UK/EU by global cement companies. Carbon leakage is occurring and will likely increase unless playing fields is levelled. Global agreements are required to create more level playing field, but unlikely in short term due to vested interests. One suggested action was to	Workshop participants and interviewees have noted that EU companies are at a disadvantage with global producers, principally due to the EU ETS as well as high production and energy costs. Although the industry is impacted by carbon leakage, during the workshop it was noted that currently low carbon prices and the economic recession have temporarily limited the impact of carbon leakage on the

		playing field)	above €35/t (expected for the 2013-2020 period3) the current proposal of the Directive will lead to the complete offshoring of the cement industry. At CO2 price of €25/t4, more than 80% of EU clinker production will be at risk of offshoring by 2020: 100% of the Italian, Greek, Polish and UK production, almost 100% of Spanish, ~75% of German and 65% of the French, ~70% of the production of the smaller EU producers. - EU ETS could make European cement manufacturers uncompetitive with global competitors / plants leading to possible carbon leakage" CIVITAS 2012 found that: "the industry incurs carbon prices through various UK and EU regulations. The industry trade group, the Mineral Products Associations (MPA), estimates that these costs will be €65m in 2013 alone, or over ten per cent of the industry's revenue."	we can work on phase 5" Interviewee: "Key issues are at the European level - EU and non-EU cement companies have different advantages. How do you maintain competitive advantage at the global level? As you know in the UK, the indirect prices are higher than in other European (EU ETS) states, so we do not have the same level field. cement should be compensated for the indirect costs in the UK, especially for the carbon price floors. In the UK construction market, cement competes against steel, then there's the second field UK versus EU, and then EU field versus Global." Interviewee: "There needs to be investment certainty. We are part of a global organization, when we are making investment proposals we are competing on a global basis. So return on investment and fewer risks are important. All of the cement companies in the UK have capacity developed on the global basis. If companies in the UK cannot be competitive, operations are going to move offshore"	implement a global "Embodied Carbon" system taking into account of true life cycle emissions of cement from different markets (inc. transport carbon). Procurement drivers to 'reward' low embodied carbon.	sector. However, interviewees, and some workshop participants, indicated that they are beginning to experience carbon leakage and are seeing an increase in imports as a result. Interviewees wished for reform of the EU ETS system to make it fairer for their sectors and also to ensure long term certainty over allowances and carbon prices. The sector would like to see global agreements and equalised carbon pricing to level the playing field on carbon, but there is scepticism that this will happen any time in near future – partly due to vested global interests.

			Boston Consulting Group 2011 found: "An even playfield in compliance with regulatory requirements to guarantee that all competing players are subject to the same impositions across the region and, at the same time, that European players are not at a disadvantage when facing competition from outside the region − Challenge unfair subsidy regimes from non EU jurisdictions that have a negative impact on Europe's competitiveness and design proper regulatory mechanisms that can secure a level playing field in full compliance with the World Trade Organization rules as long as no equivalent measures apply to industry globally."			
7	**Legislation**	**Un-level EU playing field** with overseas competition due to differences in UK climate change and energy	**2 literature sources:** Boston Consulting Group 2008 found that: "Compared to the EU as a whole, UK clinker production is exposed to a higher risk of offshoring for three main reasons: a less competitive production cost, **a higher expected carbon price** and the geographic configuration of the country	**4 Interviews** Interviewee: "cement industry are only being treated with the stick and no carrot – costs from regulations are continually rising in UK with little incentives being offered to do business here. It is a global industry. ICF Cost of climate change policies showed that it would cost more to do business in UK in most industries and in particular the cement sector."	**(3)** Workshop participants indicated that there needs to be EU-wide harmonisation of carbon legislation and associated costs to enable UK-based cement producers to remain competitive with EU-based producers. Vested interests are playing a role in preventing harmonisation	While it was found that the EU ETS affects all EU cement producers, interviewees and workshop participants consistently stated that the UK has unilaterally implemented further climate change-related policies that are increasing sector costs and starting to make the

		policies. (Two distinct levels – Global playing field & EU playing field)	itself. Clinker production in the UK is 5 to 10% less competitive than in other EU countries (like France or Germany) mainly due to labour and energy cost." CIVITAS 2012 found that: "UK regulations only add to already considerable costs created by EU legislation. As a consequence, government policy is likely to be environmentally and economically self-defeating by encouraging mobile EIIs to relocate to less carbon-constrained developing economies. This problem is known as 'carbon leakage' and paradoxically results from the ambition of the government's decarbonisation strategy."	Interviewee: "In the UK we are not being compensated for energy costs whereas some other sectors are being supported (e.g. paper and steel industries are being compensated – they have stronger lobbying power as well as passing the EU test on this). Currently UK cement sector would pass the test, but as a Europe wide industry we did not pass when test was carried out several years ago. BIS have tried to support us to the EU, but have other priorities so we are still stuck with no compensation" Interviewee: "sector needs to appear in Annex 2 of the emissions trading directive, but it does not unlike the iron and steel sectors. Basically when thresholds were set cement fell under that. So cement sector does not receive any compensation for carbon price floor and increased energy costs." Interviewee: "Carbon price floor could be abolished, UK unilaterally implemented this and it's purely a stick." Interviewee: "We would like the removal of carbon price floor as fundamental differentiator between	taking place. It was noted that imports have already reached price parity with UK-produced cement and in some instances it is cheaper to import from abroad from countries such as Spain. Some participants said the Carbon Price Floor should be scrapped or that there should be compensation for cement companies. Some participants expressed a desire that the "UK govt should stop discriminating against UK industries".	UK uncompetitive with imports from European neighbours such as Spain. The Carbon Price Floor, Climate Change Agreements and high pass-through electricity costs were all cited by multiple interviewees as presenting additional costs that are not faced by EU competitors. The uncertainty of EU and UK policy over the 30+ year timeframe of major investment in new kilns makes potential investors very uncertain about whether they will get a return on such investments

				UK and Europe and to be approved for relief from the renewable feed in tariff" Interviewee: "A barrier in UK is our green electricity taxes and other pass through costs."		
8	**Market**	**Highly competitive international market** – UK is at risk from lower cost imports	**4 Literature sources:** Boston Consulting Group 2008 states: "Compared to the EU as a whole, UK clinker production is exposed to a higher risk of offshoring for three main reasons: a less competitive production cost, a higher expected carbon price and the geographic configuration of the country itself. UK's geographic configuration offers limited protection against imports by sea, as clinker can be shipped all around its perimeter and inland distances to be covered are minimal. As most of the plants are located south of Liverpool, inland transportation costs from the ports of Liverpool, Grimsby, Southampton and London are low, so representing a limited barrier against offshoring."	**4 Interviews** Interviewee: "Need to get into govt a better understanding of the industry – you just can't raise the price and put the impact onto the customer. The margins are too low. Essentially you'll just eliminate the UK industry altogether as imports increase. Basically we are and will be just slowly squeezed out by all these small additional costs that our foreign competitors don't have" Interviewee: "cement industry are only being treated with the stick and no carrot – costs from regulations are continually rising in UK with little incentives being offered to do business here. It is a global industry." Interviewee: "Our top barrier to decarbonisation is competitiveness – some of this is to do with UK generally, but also to do with policy and regulations"	**(4)** Workshop participants noted that cement imports into the UK have increased substantially in the last 10 years despite reduced demand and sector consolidation in UK. UK cement companies have no control over their cost disadvantages. To overcome this barrier, participants said that there needs to be: - Certainty over carbon leakage protection - Global comparable GHG agreement - Same carbon policies across EU and world	cement imports into the UK from those companies that don't manufacture in the UK have increased from approximately 3-4% to 13-15% over the last ten years despite significantly reduced demand (-35% compared with 2007 levels) and consolidation of sector in UK during that time. A range of factors are making the UK uncompetitive and vulnerable to imported cement. These include the additional costs of producing cement in UK due to UK-specific regulations such as the CPF or due to pass through costs that have raised energy prices. The UK is more vulnerable

			MPA 2009 states: “Growth in the construction sector will provide a platform for investment in new products. Without construction sector growth UK assets will continue to decline and will place the UK vulnerable to imports when demand returns. To date UK industrial consumers have experienced higher electricity costs than our competitors. Analysis carried out by BIS has confirmed that UK energy consumers will pay more for their electricity than competing nations as a result of the UK’s decarbonisation policies. Industries that are significantly vulnerable to carbon leakage such as cement will need protection from these unilaterally applied costs so that they are able to compete with importers on an equivalent basis.” DECC 2013 states: “cement production in UK is a highly competitive market which limits the ability to pass through costs of energy or	Interviewee: “Last resort is to put our prices up, but then we’ll be uncompetitive internationally and we’ll be beaten out by imports.” Interviewee: “UK is particularly vulnerable to offshoring. In 2014, 14-15% of the market is offshore. Because they are more competitive. In just over 10 years the increase in around 10%. Also the increase is seen at the time of market contraction” Interviewee: “In future we have a decision – do we invest in new kilns or do we simply import instead?”		than many other countries to imports and offshoring of production due to its already installed terminal capacity and coastal geography which makes importing to sites around the UK comparatively cheap and straightforward. As UK cement companies operate in a highly competitive international market they have only limited ability to pass on any additional costs to their customers in the UK. The impact on profitability means that companies are finding it difficult to justify further investment in UK operations and the entirety of UK production is currently at risk of offshoring in coming years.

			investment to consumers." Boston Consulting Group 2011 states: "These insufficient rates of return are also due to the fact that the cement and concrete sector is unable to pass on rising costs to customers. cement is one of the few energy-intensive materials that has seen its prices fall by 13 percent between 2007 and 2011, despite a rising cost base of between 6 and 26 percent during the same period."			
9	**Operational**	**Long plant life (longevity of current equipment)/ investment cycle-** allowing limited opportunity to invest in major technological manufacturing changes (20-30 years).	**1 Literature source:** DECC 2013 notes that the cement sector has "Long Investment cycles and high capital costs"	**5 Interviews** Interviewee: "A cement plant will cost a minimum of £250m and will last 30-40 years. Therefore there is only really likely to be one more significant investment cycle between now and 2050" Interviewee: "When building new plants you are looking at 50 years minimum. In theory new plants will have the least intensive carbon footprint, but it's not financially possible to upgrade 1960/70s factories to that level. If you try to regulate/price these old factories then you'll suffer carbon leakage to imports. Govt needs to just recognise that we can't just upgrade	**(4)** Workshop participants indicated that the largest plant change is to replace a kiln, but that all kilns in UK had already been switched from wet kilns to dry kilns in previous years as this had a short payback period. Kilns have a lifespan of approximately 30 -40 years. UK cement companies are currently unlikely to make any new kiln replacements in near future. This is partly because potential energy savings would be much smaller than the wet to dry switch so would not offer an acceptable ROI.	Due to the long plant lives of cement kilns, there are limited opportunities to rebuild by 2050 and therefore limited opportunities to invest in advanced technology that can significantly reduce a company's carbon emissions. The switch from wet to dry kilns over past 15 years has had biggest positive impact although this process is already complete in UK. The workshop highlighted that rebuild feasibility studies can help reduce

		High capital costs for new plants or significant projects.		everything as it's too expensive." Interviewee: "New plant is main opportunity to install big ticket items at that time - retrofitting is very costly and not always feasible." Interviewee: "We are very capital intensive with very long payback periods, 30-40 years and 7 years to plan and build new plants." Interviewee: "You see the really big step changes at point of plant construction. Typical payback is 30-40 years. At point of construction you install the best available tech at the time. Plants are highly integrated so it's not easy or cheap to replace parts of already built plants. More common is continuous improvements such as switching to different fuel types."	Participants also said they would struggle to justify building of any new plants/kilns at present due to instability of UK cement demand. There are currently 12/13 kilns operating in UK.	the risk and test out more innovative rebuild designs with higher emission reduction potentials. However, it was also noted in both the workshops and interviews that there are no major carbon-reducing technological breakthroughs that are waiting to be deployed such as the recent switch from wet to dry kilns. No new plants or kilns are currently being built in the UK due to continuing market uncertainty and limited growth.
10	**Market & economy**	**Increasing competition for diversion of alternative fuels and biomasses** - to other users who hold advantages over the	**2 Literature sources:** IEAGHG 2013 states: "Competing demands for as well as the current waste hierarchy in the EU Waste Framework Directive is restricting the availability of certain types of alternative fuels" MPA 2009 states that: "In 2011 almost 17% of fuel was from biomass fuel and	**6 Interviews** Interviewee: "Most important reason for alternative fuel investments is cost of fossil fuels (e.g. Pet coke) compared with alternative fuels – side benefit is reduction in carbon. If fossil fuels are significantly cheaper than alt fuels again in future this will influence decision-making" Interviewee: "Some UK policies give incentives for use of biomass by other sectors e.g. Renewable	**(3)** Workshop participants indicated that there is increasing demand for biomass-containing fuels from the energy from waste sector and power generators. In particular there has been a significant adverse impact on cement sector due to the Renewable Heat Incentive which is not currently available	All information sources indicated that competition for alternative fuels and biomass is significantly increasing or being diverted to recycling/reuse or other combustion which is incentivised. Interviewees argued that some of this is down to UK market distortions such as RHI and other policy

		cement sector	biomass fractions. It is assumed that 40 per cent of fuel use will comprise of biomass by 2050. This is an ambitious assumption for the same reasons as outlined above for AWDF but is also likely to be principally influenced by the pressure on the power generators and others to fuel switch. Current Government policies to enhance the use of renewable heat are poorly focused and incentivise the use of biomass for some activities but not others, potentially creating a shift in biomass use from one sector to another without an overall environmental benefit. The current Renewable Heat Incentive creates an incentive to move biomass use from cement kilns to other potentially less efficient uses. This is an unwelcome intervention in the market by a poorly designed policy.”	Obligation, Feed in Tariffs, Contracts for Difference power, RHI, but similar incentives are not available to the cement sector. Such incentives drive up the price of biomass and can shift biomass from cement to other sectors with no net environmental gain.” Interviewee: “ We are having some issues with alt fuel availability” Interviewee: “You tend to get cost savings by using alt fuels, but there are risks on technology, permits/permission and fuel availability.” Interviewee: “Many fuels have become scarcer, particularly as international competitors buy our alt fuels (e.g. China, Eastern Europe buying tyres). Bone meal producers realised they could use it themselves. The waste derived market is constantly evolving, but we want an even playing field.” Interviewee: “Yes, we’re concerned about a lot more pressure on the supply chain. We signed long term agreement with a waste management company. We can secure most of our supply chain but need to continue monitoring.”	to the cement sector. This has led to other buyers out-competing cement companies when purchasing alternative fuels. Participants requested that RHI be made available to cement sector or that a new, more equal policy replace RHI. It was suggested that ideally there would be assessments of the optimum places for biomass to be used as a fuel as some participants argue that their use of biomass has a better carbon impact compared with other users (e.g. households). However, ‘circular economy’ policies are a threat as this requires wastes to be reused or recycled before being considered for use as a fuel.	drivers such as the Renewables Obligation which encourage the use of such fuels. All UK cement companies argue their sector is unfairly excluded from policies and incentives that are offered to other sectors for no clear reason. It was also noted that increased international competition for alternative fuels – especially tyres – has also had an impact. the EU Waste Framework Directive was also noted in literature review and interviews as being responsible for diverting fuels that were judged to be suitable for recycling as the Directive requires the prioritisation of recycling over incineration and does not currently recognise co-processing as a combined recycling and recovery process.

				Interviewee: "We have to do feasibility study for any new fuel. Has to make sense commercially and geographically. We also need to understand how it will behave in the kiln. Does it have an impact on quality or output? How many tonnes per hour do we need to burn versus coal? It is expensive investing in a new fuel so in order to pay back you need to have a sufficient and secure source." Interviewee: "Unlike other users we can also use the ash left over to become cement. We'd like to achieve 70% of firing heat from biomasses and waste fuels."		
11	**Financial**	**Risk aversion in cement industry –** companies are wary of being locked in to the 'wrong' investment choices (in part due to high technology costs, long investment cycles and concerns	**1 Literature source:** DECC 2013 notes that cement sector suffers from risk-averse thinking - wary of risks to product quality or being locked in to 'wrong' investment choice.	**2 interviews** Interviewee: " Risk aversion – due to poor economic conditions we've had ideas we could do work on, but concern over payback period and technical hiccups/delays related to quality of supply, etc. has put industry off quicker investments" Interviewee: "Investors need real confidence before investing the £250-300m it takes to build a new plant. Need investment certainty to 2030 and beyond."	**(4)** Workshop participants indicated this was a major barrier, as often new legislation requires unproven technologies. No one wants to take the first risk. There is also no large spare pot of money to invest in potentially risky new innovations. This risk particularly applies to CCS which could result in a pilot plant costing £500m+ which is approximately double the cost of a traditional, CCS-free cement plant.	While risk aversion was only noted briefly as an issue in interviews and the literature review, but it was determined to be an important barrier by workshop participants. Risk aversion in the cement sector is predominantly based on the long investment and costly cycles that are a feature of the industry as well as being partly due to the highly cost competitive aspect of the market.

		over product quality)			Workshop participants also said that because cement sector equipment/plants are built with very long life cycles planned this means that cement companies have to very careful not to sink funds into new equipment that may end up not meeting industry standards on product quality and/or cost competitiveness. To mitigate this barrier it was suggested that there needs to be more ways for the risks to be shared or be underwritten by the government.	Multiple interviewees said it typically made more sense to be a first follower of proven technologies rather than a first mover who takes the financial risk on new technologies. Without some mechanism for sharing such risks with other stakeholder's interviewees indicated that this barrier was unlikely to change.
12	**Legislati on**	**EU ETS – Risk induced by future ETS uncertaint y** (unknown future carbon prices, caps, proportion of allocations, etc.)	**2 Literature sources:** Boston Consulting Group 2011 found: "the high level of regulatory uncertainty in Europe discourages companies from making the investments required in order to improve the efficiency of cement plants and the lack of an appropriate legal framework deters companies from adopting structural adjustments" Boston Consulting Group 2008 states that: "EU ETS could make European cement manufacturers uncompetitive	**5 Interviews** Interviewee: " Uncertainty over regulations such as ETS are a problem" Interviewee: " Fluctuations in things like a carbon price are not incorporated into current decision making as carbon floor – even when the price was higher it wasn't a big factor – ENERGY COSTS are driving the move to lower energy use rather than the carbon price" Interviewee: "EU ETS: the way the last round of allowances were made – we ended up with a lower than needed allocation for two plants	**(4)** Workshop participants expressed the view that the EU ETS cross-sectorial correction factor will reach a point where it is not technically possible to get full allocations. They also did not feel happy with the data being used. The EU ETS is having a cumulative negative impact on UK cement companies and there is a need for the system to be overhauled and made fairer between industries and sectors.	Uncertainty and other concerns about the EU ETS were found to be a barrier across all information sources. The cement sector across EU feel that their allowance as an industry has been set too low. Interviewees and workshop participants argued that while carbon prices from the EU ETS are currently manageable, there is significant uncertainty over what level

			with global competitors / plants leading to possible carbon leakage”	because of the arithmetic. Almost like being punished for being too efficient! We need a recognition that we can’t just keep lowering the limit for us.” Interviewee: “One barrier is EU ETS and carbon leakage (it prohibits investment due to regular review process because unless long term certainty the EU is not the best place to invest).” Interviewee: “EU ETS new entrant rules are a problem. There is no certainty about availability of free allocation before invest >£250m and no certainty about the level of free allocation following investment. Too risky.” “EU ETS creates a difficulty. Every 5 years get a level of free allocation, but this declines every year. We are vulnerable to carbon leakage as an industry and at some point leakage will start to take place – only the recession and relatively low carbon price has prevented this so far. Next review is in 2019 and the decisions made are so absolutely critical that it’s almost a case of go or no go for staying in UK.”	However, participants were sceptical that significant reform would take place in short term and that carbon leakage will increase for foreseeable future.	the allowances will be set at during the next review in 2019. They also noted that the industry requires much longer term predictability and consistency in the EU ETS to enable them to appropriately forecast and plan their activities. One interviewee commented that if the outcome of the 2019 review is particularly negative for the cement sector then it could lead to divestment in the UK altogether as the EU ETS combined with UK climate change and energy costs would leave the UK uncompetitive compared with imports.

13	**Market & economy**	**UK energy prices are higher than those in many competing EU and global countries** (and likely to rise significantly higher in coming years)	**2 Literature sources:** MPA 2009 states that: "date UK industrial consumers have experienced higher electricity costs than our competitors. Analysis carried out by BIS has confirmed that UK energy consumers will pay more for their electricity than competing nations as a result of the UK's decarbonisation policies. Industries that are significantly vulnerable to carbon leakage such as cement will need protection from these unilaterally applied costs so that they are able to compete with importers on an equivalent basis." Centre for Low Carbon Futures 2011 states that: "number of representatives identified the high and rising costs of energy and energy taxes in the UK, as well as rising commodity prices, as a barrier to investment. Parent companies see relatively poor returns on investment in the UK compared with other countries. The representatives consulted referenced the TUC/EIUG report (2010) on the cumulative impacts of climate	**3 Interviews** Interviewee: "About 30% of all our investments and upgrades to plants are centred around energy and carbon efficiency savings" Interviewee: "When you look back to the 80s the difference was energy was cheap, capital was expensive and we're living with the decisions to have gone for more energy intensive processes from that time" Interviewee: "New high energy prices have forced companies into improving energy performance" Interviewee: "Electricity costs are a big issue – cheap coal and electricity abroad mean their production costs are lower" Interviewee: "Bottom line is the UK has the most expensive energy in Europe so therefore every extra bit of cost makes us that bit more uncompetitive"	**(4)** Workshop participants felt that high UK energy prices are a significant burden on their competitiveness. They noted that imports have now increased to almost 14% of total UK demand from around 3-4% ten years ago. They highlighted that part of this price parity is the high cost of electricity and fuels in the UK.	All information sources highlighted that fluctuating energy prices makes it difficult for cement manufacturers to plan the return on their investments, and are a major operational cost. Interviewees and workshop participants believed the electricity grid would become more decarbonised, but that the price of electricity is too high already to allow cost competitiveness with foreign producers. Interviewees were concerned about UK's competitiveness in relation to Europe and other markets due to the higher energy prices in the UK.

			change policy on the energy intensive industries, with both electricity and gas costs expected to rise by up to 22% by 2020."			
14	**Market & economy**	**UK demand for cement is still significantly below 2007 levels** and growth forecasting is difficult which impacts on investment decisions	**1 Literature source:** MPA 2009 states that: "It is very difficult to accurately forecast future demand and production - therefore assumptions used for roadmaps and milestones may not be accurate. Growth in the construction sector will provide a platform for investment in new products. Without construction sector growth UK assets will continue to decline and will place the UK vulnerable to imports when demand returns."	**1 Interview** Interviewee: "cement consumption in the UK per capita is the lowest in Europe. So we're not spending enough on construction or using different materials"	**(3)** Workshop participants noted that there has been significant consolidation of the cement sector in UK since 2007 and an overall reduction in production capacity. However, with demand currently rising this means that UK production will soon be at maximum capacity. This means cement companies will be left with a choice of whether to build new plants or to import cement instead. One action that would enable UK cement companies to commit investment to building new plants in the UK would be for the government to commit to and deliver the 'National Infrastructure Plan' as this would significantly increase cement demand.	Findings were slightly mixed on this barrier as some companies stated that demand was still depressed compared with 2007 (approx. -35%) and significant new growth in UK economy and construction would be of great benefit to the industry. It was also noted that a better business environment would be helpful in generating or competing for capital for further investments. However some workshop participants claimed that due to industry consolidation production capacity was now much lower and the modest improvements in the UK economy have brought demand up and full capacity may soon be reached. This would leave companies with difficult decisions on whether to simply import cement or

						trust that the economic recovery is long term and invest in new plant capacity relatively soon after shutting down plants in the recession. There was no consensus on which approach would be better and which way companies would go.

15	**Technology**	**UK government is not backing CCS R&D as strongly as other countries**	**2 Literature sources:** MPA 2009 states that: “The European industry is undertaking practical research and collaborating with equipment suppliers to find the best capture methods for cement but if the UK wants to be a leader then UK Government financial support is necessary for the UK cement industry. Without this support the UK cement industry will miss its most ambitious scenario of an 81 per cent emission reduction by 2050.” Centre for Low Carbon Futures 2011 found that: “Some sector respondents commented on the difficulty of accessing government support to promote industry R&D.” IEAGHG 2013 states that: “CCS will be required if cement manufacturers are to meet overall decarbonisation targets as efficiency savings have limitations. With current legal and economic conditions around CCS would impair the competitiveness of cement production and this	**3 Interviews** Interviewee: “Even if we reached 100% elimination of fossil fuels we’ll still have CO2 emissions as alternative fuels are not all biomass and there is the automatic calcination problem in our cement production. CCS is the key to our long term low carbon future – who will finance it? Who will be brave enough to make first steps? Will govt do anything to support that?” Interviewee: “Our big wish is for proper government funding for CCS!” Interviewee: “Yes, could accelerate the work that companies are doing individually. It depends on whether companies are seeing it as a competitive lead or as a general sector need.”	**(3)** Currently support is only being provided to power sector to implement CCS, not other sectors such as cement. There will need to be specific CCS solutions for cement plants. UK has an opportunity to be a CCS research leader and also has better options for carbon storage than other countries. Some participants indicated that there is a lack of understanding of the CCS transition for the cement sector. There are significant cost barriers – one participant said that implementing CCS at a new plant would approximately double the cost to build the plant. The large physical footprint of implementing CCS at a plant would be a further barrier.	A clear finding from the information sources was that CCS will be required if cement plants are to reach the target of an 80% reduction in carbon by 2050. This is because the calcination process in heating limestone is an unavoidable source of the sector’s carbon emissions. The only way to eliminate the emissions from calcination is to use CCS or to create completely new types of cement, but the latter approach has its own barriers obstructing it (See Barrier 3) All companies in the UK said that they could not afford the capital or be willing to take the risk on researching or piloting such an uncertain and expensive technology without government and/or cross-sector support. Even if CCS does become technically viable in future there are significant concerns over capital and running costs as current estimates are that a new plant with post combustion

			inhibits the development of CCS"			CCS installed would cost approximately double the cost of a plant without CCS and this could make cement produced at CCS-equipped plants fundamentally uncompetitive with traditional plants. However, enthusiasm for researching and ultimately deploying CCS was found from the majority of workshop participants. Some of the interviewees stated that strong govt support for CCS for the sector was one of the actions they would most like to see from government.
16	**Technology**	**CCS forms integral part of established sector roadmaps, but the technological feasibility or affordability is still highly**	**1 Literature source:** Centre for Low Carbon Futures 2011 states that: "Transformative technologies, such as carbon capture and storage, remain perhaps 10-15 years away from commercial deployment."	**4 Interviews** Interviewee: "The capital cost of doing CCS would basically double the cost of a plant. A new plant in UK would be £200-250m, but price and plant size would double with CCS in place. And if we captured the carbon, then what do we do with it? Many plants are a long way from storage in seas and the plants can't be moved away from their quarries easily or cheaply. Biggest issues would mainly be transport and storage of the carbon along with	**(3)** Workshop participants said CCS is technically achievable, but challenges are economic/commercial and legislative. CCS will add significant costs and it will be a challenge to fund and incentive implementation. Need equivalent of FiT CfD available to power sector CCS	From all information sources there was optimism that CCS (or carbon capture and use) is technically feasible. However, nearly all interviewees and workshop participants are sceptical about the commercial viability of CCS both from an R&D/piloting perspective as well as the long term costs of installing

		uncertain		capital costs. If you were first to do it then you'd need it to be supported by govt as the risk and cost is just so big. Why would you invest in that if you weren't sure it would work?" Interviewee: "Other than a few projects that have been happening elsewhere, there is still a lack of understanding about whether CCS will ever be commercially and technically viable. I cannot see that the cement industry would be the first to prove success of this technology." Interviewee: "We think we can achieve a 62% reduction in emissions from 1990 levels if allowed to use biomass and alternative fuels. But to get over 80% the only technology is CCS. Don't think it will be technically or economically feasible for more than ten years, but there is a role for CCS post-2025/30." Interviewee: "We need support for Carbon Capture and USE more than storage. Transporting and storage might be more difficult than using the carbon instead."	to compensate industrial CCS installation. Will also need carbon transport infrastructure to take carbon away from plants to storage/use elsewhere. There is uncertainty over who is willing to take ownership of driving CCS forward and making it viable in future for the cement sector.	and running expensive CCS equipment. Some participants argued that the sector would require significant support for the technology to ever become financially viable.

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APPENDIX C TECHNOLOGY OPTIONS REGISTER

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Technology options identified in the below tables come from sources listed in the references in section 6 of the main cement roadmap document

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Kiln process technology (BAT kiln)	5	0%	100%	£180,000,000	Adapted for this project based on the following references (Global CCS Institute, 2013; Cement Sustainability Initiative, 2009) and review by sector team	1%	0%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team
Electrical efficiency improvements	9	0%	100%	£30,000,000	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team	0%	5%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team

[6] Please note that for cases where no source is provided, expert opinion has been used to evaluate the TRL.

[7] Capex values shown in the table are for a representative site to which that option applies. While cost input data on some options was available on a per site basis, data for others was expressed differently e.g. cost/tonne of production capacity, cost/tonne of emission. Where necessary, these data have been used to derive representative capex estimates per site, as shown in the table. To account for sectors with diverse site sizes, a range of capex values for standard site categories (e.g. small and large sites) have been developed and then multiplied by the relevant proportion of sites in the sector of that category.

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Electricity from waste heat	8	0%	25%	£11,000,000	Adapted for this project based on the following references (Global CCS Institute, 2013; Cement Sustainability Initiative, 2009) and review by sector team	0%	1%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team
Cementitious substitution	8	8%	10.5%	0	Directly from literature (Ricardo AEA, 2013) and review by sector team	100%	0%	Adapted for this project based on the following references (Ricardo AEA, 2013; MPA, 2013; European Cement Association, 2013) and review by sector team
Alternative raw materials (calcined)	7	1%	2%	0	Expert judgement (PB/DNV GL consortium) – assumed same cost as “Cementitious substitution”	67%	0%	Provided by trade association with review by sector team and PB/DNV GL

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Fuel switching to natural gas	5	0%	25%	£7,500,000	Directly from literature (Ricardo AEA, 2013) and review by sector team	7%	-10%	Expert judgement (PB/DNV GL consortium) with review from trade association
Fuel switching to biomass	9	18%	80%	£7,500,000	Directly from literature (Ricardo AEA, 2013) and review by sector team	31%	-10%	Adapted for this project based on the following references (Ricardo AEA, 2013; European Cement Association, 2013) and review by sector team
Hydrogen fuel	4	0%	0%	-	Option not included in pathways	10%	-20%	Expert judgement (PB/DNV GL consortium) with review from trade association

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Alternative cements	9	0%	5%	£220,000	Directly from literature (Ricardo AEA, 2013) and review by sector team	50%	0%	Adapted for this project based on the following references (Ricardo AEA, 2013; Cement Sustainability Initiative, 2009; Global Magazine of the Concrete Society, 2014; ZKG International, 2014) and review by sector team
Fluidised bed kiln	4	0%	100%	-	Option not included in pathways	3%	-5%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team

Name / Description	Technology Readiness Level[6]	Adoption rate	Practical Applicability	Capex (per site)	Capex data source[7]	CO_2 reduction	Electricity reduction	Carbon Dioxide Reduction Data Source
Carbon capture[8]	6[9]	0%	50%	£100,000,000	Adapted for this project based on the following references (Ricardo AEA, 2013; International Energy Agency & World Business Council for Sustainable Development, 2009; Cement Sustainability Initiative, 2009) and review by sector team	90%	-100%	Adapted for this project based on the following references (Ricardo AEA, 2013; International Energy Agency & World Business Council for Sustainable Development, 2009) and review by sector team
Oxygen enrichment technology	7	0%	75%	£6,000,000	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team	3%	-50%	Directly from literature (Cement Sustainability Initiative, 2009) and review by sector team

[8] We have assumed oxy-combustion capture as the most appropriate technology for use in the cement sector, on the basis of cost and efficiency. Oxygen enrichment is a separate option, which uses oxy-combustion to improve efficiency, but without carbon capture. All costs are for CO_2 capture alone, including CO_2 purification and compression. Costs associated with transport and storage/utilisation are excluded.

[9] Element Energy, 2014 (Note – for oxy-combustion capture; post-combustion TRL 7)

APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Option Deployment for Pathways under Different Scenarios

Challenging World

Pathway: BAU Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	75%	75%
03 Electricity from waste heat	On site	0%	25%	0%	0%	0%	0%	0%	25%	25%	50%	50%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	10%	10%	25%	25%	40%	40%	50%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	10%	10%	25%	25%	40%	40%	50%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 3: BAU pathway, challenging world scenario

Pathway: 20 - 40% Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	75%	75%
03 Electricity from waste heat	On site	0%	25%	0%	0%	0%	0%	0%	25%	25%	50%	50%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	10%	10%	25%	25%	40%	40%	50%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	10%	10%	25%	25%	40%	40%	50%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	5%	10%	15%	25%	25%	33%	33%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 4: 20-40% pathway, challenging world scenario

Pathway: Max tech, no CCS   Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	10%	25%	50%	75%	100%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	25%	25%	50%	50%	75%	75%	100%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	25%	25%	50%	50%	75%	75%	100%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	25%	50%	100%

Figure 5: Max Tech pathway without CCS, challenging world scenario

Pathway: Max tech with CCS   Scenario: Challenging World (CW)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	10%	25%	50%	75%	100%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	25%	25%	50%	50%	75%	75%	100%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	25%	25%	50%	50%	75%	75%	100%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	10%	25%	50%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	25%	50%	66%

Figure 6: Max Tech pathway with CCS, challenging world scenario

Collaborative Growth

Pathway: BAU   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	0%	0%	0%	10%	10%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	10%	10%	25%	25%	40%	40%	50%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	10%	10%	25%	25%	40%	40%	50%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	0%	0%	0%	0%	0%	0%	0%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	10%	25%	50%	50%	75%	75%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	0%	25%	25%

Figure 7: BAU pathway, collaborative growth scenario

Pathway: 0 - 20%   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	0%	0%	0%	10%	10%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	25%	25%	50%	50%	75%	75%	100%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	25%	25%	50%	50%	75%	75%	100%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	5%	10%	15%	25%	25%	33%	33%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	10%	25%	50%	50%	75%	75%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	0%	0%	25%	25%

Figure 8: BAU+ pathway, collaborative growth scenario

Pathway: Max tech, no CCS   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	10%	25%	50%	75%	100%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	25%	25%	50%	50%	75%	75%	100%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	25%	25%	50%	50%	75%	75%	100%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	10%	25%	50%	50%	75%	100%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	25%	50%	75%	100%

Figure 9: Max Tech pathway without CCS, collaborative growth scenario

Pathway: Max tech with CCS   Scenario: Collaborative Growth (CG)

OPTION	Category	ADOP.	APP.	2014	2015	2020	2025	2030	2035	2040	2045	2050
01 Kiln process technology (BAT kiln)	Energy efficiency	0%	100%	0%	0%	0%	0%	10%	25%	50%	75%	100%
02 Electrical efficiency improvements	Energy efficiency	0%	100%	0%	0%	75%	75%	75%	75%	75%	100%	100%
03 Electricity from waste heat	On site	0%	25%	0%	0%	25%	25%	50%	50%	75%	75%	100%
04 Cementitious substitution	Raw material or fuel	8%	11%	0%	0%	25%	25%	50%	50%	75%	75%	100%
05 Alternative raw materials (calcined)	Long term	1%	2%	0%	0%	25%	25%	50%	50%	75%	75%	100%
06 Fuel switching to natural gas	Raw material or fuel	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
07 Fuel switching to biomass	Raw material or fuel	18%	80%	0%	0%	25%	25%	50%	50%	75%	75%	100%
08 Hydrogen fuel	Long term	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
09 Alternative cements	Long term	0%	5%	0%	0%	0%	10%	25%	50%	50%	75%	100%
10 Fluidised bed kiln	Long term	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11 Carbon capture	Long term	0%	50%	0%	0%	0%	0%	10%	25%	50%	75%	100%
12 Oxygen enrichment technology	Long term	0%	75%	0%	0%	0%	0%	0%	10%	20%	25%	33%

Figure 10: Max Tech pathway with CCS, collaborative growth scenario

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