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

Industrial Decarbonisation & Energy Efficiency Roadmaps to 2050

Ceramic Sector Appendices

MARCH 2015

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CERAMICS

APPENDIX A - METHODOLOGY

APPENDIX A METHODOLOGY

The overall methodology used in this project to develop a decarbonisation roadmap for the Ceramic 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 British Ceramic Confederation (BCC) 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, surveys and evidence 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, surveys and workshops. In a similar way, information gaps during the interviews, surveys and workshops could be populated using literature data.

The sources of evidence were used to develop a consolidated list of enablers and barriers for decarbonisation, and a register of technical options for the ceramic sector. This information was subsequently used to inform the development of a set of pathways to illustrate the decarbonisation potential of the ceramic 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 companies interviewed represented over 35% of carbon emissions produced in the UK ceramic sector and captured both UK decision makers and technical specialists in the 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 dominant technologies and process types, global production and Carbon Dioxide (CO_2) emissions (in the EU28) and the global outlook to 2050, including the implications for ceramic 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 ceramic producers, dominant technologies and processes were also reviewed.

Options examined were (i) generic options that could apply across much of the sector (e.g. energy efficiency measures, waste heat recovery, fuel switching, carbon capture and storage (CCS) etc.) and (ii) process-specific options relating to major emitting processes. The process-specific options related to additional options that could apply to the major emitting processes over and above the generic options (which could also apply to the major emitting processes). These could include modifications to existing processes, or new processes altogether.

2. Literature Review

A literature review was undertaken on the ceramic sector. Its aim was to help to identify options, enablers and barriers for decarbonisation throughout the sector. It seeks to answer the principal questions, determine the enablers and barriers for implementing decarbonisation technologies 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 20 documents. This was not a thorough literature review or Rapid Evidence Assessment (REA) but a desktop research exercise deemed sufficient 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 evidence gathering. 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 2000), 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 drivers/barriers;
- Information on adoption rate (ADOPT), applicability (APP), improvement potential, ease of implementation, capital expenditure (capex), Return on Investment (ROI) and the saving potential for all options where available;
- Construction of decarbonisation options list; and
- Provision of information on strengths, weaknesses, opportunities, threats, enablers and barriers. This information was used in the evidence 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.

	Details
Main focus (all in the ceramic sector)	Energy efficiency improvements CO_2 and carbon reduction Fuel switching
Secondary focus	Drivers, barriers, policy CCS
Excluded	Carbon offsetting Technologies not applicable to the UK ceramic sector

Table 1 Scope of Review

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 publications, such as academic papers, existing roadmap documents or governmental publications. Information from equipment manufacturers (grey literature) was interesting as sector-related info. However, as there is no objective standard with which to compare this information, no extensive search in this domain was executed. The grey literature was used as input to the workshops.	Preference was given to published papers and published official reports.
Time period to be covered	Given the changing global competitive environment for the sector, preference was given to information which was (very) recently published. Some valuable, but older, information was included, where it was considered to be still relevant to the sector.	No constraint was set on the date of the publication, but older information was given a lower quality rating, due to its lower relevance.
Geographical area	Preference was given to the UK industry, with a broader look to Europe also included. Other geographies were used to provide background information where needed.	No geographical exclusion criteria were used, but information on the UK ceramic sector was given a higher quality rating, due to its higher relevance.
sector specifics	Given the specific nature of the UK ceramic sector, some technologies could be discarded, as there are no plants using them.	Options not relevant to the processes used in the UK 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.

Table 2 High level selection criteria

For academic literature, the primary source was ScienceDirect. Of the documents that came on top in the search result (typically the first 25 papers), a skim-read of the abstract decided on the relevance of the paper.

A total of around 30 papers, official publications and grey literature documents on ceramic were collected using this search methodology. The quality, source 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, drivers or 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 iron and steel sector (0/+/++/+++)
- Information on technological aspects (0/+/++/+++)
- Information on drivers and barriers: (0/+/++/+++)
- Information on policy/legislation: (0/+/++/+++)
- 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 Figure 2.

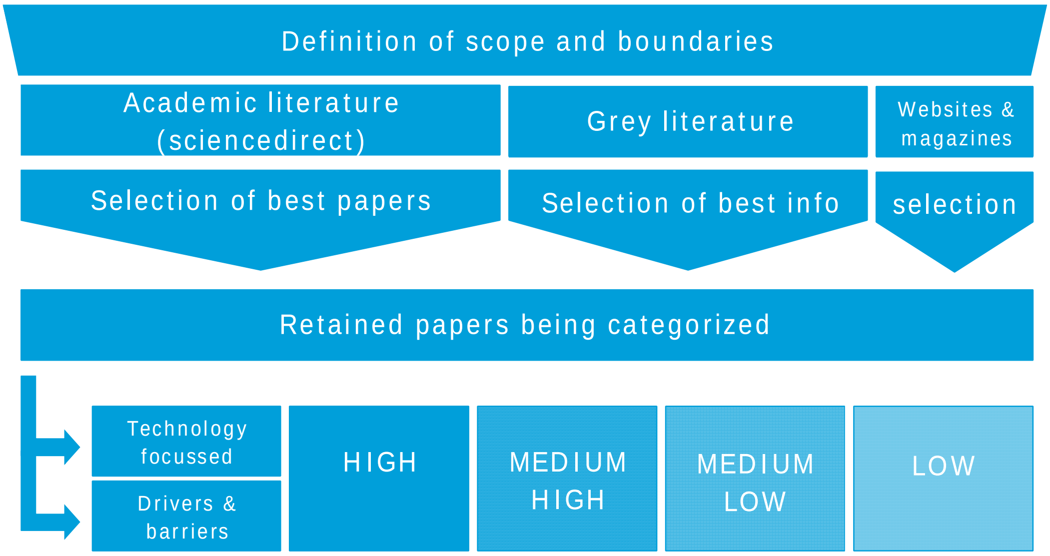

Figure 2: Diagram of the selecting and categorising process

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.

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 (e.g. kWh/tonne of product).
5. For financial savings, the amounts were kept in their original currency.

4. Technical Literature Review

Identifying Literature

The primary aim of the technical literature review was to gather evidence on potential technologies that could contribute to the decarbonisation of energy use and improved energy efficiency for the ceramic sector in the UK.

In parallel to the above 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 ceramic 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 Ceramic 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.

Strengths, Weaknesses, Opportunities, Threats (SWOTs) analysis: Check for any information using terms strengths, weaknesses, threats and opportunities.

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 Google and by following up references identified in initial documents or by the Ceramic sector team. The search terms used in Google were:

- “Ceramic” AND “decarbonisation”
- “Ceramic” AND “energy efficiency”
- “Ceramic” AND “emissions”
- “Ceramic” AND “energy”

In addition, specific subsector names (e.g. “whitewares”, “refractories” etc.) were used in place of “Ceramic” where required to fill gaps in the data.

5. Social and Business Literature Review

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

- We reviewed over 20 documents (some of them the same as the technical literature review) to create a broad overview of the sector SWOT and identification of drivers and barriers to energy efficiency improvement and decarbonisation, and identification of main uncertainties in generic and business environment.
- The literature review included documents listed in the ITT (Invitation to Tender) as well as grey literature 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.
- Based on table of contents and a quick assessment, we presented the results in a table as below. The analysis resulted in the identification of documents to be used for detailed analysis and evidence 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, Drivers and Barriers	Uncertainties future trends	Options	Pathways
Title 1		+++	++	0	++++	++	0	++++
…		++	+++	++	0	+++	+	+
…		+	++	+	0	++++	++	0
Title 10		++	++++	+++	++	+++	+++	++

Table 3: 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 evidence gathering workshop as a starting point for discussion.

6. Interviews

The evidence gathering stage of the project also involved a series of interviews. These aimed to obtain further details on the different subsectors within the UK ceramic sector and to gain a deeper understanding of the principal questions, including how companies make investment decisions, how advanced technologies are financed, what companies' strategic priorities are and where climate change sits within this. The interviews were also used to refine the top list of enablers and barriers identified from the literature review, which feeds into the evidence gathering survey and workshop.

Based on the type of product and manufacturing process, the ceramic industry was divided into four subsectors: heavy clays, whitewares, refractories and technical ceramics. Companies within the different subsectors have similar manufacturing equipment and are facing the same type of challenges. It was agreed to invite nine interviews covering large and small-and-medium enterprises from all four subsectors. We identified the proposed interviewees in liaison with BCC, DECC and BIS, which met the pre-defined criteria. Out of the nine companies who originally were selected to be interviewed, three declined to participate and a further three invited companies declined.

Six interviews were completed with the following organisations:

Company name	Interviewee role	Subsector	Size
Ibstock	Environmental Manager	Heavy clays	Large
Naylor Industries Plc.	General Manager	Heavy clays	Small and Medium Sized Enterprises (SME)
Portmerion Group	General Manager	Whitewares	Large
Ideal Standard	Environmental Manager	Whitewares	Large

DSF	General Manager	Refractories	SME
Mantec	General Manager	Technical ceramics	SME

Table 4: List of interviewees

Comments collated via BCC 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.

Assumptions

Going into each interview, a number of assumptions were made to refine the approach to be taken:

1. Results from the literature review are available and partially or well covered. Well-covered areas are not addressed during the interview. Results may include:
    a. Option register of technical options.
    b. Sector and subsector characteristics.
    c. Sector SWOT analysis.
    d. Main trends and drivers.
    e. Some hurdles to and barriers for change and/or energy or decarbonisation.
2. Preparation of interviews includes rapid review of website and annual reports information related to business and energy and emissions reduction strategies.
3. The technical review covered any gaps in data or information (e.g. specifically related to that company’s data) which may be appropriate to obtain during the interview process.
4. Interviewee role is reviewed prior to conducting the interview.
5. All interviews are conducted by interviewers in their own proficient way of dealing with issues around openness, consent, and follow-up.
6. There might be follow-up with interviewees to obtain additional information discussed during the interview.

Interview Protocol

Preparation

1. Interviewee identification

Interviewees are identified in liaison with DECC and BIS in order to achieve good coverage of each sector. The steps taken to identify relevant candidates are:

- Identify the number of subsectors using SIC (standard industrial classification) 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
- Identify which subsectors and/or organisations were most significant using the following criteria:
    - Size (e.g. by revenue 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

3. Interview format

Introductions

Interviewer sets out the project context and interview agenda.

Goals

Interviewer introduces the goals of the project as follows:

1. To determine the current state, ambitions or plans, successes and problems or challenges of each of the interviewee's organisation 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 or 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)

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 or 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 or 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.

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

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 or 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 or presentations on this innovation be supplied?

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 the last ten 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/ or sector?
2. Main innovators or early adopters in the sector:
    a. Who influences action (whom or what are they listening to? Why?
        i. Organisations and people within organisations (role or function)?
        ii. Within or outside the sector (other sectors, academics, non-government organisations, politicians, etc.)?
3. Questions on the dimensions of innovations[1] . These questions will be on a multiple choice list (answer categories strongly disagree, disagree, neither agree or not agree, agree, strongly agree[2]). 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 research and development (R&D), pilots, experiments
    b. Human capital: improvement projects, multi-disciplinary teams, training on innovation/change/improvement

[1] Questions are asked to get a better (and broad overview of space or possibilities for change (not only including investments but also the change that potential of option will materialise.
[2] 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.

   c. Organisation: horizontal communication lines, clear goals or 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 or 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.

Enablers 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:

Intro	5-10 minutes
Current state and plans energy efficiency and decarbonisation	20-30 minutes
Stories of energy efficiency/decarbonisation	30-45 minutes
Business environment and innovation power	15-20 minutes

Drivers and hurdles for sector change (to test survey/workshop questionnaire)	If time left

Table 5: General interview timeline

7. Survey

As part of the evidence gathering exercise and to help build a list of the enablers and barriers, a short bespoke survey was conducted with some of the UK chemical manufacturers.

The survey was distributed to around 100 general managers and energy/environment managers from member organisations of BCC. The questions in the survey were tailored to ceramic producers, and were developed in consultation with BCC and DECC. These aimed to:

a. Collect background information such as role, size of organisation represented and innovation adoption appetite.
b. Assess the impact on the implementation of energy efficiency and decarbonisation technologies of 15 enablers and 15 barriers identified from the literature review and interviews.
c. Prioritise top 5 Strengths, Weaknesses, Opportunities and Threats of the sector.
d. Assess current conditions and capacity of the organisations to respond to decarbonisation.

Survey Questions:
1. What subsector are you working in or what is your relation to the ceramic industry?
2. What is the number of employees within your organisation?
3. What is your function within your organisation?
4. How would you describe your company's position in the sector regarding carbon and energy reduction? Please see the definitions below for reference.
5. What impact do the following enablers have in relation to implementing energy efficiency and decarbonisation technologies in your organisation? (A list of 15 enablers identified from the literature review was provided for assessment).
6. Are there any additional enablers that you think are relevant? Please provide details of these and an impact score based on the same scale.
7. What impact do the following barriers have in relation to implementing energy efficiency and decarbonisation technologies in your organisation? (A list of 15 barriers identified from the literature review and interviews was provided for assessment).
8. Are there any additional barriers that you think are relevant? Please provide details

Survey Questions:
of these and an impact score based on the same scale.
9. Please select the 5 strengths that are the most relevant to your organisation. (A list of 15 strengths identified from the literature review and interviews was provided for assessment).
10. Please add any other strengths of your organisation that are not included in the list.
11. Please select the 5 weaknesses that are the most relevant to your organisation. (A list of 12 weaknesses identified from the literature review and interviews was provided for assessment).
12. Please add any other weaknesses of your organisation that are not included in the list.
13. Please select the 5 opportunities that your company could potentially explore to maximise the implementation of energy efficiency and decarbonisation technologies. (A list of 15 opportunities identified from the literature review and interviews was provided for assessment).
14. Please add any other opportunities of your organisation that are not included in the list.
15. Please select the 5 threats that will potentially hinder your organisation in implementing energy efficiency and decarbonisation technologies. (A list of 15 threats identified from the literature review and interviews was provided for assessment).
16. Please add any other threats of your organisation that are not included in the list.
17. Please assess to what degree each statement is true for your organisation. • We have well defined goals/objectives and/or targets on energy efficiency and decarbonisation; • Our goals/objectives are translated to targets at site level; • We have a systematic decision-making process for new initiatives with regards to energy efficiency and decarbonisation; • Our decision-making process works well for new energy efficiency and decarbonisation initiatives; • We track progress of energy/carbon improvement projects in management meetings; • We have specific roles or allocated responsibilities within the company with regards to energy efficiency and decarbonisation; • We have strong communication and information sharing channels that support the successful implementation of options with regards to energy

Survey Questions:
efficiency and decarbonisation; • We understand which energy efficiency and decarbonisation technologies can be implemented in our organization; and • We have sufficiently skilled workforce to implement and handle energy efficiency and decarbonisation technologies.

Table 6: Survey quesions

For questions 5, 6, 7 and 8, respondents were given the following impact scale for assessing each enabler and barrier: (0) no impact, (1) no to limited impact, (2) low to medium impact, (3) medium to high impact and (4) very high impact.

Out of the invited participants, 31 responses were received across the various subsectors.

The resulting impact scores for each enabler and barrier can be found in appendix B. The percentage of respondents who selected the impact level has been provided for each enabler and barrier.

8. Evidence Gathering Workshop

The evidence gathering stage of the project also involved Workshop 1, the 'evidence gathering workshop'.

We worked with BCC, 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 four key activities. The first activity focused on reviewing the potential generic technological options for decarbonisation and identifying the enablers, barriers, advantages, and disadvantages of each. Workshop participants were divided into four tables. In order to allow time for reasonable discussion of individual options, the generic options were divided before the workshop into either 'Top 10' or secondary options. Each table received half of the 'top

10’ options for discussion, as well as all the secondary options. The participants at each table were encouraged to separate into two groups: one to discuss the ‘top 10’ generic options and another to act as ‘hunter gatherers’ checking the secondary options. After the initial discussions, all of the participants reconvened at each table in order to provide a summary of their discussions and vote on the technologies that each individual felt would help the sector to decarbonise the most, and on the technologies that they felt would significantly impact on the energy efficiency of the sector.

The second activity focused on the social and business enablers and barriers for decarbonisation in general. Each of the five tables was allocated a category (e.g. market and economy, finance) of enablers and barriers, along with the top enablers and barriers that were voted on from the survey responses. Thus, each table had one or two categories and 4 to 6 enablers and barriers to discuss within that category. Participants were asked to discuss the following questions:

1. How powerful is the impact of this enabler / barrier on decarbonisation and energy efficiency in your business?
2. Why are the barriers difficult to handle and what was the contribution of the enablers?
3. How can we overcome the barriers and maximise the enablers?

After the workshop participants had discussed these questions, as a table, the participants were asked to assign or negotiate an overall impact score for each enabler and barrier. In some cases, two scores were allocated as the enabler was seen as a barrier. Table facilitators were asked to note down the reasoning behind the voting, and to write down any enablers and barriers for that category which were missing. The outcomes of this session are being fed into the options register, pathways and action plans.

The third activity involved discussion of the process-specific options assigned to each table, along with further discussions of the generic technology options, with the aim of including identifying the ADOPT, APP, improvement potential, ease of implementation, capex, ROI, saving potential and timeline for the different options. This was done through breakout sessions at each table.

The fourth activity involved a breakout session where each table was asked to develop a pathway to illustrate its view of the maximum technical decarbonisation possible in the sector through to 2050 and to place the available options on a timeline to indicate when they could be deployed.

We recognise that the voting process is based on initial reactions and that everyone voting may not have the expertise required on specific technical solutions to decarbonisation. Therefore, the outcome from the workshop is used to inform the remainder of the sectoral analysis; it is not taken as an absolute technology selection.

The outcome of the evidence gathering workshop (and all evidence 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.

9. 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 pathway
- 40-60% CO_2 reduction pathway
- 60-80% CO_2 reduction pathway

In addition, two purely technology-driven pathways were developed: a business as usual (BAU) pathway and a maximum technical (Max Tech) pathway.

The BAU pathway is based on continued deployment of technologies that are currently being deployed across the sector.

Max Tech represents a pathway where all technically feasible options are deployed when they become available without cost being a limitation, but while also being reasonably foreseeable.

The approach taken by the pathways development team was to develop the BAU pathway and Max Tech pathway first. These provided the “boundary” pathways representing the lowest and highest potential levels of overall decarbonisation. The deployment of options within these pathways was then examined and further pathways were developed. One of these included a “Max Tech (no biomass)” pathway which was developed as a sensitivity when it became clear that the Max Tech pathway included a significant contribution from biomass. Under Max Tech (no biomass) it was assumed that no low-carbon biomass is available and so some other options were deployed more extensively.

10. 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.

The principal vehicle for developing the pathways was a pathways development meeting held between Parsons Brinckerhoff, BCC and DECC in early September 2014. 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 'disruptive' 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 deployed 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 deployment
6. The deployment 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 5-9
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. Deployment 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 register is provided in appendix C.

Deployment of Options

For each pathway, options were selected and deployed over time according to their technical readiness, 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 deployment 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:

1. **One option excludes another:** This is taken into account by the user in the deployment inputs in the option selector by ensuring that no exclusive options are deployed to a conflicting level in the same time period.
2. **One option depends upon another being adopted:** This is taken into account by the user in the deployment section of the option selector by ensuring that if any option requires a precursor that this precursor is deployed to the appropriate level.
3. **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.
4. **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 the remaining options to act upon.

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 would increase efficiency (in terms of kWh/tonne product or Mt CO_2/tonne product), 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 that development is high.

The ADOPTs and APPs 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.

11. 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 7: Summary of scenario context and specific assumptions applicable to the scenarios below.

Current Trends

The current trends scenario projected moderate UK and global growth. 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.

Future production assumptions were in two parts; the heavy clay construction subsector production was assumed to increase by 1.5% annually to 2025 and then to remain static to 2050, while the other subsectors were assumed to grow at 1% annually to 2025 then remain static to 2050. These changes reflect recovery of production following the recession of 2008 followed by a period of sustained international competition restricting sector growth despite UK and global economic growth.

Challenging World

The challenging world scenario was characterised by lower global growth rates. 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.

The ceramic industry was assumed to be subject to adverse cost competition due to higher UK energy costs and lower global growth rates and weaker international trade. The heavy clay construction subsector production was projected to remain static to 2025 then to decline at 2% annually. Production in the other subsectors was projected to remain static to 2025 and then to decline at 1% per year to 2050. Lower levels of investment and innovation were also assumed as a result.

Collaborative Growth

The collaborative growth scenario was represented by higher levels of global growth 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.

The wider growth of demand and the improved international competitiveness of UK production in this scenario enables the heavy clay construction subsector to grow at 4% annually to 2025 and 2% annually from 2025 to 2050, while the other subsectors achieve growth of 1.5% annually to 2025 and 0.5% annually from 2025 to 2050. These levels of growth enable higher levels of investment and innovation.

	Challenging world	Current trends	Collaborative growth
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 Information and Communication Technologies (ICT).
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	Current trends	Collaborative growth
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.

	Challenging world	Current trends	Collaborative growth
UK Economic outlook	Weaker Office of Budget Responsibility (OBR) growth assumption.	Current OBR growth assumption	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	Central prices	Likely to be higher
Fossil Fuel	Higher and volatile fuel prices Updated Energy Projection (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 7: Summary of scenario context and specific assumptions applicable to the scenarios

12. Options

Options Processing

The options register 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 and the evidence gathering workshop. 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 cross-checked with the evidence gathering workshop, survey 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 evidence 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.

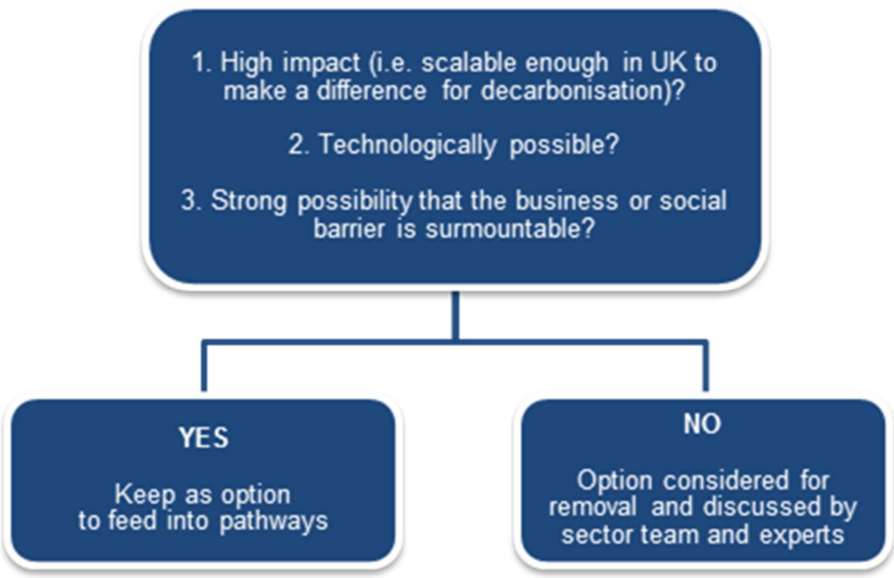

Figure 3: Social and Business pathways impact tree

13. Pathway and Action Plan Workshop

The second workshop focused on reviewing the draft decarbonisation and energy efficiency pathways and identifying potential actions for delivering them. This included presenting and discussing draft pathways in groups and then asking the question, "taking into account the identified barriers and enablers, what next steps would assist in delivering the pathways?"

The outputs of the 2nd workshop were used to validate the pathways and to inform the conclusions of the roadmap – which include example next steps and actions.

14. 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
- Decarbonisation and energy efficiency in the ceramic sector more generally

To draw conclusions, the analysis of enablers and barriers 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 ceramic 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 and energy efficiency 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.

INDUSTRIAL DECARBONISATION AND ENERGY EFFICIENCY ROADMAP TO 2050 – CERAMICS

APPENDIX B – FULL SOCIAL AND BUSINESS FINDINGS

APPENDIX B FULL SOCIAL AND BUSINESS FINDINGS

1. SWOT Outcomes

The table below highlights the top strengths, weaknesses, opportunities and threats in relation to decarbonising the ceramics sector in the UK.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
The sector is an active exporter	There is little technology and process change	Level the 'playing field' with competing countries	The relentless low-cost competition from overseas manufacturers
Ceramics exhibit low maintenance and lifecycle cost.	Labour intensive sector	Pursue flexibility, customisation and personalisation in new product development	Tightening environmental regulation and policies
The sector is an international leader in producing value added, high-quality products	High variety of products does not lend itself to continuous production	Specialise in selling high value-added ceramics.	Increasing concerns regarding UK/EU energy security
Durable products with high material efficiency and low cradle-to-grave carbon footprint.	The need for high-temperature kiln firing leads to perception of high carbon-embedded products	Develop brand and customer loyalty	Increasing energy prices and price volatility.
Long established international reputation for high-value, unique designs and products.		Diversify into new export, growing markets.	Carbon leakage to countries with weaker (or no) climate change policies).

Table 8: SWOT analysis outcomes

2. 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 Ceramics sector Good financial-economic decarbonisation data Recent information (after 2000[3]) Provides a good example/story of decarbonisation Validated across all evidence gathering methods
Medium high	Relevance for the UK Ceramics 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 Ceramics 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 1 of this appendix B.

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

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

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.

3. Detailed analysis of enablers and barriers

Enablers

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
1	Investment	Projects providing multiple benefits (energy and labour cost reduction, improved production yield, etc.) are more likely to be invested in.	1 source: CSE, ECI (2012) - *"The most successful projects joined up different kinds of low-carbon behaviours (energy, waste, transport etc.);"*	2 Interviews: *"Very often the ROI is quite small, so we need to bring other benefits to the bottom line of the project such as labour cost reduction or yield increase. Energy reduction is only a primary focus if there is an issue to be fixed/improved. "* *"Payback is not acceptable just based on energy cost [reduction], so the other cost (e.g. labour) must be reduced as well or increase yield and output. Energy Reduction on its own is not a feasible enough benefit"*	Average impact: high Very high impact – 68% (21) Medium to high impact - 23% (7) Limited to medium impact – 6% (2) No to limited impact – 0% (0) No impact – 0% (0) I don't know - 3% (1)	Impact level: high Workshop participants assessed unanimously a very high impact. For companies it is important to look at the whole picture and build a business case and present to the board level executives.	This is the enabler with the highest impact according to survey and workshop participants. Various sources and discussions have confirmed that projects providing multiple benefits are more likely to grab decision-makers' attention. Energy cost reduction is high up on the radar but do not provide sufficient return to pass the stringent investment criteria. Increased capacity and reducing labour or maintenance cost have been identified as two of the key benefits. This enabler has applicability across all subsectors.
2	Regulation	Compliance with legal obligations (e.g. environmental licence).	1 source: Venmans (2014) - *"Policy enabler: to comply with legal obligations (e.g. environmental licence)"*	1 Interviews: *"We optimised the car fill and kiln efficiencies as we were behind CCA targets. It resulted in higher labour cost but we achieved 60% reduction on cost of carbon from the plant"*	Average impact: medium Very high impact – 35% (11) Medium to high impact – 45% (14) Limited to medium impact – 6% (2) No to limited impact – 6% (2) No impact – 3% (1) I don't know - 3% (1)	Impact level: high Enforcement is a key driver for example through policy inspections and audits. Risk of non-compliance and associated financial and reputational cost.	Probably the "elephant in the room" that nobody talks about. Very few stakeholders mentioned compliance to legal obligations a driving force and this is largely due to the fact that it is already the norm to comply fully and follow the rules.
3	Investment	A strong, evidence-	1 source:	2 Interviews:	Average impact:	Impact level: high	Capturing all benefits and cost, or the full

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		based business case for energy efficiency and decarbonisation measures that capture all benefits and cost.	Carbon Trust (2011) - *"Business case – this will need to be robust. Savings must be deliverable and all financial savings and costs captured. The sector would like to see all potential benefits captured. For example, could a decarbonisation measure also help to deliver productivity improvements or reduce maintenance requirement "*	*"Very often the ROI is quite small, so we need to bring other benefits to the bottom line of the project such as labour cost reduction or yield increase. Energy reduction is only a primary focus if there is an issue to be fixed/improved. "* *"Payback is not acceptable just based on energy cost [reduction], so the other cost (e.g. labour) must be reduced or increase yield and output. Energy Reduction on its own is not a feasible enough benefit"*	medium Very high impact – 29% (9) Medium to high impact – 48% (15) Limited to medium impact – 16% (5) No to limited impact – 3% (1) No impact – 0% (0) I don't know - 3% (1)	Workshop participants assessed unanimously a very high impact. Without it none of the proposed project can reach a discussion at board level/final stage of decision making and sign-off process.	picture, can provide support to get executive buy-in and pursue more energy efficient technologies, which help reduce carbon emissions as well. This is also supported by the fact that lack of reliable information about the potential and profitability of breakthrough/disruptive technologies has been pinned as significant barrier especially for SMEs.
4	Market	Stable and internationally competitive business and regulatory environment that encourages capital investment in innovation.	1 source: TUC - *"Stable and competitive business environment that encourages capital investment and innovation"*	n/a	Average impact: medium Very high impact – 26% (8) Medium to high impact – 45% (14) Limited to medium impact – 23% (7) No to limited impact – 0% (0) No impact – 0% (0) I don't know - 6% (2)	Impact level: medium Wording was amended after workshop participants discussed that the policies are not an issues but change of regulations and uncertainty about mid-to-long term direction of the government strategy. Often change of regulation prevents long term planning and associated investments, as it influences energy and production cost.	This enabler has been identified as having medium to high impact on decarbonisation consistently across survey and workshop participants. If government and industry agree on long-term regulation will allow businesses to plan cost development accordingly, and relax payback requirements. Additionally, such measures can send positive signals to foreign investors.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
5	Operations	Investment in new technologies is likely to succeed if they increase production capacity and yield.	n/a	4 interviews: *"The fast firing could save up to 50% of gas used per product compared to intermittent kiln. We implemented it as we got a reasonable grant and the time was right as we aimed to increase capacity exponentially".* *"We got funding for heat exchangers externally. The main driver was to be able to produce more diverse product portfolio in a cost efficient manner – thus reduce energy cost"* *"Payback is not acceptable just based on energy cost [reduction], so the other cost (e.g. labour) must be reduced as well or increase yield and output."* *"This [energy efficient driers and kilns] was commercially driven. The seed of the project was to increase capacity. We considered a longer payback for this as it was a considerable growth opportunity as well."*	Average impact: medium Very high impact – 35% (11) Medium to high impact – 42% (13) Limited to medium impact – 10% (3) No to limited impact – 6% (2) No impact – 3% (1) I don't know - 3% (1)	Impact level: medium Workshop participants assessed the current impact level as 2 – limited to medium as there is no extra capacity at the moment. However if the demand grows, around 2030, this can become a very important factor. Currently investment criteria are barrier due to capital intensity of the industry. NB! It will only have impact if there is a demand from the market. Currently production is at full capacity but this is cyclical and can change. All costs are absorbed by the manufacturer and thus margins are diminishing.	Provided the demand for UK ceramics growth, technologies that can provide better yield with less energy consumption will become number one choice for ceramic manufacturers as only the need for increase of capacity can justify such an investment. (As one of the interviewees has already done).
6	Management	Willingness of top management to make climate change a priority.	2 sources: Haydock (2013) - *"Willingness of top management to make*	1 interview: *"Commitment from senior management has been essential to implement*	Average impact: medium Very high impact – 26% (8)	Impact level: high Workshop participant agreed with the enabler's definition	Interviews and workshop discussions revealed that although reducing energy cost is paramount to maintain profitability, reducing carbon emissions is not a priority for

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			climate change a priority. This is crucial as it affects the overall culture of the firm." Venmans (2014)- *"Commitment by top management to an environmental policy"*	*some of the recent technological improvements"*	Medium to high impact – 26% (8) Limited to medium impact – 32% (10) No to limited impact – 10% (3) No impact – 3% (1) I don't know - 3% (1)	and stated that it can be further reinforced if there is a regulation in place or strong customer attitude towards climate change, which is currently missing.	executives and management. Unless that changes, the decarbonisation of the sector won't materialise. This can be significantly influenced if consumer preferences and attitude towards climate change is more favourable.
7	Operations	A need to replace obsolete equipment/expansion or rebuild.	1 source: Venmans (2014)- *"Economic enabler: Replace obsolete equipment/production expansion"*	1 interview: *"Payback is never there to upgrade incremental options such as motors, fans and lighting, as we can run with the current ones until they break. The replacement process has been gradual unless there is a compelling ROI"*	Average impact: medium Very high impact – 16% (5) Medium to high impact – 39% (12) Limited to medium impact – 32% (10) No to limited impact – 6% (2) No impact – 3% (1) I don't know - 3% (1)	Impact level: high By 2030, 30% of current equipment will be replaced as it will become obsolete and maintenance cost drastically increase at the end of the equipment lifespan. Major driver here is to save materials and energy cost.	With long lifespan of production equipment, replacement of obsolete one is a great opportunity for putting forward a case of more energy efficient options. This has been reinforced by the exponentially increasing maintenance cost at the end of the life of the equipment. Similar is the case when companies are looking to expand and add capacity.
8	Value chain	Availability and stable pricing of raw materials.	1 source: Cerame-unie (2013), - *"Availability and the undistorted pricing of raw materials."*	1 interview: *"We consider a range of criteria in evaluating investments, one of which is price of raw materials"*	Average impact: medium Very high impact – 26% (8) Medium to high impact – 29% (9) Limited to medium impact – 23% (7) No to limited impact – 6% (2) No impact – 10% (3) I don't know - 6% (2)	Impact level: medium Although prices are established by market forces of supply and demand, temporary government intervention on raw material pricing may put back the sector in a favourable product cost position internationally.	Although this has been identified as medium to high impact enabler, the price of raw materials is market driven and thus can turn into a barrier. Availability, on the other side, has been perceived as a major driver of reducing price volatility.
9	People / Organisation	Skilled employees with strong engagement into the benefits of decarbonisation and energy reduction.	1 source: European Commission (2007) - *"Training, awareness and competence –*	1 interview *"Internal Green team which supports employee engagement can be often a critical enabler"*	Average impact: medium Very high impact – 16% (5) Medium to high impact	Impact level: medium The impact in the near future is considered low to medium. However, in 2050 the	Interestingly, employee engagement and buy-in on decarbonisation is not perceived as a key driver right now but is expected to become more so in the future. On the contrary, one interviewee has brought that up as a key

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			identifying training needs to ensure that all personnel whose work may significantly affect the environmental impacts of the activity have received appropriate training.” *“Employee involvement – involving employees in the process aimed at achieving a high level of environmental performance by applying appropriate forms of participation such as the suggestion book system or project-based group works or environmental committees.“*		– 35% (11) Limited to medium impact – 32% (10) No to limited impact – 10% (3) No impact – 3% (1) I don’t know - 3% (1)	impact will increase. There is demand for specific skills such as fuel engineers, raw-material engineers, electronics engineers. Although now there is no pressure, there will be a switch of focus from energy to carbon and the mind-set of decision makers will change accordingly. Decarbonisation as of now is not measurable/tangible so it less obvious a choice and requires understanding of the whole process. Possible actions to maximise this enabler include: educating leadership on benefits of decarbonisation and they will cascade down to labour; promoting technical staff as managers to balance knowledge and increasing basic knowledge and skill requirements for manufacturing staff.	enabler to their company (SME) as this can quickly escalate up and encourage management commitment as well. This has been identified as having greater impact on heavy clays and technical ceramics manufacturers.
10	Management	Implementation of environmental management system (targets, procedures,	1 source: Venmans (2014) - “*Management enabler: Implementation of*	n/a	Average impact: medium Very high impact – 16% (5)	Impact level: medium Acquiring the right data about energy consumption is	Mostly driven by compliance and risk management, implementation of environmental management systems can provide invaluable benefits to decarbonisation

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		evaluation).	*environmental management system (targets, procedures, evaluation...)"*		Medium to high impact – 42% (13) Limited to medium impact - 19% (6) No to limited impact – 13% (4) No impact – 6% (2) I don't know - 3% (1)	essential to identify opportunities for process optimisation and equipment calibration. Environmental management data can often help us identify efficiencies as well.	by providing tangible data and helping identify inefficiencies. The majority of the survey and workshop participants have identified EMS as having medium to high impact on decarbonisation.
11	Value chain	Availability of local raw materials avoids long-distance transportation and related CO_2 emissions.	1 source: Cerame-unie (2013) - *"The use of locally-available raw materials avoids long-distance transportation and consequently higher CO_2 emissions."*	n/a	Average impact: medium Very high impact – 19% (6) Medium to high impact – 35% (11) Limited to medium impact - 19% (6) No to limited impact – 16% (5) No impact – 6% (2) I don't know - 3% (1)	Not applicable to refractories and technical ceramics.	Locally located raw materials can help reduce transportation related emissions especially in the heavy clay and whitewares subsectors.
12	Management	Proximity of the energy manager to the CEO.	1 source: CSE, ECI (2012)- *"The closer that an energy manager is to the CEO in the corporate hierarchy the more likely that energy management activity will take place."*	n/a	Average impact: medium Very high impact – 26% (8) Medium to high impact – 29% (9) Limited to medium impact – 13% (4) No to limited impact – 13% (4) No impact – 13% (4) I don't know - 6% (2)	Impact level: medium This is perceived of having high impact due to the fact that most executives do not have the technical knowledge and rely heavily on its specialised management staff.	The major benefits of having the energy manger close to the executives in the organisational hierarchy is that he or she can not only influence decision making but also build more awareness among the executive ranks on technical issues, challenges, risk and opportunities. Survey participants from technical ceramics regard this enabler as more impactful than the rest of the subsectors.
13	Investment	Financial support to develop and implement emerging/breakthroug h technologies. (E.g.	n/a	6 interviews *"The fast firing could save up to 50% of gas used per product compared to intermittent kiln. We*	Average impact: medium Very high impact – 23% (7) Medium to high impact	Although not officially discussed at the workshop due to the established prioritisation threshold	All interviewees consider that as key condition to enable the development and uptake of emerging technologies. Government-led schemes and supply-chain collaboration are two of the possibilities to reduce the financial

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		grants, government schemes, Horizon 2020 funding, equipment manufacturers collaboration)		*implemented it as we got a reasonable grant linked to increase in production (growth) and jobs".* *"We can only get only £250K from State-aid grant per annum"* *"We can only get a major [energy infrastructure development] due to a low interest loan by the Regional Growth Fund and additional funding from the Growing Places Fund. We didn't know about the funds before starting and the ideas came through networking"* *"Grants, specifically targeting energy saving, can make the investment ROI more attractive"* *"Funding has also been a challenge for Combined Heat and Power (CHP) and we explored financial support/lease options from equipment manufacturers and suppliers to make the options more financially viable."* *"Cash is paramount for such investments, so is the*	- 23% (7) Limited to medium impact – 3% No to limited impact – 23% (7) No impact – 10% (3) I don't know – 10% (3)	(60% of all 20 enablers), this enabler has been reinforced by workshop participants.	risk taken by individual companies.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
				ability to borrow money."			
14	Market	External pressures from customers, NGO, media, local community.	1 source: Venmans (2014) - *"Management enabler: External pressures (from NGO, media, local community...)"*	n/a	Average impact: medium Very high impact – 10% (3) Medium to high impact – 32% (10) Limited to medium impact - 26% (8) No to limited impact – 23% (7) No impact – 3% (1) I don't know - 6% (2)	One of the workshop participants has conducted an independent survey on importance of sustainability to their customers. The results showed that sustainability is very low on the customers' radar and cost is prevailing factor for purchasing orders.	Customer and wider community pressure on reducing carbon emissions has been identified as driver mostly by technical ceramics and refractories manufacturers. As showcased by an independent survey at the workshop – there is still no customer pressure in the heavy clay subsector on reducing carbon emissions.
15	Regulation	Expected gains from participating in (non)-voluntary carbon/energy agreements (e.g. CCA).	1 source: Venmans (2014) - *"Policy enabler: Voluntary agreements"*	2 interviews: *"CCA targets have been the main driver for energy reduction and decarbonisation in the last 10 years."* *"Carbon emissions reduction in line with CCA has been a key driver but secondary to cost saving from reduced energy use."*	Average impact: medium Very high impact – 10% (3) Medium to high impact – 29% (9) Limited to medium impact – 32% (10) No to limited impact – 19% (6) No impact – 6% (2) I don't know - 3% (1)	Not discussed at the workshop.	Similarly to regulatory requirements, CCA targets have been perceived as a must do and therefore can drive decarbonisation.
16	Innovation	In-house R&D capabilities.	1 source: Venmans (2014) - *"Economic enabler: Result of in-house R&D"*	n/a	Average impact: limited Very high impact – 16% (5) Medium to high impact – 16% (5) Limited to medium impact – 26% (8) No to limited impact – 26% (8) No impact – 10% (3) I don't know - 6% (2)	Not discussed at the workshop.	In house R&D is mostly focused on incremental improvements on manufacturing technologies or process improvements. Therefore, additional R&D capability working with equipment suppliers can ensure future production needs are met.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
17	Market	Designated locations for renewables self-generation projects.	n/a	1 interview: *"As we are in a rural area it will help if there were designated location to construct renewables"*	Average impact: limited Very high impact – 13% (4) Medium to high impact – 19% (6) Limited to medium impact – 19% (6) No to limited impact – 23% (7) No impact – 13% (4) I don't know - 13% (4)	Not discussed at the workshop.	Identified by one of the interviewees, this enabler can work specifically in rural areas where renewable energy generation projects can be deployed.
18	Production	Moving from intermittent (batch) to continuous (tunnel or fast-fire roller kiln) technology.	1 source: Cerame-unie (2013) - *"Moving, where appropriate for the scale of operation, from intermittent (batch) to continuous (tunnel or fast-fire roller kiln) technology."*	1 interview: *"The fast firing could save up to 50% of gas used per product compared to intermittent kiln. Labour savings are incurred too, which provides better ROI. We implemented it as we got a reasonable grant and the time was right as we aimed to increase capacity exponentially".*	Average impact: limited Very high impact – 19% (6) Medium to high impact – 13% (4) Limited to medium impact - 13% (4) No to limited impact – 26% (8) No impact – 19% (6) I don't know - 10% (3)	Not discussed at the workshop.	Currently largely applicable to whitewares and refractories, fast-firing kilns consume less energy and can incur labour cost savings.
19	Innovation	Collaborative R&D with other sectors, universities, RTO, research institutions, etc.	n/a	1 interview *"The availability of new technology and the research that needs to go into that technology is limited as nobody is willing to pay for it. It needs to be an industry-wide initiative. Our R&D is mostly on site improvement not on key equipment."*	Average impact: limited Very high impact – 3% (1) Medium to high impact – 26% (8) Limited to medium impact – 29% (9) No to limited impact – 19% (6) No impact – 13% (4) I don't know - 10% (3)	Not discussed at the workshop.	Sharing the cost of R&D can help the faster development and uptake of disruptive technologies. Commercial confidentiality can be an issue to overcome to maximise the impact of this enabler.
20	Regulation	Expected gains or cost savings from Emission	1 source: Venmans (2014) -	n/a	Average impact: limited	Not discussed at the workshop.	Very few survey respondents see opportunities for gains from ETS with nearly a

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		Trading Scheme (ETS).	*"Policy enabler: Avoid risk induced by future ETS (unknown prices, cap, proportion of free allocations)"*		Very high impact – 10% (3) Medium to high impact – 26% (8) Limited to medium impact - 16% (5) No to limited impact – 19% (6) No impact – 23% (7) I don't know - 6% (2)		quarter of them assessing it as none.

Table 10: Detailed analysis of enablers

Barriers

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
1	Investment	Long investment cycles (equipment lifespan) and high capital costs of new technologies.	7 sources: Cerame-unie (2013) - *"As the life of a kiln can be more than 40 years and represents major capital investment, it is not financially-feasible to routinely upgrade kilns before the end of their life and replace them with more energy-efficient models."* Carbon Trust (2011) Haydock (2013) CSE, ECI (2012) – *"Upfront costs are cited as a significant disincentive"* DECC (2013) - *"Investment cycles and capital costs: Investment in new more efficient plant requires major investment, and is unlikely to be possible outside normal investment cycles, which can sometimes be 40 years or longer."* McKenna (2009)	2 interviews *"Availability of funding and high cost of equipment is a top barrier for us"* *"Financing is a key issue for us as we do not have the cash to invest upfront".*	Average impact: high Very high impact – 48% (15) Medium to high impact – 35% (11) Limited to medium impact – 10% (3) No to limited impact – 0% (0) No impact – 3% (1) I don't know - 3% (1)	Impact level: high With a 40 year lifespan of kilns there is no drive for kiln manufacturers to build 2050 capable kilns. There is a need for collaboration to reduce the investment or the risk taken by individual players.	The industry investment cycles are to a large extend dictated by the lifespan of manufacturing equipment (kilns), which can often be 40 years. This in itself presents very few opportunities to upgrade the entire kiln and achieve major energy and carbon savings. Additionally, high upfront cost of such investments often limits the financial ability of UK ceramic companies to upgrade multiple kilns at the same time. Rather, companies take gradual approach to upgrading their plants' equipment.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			Venmans (2014)				
2	Operations	An innovation would be unlikely to be adopted if it could diminish product quality or cause production disruption.	3 sources: Carbon Trust (2011) – *"an innovation would be unlikely to be adopted if it could affect product quality"* Haydock (2013) - *"Continuity of production is of primary importance to firms. This is one of the reasons that energy efficiency technologies tend to have more stringent economic criteria compared to investments that are more closely related to the core business."* CSE, ECI (2012) Venmans (2014) - *"Risk of production disruptions, hassle, inconvenience"*	1 interview: *"We cannot guarantee the product high quality unless we do it in a high-temperature environment"*	Average impact: high Very high impact – 55% (17) Medium to high impact – 26% (8) Limited to medium impact – 6% (2) No to limited impact – 6% (2) No impact – 3% (1) I don't know – 3% (1)	Impact level: high Mostly it is driven by client specifications and demand for low cost, appealing products (which may exclude refractories and technical).	Risk of production disruptions from retrofit technologies is an even larger concern for small companies with limited production capacity. One interviewee indicated that management commitment was needed for any energy efficiency retrofit project as if anything goes wrong, it impacts profitability of the entire plant. Interviewees were concerned about retrofits/ installing new technologies and its implications on quality and being able to continue to meet customer demands and specifications.
3	Market	Increasing concern of electricity and gas security.	n/a	2 interviews: *"Lack of sufficient gas storage affects gas prices"* *"UK natural gas stocks availability and utility procurement"*	Average impact: high Very high impact –35% (11) Medium to high impact – 32% (10) Limited to medium impact – 16% (5) No to limited impact – 13% (4) No impact – 0% (0)	Impact level: high Unplanned interruption of energy supply can affect negatively production and kiln efficiency and raise production cost per unit.	Majority of survey respondents and workshop participants agreed that shortage of gas stored supplies can cause major production disruptions and drastically increase the cost of natural gas. If not handled, this may cause some businesses to close.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
					I don't know – 3% (1)		
4	Market	Threat of rising energy prices and cost of carbon.	3 sources: Haydock (2013) – *"Threat of rising energy prices"* Centre for Low Carbon Futures (2011) – *"A 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."* ECORYS (2008) – *"Energy saving techniques become ever more important in the long run for securing a competitive position. The main concern for the ceramics sector is the impact of the ETS (Emissions Trading Scheme) on gas prices. The ETS is likely to raise energy prices, which will feed into operating costs and will*	3 interviews@ *"Cost of firing is really high, so we try to reduce fuel cost in any way possible to remain competitive on a global scale"* *"We are an intrinsically energy intensive industry (EII). Gas prices increasing is a threat to our profitability"* *"Business is growing however penalised for this growth by cost of carbon and thus at disadvantage compared to non-UK competitors."*	Average impact: high Very high impact – 45% (14) Medium to high impact – 26% (8) Limited to medium impact – 6% (2) No to limited impact – 13% (4) No impact – 6% (2) I don't know – 3% (1)	Impact level: high There is a risk for future orders when prices are not known. High energy prices also make UK products less competitive on the global market as UK energy prices are significantly higher than those in emerging markets.	With energy cost comprising 30-35% of total manufacturing cost, there is a major threat to profitability of the UK ceramic manufacturers, especially since margins have been shrinking in the past years. This has emerged as a high concerns on whitewares survey respondents. Higher cost of energy and carbon also puts UK companies in less-competitive position against Asian manufacturers.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			consequently decrease profitability and also the uncertainty created by the long decision period in re-evaluating the ETS makes decision-making within the sector difficult. This could lead to a reduction of investment levels in firms located in the EU, with production and job losses following."				
5	Investment	Requirement for very high rates of return/short payback time on all projects including energy efficiency.	4 sources: CSE, ECI (2012) - *"Businesses generally appear to require very high rates of return on energy efficiency projects before they will invest. Resistance to invest in energy efficiency despite reasonable rates of return is sometimes termed the efficiency "paradox"."* DECC (2013) -*"Also returns from energy efficiency investment are low and can be uncertain, and in many companies, bids for investment will compete at a global level against spend on*	3 interviews: *" We typically require 3 year payback time for major capex projects and new technologies rarely fit within that threshold"* *"Acceptable ROI is the number one requirement for us to invest"* *"Payback is crucial factor as projects have to be economically viable"*	Average impact: high Very high impact – 39% (12) Medium to high impact – 32% (10) Limited to medium impact – 16% (5) No to limited impact – 6% (2) No impact – 6% (2) I don't know – 0% (0)	Impact level: high As a rule of thumb a maximum of 3 years payback time is acceptable for energy efficiency projects and often these projects are competing for financing against other projects.	Various sources confirmed that the sector in general has a 3-year payback threshold for capex projects. This often puts decarbonising options in unfavourable position as rising energy prices and high upfront cost make their payback too long to be accepted by companies' executives.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			process and products." Venmans (2014) McDermott - *"Many technologies have longer payback than shareholders / banks will lend for."*				
6	Innovation	Shortage of proven and demonstrated energy-efficiency technologies.	2 sources: Carbon Trust (2011) – *"The sector has implemented some innovations in the past which have failed. This has resulted in concerns about the potential of some of the projects to deliver over the long term"* Venmans (2014) – *"We waited (are waiting) to see if the application of the technology by other companies/plants turned (turns) out to be reliable and profitable"*	4 interviews: *"A lot of research is conducted by the Ceram Research Institution on new firing technologies but they are far away from demonstrating these technologies"* *"The availability of new technology and the research that needs to go into that technology is limited as nobody is willing to pay for it. It needs to be an industry-wide initiative. Our R&D is mostly on site improvement not on key equipment."* *"Lack of technical solutions of flexible firing"* *"Implementing unproven technologies is also of major concern as that may cause production disruptions and financial loses"*	Average impact: medium Very high impact – 32% (10) Medium to high impact - 35% (11) Limited to medium impact – 13% (4) No to limited impact – 10% (3) No impact – 6% (2) I don't know - 3% (1)	Impact level: limited Some workshop participants expressed a disagreement that there is no shortage but lack of investment in new technologies. The impact will be high if asking about effectiveness of such technologies.	Literature reviewed and Interviews highlighted that Ceramic manufacturers are highly risk averse and are not likely to implement technologies that might lead to production disruptions due to malfunctioning retrofits. Therefore, technologies that have been tried before are more likely to gain traction. Only 10% of the sector survey respondents identified themselves as first mover/innovators, which is another indicator about the slow adoption of new technologies.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
7	Regulation	The absence of an international levelled 'playing field' on environmental regulations.	1 source: ECORYS (2008) – *"The absence of an international level playing field on environmental regulations is perceived as a noteworthy threat for European global players."*	1 interview: *"Ever changing and over complicated carbon related compliance schemes that do not engage or encourage, just burden business"*	Average impact: medium Very high impact – 39% (12) Medium to high impact – 23% (7) Limited to medium impact – 23% (7) No to limited impact – 3% (1) No impact – 10% (3) I don't know – 3% (1)	Impact level: high Unanimously agreed by workshop participants.	Although the industry is impacted by carbon leakage, during the workshop it was noted that exemptions for the EU ETS and the economic recession have limited the impact of carbon leakage on the sector. However, interviewees, and some workshop participants, indicated that they are beginning to experience carbon leakage and are seeing a reduction in exports and increase in imports as a result.
8	Operations	Technology limitations due to different firing temperature requirement for different products.	2 sources: Centre for Low Carbon Futures (2011) – *"For many companies, much has already been done to improve the efficiency of the processes involved; there are efficiency limitations on current processes"* Venmans (2014)	2 interviews: *"However, fast firing kilns are less flexible and may be inefficient if there is high volatility of product demand"* *"The challenge as a small manufacturer is that if we want to fire products with the lowest energy consumption we need to use tunnel kiln but the issues is that tunnel kilns run at one temperature, which doesn't fit our business and product portfolio"*	Average impact: medium Very high impact –26% (8) Medium to high impact – 42% (13) Limited to medium impact – 13% (4) No to limited impact – 10% (3) No impact – 6% (2) I don't know – 3% (1)	Impact level: limited Not a big issue for heavy clays but essential for refractories and technical ceramics. Quality of product will be impacted as lower temperatures affect negatively mineral and chemical transformation of the materials. Firing temperature can be optimised at some control stages that do not require precise controlled environment. Fast firing has been implemented by all subsectors but heavy clay.	Interviews revealed that high-temperature firing is essential to maintain the specified quality and capabilities of products. Until, entirely new production processes are invented this will be a major barrier for refractories, whitewares and technical ceramics and to a lesser degree for heavy clays (according to survey respondents and workshop participants).
9	Innovation	Lack of government support (e.g. financial) for industry R&D of	**1 source:** Centre for Low Carbon Futures (2011) – *"Lack of*	2 interviews: *"The fast firing could save up to 50% of gas used per*	Average impact: medium Very high impact –29%	Impact level: high Other avenues for obtaining funding are	As discussed by workshop participants, there are limited financing alternatives for UK ceramic manufacturers who wish and have the

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		emerging/ breakthrough technologies.	*financial support for R&D: Some respondents commented on the difficulty of accessing government support to promote industry R&D; A large proportion of UK companies operating in the energy intensive sector are subsidiaries of global organisations. They compete internally for capital investment. Higher costs make it more difficult to justify internal group investment in the UK. The Green Investment Bank was, however, seen as potential source of capital for energy efficiency projects"*	*product compared to intermittent kiln. We implemented it as we got a reasonable grant linked to increase in production (growth) and jobs".* *"We can only get only £250K from State-aid grant per annum"*	(9) Medium to high impact – 35% (11) Limited to medium impact – 13% (4) No to limited impact – 10% (3) No impact – 10% (3) I don't know – 3% (1)	limited at the moment largely due to slowed growth of the UK ceramic sector and reduced profitability.	capabilities to develop breakthrough technologies. Various sources agree on the need of industry wide collaboration in the form of research centres, supply chain collaboration initiatives, etc. The sector growth outlook makes it even more evident that this task is too big for one company to solve alone, despite the commercial benefits it can yield as a first mover.
10	Regulation	Regulatory uncertainty affects high cost and long-term investments.	**3 sources:** Centre for Low Carbon Futures (2011) – *"Long term clarity was seen as vital to underpin high cost, long term technology investment"* Venmans (2014) –*"Risk induced by future ETS uncertainty (unknown prices, cap, proportion of free allocations)"*	3 interviews: "Government has a pivotal role in improving the investment climate in the UK (reduce cost of electricity, support modernisation of plants and improve the renewable mix of electricity" "We do have regulatory constraints in the UK which hamper us to plan long term"	Average impact: medium Very high impact – 26% (8) Medium to high impact – 26% (8) Limited to medium impact – 26% (8) No to limited impact – 13% (4) No impact – 3% (1) I don't know – 6% (2)	Impact level: none Not an important consideration for investment decisions. Viability of cost of energy is a big concern, though.	The impact of this barrier on decarbonisation varies from medium to very high according to survey respondents. Interviewees and some workshop participants, though, agree on the fact that setting long-term targets and policies will improve the investment climate by providing some certainty around energy prices and the direction the government wants to take.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			McDermott – *"Regulatory certainty is also vital to underpin high cost, long-term investment"*	*"Ever changing and over complicated carbon related compliance schemes that do not engage or encourage, just burden business"*			
11	Innovation	Lack of reliable information and knowledge transfer about technical feasibility or profitability potential. (Imperfect information).	4 sources: CSE, ECI (2012) – *"Hidden costs (e.g. disruptions to production and evidence gathering) erode the apparent profitability of an efficiency investment and are considered by some to be the primary explanation for the "efficiency gap"."* DECC (2013) – *"Information on the technical solutions to decarbonise and the costs and technology readiness (for example on industrial CCS) is imperfect among industry players."* Venmans (2014)– "when the technical feasibility or the profitability of an investment is not studied, cost-effective investments	2 interview: *"Specialist advice on specific technologies and their energy reduction potential is not well spread across the sector."* *"There is currently no sensible way for us to know what options are out there and what are the benefits of various technologies"*	Average impact: medium Very high impact –19% (6) Medium to high impact – 32% (10) Limited to medium impact – 32% (10) No to limited impact – 10% (3) No impact – 6% (2) I don't know – 0% (0)	Impact level: medium Of high importance as currently very limited information is available. BCC can play a more active role in facilitating evidence gathering and dissemination.	There is a shortage of technical knowledge and capacity within the UK ceramic business to identify new technologies and measures. Several interviewees expressed concern that they don't know where to start looking for new options and industry wide support can be a key to resolve this. This has been identified as a stronger barrier for SMEs in the sector.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			opportunities may remain non-implemented" ECORYS (2008) – "Competitiveness of the Ceramics sector - final report'				
12	Market	The relatively high dependency on the construction and renovation activities.	1 source: ECORYS (2008)	n/a	Average impact: medium Very high impact – 23% (7) Medium to high impact – 23% (7) Limited to medium impact – 19% (6) No to limited impact – 13% (4) No impact – 10% (3) I don't know – 13% (4)	Not assessed as not applicable to all subsectors.	The dependency on construction trends is particularly evident for heavy clay manufacturers as indicated by the survey respondents.
13	People / Organisation	Shortage of qualified and engaged staff (esp. heat engineers) and aging of the workforce.	5 sources: Carbon Trust (2011) – *"Staff would also need to be trained in the upkeep of new equipment, and this needs to be addressed by solution providers."* DECC (2013) – *"The transition to low carbon industrial heat will require specialised, highly skilled and experienced heat focused engineers. These skills are not readily available in the*	3 interviews: *".. the challenge is to find the required expertise in combustion/ engineering and do the work themselves – not a pool of skills that can be found easily"* *"Lack of technical expertise (e.g. heat exchange engineers)"* *" We do struggle to find adequately skilled labour for new technologies implementation or processes improvement"*	Average impact: medium Very high impact – 16% (5) Medium to high impact - 35% (11) Limited to medium impact – 23% (7) No to limited impact – 13% (4) No impact – 10% (3) I don't know – 3% (1)	Not discussed at the workshop.	Literature reviewed and interviews revealed an increasing demand for specialised engineers in heat exchange, combustion, firing technologies, etc. Some workshop participants expressed concern that ceramic industry is not attractive to young engineers anymore and that trend will continue unless something is done on an industry level.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			industry" McKenna (2009) – *"Lack of staff/de-skilling and aging of work force"* Venmans (2014)– *"Need for training of employees or engagement of specifically skilled employees (e.g. energy auditor)"* ECORYS (2008) – *"An increasing demand for high-skilled labour, which is not always the perception that job-seekers have of the ceramics sector."*				
14	Market	Low demand for firing technologies prevents equipment supplier from developing more efficient alternatives.	n/a	1 interview: *"All kilns are from UK manufacturers but with the supply capability decreasing."*	Average impact: medium Very high impact – 13% (4) Medium to high impact - 35% (11) Limited to medium impact – 23% (7) No to limited impact – 10% (3) No impact – 10% (3) I don't know -10% (3)	Not discussed at the workshop.	As explained by one of the interviewees, kiln manufacturers currently have no incentives to produce more energy efficient kilns there is no demand for them in short term. This will remain a barrier unless the investment for developing such technologies is shared or subsidised.
15	Market	Globalisation (low-priced imports) and trade barriers (EU access to third	2 sources: DECC (2013) – *"Many industries in the UK operate in highly*	n/a	Average impact: medium Very high impact – 23% (7)	Not discussed at the workshop.	There is limited evidence to support how globalisation may affect decarbonisation of the UK ceramic industry beyond threatening profitability and competitiveness due to higher

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
		countries) affect demand.	*competitive markets, which limit their ability to pass through costs of energy or investment to consumers."* ECORYS (2008) – *"Globalisation (low-priced imports) and trade barriers (EU access to third countries)"*		Medium to high impact – 23% (7) Limited to medium impact – 19% (6) No to limited impact – 16% (5) No impact – 13% (4) I don't know – 6% (2)		energy prices in the UK.
16	Investment	Scarcity of capital and difficulties of funding capex and R&D, often due to internal competition.	6 sources: Carbon Trust (2011) – *"In the current economic climate essential maintenance consumes the bulk of funding. Projects that enable third party funding such as an ESCO type model are likely to be adopted more quickly."* Haydock (2013) – *"Lack of resources, both in terms of time and capital"* Centre for Low Carbon Futures (2011) – *"A large proportion of UK companies operating in the energy intensive sector are subsidiaries of global organisations. They compete*	5 interviews: *"Capital availability is paramount … as we have to compete internally for funding with non-energy related projects"* *"Capital is a key barrier for us" x3* *"Cash is paramount for such investments, so is the ability to borrow money."*	Average impact: medium Very high impact – 23% (7) Medium to high impact – 29% (9) Limited to medium impact – 10% (3) No to limited impact – 23% (7) No impact – 13% (4) I don't know - 3% (1)	Not discussed at the workshop.	Lack of resources deployed to identifying the funding available, and reluctance to move to third party financing are seen as additional barriers to finding financing. Interviewees also indicated that there is a lack of collaboration on financing demonstration projects as this is seen as a competitive advantage and thus sharing the financial burden amongst manufacturers is limited. One interviewee indicated that they would go through with a new technology implementation if equipment suppliers could offer financial incentives in the form of leasing to reduce the upfront cost and share the risk of a longer payback. Large multinational companies expressed concern that energy reduction projects often compete with core business capex and projects overseas for limited funding and longer payback times do not help secure that funding as risk is seen as too high.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
			internally for capital investment. Higher costs make it more difficult to justify internal group investment in the UK. The Green Investment Bank was, however, seen as potential source of capital for energy efficiency projects." McKenna (2009) - *'access to capital"* Venmans (2014) – *"Difficulties in finding (internal or external) financing for investments. Other (non-energy-related) investments received prior financing."* McDermott – *"Industry needs affordable finance to facilitate uptake"*				
17	Management	Other manufacturing cost such as labour cost.	n/a	1 interview: *"Other manufacturing cost such as labour are often a barrier to decarbonisation too"*	Average impact: limited Very high impact – 16% (5) Medium to high impact - 19% (6) Limited to medium impact – 32% (10) No to limited impact –	Not discussed at the workshop.	As expressed by one of the interviewees, labour and maintenance cost can be a barrier as well if the new technologies require more staff or more expensive maintenance.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
					13% (4) No impact – 10% (3) I don't know – 10% (3)		
18	Market	Competition from substituting materials affects demand.	1 source: ECORYS (2008) – Competitiveness of the Ceramics sector - final report' – *"Competition from substitute materials."*	n/a	Average impact: limited Very high impact – 19% (6) Medium to high impact – 23% (7) Limited to medium impact – 26% (8) No to limited impact – 16% (5) No impact – 26% (8) I don't know – 0% (0)	Not discussed at the workshop.	Substitution is a significant threat but is out of scope for this study. It has been identified as a threat to whitewares as alternative low-cost materials have increased their market share on the UK market and can diminish the profitability of whitewares manufacturers in mid-to-long term and thus their ability to invest. Alternatives to heavy clay products, such as concrete building blocks and alternative facing materials represent a longer term challenge to the subsector.
19	Innovation	SMEs don't have the capacity to notice, interpret and respond to energy efficiency opportunities.	1 source: CSE, ECI (2012) – *"The size of the organisation has a direct influence on its capacity to notice, interpret and respond to energy efficiency opportunities."*	n/a	Average impact: limited Very high impact – 19% (6) Medium to high impact – 19% (6) Limited to medium impact – 13% (4) No to limited impact – 13% (4) No impact – 26% (8) I don't know – 10% (3)	Not discussed at the workshop.	There is a shortage of technical knowledge and capacity within the UK ceramic business to identify new technologies and measures. Several interviewees expressed concern that they don't know where to start looking for new options and industry wide support can be a key to resolve this. This has been identified as a stronger barrier for SMEs in the sector.
20	Market	Lack of cross industry national level infrastructure (e.g. for CCS)	1 source: Centre for Low Carbon Futures (2011) – *"Some respondents noted the need for investment in national level infrastructure, particularly in relation toCCS, and electricity decarbonisation and recycling."*	n/a	Average impact: limited Very high impact – 10% (3) Medium to high impact - 19% (6) Limited to medium impact – 29% (9) No to limited impact – 6% (2) No impact – 23% (7)	Not discussed at the workshop.	Almost a quarter of the survey respondents see no impact of cross industry national level infrastructure on the decarbonisation of the ceramic sector. Yet literature has identified CCS as a major opportunity to reduce emissions of EEIs in the UK.

#	Category	Enablers	Literature review	Interviews	Survey (distribution of responses - % and number)	Workshops	Analysis and Interpretation
					I don't know – 13% (4)		

Table 11: Detailed analysis of barriers

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APPENDIX C – FULL TECHNOLOGY OPTIONS REGISTER

APPENDIX C TECHNOLOGY OPTIONS REGISTER

Column	Description
Option	Option title
CO_2 Savings %	Change in total CO_2 emissions from associated process
Natural gas energy use %	Change in natural gas consumption of associated process
Biomass energy use %	Change in biomass contribution to total heat input of associated process
Electricity Use %	Change in electricity consumption of associated process
Adoption %	Percentage of subsector already employing this option
Applicability %	Percentage of subsector to which the option could be applied
% attributable to CO_2 reduction	Percentage of capital cost that is attributed to decarbonisation rather than new capacity
Number of Sites	Number of sites to which the option is applicable
Capex per site	Estimated cost of application of the option to an average site
Capex £m	Capital cost if option applied to whole sector
Longer description	A description explaining the scope of the option

Table 12: Glossary of terms used in option register

Subsector/ product key		Technology Readiness Level (TRL)		Data Source Key	
1	Total sector	1	Basic principles observed and reported	1A	Cerame-Unie, reviewed by sector team, sector specialists and BCC
2	Heavy Clays (Brick) subsector	2	Technology concept and/or application formulated	1B	Carbon Trust, reviewed by sector team, sector specialists and BCC
3	Refractories subsector	3	Analytical and experimental critical function and/or characteristic proof of concept	1C	IPPC Bureau, reviewed by sector team, sector specialists and BCC
4	Technical Ceramics	4	Technology/part of technology validation in a laboratory environment	2	Workshop or sector team reviewed by sector specialists and BCC
5	White wares subsector	5	Technology/part of technology validation in working environment		
		6	Technology model or prototype demonstration in a working environment		
		7	Full-scale technology demonstration in working environment		
		8	Technology completed and ready for deployment through test and demonstration		
		9	Technology deployed		

Table 13: Key of references used in option register

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
All: Apply Variable Speed Drive (VSD) to variable duty pumps/ fans	1	0.0%	1A	0.0%	0.0%	0.7%	9	10.5%	15.0%	Energy consumption of fans, pump and other variable duty applications can be reduced by minimising the use of throttling by the use of variable speed drives.
All: Electric Kiln and Dryer	1	80.0%	1A	100.0%	0.0%	-666.0%	5-6	5.0%	60.0%	As a means of substitution of low carbon electricity for gas in tunnel kilns install electrically heated kilns and dryers
All: Improve combustion efficiency	1	3.9%	1A	3.9%	0.0%	0.0%	9	68.0%	85.0%	Efficient control of combustion minimises fuel consumption for a required heating duty. Maintaining a constant air/fuel ratio over the range of burner outputs will enhance fuel efficiency.
All: Improve control of process	1	2.0%	1A	2.0%	0.0%	-1.0%	8-9	65.0%	100.0%	The effectiveness of energy use can be improved by better monitoring and control of the firing process to achieve better uniformity of product and reduced fuel consumption.

[4] Please note that expert opinion has been used to evaluate the TRL.

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
All: Organic Rankine Cycle (ORC) on heat recovery	1	0.0%	2	0.0%	0.0%	2.0%	8-9	0.0%	25.0%	An ORC unit is a thermal cycle with a boiler and turbine that recovers heat (generally low temperature) in a similar way to a steam rankine cycle, but opeates on a heat transfer fluid such as pentane.
All: Reduce radiant, convective and hot gas losses and leakage	1	7.5%	1A	7.5%	0.0%	0.0%	9	36.0%	90.0%	Heat losses are controlled by the quality of insulation along the kiln. Taking advantage of ongoing improvements in insulation/ refractory technology and maintaining good condition of installed insulation will minimise fuel consumption. Improved seals and maintenance of kiln seals will reduce hot gas leakage and associated fuel consumption.
B: Add biomass to clay	2	5.0%	1A	5.0%	0.0%	0.0%	5-6	0.0%	20.0%	Adding finely divided biomass to clay before forming reduces fossil fuel requirement for firing.
B: Adopt available lowest carbon process (BAT, new kilns)	2	20.0%	1A	20.0%	0.0%	1.0%	9	5.6%	70.0%	Kiln technology continues to develop offering progressively lower fuel consumption. Investment in the most advanced available kilns will reduce fuel consumption.

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
B: Avoid firing yellow bricks	2	10.0%	2	0.0%	0.0%	0.0%	7-8	0.0%	5.0%	Clay used for production of yellow bricks has a high process emission from its carbonate content. Alternative production using low carbonate clay with colorant avoids this emission.
B: CC from exhaust gases	2	50.0%	1A	0.0%	0.0%	-50.0%	5-6	0.0%	40.0%	CC from flue gases will be challenging but offers a means of radically reducing carbon emissions from kilns.
B: CHP heat into dryer	2	-15.0%	1A	-15.0%	0.0%	80.0%	5-6	0.0%	25.0%	The soft mud process has a higher heat demand than extrusion; CHP using of small gas turbine would increase overall energy efficiency .
B: Gasification of biomass	2	29.0%	1A&B	35.0%	-50.0%	-50.0%	5-6	0.0%	35.0%	The substitution of a syngas from gasification of biomass would enable a renewable fuel to replace a large part of the fossil fuel input.
B: Improve heat use by regenerative processes	2	15.0%	1A&C	15.0%	0.0%	0.0%	7-8	60.0%	100.0%	Large modern tunnel kilns have very sophisticated designs to minimise energy use. Optimising and maintaining the correct operating conditions throughout life can reduce energy consumption.

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
B: Lighter bricks to reduce firing energy	2	5.0%	1C	5.0%	0.0%	0.0%	7-8	22.5%	30.0%	Reducing the mass of material in each brick will reduce the fuel required for firing and drying per brick.
B: Low mass refractory for kiln cars	2	7.5%	1A	7.5%	0.0%	0.0%	7-8	27.0%	90.0%	The heat load represented by continuously heating the cold kiln car refractory as it travels through the kiln would be reduced by the use of low mass refractory.
B: Pre-calcining of clay	2	5.0%	2	5.0%	0.0%	2.0%	7-8	2.0%	100.0%	Pre-calcining of 80% of the clay in a fluidised bed will enable a large part of the transformation to be completed with lower energy consumption. The calcined clay would be mixed with a small amount of raw clay before conventional brick making.
B: Preheat water added for forming	2	3.0%	1A	3.0%	0.0%	0.0%	7-8	0.0%	40.0%	Using hot water instead of cold for forming is more effective, allowing less to be added therby reducing drying heating requirements.
B: Reduce air/product mass ratio	2	10.0%	1A&B	10.0%	0.0%	0.0%	9	20.0%	50.0%	The proportion of kiln energy input that is delivered to product depends on kiln loading. Maximising the kiln loading by reducing the air to product ratio will reduce energy consumption per tonne of product.

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
R: Adopt available lowest carbon process (BAT, new kilns)	3	11.0%	1A&C	11.0%	0.0%	0.0%	9	10.0%	50.0%	Kiln technology is continuously developing to reduce energy costs. Applying the highest performance kilns would reduce fuel consumption.
R: Low mass insulation/ refractory	3	20.0%	2	20.0%	0.0%	0.0%	5-6	0.0%	20.0%	Refractories for extreme temperatures are being developed and improved. Application of the new materials as they become available would minimise energy use in high temperature kilns.
R: Oxy-fuel firing/ oxygen enrichment	3	12.5%	2	12.5%	0.0%	0.0%	7-8	7.0%	70.0%	Extreme temperature firing benefits from the higher flame temperature and reduced exhaust gas losses resulting from oxygen enriched or Oxy-fuel combustion. Wider application of oxygen enrichment would reduce energy consumption.
R: Pulse firing of kilns	3	6.5%	1A	6.5%	0.0%	20.0%	9	10.0%	50.0%	Maintaining conditions for soak periods requires reduced burner heat input. Pulse firing rather than continuous firing reduces the gas flow through the kiln and hence heat losses.
R: Re-use heat regeneratively	3	20.0%	1A&C	20.0%	0.0%	0.0%	7-8	18.0%	60.0%	Preheat of combustion air to high temperatures by heat exchange with flue gases would

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL [4]	Adoption %	Applicability %	Longer description
										reduce fuel consumption but require suitable heat exchangers.
T: Adopt available lowest carbon process (BAT, new kilns)	4	15.0%	1A&C	0.0%	0.0%	0.0%	9	10.0%	100.0%	Tunnel kilns offer a substantial reduction in energy use when fully utilised. Maximising their application would reduce energy consumption.
T: Extreme condition refractory	4	50.0%	2	50.0%	0.0%	0.0%	5-6	0.0%	10.0%	Refractories for extreme temperatures are being developed and improved. Application of the new materials as they become available would minimise energy use in high temperature kilns.
T: Improve emissions abatement	4	10.0%	2	10.0%	0.0%	-5.0%	7-8	0.0%	15.0%	Some processes on particular materials have high emissions requiring energy intensive clean-up processes. Adopting lower energy alternatives will reduce energy use.
T: Low mass kiln furniture	4	20.0%	2	20.0%	0.0%	0.0%	5-6	21.0%	70.0%	The heat load represented by continuously heating the cold kiln furniture as it travels through the kiln would be reduced by the use of low mass refractory.
T: Reduce number of firings	4	15.0%	1A	15.0%	0.0%	5.0%	7-8	0.0%	10.0%	Reducing the number of firings will significantly reduce the specific energy consumption

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
T: Re-use heat regeneratively	4	10.0%	1C	10.0%	0.0%	0.0%	7-8	12.0%	80.0%	Preheat of combustion air by heat exchange with flue gases would reduce fuel consumption but require suitable heat exchangers.
W: Adopt available lowest carbon process (BAT, new kilns)	5	30.0%	1A&C	30.0%	0.0%	0.0%	9	15.0%	50.0%	Tunnel kilns offer a substantial reduction in energy use when fully utilised. Maximising their application would reduce energy consumption.
W: Improve heat capture	5	6.5%	1C	6.5%	0.0%	-2.0%	7-8	0.0%	70.0%	Recovery of waste heat from flue gases or from cooling ware can be used to reduce energy consumption for drying.
W: Improve heat use	5	2.0%	1C	2.0%	0.0%	0.0%	7-8	5.0%	50.0%	Heat recovery from the kiln room environment for use elesewhere, e.g. for space heating.
W: Increase pack density	5	30.0%	1B	30.0%	0.0%	30.0%	7-8	0.0%	30.0%	Increasing pack density will allow better utilisation of the kiln so that specific energy consumption is reduced
W: Low mass refractory on kiln cars	5	5.0%	2	5.0%	0.0%	0.0%	7-8	20.0%	50.0%	The heat load represented by continuously heating the cold kiln car refractory as it travels through the kiln would be reduced by the use of low mass refractory.

Options	Sub sector / product	CO2 savings %	Source	Natural gas energy use %	Biomass energy use %	Electricity use %	TRL[4]	Adoption %	Applicability %	Longer description
W: Optimisation of kiln circulation	5	5.0%	1A	5.0%	0.0%	0.0%	7-8	5.0%	50.0%	Improved management of the air flows within a kiln would reduce temperatures and hence heat losses.
W: Reduce number of firings	5	17.0%	1A	17.0%	0.0%	5.0%	5-6	0.0%	30.0%	Reducing the number of firings will significantly reduce the specific energy consumption
W: Reduce product weight	5	10.0%	1C	10.0%	0.0%	10.0%	7-8	0.0%	40.0%	Lower product weight will reduce the heating requirement of each firing
W: Reduce temperature of process	5	5.5%	1A	5.5%	0.0%	0.0%	5-6	21.0%	30.0%	Optimisation of body and glaze materials within the product quality parameters would allow firing temperatures to be reduced.
W: Re-use heat regeneratively	5	7.5%	1C	7.5%	0.0%	0.0%	7-8	16.0%	40.0%	Preheat of combustion air by heat exchange with flue gases would reduce fuel consumption but require suitable heat exchangers.

Table 14: Option register sector applicability and fuel use

Options	Cost attributable to CO_2 reduction	Capex per site £m	Source	Number of applicable sites	Life of option, years
All: Apply VSD to variable duty pumps/ fans	100%	0.1	2	138	20
All: Electric Kiln and Dryer	50%	20	2	68	40
All: Improve combustion efficiency	100%	0.2	2	138	20
All: Improve control of process	100%	0.25	2	138	20
All: ORC on heat recovery	100%	0.25	2	68	20
All: Reduce radiant, convective and hot gas losses and leakage	100%	5	2	138	20
B: Add biomass to clay	100%	0	2		20
B: Adopt available lowest carbon process (BAT, new kilns)	50%	20	2	68	40
B: Avoid firing yellow bricks	100%	0	2		20
B: CC from exhaust gases	100%	10	2	68	20
B: CHP heat into dryer	100%	2	2	68	20
B: Gasification of biomass	100%	15	2	68	40

Options	Cost attributable to CO_2 reduction	Capex per site £m	Source	Number of applicable sites	Life of option, years
B: Improve heat use by regenerative processes	100%	2.5	2	68	20
B: Lighter bricks to reduce firing energy	100%	0.5	2	68	40
B: Low mass refractory for kiln cars	100%	1.75	2	68	40
B: Pre-calcining of clay	100%	5	2	68	40
B: Preheat water added for forming	100%	0.1	2	68	40
B: Reduce air/product mass ratio	100%	0.1	2	68	40
R: Adopt available lowest carbon process (BAT, new kilns)	50%	1	2	16	40
R: Low mass insulation/ refractory	100%	0.2	2	16	40
R: Oxy-fuel firing/ oxygen enrichment	100%	0.1	2	16	40
R: Pulse firing of kilns	100%	0.1	2	16	20
R: Re-use heat regeneratively	100%	0.02	2	16	20
T: Adopt available lowest carbon process (BAT, new kilns)	50%	3	2	23	40

Options	Cost attributable to CO_2 reduction	Capex per site £m	Source	Number of applicable sites	Life of option, years
T: Extreme condition refractory	100%	0.5	2	23	20
T: Improve emissions abatement	100%	0.5	2	23	20
T: Low mass kiln furniture	100%	0.1	2	23	40
T: Reduce number of firings	100%	0	2	23	40
T: Re-use heat regeneratively	100%	0.2	2	23	20
W: Adopt available lowest carbon process (BAT, new kilns)	50%	2	2	31	40
W: Improve heat capture	100%	0.1	2	31	20
W: Improve heat use	100%	0.1	2	31	20
W: Increase pack density	100%	0	2	31	40
W: Low mass refractory on kiln cars	100%	1	2	31	40
W: Optimisation of kiln circulation	100%	0.1	2	31	20
W: Reduce number of firings	100%	0	2	31	40

Options	Cost attributable to CO_2 reduction	Capex per site £m	Source	Number of applicable sites	Life of option, years
W: Reduce product weight	100%	0	2	31	40
W: Reduce temperature of process	100%	0	2	31	40
W: Re-use heat regeneratively	100%	0.1	2	31	20

Table 15: Option register cost information

Note on capital cost information

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.

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APPENDIX D – ADDITIONAL PATHWAYS ANALYSIS

APPENDIX D ADDITIONAL PATHWAYS ANALYSIS

1. Pathways under Challenging World Scenario

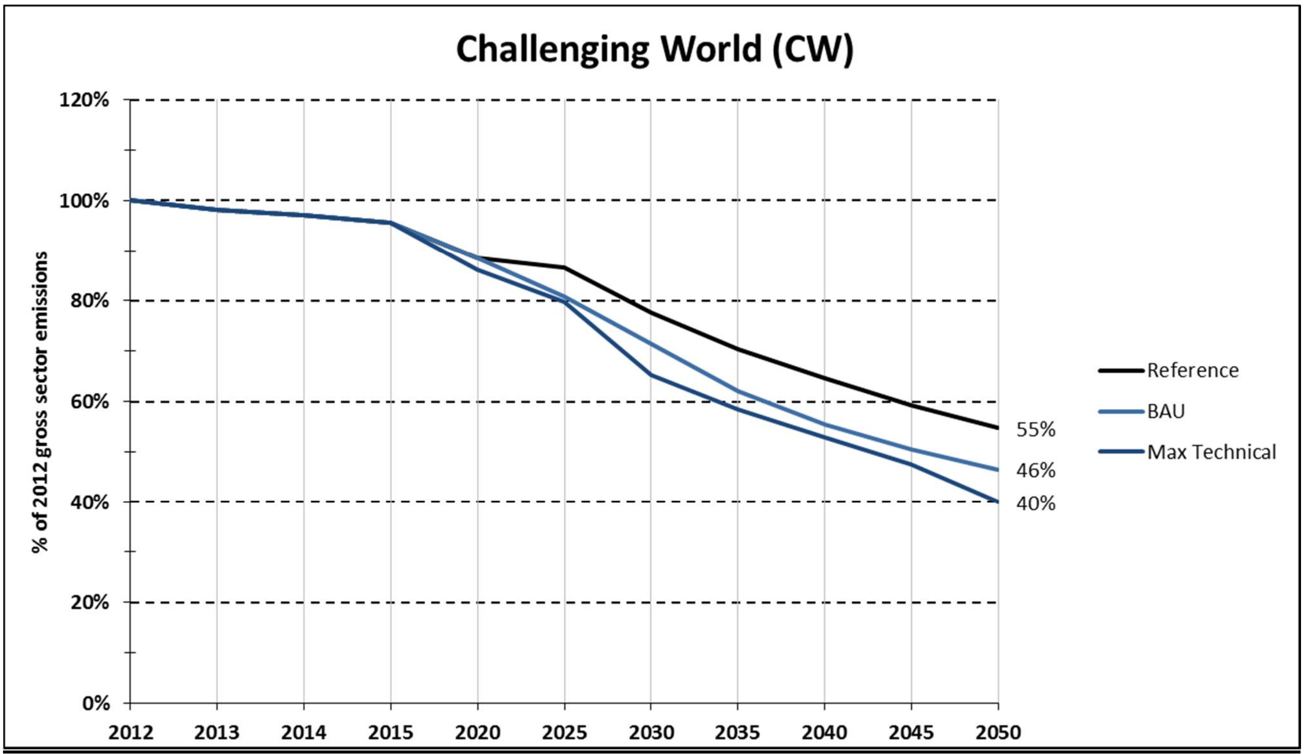

Figure 4: Comparison of pathways, challenging world scenario

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
All: Apply VSD to variable duty pumps/ fans	incremental	11%	15%	0%	0%	0%	25%	50%	50%	50%	50%	50%
All: Electric Kiln	major	5%	60%	0%	0%	0%	0%	0%	0%	0%	0%	0%
All: Improve combustion efficiency	incremental	68%	85%	0%	0%	0%	25%	25%	25%	50%	50%	50%
All: Improve control of process	incremental	65%	100%	0%	0%	0%	25%	25%	25%	25%	50%	50%
All: Organic Rankine Cycle (ORC) on heat recovery	major	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
All: Reduce radiant, convective and hot gas losses and	incremental	36%	90%	0%	0%	0%	25%	25%	50%	50%	50%	50%
B: Add biomass to clay	incremental	0%	20%	0%	0%	0%	0%	0%	0%	25%	25%	25%
B: Adopt available lowest carbon process (BAT, new kilns)	major	6%	70%	0%	0%	0%	0%	0%	25%	25%	25%	25%
B: Avoid firing yellow bricks	major	0%	5%	0%	0%	0%	0%	0%	25%	25%	50%	50%
B: Carbon capture from exhaust gases	disruptive	0%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: CHP heat into dryer	major	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: Gasification of biomass	disruptive	0%	35%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: Improve heat use by regenerative processes	incremental	60%	100%	0%	0%	0%	25%	25%	25%	25%	25%	25%
B: Lighter bricks to reduce firing energy	major	23%	30%	0%	0%	0%	0%	0%	25%	25%	50%	50%
B: Low mass refractory for kiln cars	incremental	27%	90%	0%	0%	0%	25%	25%	25%	25%	25%	25%
B: Pre-calcining of clay	major	2%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: Preheat water added for forming	incremental	0%	40%	0%	0%	0%	25%	25%	50%	50%	50%	50%
B: Reduce air/product mass ratio	incremental	20%	50%	0%	0%	0%	0%	25%	25%	25%	25%	25%
R: Adopt available lowest carbon process (BAT, new kilns)	major	10%	50%	0%	0%	0%	25%	25%	25%	50%	50%	50%
R: Low mass insulation/ refractory	major	0%	20%	0%	0%	0%	25%	25%	25%	50%	50%	50%
R: Oxy-fuel firing/ oxygen enrichment	major	7%	70%	0%	0%	0%	25%	25%	25%	50%	50%	50%
R: Pulse firing of kilns	incremental	10%	50%	0%	0%	0%	25%	50%	50%	50%	50%	50%
R: Re-use heat regeneratively	major	18%	60%	0%	0%	0%	25%	25%	25%	50%	50%	50%
T: Adopt available lowest carbon process (BAT, new kilns)	major	10%	100%	0%	0%	0%	25%	25%	25%	50%	50%	50%
T: Extreme condition refractory	major	0%	10%	0%	0%	0%	25%	25%	25%	50%	50%	50%
T: Improve emissions abatement	major	0%	15%	0%	0%	0%	0%	25%	25%	50%	50%	50%
T: Low mass kiln furniture	incremental	21%	70%	0%	0%	0%	0%	25%	25%	50%	50%	50%
T: Reduce number of firings	incremental	0%	10%	0%	0%	0%	0%	25%	25%	50%	50%	50%
T: Re-use heat regeneratively	incremental	12%	80%	0%	0%	0%	0%	25%	25%	50%	50%	50%
W: Adopt available lowest carbon process (BAT, new kilns)	major	15%	50%	0%	0%	0%	25%	25%	25%	50%	50%	50%
W: Improve heat capture	major	0%	70%	0%	0%	0%	25%	25%	25%	50%	50%	50%
W: Improve heat use	incremental	5%	50%	0%	0%	0%	25%	25%	25%	50%	50%	50%
W: Increase pack density	incremental	0%	30%	0%	0%	0%	25%	50%	50%	50%	50%	50%
W: Low mass refractory on kiln cars	incremental	20%	50%	0%	0%	0%	25%	25%	25%	50%	50%	50%
W: Optimisation of kiln circulation	incremental	5%	50%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Reduce number of firings	major	0%	30%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Reduce product weight	incremental	0%	40%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Reduce temperature of process	major	21%	30%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Re-use heat regeneratively	major	16%	40%	0%	0%	0%	25%	25%	25%	50%	50%	50%

Figure 5: BAU pathway deployment, challenging world scenario

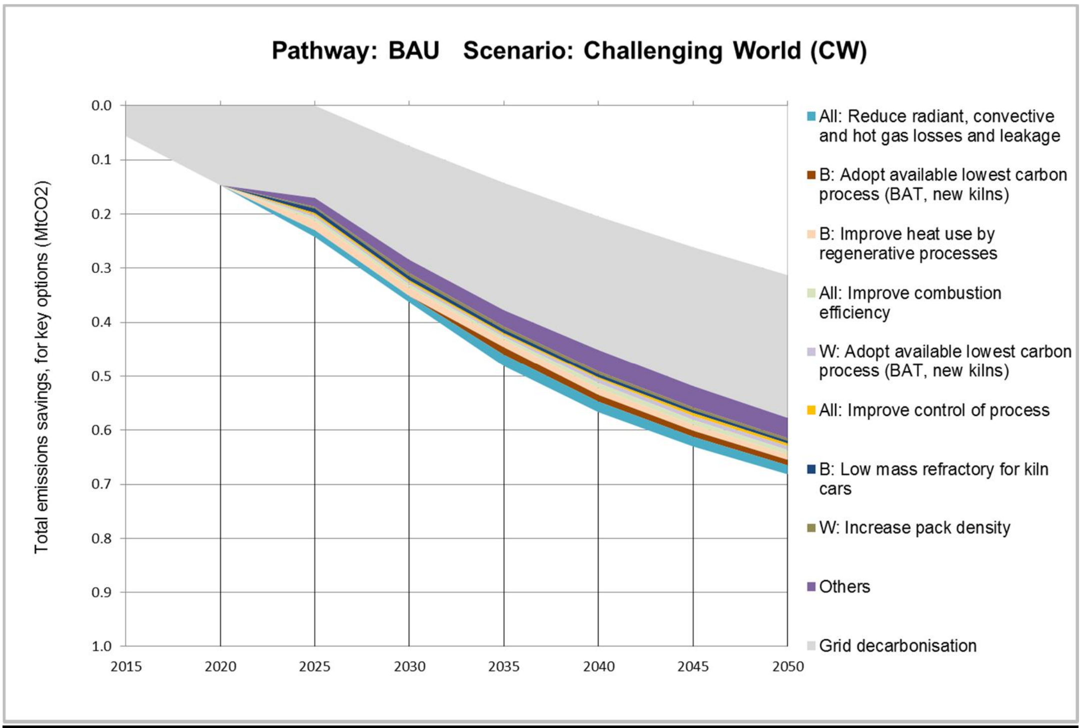

Figure 6: BAU pathway decarbonisation profile, challenging world scenario

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
All: Apply VSD to variable duty pumps/ fans	incremental	11%	15%	0%	0%	25%	50%	50%	50%	25%	25%	25%
All: Electric Kiln	major	5%	60%	0%	0%	0%	0%	0%	0%	0%	25%	25%
All: Improve combustion efficiency	incremental	68%	85%	0%	0%	0%	25%	50%	50%	50%	25%	25%
All: Improve control of process	incremental	65%	100%	0%	0%	25%	25%	50%	50%	25%	25%	25%
All: Organic Rankine Cycle (ORC) on heat recovery	major	0%	25%	0%	0%	0%	0%	25%	25%	25%	25%	25%
All: Reduce radiant, convective and hot gas losses and	incremental	36%	90%	0%	0%	0%	25%	50%	50%	25%	25%	25%
B: Add biomass to clay	incremental	0%	20%	0%	0%	0%	25%	50%	50%	75%	75%	75%
B: Adopt available lowest carbon process (BAT, new kilns)	major	6%	70%	0%	0%	0%	0%	25%	25%	50%	50%	75%
B: Avoid firing yellow bricks	major	0%	5%	0%	0%	0%	25%	50%	50%	75%	75%	75%
B: Carbon capture from exhaust gases	disruptive	0%	40%	0%	0%	0%	0%	0%	0%	25%	50%	100%
B: CHP heat into dryer	major	0%	25%	0%	0%	0%	25%	50%	50%	25%	25%	25%
B: Gasification of biomass	disruptive	0%	35%	0%	0%	0%	0%	0%	0%	25%	50%	100%
B: Improve heat use by regenerative processes	incremental	60%	100%	0%	0%	0%	25%	50%	50%	25%	25%	25%
B: Lighter bricks to reduce firing energy	major	23%	30%	0%	0%	0%	0%	25%	25%	50%	50%	75%
B: Low mass refractory for kiln cars	incremental	27%	90%	0%	0%	25%	25%	50%	50%	25%	25%	25%
B: Pre-calcining of clay	major	2%	100%	0%	0%	0%	25%	25%	25%	50%	50%	50%
B: Preheat water added for forming	incremental	0%	40%	0%	0%	0%	25%	50%	50%	50%	75%	75%
B: Reduce air/product mass ratio	incremental	20%	50%	0%	0%	25%	25%	50%	50%	50%	75%	75%
R: Adopt available lowest carbon process (BAT, new kilns)	major	10%	50%	0%	0%	0%	0%	25%	50%	50%	75%	100%
R: Low mass insulation/ refractory	major	0%	20%	0%	0%	25%	25%	50%	50%	25%	25%	25%
R: Oxy-fuel firing/ oxygen enrichment	major	7%	70%	0%	0%	0%	25%	25%	50%	50%	50%	50%
R: Pulse firing of kilns	incremental	10%	50%	0%	0%	25%	25%	50%	50%	25%	25%	25%
R: Re-use heat regeneratively	major	18%	60%	0%	0%	0%	25%	50%	50%	25%	25%	25%
T: Adopt available lowest carbon process (BAT, new kilns)	major	10%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
T: Extreme condition refractory	major	0%	10%	0%	0%	0%	25%	50%	50%	25%	25%	25%
T: Improve emissions abatement	major	0%	15%	0%	0%	0%	25%	25%	50%	50%	50%	75%
T: Low mass kiln furniture	incremental	21%	70%	0%	0%	25%	25%	50%	50%	25%	25%	25%
T: Reduce number of firings	incremental	0%	10%	0%	0%	0%	25%	50%	50%	50%	75%	75%
T: Re-use heat regeneratively	incremental	12%	80%	0%	0%	0%	25%	50%	50%	25%	25%	25%
W: Adopt available lowest carbon process (BAT, new kilns)	major	15%	50%	0%	0%	0%	25%	25%	50%	50%	75%	100%
W: Improve heat capture	major	0%	70%	0%	0%	0%	25%	50%	50%	25%	25%	25%
W: Improve heat use	incremental	5%	50%	0%	0%	0%	25%	50%	50%	25%	25%	25%
W: Increase pack density	incremental	0%	30%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Low mass refractory on kiln cars	incremental	20%	50%	0%	0%	25%	25%	50%	50%	25%	25%	25%
W: Optimisation of kiln circulation	incremental	5%	50%	0%	0%	25%	25%	50%	50%	25%	25%	25%
W: Reduce number of firings	major	0%	30%	0%	0%	0%	25%	50%	50%	50%	75%	75%
W: Reduce product weight	incremental	0%	40%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Reduce temperature of process	major	21%	30%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Re-use heat regeneratively	major	16%	40%	0%	0%	0%	25%	50%	50%	25%	25%	25%

Figure 7: Max Tech pathway deployment, challenging world scenario

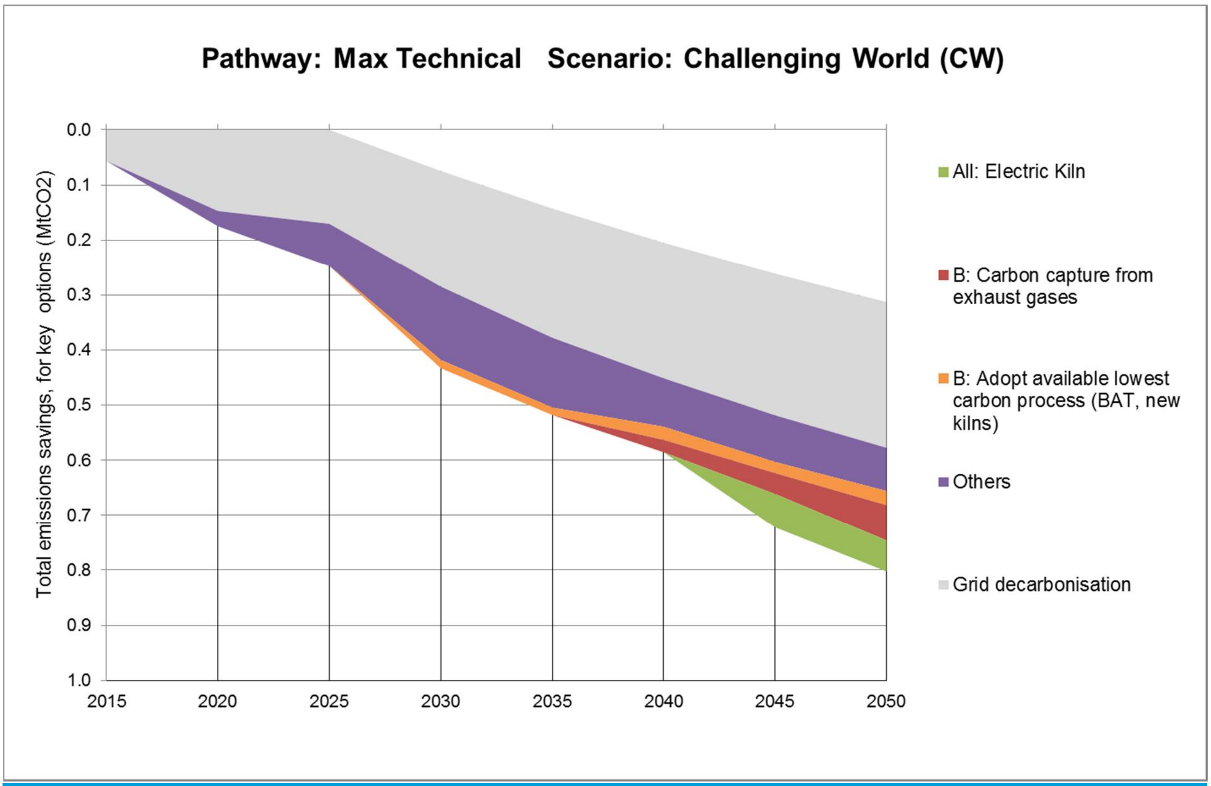

Figure 8: Max Tech pathway decarbonisation profile, challenging world scenario

2. Pathways under Collaborative Growth Scenario

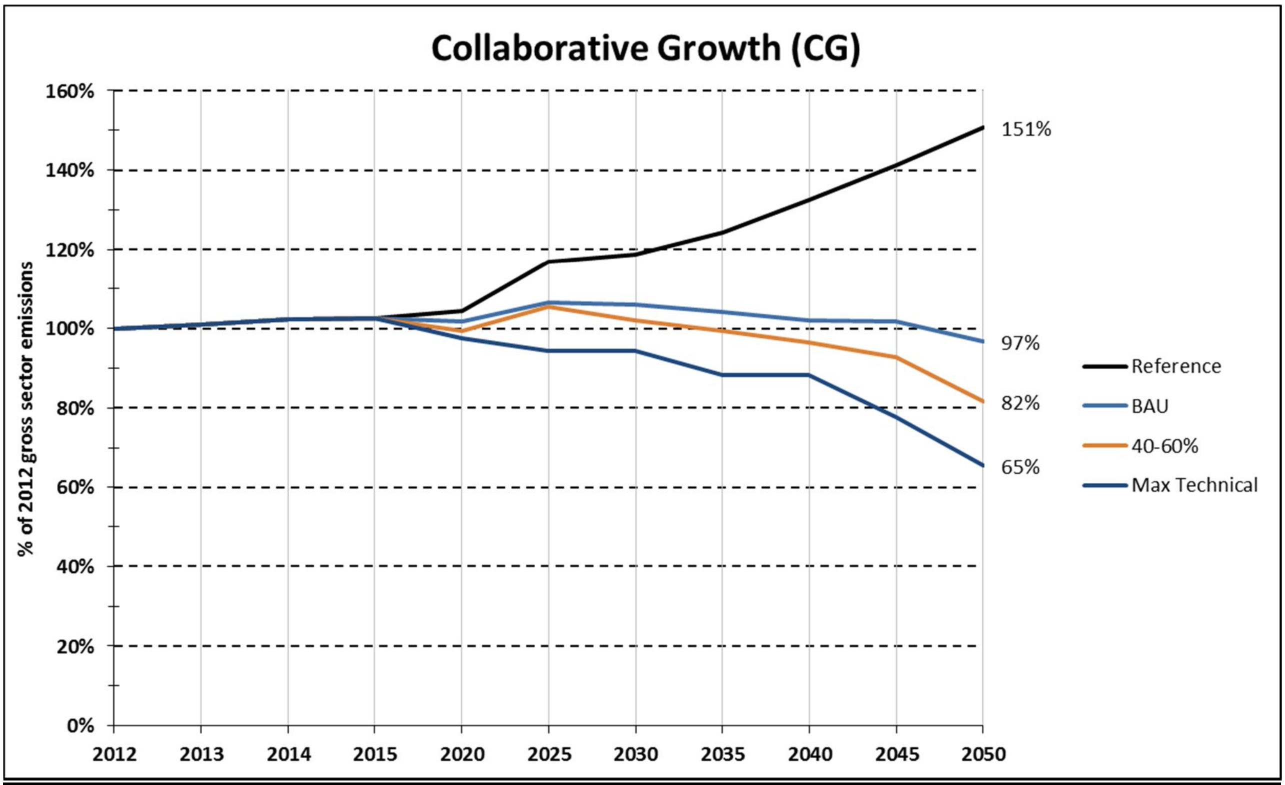

Figure 9: Comparison of pathways, collaborative growth scenario

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
All: Apply VSD to variable duty pumps/ fans	incremental	11%	15%	0%	0%	25%	25%	50%	50%	50%	50%	50%
All: Electric Kiln	major	5%	60%	0%	0%	0%	0%	0%	0%	25%	25%	50%
All: Improve combustion efficiency	incremental	68%	85%	0%	0%	0%	25%	25%	50%	50%	50%	50%
All: Improve control of process	incremental	65%	100%	0%	0%	0%	25%	25%	25%	25%	50%	50%
All: Organic Rankine Cycle (ORC) on heat recovery	major	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
All: Reduce radiant, convective and hot gas losses and	incremental	36%	90%	0%	0%	25%	25%	25%	50%	50%	50%	50%
B: Add biomass to clay	incremental	0%	20%	0%	0%	0%	0%	0%	0%	25%	25%	25%
B: Adopt available lowest carbon process (BAT, new kilns)	major	6%	70%	0%	0%	0%	25%	25%	50%	50%	50%	50%
B: Avoid firing yellow bricks	major	0%	5%	0%	0%	0%	0%	0%	25%	25%	50%	50%
B: Carbon capture from exhaust gases	disruptive	0%	40%	0%	0%	0%	0%	0%	0%	0%	25%	25%
B: CHP heat into dryer	major	0%	25%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: Gasification of biomass	disruptive	0%	35%	0%	0%	0%	0%	0%	0%	0%	25%	50%
B: Improve heat use by regenerative processes	incremental	60%	100%	0%	0%	0%	25%	25%	25%	25%	25%	25%
B: Lighter bricks to reduce firing energy	major	23%	30%	0%	0%	0%	0%	0%	25%	25%	50%	50%
B: Low mass refractory for kiln cars	incremental	27%	90%	0%	0%	0%	25%	25%	25%	25%	25%	25%
B: Pre-calcining of clay	major	2%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
B: Preheat water added for forming	incremental	0%	40%	0%	0%	25%	25%	50%	50%	50%	50%	50%
B: Reduce air/product mass ratio	incremental	20%	50%	0%	0%	0%	0%	25%	25%	25%	25%	25%
R: Adopt available lowest carbon process (BAT, new kilns)	major	10%	50%	0%	0%	0%	25%	25%	50%	50%	50%	75%
R: Low mass insulation/ refractory	major	0%	20%	0%	0%	0%	25%	25%	50%	50%	50%	25%
R: Oxy-fuel firing/ oxygen enrichment	major	7%	70%	0%	0%	25%	25%	25%	50%	50%	50%	50%
R: Pulse firing of kilns	incremental	10%	50%	0%	0%	25%	25%	50%	50%	50%	50%	50%
R: Re-use heat regeneratively	major	18%	60%	0%	0%	25%	25%	25%	50%	50%	50%	25%
T: Adopt available lowest carbon process (BAT, new kilns)	major	10%	100%	0%	0%	0%	25%	25%	50%	50%	50%	75%
T: Extreme condition refractory	major	0%	10%	0%	0%	0%	25%	25%	50%	50%	50%	25%
T: Improve emissions abatement	major	0%	15%	0%	0%	0%	0%	25%	50%	50%	50%	50%
T: Low mass kiln furniture	incremental	21%	70%	0%	0%	0%	0%	25%	50%	50%	50%	25%
T: Reduce number of firings	incremental	0%	10%	0%	0%	0%	0%	25%	50%	50%	50%	50%
T: Re-use heat regeneratively	incremental	12%	80%	0%	0%	0%	0%	25%	50%	50%	50%	25%
W: Adopt available lowest carbon process (BAT, new kilns)	major	15%	50%	0%	0%	0%	25%	25%	50%	50%	50%	75%
W: Improve heat capture	major	0%	70%	0%	0%	25%	25%	25%	50%	50%	50%	25%
W: Improve heat use	incremental	5%	50%	0%	0%	25%	25%	25%	50%	50%	50%	25%
W: Increase pack density	incremental	0%	30%	0%	0%	25%	25%	50%	50%	50%	50%	50%
W: Low mass refractory on kiln cars	incremental	20%	50%	0%	0%	25%	25%	25%	50%	50%	50%	25%
W: Optimisation of kiln circulation	incremental	5%	50%	0%	0%	25%	25%	50%	50%	50%	50%	25%
W: Reduce number of firings	major	0%	30%	0%	0%	0%	25%	50%	50%	50%	50%	50%
W: Reduce product weight	incremental	0%	40%	0%	0%	0%	25%	50%	50%	50%	50%	50%
W: Reduce temperature of process	major	21%	30%	0%	0%	25%	25%	25%	50%	50%	50%	50%
W: Re-use heat regeneratively	major	16%	40%	0%	0%	25%	25%	25%	50%	50%	50%	25%

Figure 10: BAU pathway deployment, collaborative growth scenario

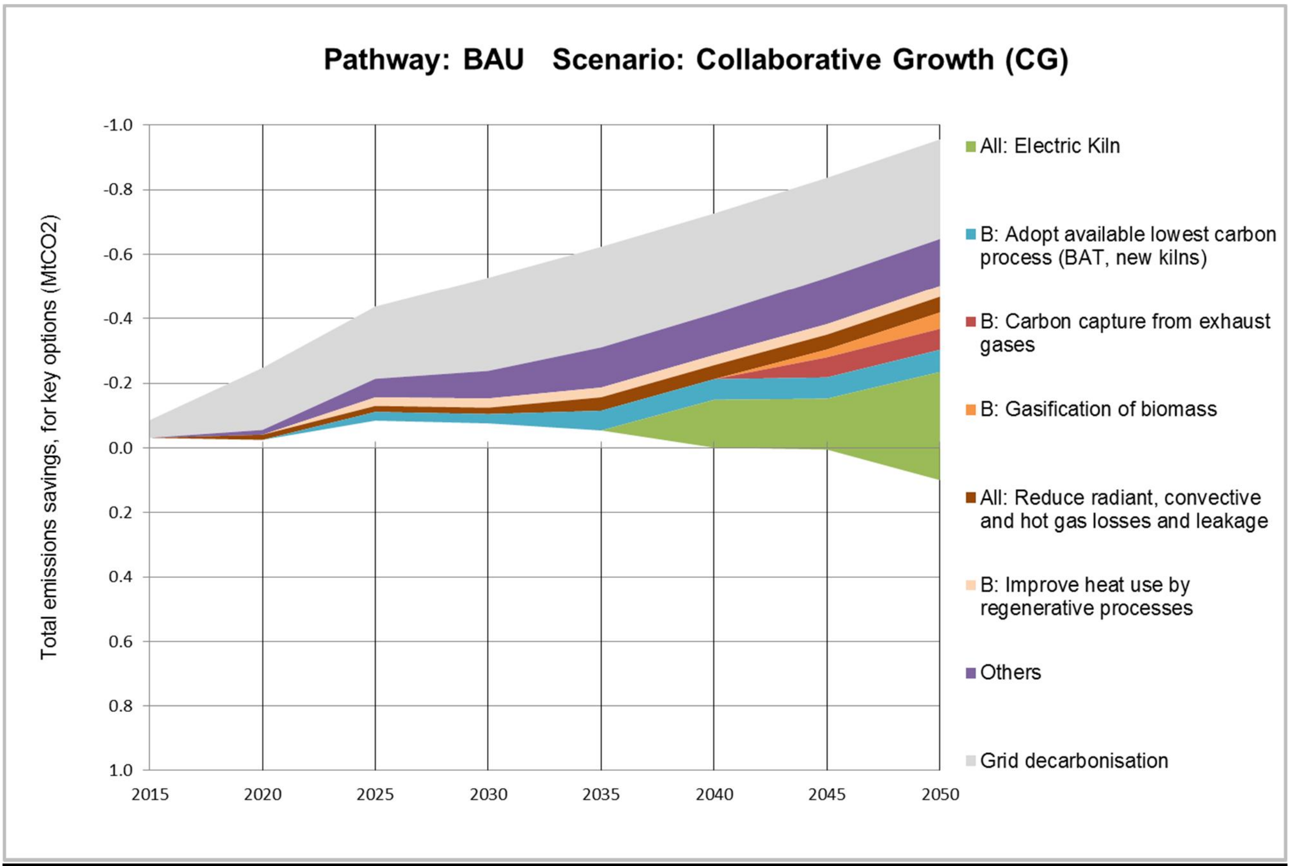

Figure 11: BAU pathway decarbonisation profile, collaborative growth scenario

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
All: Apply VSD to variable duty pumps/ fans	incremental	11%	15%	0%	0%	25%	25%	50%	50%	25%	25%	25%
All: Electric Kiln	major	5%	60%	0%	0%	0%	0%	0%	0%	25%	50%	75%
All: Improve combustion efficiency	incremental	68%	85%	0%	0%	25%	25%	50%	50%	25%	25%	25%
All: Improve control of process	incremental	65%	100%	0%	0%	25%	25%	50%	50%	25%	25%	25%
All: Organic Rankine Cycle (ORC) on heat recovery	major	0%	25%	0%	0%	0%	0%	0%	25%	25%	25%	25%
All: Reduce radiant, convective and hot gas losses and	incremental	36%	90%	0%	0%	25%	25%	25%	50%	25%	25%	25%
B: Add biomass to clay	incremental	0%	20%	0%	0%	0%	25%	25%	50%	50%	75%	75%
B: Adopt available lowest carbon process (BAT, new kilns)	major	6%	70%	0%	0%	0%	25%	25%	50%	75%	50%	50%
B: Avoid firing yellow bricks	major	0%	5%	0%	0%	0%	25%	25%	50%	50%	75%	75%
B: Carbon capture from exhaust gases	disruptive	0%	40%	0%	0%	0%	0%	0%	0%	25%	25%	50%
B: CHP heat into dryer	major	0%	25%	0%	0%	0%	0%	25%	25%	25%	25%	25%
B: Gasification of biomass	disruptive	0%	35%	0%	0%	0%	0%	0%	0%	25%	25%	50%
B: Improve heat use by regenerative processes	incremental	60%	100%	0%	0%	0%	25%	25%	50%	25%	25%	25%
B: Lighter bricks to reduce firing energy	major	23%	30%	0%	0%	0%	0%	25%	25%	50%	50%	75%
B: Low mass refractory for kiln cars	incremental	27%	90%	0%	0%	25%	25%	50%	50%	25%	25%	25%
B: Pre-calcining of clay	major	2%	100%	0%	0%	0%	0%	25%	25%	25%	50%	50%
B: Preheat water added for forming	incremental	0%	40%	0%	0%	25%	25%	50%	50%	50%	75%	75%
B: Reduce air/product mass ratio	incremental	20%	50%	0%	0%	25%	25%	50%	50%	25%	25%	25%
R: Adopt available lowest carbon process (BAT, new kilns)	major	10%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
R: Low mass insulation/ refractory	major	0%	20%	0%	0%	25%	25%	50%	50%	25%	25%	25%
R: Oxy-fuel firing/ oxygen enrichment	major	7%	70%	0%	0%	25%	25%	25%	50%	50%	50%	50%
R: Pulse firing of kilns	incremental	10%	50%	0%	0%	25%	25%	25%	50%	25%	25%	25%
R: Re-use heat regeneratively	major	18%	60%	0%	0%	0%	25%	25%	50%	25%	25%	25%
T: Adopt available lowest carbon process (BAT, new kilns)	major	10%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
T: Extreme condition refractory	major	0%	10%	0%	0%	25%	25%	50%	50%	25%	25%	25%
T: Improve emissions abatement	major	0%	15%	0%	0%	0%	25%	25%	50%	50%	50%	75%
T: Low mass kiln furniture	incremental	21%	70%	0%	0%	25%	25%	50%	50%	25%	25%	25%
T: Reduce number of firings	incremental	0%	10%	0%	0%	0%	25%	50%	50%	50%	75%	75%
T: Re-use heat regeneratively	incremental	12%	80%	0%	0%	0%	25%	25%	50%	25%	25%	25%
W: Adopt available lowest carbon process (BAT, new kilns)	major	15%	50%	0%	0%	0%	25%	25%	50%	50%	75%	75%
W: Improve heat capture	major	0%	70%	0%	0%	0%	25%	25%	50%	25%	25%	25%
W: Improve heat use	incremental	5%	50%	0%	0%	0%	25%	25%	50%	25%	25%	25%
W: Increase pack density	incremental	0%	30%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Low mass refractory on kiln cars	incremental	20%	50%	0%	0%	25%	25%	50%	50%	25%	25%	25%
W: Optimisation of kiln circulation	incremental	5%	50%	0%	0%	25%	50%	50%	50%	25%	25%	25%
W: Reduce number of firings	major	0%	30%	0%	0%	0%	25%	50%	50%	50%	75%	75%
W: Reduce product weight	incremental	0%	40%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Reduce temperature of process	major	21%	30%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Re-use heat regeneratively	major	16%	40%	0%	0%	0%	25%	25%	50%	25%	25%	25%

Figure 12: 40-60% CO_2 reduction pathway deployment, collaborative growth scenario

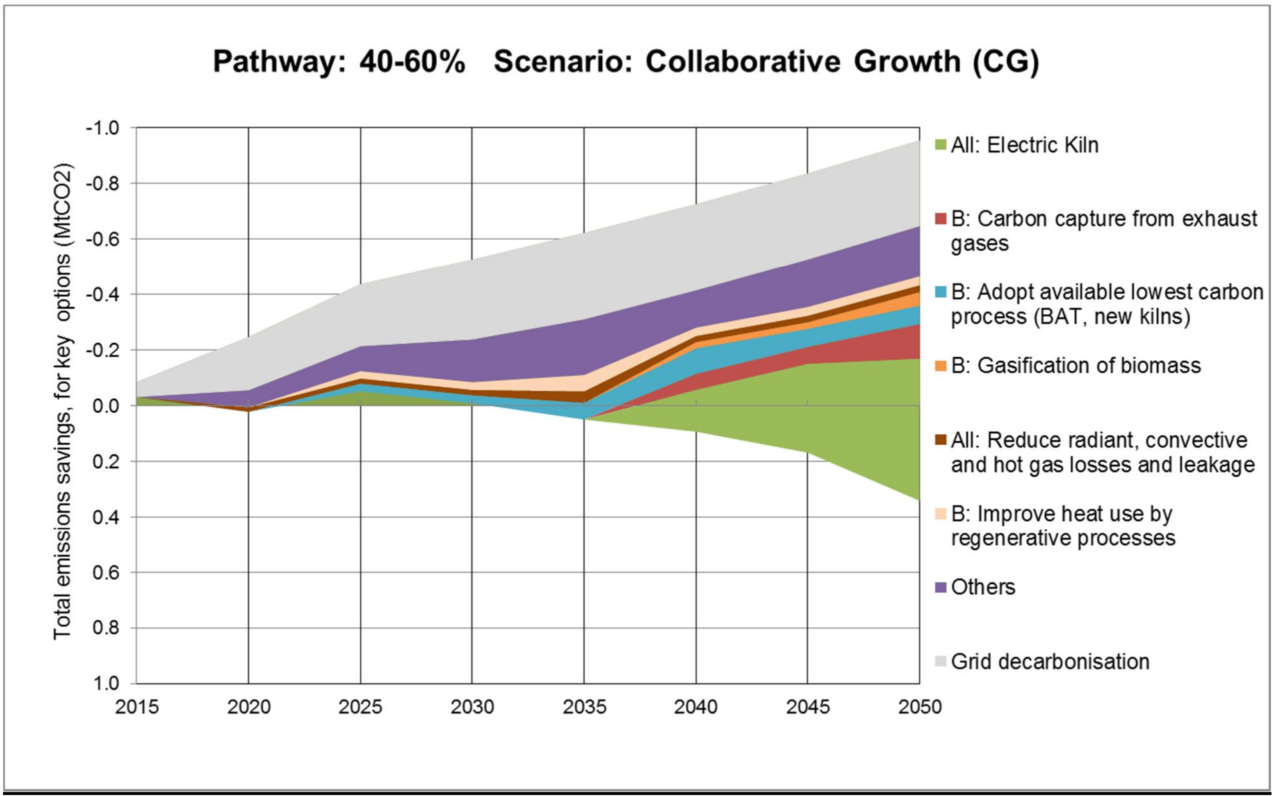

Figure 12: 40-60% CO_2 reduction pathway decarbonisation profile, collaborative growth scenario

OPTION	Category	ADOP.	APP.	DEPLOYMENT 2014	2015	2020	2025	2030	2035	2040	2045	2050
All: Apply VSD to variable duty pumps/ fans	incremental	11%	15%	0%	0%	25%	50%	50%	25%	0%	0%	0%
All: Electric Kiln	major	5%	60%	0%	0%	0%	0%	0%	25%	50%	75%	100%
All: Improve combustion efficiency	incremental	68%	85%	0%	0%	25%	50%	25%	25%	0%	0%	0%
All: Improve control of process	incremental	65%	100%	0%	0%	25%	50%	50%	25%	0%	0%	0%
All: Organic Rankine Cycle (ORC) on heat recovery	major	0%	25%	0%	0%	0%	0%	25%	25%	25%	25%	25%
All: Reduce radiant, convective and hot gas losses and	incremental	36%	90%	0%	0%	25%	50%	50%	25%	0%	0%	0%
B: Add biomass to clay	incremental	0%	20%	0%	0%	0%	25%	50%	50%	75%	75%	75%
B: Adopt available lowest carbon process (BAT, new kilns)	major	6%	70%	0%	0%	0%	25%	50%	50%	50%	25%	25%
B: Avoid firing yellow bricks	major	0%	5%	0%	0%	0%	25%	50%	50%	75%	75%	75%
B: Carbon capture from exhaust gases	disruptive	0%	40%	0%	0%	0%	25%	25%	50%	50%	75%	100%
B: CHP heat into dryer	major	0%	25%	0%	0%	25%	25%	50%	25%	25%	0%	0%
B: Gasification of biomass	disruptive	0%	35%	0%	0%	0%	0%	25%	25%	50%	75%	100%
B: Improve heat use by regenerative processes	incremental	60%	100%	0%	0%	25%	50%	25%	25%	0%	0%	0%
B: Lighter bricks to reduce firing energy	major	23%	30%	0%	0%	0%	25%	25%	25%	50%	50%	75%
B: Low mass refractory for kiln cars	incremental	27%	90%	0%	0%	25%	50%	50%	25%	0%	0%	0%
B: Pre-calcining of clay	major	2%	100%	0%	0%	0%	25%	25%	25%	50%	50%	50%
B: Preheat water added for forming	incremental	0%	40%	0%	0%	25%	50%	50%	50%	50%	75%	75%
B: Reduce air/product mass ratio	incremental	20%	50%	0%	0%	25%	50%	50%	50%	50%	75%	75%
R: Adopt available lowest carbon process (BAT, new kilns)	major	10%	50%	0%	0%	0%	25%	50%	50%	75%	75%	100%
R: Low mass insulation/ refractory	major	0%	20%	0%	0%	25%	50%	50%	25%	0%	0%	0%
R: Oxy-fuel firing/ oxygen enrichment	major	7%	70%	0%	0%	25%	25%	50%	50%	50%	50%	50%
R: Pulse firing of kilns	incremental	10%	50%	0%	0%	25%	50%	50%	25%	0%	0%	0%
R: Re-use heat regeneratively	major	18%	60%	0%	0%	25%	50%	25%	25%	0%	0%	0%
T: Adopt available lowest carbon process (BAT, new kilns)	major	10%	100%	0%	0%	0%	0%	0%	25%	25%	50%	50%
T: Extreme condition refractory	major	0%	10%	0%	0%	25%	50%	25%	25%	0%	0%	0%
T: Improve emissions abatement	major	0%	15%	0%	0%	0%	25%	25%	50%	50%	50%	75%
T: Low mass kiln furniture	incremental	21%	70%	0%	0%	25%	50%	50%	25%	0%	0%	0%
T: Reduce number of firings	incremental	0%	10%	0%	0%	0%	25%	50%	50%	50%	75%	75%
T: Re-use heat regeneratively	incremental	12%	80%	0%	0%	25%	50%	25%	25%	0%	0%	0%
W: Adopt available lowest carbon process (BAT, new kilns)	major	15%	50%	0%	0%	0%	25%	25%	50%	50%	75%	100%
W: Improve heat capture	major	0%	70%	0%	0%	25%	50%	25%	25%	0%	0%	0%
W: Improve heat use	incremental	5%	50%	0%	0%	25%	50%	25%	25%	0%	0%	0%
W: Increase pack density	incremental	0%	30%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Low mass refractory on kiln cars	incremental	20%	50%	0%	0%	25%	50%	25%	25%	0%	0%	0%
W: Optimisation of kiln circulation	incremental	5%	50%	0%	0%	25%	50%	25%	25%	0%	0%	0%
W: Reduce number of firings	major	0%	30%	0%	0%	0%	25%	50%	50%	50%	75%	75%
W: Reduce product weight	incremental	0%	40%	0%	0%	25%	25%	50%	50%	50%	75%	75%
W: Reduce temperature of process	major	21%	30%	0%	0%	0%	25%	25%	50%	50%	50%	50%
W: Re-use heat regeneratively	major	16%	40%	0%	0%	25%	50%	25%	25%	0%	0%	0%

Figure 13: Max Tech pathway deployment, collaborative growth scenario

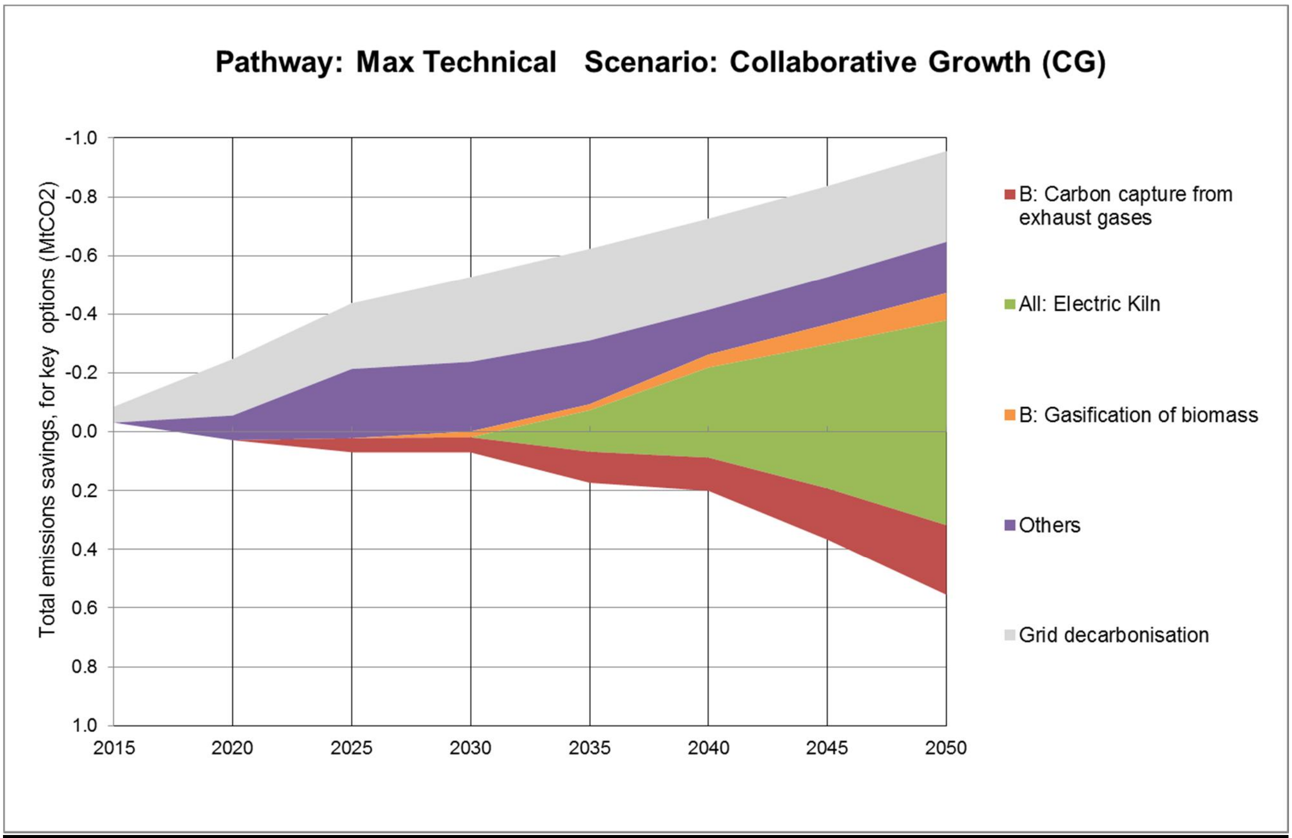

Figure 14: Max Tech pathway decarbonisation profile, collaborative growth scenario

3. Sensitivity Analysis

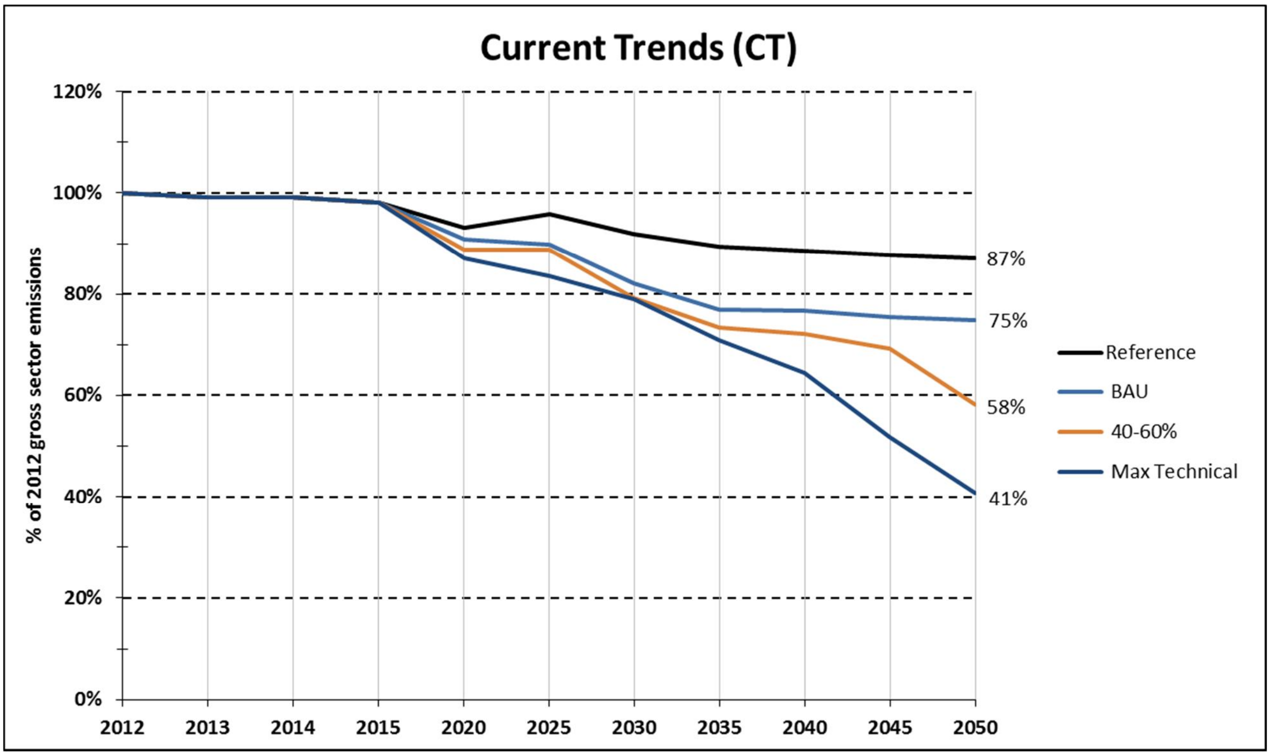

Figure15: BAT kiln sensitivity; deployment in all subsectors deferred to 2030

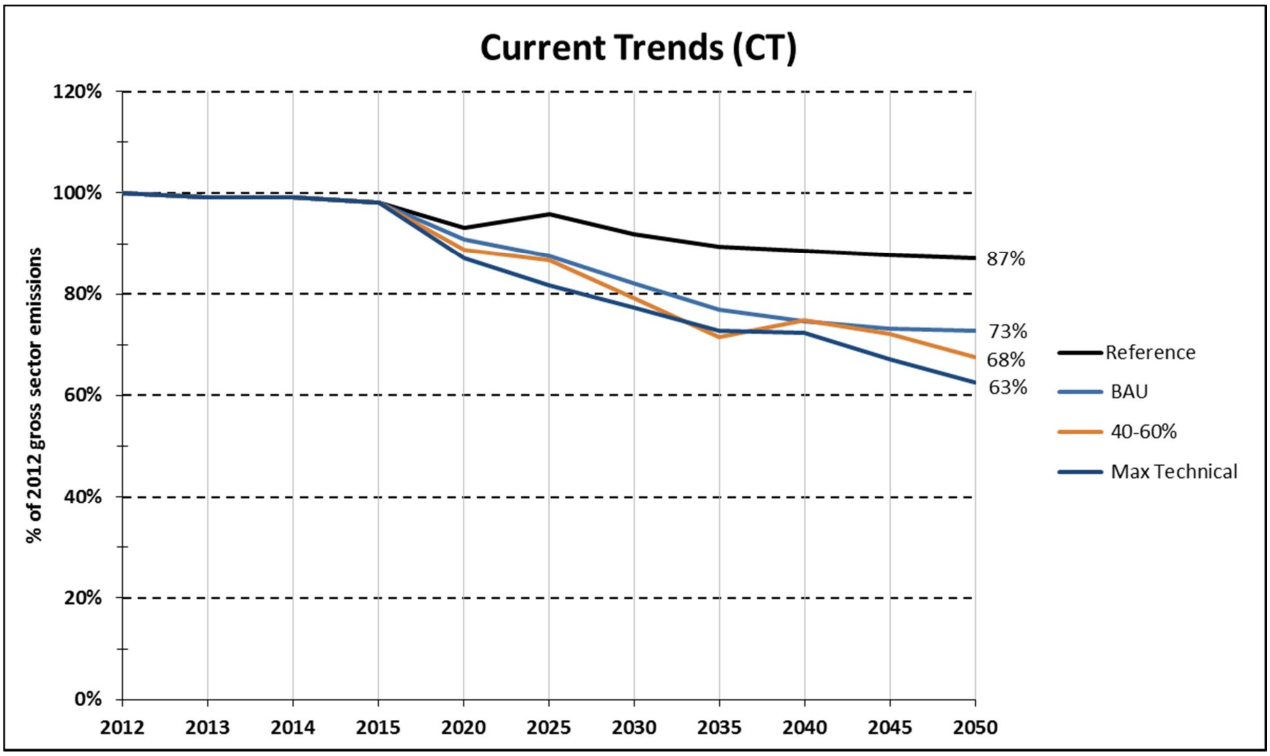

Figure16: Electric kiln sensitivity; no electric kilns and driers deployed in any subsector

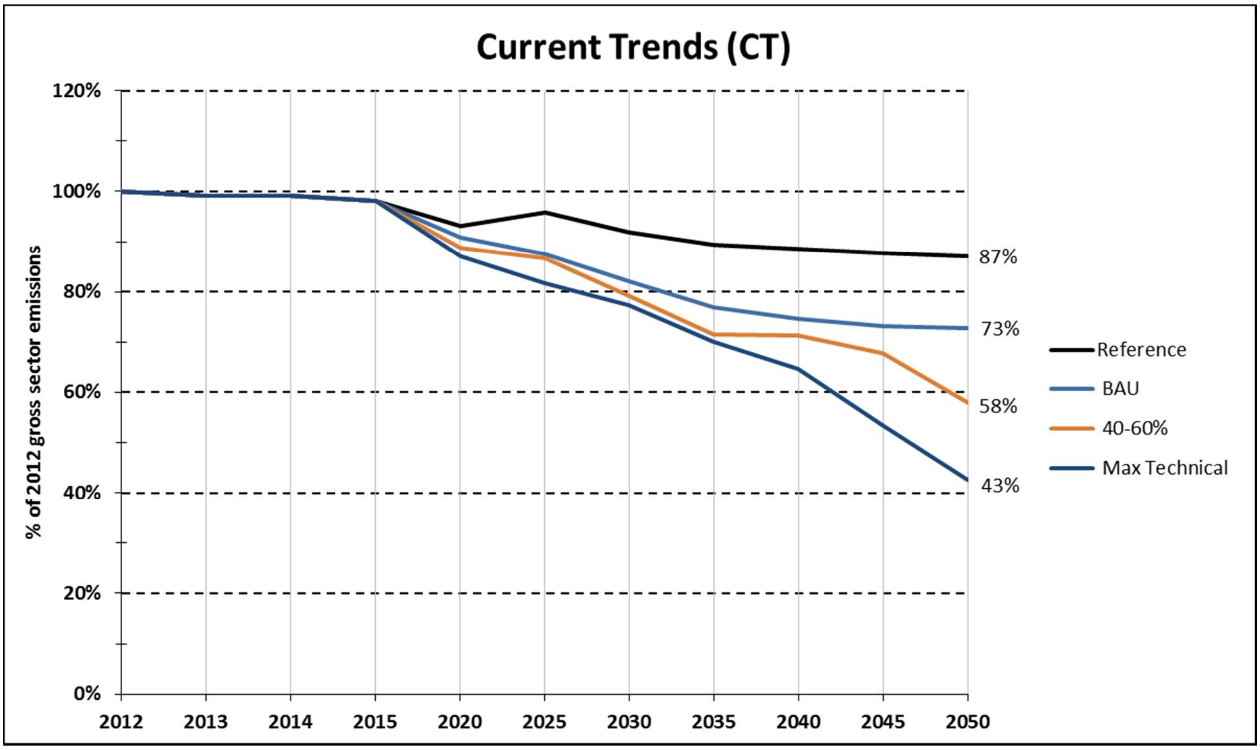

Figure17: Biomass sensitivity, no deployment of biomass gasification in any subsector

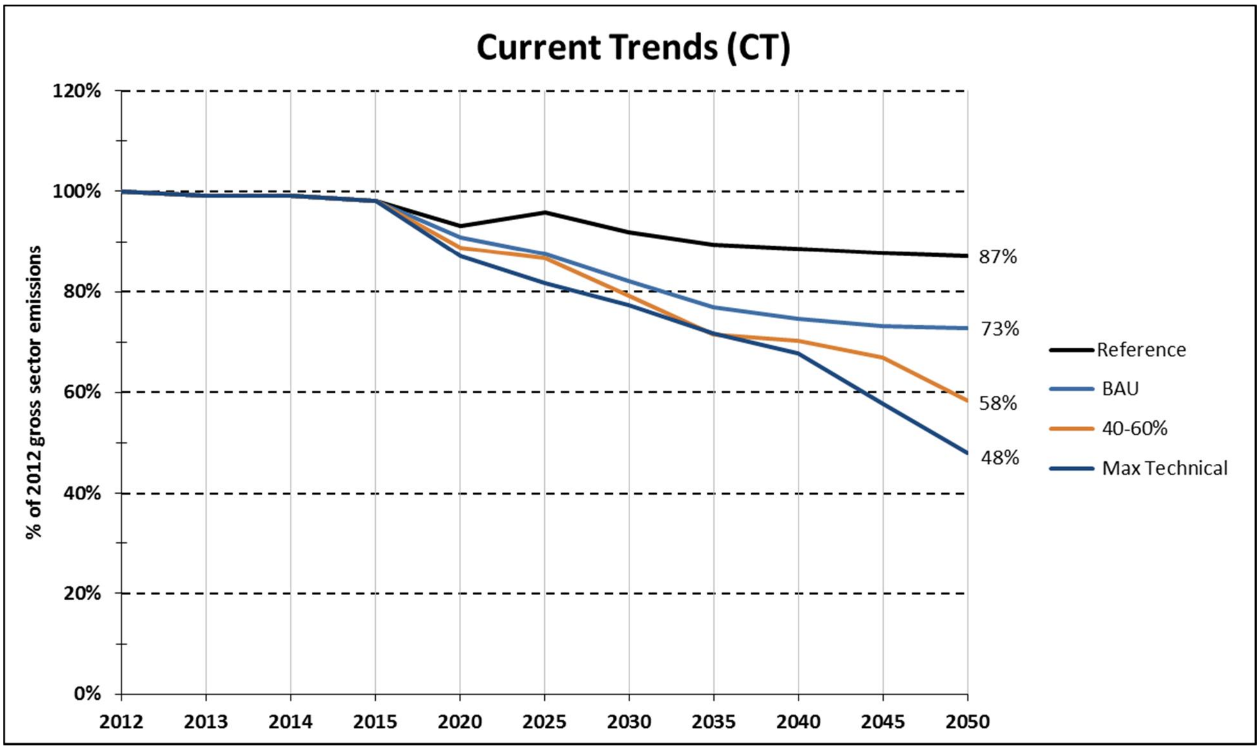

Figure18: CCS Sensitivity; no deployment of CCS in any subsector

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